User's Guide to ASTM Specification C 94 on Ready-Mixed Concrete

D. Gene Daniel and Colin L. Lobo

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Foreword

THIS PUBLICATION, *User's Guide to ASTM Specification C 94 on Ready-Mixed Concrete*, was co-published by ASTM International and The National Ready Mixed Concrete Association (NRMCA). It was both authored and edited by D. Gene Daniel, Concrete Consultant, Rogers, Arkansas; and Colin L. Lobo, The National Ready Mixed Concrete Association, Silver Spring, Maryland. This publication is Manual 49 of ASTM's manual series.

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Preface

What is ASTM?

TO FULLY UNDERSTAND ASTM C 94/C 94M, *Specification on Ready-Mixed Concrete*, it is necessary to understand ASTM and the consensus process for developing standards such as ASTM C 94/C 94M. Getting a view of ASTM from its conception takes us back more than a century. The time period involved is between the American Civil War, which ended in 1865, and World War I, which began in 1914. The true beginning of ASTM coincided with the Spanish-American War fought in 1898.

The world and, more specifically, the United States was in the midst of the second phase of the Industrial Revolution. Major advances in communication and transportation were taking place in a country that in the late 1890s consisted of 45 states. The diesel engine, electrical power, and the steel industry were all coming into prominence. The U.S. was a growing, developing, and prosperous nation with some industrial corporations growing into giants that remain today. William McKinley was elected President in 1896, re-elected in 1900, and assassinated in 1901.

This growth period and the industrial revolution were the backdrop that fostered ASTM. The North American railroad network was expanding in all directions less than 30 years after the completion of the first transcontinental railroad. Charles Dudley, holder of a Ph.D. from Yale University, was a chemist for the Pennsylvania Railroad. Mr. Dudley's degree preceded by two years Custer's last stand at the battle of the Little Big Horn in the hills of Montana. A portion of his duties included research to develop more durable steel for use as rails and then to write a specification conveying those specifics to the rail manufacturers. Mr. Dudley's ideas did not always coincide with those of the steel manufacturers or other railroads who were also buying steel rails. These problems and differing view points led to the first meetings of manufacturers, chemists, engineers, and others in the steel and railroad or bridge business to develop some standards everyone could tolerate. The idea that emerged was that good material standards require the input of manufacturers, designers, builders, and users. This was the idea in June of 1898 when ASTM was first formed under another name, American Section of the International Association for Testing Materials. From the first meeting, the goal was to develop consensus standards.

The first committee dealing with cement, C-1, was formed in 1902, and the concrete and concrete aggregates committee, C9, formed in 1914.

The scope of ASTM has continued to expand, and its name has continued to change. The name today is ASTM International, reflecting both its wide use and its broad international membership. From the original 70 members, ASTM International (ASTM) has grown to more than 30,000 members. For the 100 plus years of its existence, the committee work has remained in the hands of volunteers.

What is Subcommittee C 09.40?

At the bottom of the first page of the document ASTM Standard Specification for Ready-Mixed Concrete (C 94/C 94M) is a notation: "This specification is under the jurisdiction of ASTM Committee C 09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C 09.40 on Ready-Mixed Concrete." Very simply, subcommittee C 09.40 is the group of people who do the actual writing of ASTM C 94/C 94M. This subcommittee is typically composed of approximately 50 people with a wide variety of interests related to the production, delivery, and use of ready-mixed concrete. Some of the groups represented on the subcommittee include producers of ready-mixed concrete, private engineers from both design firms and material testing firms, state highway department engineers, representatives of federal agencies, representatives of trade organizations, professors from universities, both foreign and domestic, contractors, representatives from concrete material producers, such as cement and chemical admixtures, as well as others who have a relationship to the industry. Most of these people are engineers or scientists whose daily activities involve them with the concrete industry. Most, but not all, live in the United States.

Members of subcommittee C 09.40 currently meet twice a year to propose and draft potential updates or changes and to commence the balloting process needed to alter the ASTM C 94/C 94M standard. The C 09.40 subcommittee is responsible for only two ASTM documents. The most widely used is ASTM C 94/C 94M, and the other is ASTM Specification for Concrete Made by Volumetric Batching and Continuous Mixing (C 685/C 685M). The latter is the specification for concrete made from materials continuously batched by volume, mixed in a continuous mixer, and delivered in a freshly mixed condition. Historically, the method of batching and mixing takes place in a truck-mounted unit specifically designed for this purpose.

The C 09.40 subcommittee is only one of many subcommittees which function as a part of the Committee C 09 on Concrete and Concrete Aggregates. The main C 09 committee divides into approximately 25 to 30 subcommittees to develop consensus standards for the concrete and concrete aggregates industry.

ASTM Standards Development Process

The development of standards using a consensus process can be a painstaking adventure. The rewards are meaningful standards that benefit users with due consideration of the concerns of all involved parties.

New standards or alterations to existing standards often begin their formation at the task group level of a subcommittee. The task group prepares a letter ballot for the subcommittee membership to review for up to 30 days prior to voting. For a subcommittee letter ballot to proceed to the next level, several things must occur. At least 60 % of the subcommittee must return a ballot, and of those voting affirmative and negative, at least 2/3 must be affirmative. Negative voters must provide a reason for their negative vote. Each negative will be considered at the next biannual subcommittee meeting. The negative vote will be discussed, and the negative voter is provided the opportunity to speak in defense of the negative and to expound on the reason for it. During this discussion, the Committee may accept the negative voter's point of view and consider it for a revised ballot. If a resolution cannot be reached, a vote is then taken of members present, with affirmative votes required from at least 2/3 of those voting affirmative and negative to find the negative voter not persuasive and allow the item to advance to a committee letter ballot.

If the subcommittee had a majority of manufacturers (producers), it would be possible that the proposed changes or new standards would favor the producers. Control by any single group is prevented by limiting votes to one per company or organization and by balance. Each subcommittee and each committee must have a balance between producers and non-producers. A balanced committee or subcommittee must meet the criterion that voting producer members cannot outnumber the combined votes of the other voting membership groups (users, consumers, and general interest). This is a strictly enforced requirement by ASTM.

Items passing successfully through the subcommittee process are placed on a committee letter ballot and again go through the same process, where a larger group of peers has the opportunity to evaluate the proposal. Committee C 09 consists of many subcommittees, with each of these members now eligible to vote. The primary difference in the committee procedure from the subcommittee procedure is that a 90 % affirmative vote of those voting affirmative and negative is now required for passage, rather than 2/3. If a negative vote is found persuasive, the item fails and is sent back to the subcommittee and task group for a decision on whether to simply drop the proposed change or make alterations in line with the thoughts of the negative voter, thereby beginning the process again.

Simultaneously with the committee level vote, the proposed change is also subject to a vote by the entire ASTM Society, which includes all the ASTM members in various committees. No voting percentages are required at this level, but negative votes must again be considered.

The consensus system also provides for appeals by a negative voter. The appeals system varies depending upon the grounds stated for the appeal.

The primary point in the entire process is that each negative voter's voice and arguments are heard, and the subcommittee or committee is then afforded the opportunity to vote on an issue based on the thoughts and reasoning of one member of the group. A single objection often influences others and alters the content of a proposal or kills the proposal completely. ASTM firmly believes in the old adage that two heads are better than one and has set up a system to ensure that each member's voice is heard.

Original ASTM Specification for Ready-Mixed Concrete

The original C-9 (now C 09) committee required six years (1914–1920) to issue its first standard. The report consisted of the proper means of molding and storing concrete cylinders in the field, describing methods still in use today. The report also included tentative test methods for the unit weight of concrete aggregates and a method for determining voids in concrete fine aggregate. Some additional test methods were also included in the C-9 report, but nothing on ready-mixed concrete was included at that time.

The first such specification was issued in 1933 as a tentative specification for ready-mixed concrete. A copy of the original document that was approved in 1935 is included in the Appendix. The identification number, or designation, was C 94-35. The topics covered did not vary much from today's standard, over 70 years later. One example is that central mixing, partial mixing (shrink mixing), and truck mixing are each included within the specification. The time of hauling was limited to 1 ½ hours, as it is today. Testing was specified but did not include any mention of air content tests, because the advantages of entrained air did not become known until later in the same decade.

The specification has been revised many times since 1935 and continues to undergo revisions to remain in step with technological advances, such as load-cell weighing, and environmental issues, such as limiting plant runoff water by the use of non-potable water in the batching process.

The roots of a successful specification go back to the abilities of the committee prior to 1933 that published a very comprehensive document for the materials, proportioning, mixing, delivery, quality, inspection, testing, and acceptance of ready-mixed concrete delivered to the job site ready for use.

End Result Specification

Specifications are basically one of three types: Proprietary, Prescriptive, or Performance (End Result). Concrete specifications are definitely not Proprietary, because brand names are seldom mentioned, and even when they are, it is usually in the context of Brand Z or approved equal.

Prescriptive specifications provide detailed descriptions of required materials and their properties but do not provide brand names. This type of specification also provides details of how to perform specific parts of the process. The "how to" segment is what ASTM C 94/C 94M does not do. Within the materials segment, ASTM C 94/C 94M does specify specific material requirements such as Specification C 150, Type I portland cement and Specification C 33 aggregates meeting a specific coarse aggregate grading. Minimum cement quantities and maximum water quantities may be specified (prescriptive). Ordering Option B provides the purchaser the opportunity to specify the exact quantities for specific materials and by doing so forfeits any restrictions for final consistency of the delivered product or strength of the hardened product.

The bulk of the ASTM C 94/C 94M standard is a performance or end-result specification. The end result is actually divided into two phases. The first phase is the fresh concrete as delivered in terms of uniformity for placeability and finishability and features such as slump, air-content, and temperature. ASTM C 94/C 94M does provide a slump range (prescriptive) within which the concrete must be, as a consistency requirement, but ASTM C 94/C 94M makes no attempt to describe how to achieve the slump, the air content, or the temperature. The control of placeability and finishability is assisted by the batching accuracy requirements, but there is no hint of describing a method to fulfill these requirements. Thus, phase one of meeting specified numerical requirements is primarily an end-result specification.

Phase two is the hardened concrete requirement for strength. ASTM C 94/C 94M does not prescribe a method of achieving these minimum strengths, thus it is an end-result specification when hardened concrete is considered.

As a whole, ASTM C 94/C 94M is a combined specification with a heavy emphasis on performance (end result) as compared to the prescriptive segments.

Documents Similar to ASTM C 94/C 94M

There are numerous specifications available that address the manufacturing and delivery of ready-mixed concrete. Most of these have been developed by governmental agencies that are typically Federal or State. The general purpose of these specifications is the same as that of ASTM C 94/C 94M with the difference that they are tailored to the specific purpose of the sponsoring agency. This is the reason that such specifications should be viewed with caution by other potential users.

The Forest Service under the umbrella of the U.S. Department of Agriculture has a mini specification within its document, "Specifications for Construction of Roads & Minor Drainage Structures." The title gives a clue regarding the concrete specification when it says "Minor Drainage Structures." The specification primarily deals with material requirements, proportions to attain the proper strength, and the testing of the mixture as delivered. The portion of the specification dealing with manufacture and delivery reads as follows:

> "When a commercial supplier is used, the contractor shall furnish a certification with each truckload of concrete certifying that the material and mix proportions used are in conformance with the approved mixture."

This single sentence specification is adequate for a minor drainage structure when the owner and specifier are one and the same.

Some of the U.S. Army Corps of Engineers guide specifications for concrete and concrete batch plants can be quite the opposite of a single-line performance specification. The USACE specifications, if proposed for use on a civilian project, should be studied closely by both purchaser and manufacturer. The specification may be extremely detailed and severe in requirements, causing unnecessary expenses for civilian projects. Such items as monthly scale checks, repeated uniformity tests and measurement of mixing blade wear, varying levels of requirements for automation and recording, and acceptance testing for cementitious materials rather than accepting mill tests are a few of the items to watch. Few civilian projects have the life expectancy of a USACE project and do not require the same degree of caution. A purchaser can unwittingly reference such a specification if not careful, and a manufacturer can agree to conform if not diligent in checking specifications beforehand.

A major specification that is very similar to ASTM C 94/C 94M is the American Association of State Highway and Transportation Officials (AASHTO) M 157 "Standard Specification for Ready-Mixed Concrete." As the association name implies, this organization includes representatives from each state plus some other entities. Like ASTM, the AASHTO specification is a consensus process specification. The ASTM voting membership includes designers, academia, manufacturers, general interest, and users, while AASHTO limits voting interests to designers and users (State DOTs). Each of the 52 state highway agencies are represented and allowed one vote per agency on revisions and requirements of this document. A 2/3 majority is required by AASHTO for passage of any proposal, and every negative vote must be considered and evaluated for merit. The technical differences in C 94/C 94M and M 157 are slight. The first difference noted is that all references to material specifications and test methods are AASHTO documents rather than ASTM designations. The second difference noted also becomes apparent in the Referenced Documents section. ASTM C 94/C 94M references American Concrete Institute Standard CP-1 Technician Workbook for ACI Certification of Concrete Field Testing Technician—Grade I. This reference is due to the ASTM C 94/C 94M requirement that all testing technicians be certified ACI Concrete Field Testing Technicians, Grade I or equivalent. AASHTO M 157 does not contain such a requirement because each state Department of Transportation (DOT) will have individual requirements. Many states will do all the testing in-house and will address this in other parts of their specification document. This is addressed in AASHTO M 157 by a statement that "Testing shall be conducted by the specifying agency or, with specifying agency approval, by a testing laboratory meeting the requirements of ASTM Recommended Practice E 329."

There are minor technical differences in such items as chemical limitations for wash water and the minimum concrete temperature in cold weather. A major departure of AASHTO M 157 from ASTM C 94/C 94M is that criteria for acceptance of the concrete based upon strength tests are omitted, as is any mention of steps to be taken to resolve any low-strength tests.

The greatest difference in the two specifications is in the ordering information. ASTM C 94/C 94M has three options providing a wide latitude to the purchaser. AASHTO M 157 does not provide a section on ordering, only a quality of concrete section, which concerns submittals to the engineer by the Contractor or the proportioning prescribed by the engineer and directed to the Contractor. A note at the end of AASHTO M 157 recognizes this difference and suggests: "users other than specifying agencies should consider ASTM C 94."

State Department of Transportation specifications for the construction of highways and bridges typically take one of two approaches. They will reference AASHTO M 157 as the specification for ready-mixed concrete, or the state DOT will prepare a concrete specification unique to local needs, climatic conditions, and local materials. The provisions of these DOT specifications will vary with each state. The differences can include such items as mandatory computer batching, weighing hoppers fed by overhead bins, scale weight tolerances extremely close, or some very loose regulations based on the knowledge that state DOT inspectors will be at the plant during the batching of concrete for DOT usage.

ASTM C 94/C 94M is the only ready-mixed concrete specification available to private owners, many state and federal agencies, and the design professional community when the technical specifications for a project are prepared. The American Concrete Institute relies on ASTM C 94/C 94M in its document ACI 301 "Specifications for Structural Concrete." The great majority of substitute specifications available to choose from are written for highway construction, and very few non-DOT projects include highways.

Discussion of New Water Standards for Ready-Mixed Concrete

Environmental aspects facing the concrete industry served as the motivation for a change in ASTM Specification C 94/C 94M during the later portion of 2004. The specific items involved are associated with the use of alternative sources of water, including recycling mixer-truck washout water and on-site storm runoff water as both settled water and as a water slurry including larger quantities of suspended solids. To avoid making significant changes to the Specification for Ready Mixed Concrete, a new specification was created for water to be used in concrete and is referenced by ASTM Specification C 94/C 94M. The new water requirement document is identified as ASTM C 1602/C 1602M (approved 9/2004) *Specification for Mixing Water Used in the Production of Hydraulic-Cement Concrete*.

One of the aspects of the new water specification is a series of definitions categorizing several types of water that could be used in concrete. The four categories of water defined are as follows:

- **potable water**—water suitable for human consumption.
- **non-potable**—water that is not fit for human consumption or that contains quantities of substances that discolor it or make it smell or have objectionable taste but does not contain water from concrete production operations.
- **water from concrete production operations**—water recovered from processes of hydraulic cement concrete production that includes wash water from mixers or that

was a part of a concrete mixture; water collected in a basin as a result of storm water runoff at a concrete production facility; or water that contains quantities of concrete ingredients.

- **combined water**—a mixture of two or more sources of water blended together, before or during introduction into the mixture, for use as mixing water in the production of concrete.

These definitions provide clarity as to what types of water are acceptable for use in concrete production, and the specification provides requirements for proper monitoring and use to protect the producer and purchaser. Non-potable water is intended to cover many sources of water such as recycled water from municipal sources, wells, streams, and other sources that are not potable. Water from concrete production operations includes mixer washout water, process water from washing off drum exteriors, drum loading hoppers, spilled cementitious products, and plant yard storm water runoff. Several items remain unchanged from Chapter 5 of this book, including the properties specified for water being related to total combined water from all sources. Qualification testing is done on concrete mixtures rather than on pastes and mortars. Total combined water was previously called "total mixing water".

The addition of a second standard, ASTM C 1603/C 1603M (approved 8/2004) *Test Method for Measurement of Solids in Water* has greatly simplified the determination of properties for combination waters. This test method describes an acceptable method of water density (specific gravity) measurement, the measurement of solids content, relationships between density and solids content, and equations for the determination of blending percentages for combined water sources. Each of these relationships is important to the determination of combined water properties.

Testing requirements and frequencies for sources other than potable water are established based on the source and for water from concrete production operations on the density of the combined water. Since it is understood that using water from concrete production operations with significant quantity of solids impacts concrete properties, the testing frequency increases as the density of the combined water proposed for use increases. There are actually five (5) categories of water:

(1) Potable water
(2) Non-potable water
(3) Water from concrete production with a density less than 1.01 g/mL
(4) Water from concrete production with a density between 1.01 and 1.03 g/mL
(5) Water from concrete production with a density of 1.03 to 1.05 or greater

Tables 2 and 3 of Chapter 5 are retained in C 1602/C 1602M with respect to requirements with only the test methods and type of water being changed. Table 3 (Table 2 in C 1602/C 1602M) formerly applied only to wash water but now applies to all non-potable mixing water, but the requirements are considered optional in that they have to be invoked by the purchaser. Test methods of Table 2 (Table 1 in C 1602/C 1603M) formerly checked the effects of water, and now the test requirements apply to concrete produced with the water. The consensus of the C09.40 subcommittee was that concrete is the final product and therefore should be what is tested, rather than testing and approving water. These mixtures may be laboratory or full size production batches. The current requirement is for the density of all water from concrete production operations that will be used as mixing water in concrete to be checked at least daily.

Table 2 in C 1602/C 1602M involves only water requirements that are optional for the specifier or owner. It is nevertheless required that if the concrete producer uses non-potable water, the water must be tested for Table 2 compliance at maximum intervals of six months.

With the addition of these new standards, the following revisions were made to ASTM C 94/C 94M-04a (approved 8/2004):

(1) A statement was added to Section 4—Ordering Information—that the purchaser should include any optional requirements of Table 2 in C 1602/C 1602M.
(2) Section 5.1.3 on Water was revised to refer to C 1602/C 1602M, and Tables 2 and 3 of C 94/C 94M were removed.
(3) In Section 13, which covers requirements for the Delivery Tickets, an item was added that the producer should report the source and amount of recycled water used in the specific concrete batch when requested by the purchaser.

Be sure to check the latest version of C 1602 and C 1603 since, as with many new specifications, changes will occur as research provides more information concerning the role of high solids content slurry waters on such items as shrinkage, lower compressive strengths, and increased water demand.

ASTM Terminology System for Standards

Within Section 2, Referenced Documents of ASTM C 94/C 94M, three different types of ASTM documents are listed. These are Specifications, Test Methods, and Practices. There are other types within the ASTM collection of documents prepared to assist the overall needs of an industry. ASTM briefly defines each type of document in its September 2003 manual "Form and Style for ASTM Standards":

- **standard,** n—as used in ASTM, a document that has been developed and established within the consensus principles of the Society and that meets the approval requirements of ASTM procedures and regulations.

DISCUSSION—The term "standard" serves in ASTM as a nominative adjective in the title of documents, such as test methods, practices, or specifications, to connote specified consensus and approval. The various types of standard documents are based on the needs and usages as prescribed by the technical committees of the Society.

- **specification,** n—an explicit set of requirements to be satisfied by a material, product, system, or service.

DISCUSSION—Examples of specification include, but are not limited to, requirements for: physical, mechanical, or chemical properties and safety, quality, or performance criteria. A specification identifies the test methods for determining whether each of the requirements is satisfied.

- **guide,** n—a compendium of information or series of options that does not recommend a specific course of action.

DISCUSSION—A guide increases the awareness of information and approaches in a given subject area. A guide may have several recommendations on accomplishing the same thing and may require judgment on the part of the user to determine the best course to follow.

- **practice,** n—a definite set of instructions for performing one or more specific operations that does not produce a test result.

DISCUSSION—Examples of practices include, but are not limited to: application, assessment, cleaning, collection, decontamination, inspection, installation, preparation, sampling, screening, and training. For example, making a concrete cylinder, ASTM C 31/C 31M, is considered a practice as it contains specific procedural requirements, but there is no test result from this. The test result comes when the cylinder is broken to determine its strength, and the applicable test method is ASTM C 39/C 39M.

- **test method,** n—a definitive procedure that produces a test result.

DISCUSSION—Test methods most often produce a numerical result. In some cases, a qualitative result, such as a visual rating, will be the test result.

- **terminology standard,** n—a document comprising definitions of terms: explanations of symbols, abbreviations, or acronyms.

Three parts of some ASTM documents need an explanation of how they are used by the Society.

- **Annexes** include mandatory information that is too detailed and lengthy for inclusion in the main body of the document.
- **Appendixes** include non-mandatory supplementary information that is informative but not a part of the main text of the standard.
- **Notes** in the text are advisory and do not include mandatory requirements. Notes are used to include explanatory information, perhaps a caution concerning the potential consequences of an improper procedure, a reason for a specific requirement, or several other purposes that are helpful to the user but non-mandatory.

- **Notes to Tables and Figures** are mandatory and form a part of the table or figure and are not supplementary.

Typical User of ASTM C 94/C 94M

The potential users of ASTM C 94/C 94M, *Specification for Ready-Mixed Concrete*, are virtually endless. It is used as "the reference standard" because of its good coverage of necessary topics for batching, mixing, and delivery of ready-mixed concrete. A broad list of users includes the following:

- ACI specifications such as 301, *Specification for Structural Concrete*; 330, *Specification for Unreinforced Concrete Parking Lots* and a proposed document 305, *Specification for Hot Weather Concreting*
- Architects performing designs for private or institutional owners
- Engineers performing designs for private or institutional owners
- Educational facilities with in-house design professionals
- Municipal governments in-house or outsourced designs
- County governments in-house or outsourced designs
- State government agencies such as Parks & Tourism Departments or the Game & Fish Agency
- Federal government groups such as the Department of Defense or the Federal Aviation Administration
- Contractors doing work not requiring the design services of an architect or engineer
- Private industrial corporations with in-house or outsourced designs
- Ready-mixed concrete producers and testing laboratories, who can be considered users of the specification as they need to ensure that they comply with the requirements for batching and delivery of concrete and testing concrete, respectively

How to Use ASTM C 94/C 94M

The most common usage of ASTM C 94/C 94M is as a reference document within a design professional's specification for cast-in-place concrete. A statement such as **"Unless otherwise specified, use materials, measure, batch, and mix concrete materials and concrete and deliver concrete in approved equipment, all in conformance with ASTM C 94/C 94M"** within the concrete specifications for a project the strength, slump, air content, aggregate size, and other variable factors named in Ordering Information will be provided.

Other methods are suitable if the questions in Ordering Information are answered. A purchase order with a ready-mix manufacturer may simply state **"Produce and deliver concrete as per C 94."**

An important violation that can cause trouble is using excerpts from ASTM C 94/C 94M or any other specification without a careful reading of the entire document for related segments. Unfortunately there are design professionals following this cut and paste style. It is best to use the complete document by reference.

Definitions to be Used in Discussions

Discussions on what a word or phrase means are inevitable when technical specifications are involved. Unfortunately, different sources may provide differing definitions. A list follows of sources from which to obtain acceptable definitions in decreasing order of preference.

- ASTM C 125 Terminology Relating to Concrete and Concrete Aggregate
- ASTM C 219 Terminology Relating to Hydraulic Cement
- ACI 116R Cement and Concrete Terminology
- ASTM Dictionary of Engineering and Technology, 9th Edition
- Merriam-Webster's Tenth Edition Collegiate Dictionary
- Webster's Third New International Dictionary

Within various technical documents, a small group of words must be very carefully selected due to their precise meanings and connotations. Four such words and their proper usages follow as extracted from the Form and Style for ASTM Standards manual:

- "Shall" is used to indicate that a provision is mandatory.
- "Should" is used to indicate that a provision is not mandatory but is recommended as good practice.
- "May" is used to indicate that a provision is optional.
- "Will" is used to express futurity, but never to indicate any degree of requirement.

To the extent possible, specifications are written in terse mandatory language that indicates specific items which need to be accomplished. This ensures that the directions to and associated responsibilities of the involved parties are clearly defined. The need for a specification to always be in a mandatory language format will at times produce cumbersome language.

How to Use this Guide

The chapters in this book reflect the sections of C 94/C 94M. Text from C 94/C 94M is reproduced in italic text followed by a discussion of the section. Sentences in the specification are cross-referenced and discussed in the text with identifications S1, S2, etc. Tables, figures, and numerical examples are numbered sequentially by chapter number, except for tables excerpted from C 94, in which cases the actual table number is retained.

Disclaimer

This book represents the interpretation of the authors concerning ASTM C 94/C 94M and does not represent the views of ASTM International or Subcommittee C 09.40.

Introduction

ASTM DESIGNATION: C 94/C 94M-04 STANDARD SPECIFICATION FOR READY-MIXED CONCRETE

THIS IS THE OFFICIAL number and title for the ASTM specification for ready-mixed concrete. Portions of the designation remain constant, and other parts are always subject to change. An analysis of the parts of the alphanumeric identification for the "Specification for Ready-Mixed Concrete" entails four segments:

C 94 includes the group designation C (that comes from the 19 ASTM committees currently grouped under the "C" designation, of which committee C 09 is one of them).

ASTM committee C 09 is responsible for this ready-mixed concrete specification. The permanent number 94 was assigned in numerical sequence from all of the "C" committee standards when first developed.

C 94M means this specification is a combined standard that includes metric (SI) values as well as inch-pound values.

04 indicates the last year (2004) that alterations were made to this specification. $^{\varepsilon 1}$ superscript (ε) following the year designation would indicate that an editorial change has been made later than the substantive changes of 2004.

Footnotes on the title page are self-explanatory.[1]

[1] This specification is under the jurisdiction of ASTM Committee C 09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C 09.40 on Ready-Mixed Concrete.
Current edition approved Feb. 1, 2004. Published March 2004. Originally approved in 1933. Last previous edition approved in 2003 as C 94/C 94-03$^{\varepsilon 1}$.

1

Scope

1.1 $_{S1}$ *This specification covers ready-mixed concrete manufactured and delivered to a purchaser in a freshly mixed and unhardened state as hereinafter specified.* $_{S2}$ *Requirements for quality of concrete shall be either as hereinafter specified or as specified by the purchaser.* $_{S3}$ *In any case where the requirements of the purchaser differ from these in this specification, the purchaser's specification shall govern.* $_{S4}$ *This specification does not cover the placement, consolidation, curing, or protection of the concrete after delivery to the purchaser.*

The first sentence (**S1**) identifies that what follows is a specification. Merriam-Webster's Collegiate Dictionary, Tenth Edition, defines a specification as "a detailed precise presentation of something" and "a statement of legal particulars." The referenced document, ASTM Specification C 94/C 94M, meets both of these criteria. It is a detailed precise presentation dealing with the minimum requirements for both manufacturing and delivering ready-mixed concrete. The purpose of this document is to form a statement of legal particulars to be available for reference in a project specification, purchase order (written or oral), or contract. The legal particulars describe the minimum requirements for manufacturing and then delivering ready-mixed concrete. The statement indicates that at the time of delivery to the purchaser (or authorized agent) the concrete shall be a homogeneous mixture in a plastic and unhardened state with its original ordered qualities unimpaired. At the time and place of delivery (discharge), the concrete is to be moldable, allowing it to take the shape of the conveying equipment or the forms into which it is placed and finished by the purchaser's authorized agents.

The second sentence (**S2**) focuses on the purchaser's right to alter the ready-mixed concrete quality portion of the specification. ASTM C 94/C 94M is intended to be a general reference specification that cannot cover all specific requirements for a particular project. The purchaser can order concrete in accordance with ASTM C 94/C 94M and add clauses pertinent to the project. For example, in hot weather the purchaser may require the concrete be discharged in less than 1 ½ h. The purchaser has the right to specify central-mixed concrete rather than truck-mixed concrete. The purchaser has the right to specify a cement meeting a specific cement specification, such as one of the cements from ASTM Performance Specification for Hydraulic Cement (C 1157) or for that matter a specific brand of cement as well as the type. The purchaser may place restrictions on calcium chloride and products containing chloride additions in accordance with ACI 301-99, Specification for Structural Concrete. In short, the purchaser may alter any portion of this specification, so desired, that affects the quality of the product. The variations desired by the purchaser, however, should be provided before a price is requested. Alterations in specification requirements can have a significant effect on the cost.

The third sentence (**S3**) makes it clear that the purchaser may specify exactly what is believed to be best for the purchaser or the project, as may be the case. Perhaps after a ready-mixed concrete supplier is selected, the purchaser determines that it is in the best interest of the project to add a restriction that the concrete aggregates meet the optional alkali-silica reactivity (ASR) requirements of ASTM Specification for Concrete Aggregates (C 33). The purchaser has every right to demand this, and if a price agreement was reached prior to the imposition of these requirements, the supplier has every right to demand monetary compensation for the change. The point here is that the concrete should not be delivered until an agreement is reached, and in this example concrete containing aggregates not meeting the specified ASR requirements should not be delivered. The purchaser's specification overrides stated requirements in ASTM C 94/C 94M and shall govern.

The fourth sentence (**S4**) defines what this specification does not cover. It does not cover and does not address the placement of the concrete, the consolidation of the concrete, finishing of the concrete, the curing methods, or the protection of the concrete after delivery to the purchaser. This specification is solely intended for the production and manufacture of concrete. There are other reference specifications such as ACI 301, Standard Specification for Structural Concrete, that address the subsequent operations that are listed in this sentence. This specification covers none of these items, which occur after the concrete has been discharged from the concrete delivery unit. After the concrete leaves the discharge chute or tailgate in an acceptable condition, the purchaser becomes responsible for all future phases of this product. This does not negate the supplier's responsibility for the concrete achieving the specified design strength at the specified age unless purchaser or designated agent directed an unspecified alteration of concrete mixture or its properties. It does mean that the strength tests for approval or rejection shall be made on samples taken from the delivery vehicle and not from another location. When parties other than the supplier begin to alter or handle the concrete, they assume certain responsibilities for the finished product. After the concrete leaves the discharge chute and goes into a concrete bucket, a power buggy, or a concrete pump or is pulled and moved by a laborer, changes may occur to the concrete over which the supplier has no control. The effects of these operations on the concrete quality are not addressed within this specification.

1.2 $_{S1}$ *The values stated in either SI units or shown in brackets, or inch-pound units are to be regarded separately as* *standard.* **S2** *The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other.* **S3** *Combining values from the two systems may result in non-conformance with the standard.*

Throughout the specification for ready-mixed concrete, units of measure are used, usually for mass (weight) or volume. In combined standards such as ASTM C 94/C 94M, the SI units are enclosed in brackets [ ]. **S2** instructs that either set of units may be used, but they are not to be intermixed. For example, slump should not be specified in mm and then measured in inches. If the International System of Units (SI) is used for one item, all items should be expressed and measured in SI units. Table 4 on overdesigns necessary to meet strength requirements provides a good example of this. With 15 tests and a standard deviation of 400 psi, the required overdesign is 622 psi. The companion SI values are a standard deviation of [3.0 MPa] and a required overdesign of [4.7 MPa], which converts to 682 psi, not 622 psi. Intermixing the two measurement systems could result in nonconformance as cautioned in **S3**.

1.3 **S1** *As used throughout this specification, the manufacturer shall be the contractor, subcontractor, supplier, or producer who furnishes the ready-mixed concrete.* **S2** *The purchaser shall be the owner or representative thereof.*

S1 states that anywhere the term "manufacturer" is used within ASTM C 94/C 94M, it is referencing the contractor, a concrete subcontractor, a ready-mixed concrete supplier, or the ready-mixed producer. In the original tentative ready-mixed concrete specification published in 1933 (ASTM C 94-33T), the term manufacturer was used throughout to refer to the ready-mixed concrete manufacturer. The language of the current section, 1.3, first appeared as a note in the late 1960s. At that time the first sentence read: "As used throughout this specification the manufacturer shall be understood to be the contractor, subcontractor, supplier or producer furnishing the ready-mixed concrete". The "understood to be" was later deleted, and the statement was placed in the document text rather than remaining a note.

The practice of using only the term "manufacturer" has now changed somewhat with the term "producer" now used several times within the specification. Currently "manufacturer" is being used when the ordering of concrete, batching, or plant items are involved. "Producer" is used to include delivery and job site items related to the delivery of concrete. The terms "subcontractor" and "supplier" have not been used within the current ASTM C 94/C 94M. The term "contractor" has been used, but only one time in Section 16.1. This single reference to "contractor" is used when a job site item involves the general contractor as well as the producer. The referenced item involves access, assistance, and sampling, which may take place at the job site. This is a location presumed to be under the primary authority of the general contractor.

The second sentence (**S2**) identifies the purchaser as the owner or a representative of the owner. This would include the general contractor or a concrete subcontractor who orders concrete for the owner. In this capacity, as well as some others, these contractors are the owner's representatives. The Architect/Engineer (A/E) is also in the owner representative category.

Project specifications are written usually to the general contractor who is responsible to the owner for all materials, subcontractors, and suppliers. The ready-mixed concrete manufacturer is only one of many material suppliers for which the general contractor is responsible, and the "Specification for Ready-Mixed Concrete" is only one of many specifications that may be referenced for inclusion in project documents describing the requirements for a material, which in this case is concrete.

Concreting often involves several entities including the raw material suppliers, the concrete manufacturer, those responsible for the product delivery, a subcontractor for preparing forms and setting steel, the concrete finisher, and the general contractor responsible to the owner (purchaser) for coordination of all of these activities. ASTM C 94/C 94M is written to the general contractor to allow the owner to identify who is ultimately responsible for the entire concreting operation. **S1** is needed to authorize the substitution of contractor for manufacturer throughout the specification. ASTM C 94/C 94M is also written in an attempt to separate the responsibilities of the concrete manufacturing process and product delivery from the overall responsibilities of the general contractor or a concrete subcontractor. This separation is needed for clarity in a purchase order for concrete or a delivered materials contract whether written or oral.

1.4 **S1** *The text of this standard references notes and footnotes which provide explanatory material.* **S2** *These notes and footnotes (excluding those in tables and figures) shall not be considered requirements of the standard.*

There are 20 notes within the specification and several footnotes. They all provide information that is not mandatory but is advisory or explanatory. The 20 non-mandatory notes are identified in numeric order as Note 6 or other appropriate number in numerical order of appearance. The footnotes commonly deal with sources of reference materials.

An important distinction must be made for notes accompanying tables or figures (no figures exist within ASTM C 94/C 94M). The notes with tables form a part of the table and are as mandatory as other data within the table. These notes are shown as, [A], [B], or [C] in alphabetical order for each table. Notes to tables within the standard use upper case letters to tie the referenced note to the text with which it is used in the table.

2

Referenced Documents

EVERY DOCUMENT referenced within ASTM C 94/C 94M is listed in Table 2.A with a cross-reference to the section where the referenced document appears in the specification. ASTM referenced documents do not carry a date because the reference is always to the latest edition of each document. The superscript number after an ASTM Standard refers to the footnote at the bottom of the page providing the ASTM volume number in which the Standard appears.

The term ASTM Standard refers collectively to all ASTM documents included in the reference list. Three types of standards are included within the ASTM C 94/C 94M reference list; there are three Practices, eleven Test Methods, and ten Specifications. All of the specifications referenced within ASTM C 94/C 94M are requirements for specific materials used in the manufacture of concrete. ASTM specifications can refer to other items such as a system, but in this particular case each specification describes the minimum requirements for a specific material. An example of a system specification is the ASTM Specification for Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes (C 511). As the title states, ASTM C 511 is a specification covering the requirements for each of three systems that may be used to store hardened test specimens.

Test Methods have a straightforward title because these standards describe a test procedure in sufficient detail such that consistent results are produced when the procedure is repeated consistently. A test method describes a procedure that produces a numerical result. For example, ASTM Test Method for Slump of Hydraulic-Cement Concrete (C 143/C 143M) describes the procedures for a concrete slump test. The end result is the measurement and reporting of a slump value, such as 4¾ in. for the concrete on truck No. 65.

Three of the referenced standards carry a title of "Practice." Common industry vernacular often identifies a Practice as a Test Method. A Practice, just as a Test Method, describes a definitive procedure or set of instructions for a specific operation. The three Practices referenced here describe sampling freshly mixed concrete, making and curing concrete test specimens in the field, and the duties, responsibilities, and minimum technical requirements of testing laboratory personnel, as well as the minimum technical requirements for their laboratory equipment. There is one major difference between a Practice and a Test Method. A Test Method produces a numerical result such as the 4¾ in. slump. A Practice does not produce a value or a test result. ASTM Practice for Sampling Freshly Mixed Concrete (C 172) does not culminate in a numerical result, only a sample of concrete that is believed to be representative of the entire load of concrete. ASTM Practice for Making and Curing Concrete Test Specimens in the Field (C 31/C 31M) instructs on the molding, handling, and curing of strength specimens, but it does not produce a test result. The test values come later with the compression testing of the specimens in accordance with ASTM Test Method Compressive Strength of Cylindrical Concrete Specimens (C 39/C 39M).

Section 2.2 in Table 2.A provides a list of American Concrete Institute documents which are referenced within ASTM C 94/C 94M. A footnote at the bottom of the page provides an address for obtaining copies of any desired ACI document.

Section 2.3 in Table 2.A provides a list of additional non-ASTM documents referenced within ASTM C 94/C 94M. Footnotes at the bottom of the page again provide addresses for obtaining a copy of the referenced documents.

TABLE 2.A—*Referenced document locations.*

2.1 ASTM Standards[2]	Text Location of Referenced Documents
C 31/31M Practice for Making and Curing Concrete Test Specimens in the Field	(15.1.1, 17.1, Note 19)
C 33 Specification for Concrete Aggregates	(5.1.2)
C 39/C 39M Test Method for Compressive Strength of Cylindrical Concrete Specimens	(15.1.2)
C 109/C 109M Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or 50-mm Cube Specimens)	(Table 2)
C 138/C 138M Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete	(3.2, 15.1.3, 15.1.4)
C 143/C 143M Test Method for Slump of Hydraulic-Cement Concrete	(15.1.5)
C 150 Specification for Portland Cement	(5.1.1)
C 172 Practice for Sampling Freshly Mixed Concrete	(3.2, Note 9, 11.5.1, 15.1.6, 16.3, 16.6)
C 173/C 173M Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method	(15.1.4)
C 191 Test Method for Time of Setting of Hydraulic Cement by Vicat Needle	(Table 2)
C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method	(15.1.4)
C 260 Specification for Air-Entraining Admixtures for Concrete	(5.1.6)
C 330 Specification for Lightweight Aggregates for Structural Concrete	(5.1.2)
C 494/C 494M Specification for Chemical Admixtures for Concrete	(5.1.7)
C 567 Test Method for Determining Density of Structural Lightweight Concrete	(Note 3)
C 595 Specification for Blended Hydraulic Cements	(5.1.1)
C 618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete	(5.1.4)
C 637 Specification for Aggregates for Radiation-Shielding Concrete	(5.1.2)
C 989 Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars	(5.1.5)
C 1017/C 1017M Specification for Chemical Admixtures for Use in Producing Flowing Concrete	(5.1.7)
C 1064/C 1064M Test Method for Temperature of Freshly Mixed Portland-Cement Concrete	(15.1.7)
C 1077 Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation	(15.2)
C 1157 Performance Specification for Hydraulic Cement	(5.1.1)
D 512 Test Methods for Chloride Ion in Water	(Table 3)
D 516 Test Method for Sulfate Ion in Water	(Table 3)
2.2 ACI Documents[3]	
CP-1 Technician Workbook for ACI Certification of Concrete Field Testing Technician-Grade 1	(16.2)
211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete	(Table 1 Footnote C, Note 4, Note 5)
211.2 Standard Practice for Selecting Proportions for Structural Lightweight Concrete	(Note 4, Note 5)
301 Standard Specifications for Structural Concrete	(Note 20)
305R Hot Weather Concreting	(Note 16)
306R Cold Weather Concreting	(Note 15)
318 Building Code Requirements for Structural Concrete and Commentary	(Note 20, Table 4 Footnote B)
2.3 Other Documents	
Bureau of Reclamation Concrete Manual[4]	(Note 16, Table A1.1 Footnote A)
AASHTO T26 Method of Test for Quality of Water to be Used in Concrete[5]	(Table 3)

[2] *For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.*

[3] *Available from American Concrete Institute, 38800 Country Club Drive, Farmington Hills, MI 48331.*

[4] *Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.*

[5] *Available from the American Association of State Highway and Transportation Officials, 444 N. Capitol St., NW, Suite 225, Washington, DC 20001.*

3

Basis of Purchase

3.1 The basis of purchase shall be the cubic yard or cubic meter of freshly mixed and unhardened concrete as discharged from the mixer.

Only one method of purchasing concrete is recognized by this specification, and that is in units of volume by cubic yards or cubic meters. The idea of purchasing concrete by the job or by calculated plan volumes or by total weights is not considered a feasible approach. If the contractor could pay a lump sum for all the concrete in a job, without job measurements, the overruns, grading laxities, and job wastes could be enormous. One example is that slabs designated as 4 in. thick on the plans could suddenly become 5 or 6 in. thick. If the total weights, rather than volume are used, the effects of varying air content, aggregate density, or the batching of excess aggregate could produce a problem as well as a bookkeeping nightmare.

The purchase of concrete by volume is a time tested and reasonable approach that does not penalize anyone. The volume approach makes it relatively simple for the purchaser to communicate orders as needed; the batching and the bookkeeping problems are minimal.

Freshly mixed, unhardened, and as discharged from the mixer is a very straightforward set of circumstances describing when the volume is to be measured. Trying to measure the volume of hardened concrete is difficult. A slab-on-grade would look like Swiss cheese with all the core holes needed to verify compliance with a required average thickness. Thus, the unhardened state is the best condition for volume measurements. Water and air make up a portion of the concrete volume. With air-entrained concrete, this combination easily can be 20 % of the total volume. Water evaporates and also combines chemically with the cementitious materials, and air tends to decrease with manipulation of the product. The freshly mixed and newly discharged concrete provides the only accurate measurement of volume as mixed and as delivered. Thus, one cubic yard [27 ft^3] or one cubic meter of fresh concrete is the specified unit volumetric measure for the purchase of concrete. The purchaser expects 27 ft^3 to be discharged for each cubic yard for which he is charged. Inadvertent shortages can occur easily. Batching tolerances can produce minor discrepancies on individual loads. Air contents could be low, producing a shortage. Another means of yield shortage is to proportion a mixture for summer usage. The same mixture in the winter may require 3–4 gal less water to achieve the same slump [18,40].[1,2] Three gallons [25 lb] of water changes the volume to 0.40 ft^3/yd^3. Thus, a mixture proportioned for 27.2 ft^3 per design cubic yard in the summer can be reduced easily to 26.8 ft^3 during the winter season.

A common occurrence in the summer is for entrained air contents to be lower. A drop of 1.5 % due to a higher ambient temperature also reduces the yield by 0.40 ft^3/yd^3.

3.2 *$_{S1}$ The volume of freshly mixed and unhardened concrete in a given batch shall be determined from the total mass of the batch divided by the mass per unit volume of the concrete. $_{S2}$ The total mass of the batch shall be calculated either as the sum of the masses of all materials, including water, entering the batch or as the net mass of the concrete in the batch as delivered. $_{S3}$ The mass per unit volume shall be determined in accordance with Test Method C 138/C 138M from the average of at least three measurements, each on a different sample using a ½-ft³ [14 L] container. $_{S4}$ Each sample shall be taken from the midpoint of each of three different truck loads by the procedure outlined in Practice C 172.*

A term that is disappearing from ASTM standards is weight. It is being replaced by mass as it already has been within ASTM C 94/C 94M. The preferred term of mass rather than weight came about during the same timeframe as the emphasis on using SI units in ASTM standards.

The practical difference between weight and mass is that weight changes with the gravitational pull on an object. Weight is a measure of force resulting from the effect of gravity on the mass of an object. The weight of an object in New Orleans at sea level will be greater than the weight of

[1] The 3–4 gal [25–33 lb] cited in the example represents a temperature change of 40–50°F when using Fig. 118 in the Bureau of Reclamation's *Concrete Manual* [18]. Gaynor, Meininger, and Khan [40] provide smaller changes in water contents, but their material only deals in 30°F temperature differences. Slump losses depend on several factors, including temperature, mixture proportions, and delivery times. The latter effect is displayed in Gaynor, Meininger, and Khan [40].

[2] Research and technical papers currently express concrete batch water in lb/yd^3. Because a high percentage of concrete batch plants continues to measure batch water in gal/yd^3, the latter measuring unit is deemed appropriate for this publication. The conversion factor is: 1 gal of water = 8.33 lb.

the same object in Denver, where it is 1 mile above sea level. Objects further from the earth's center weigh less due to the change in gravitational pull. Scales are calibrated to measure objects of certified mass and account for the different gravitational pull at the location of use. The difference in weight due to elevation changes is insignificant within accuracy requirements for scales used for batch or test quantity measurements in ASTM C 94/C 94M.

Mass is a measure of how much material or matter is contained in an object. Mass does not change with gravitational force or altitude. The mass of an object remains constant. It is for this purpose that we use the term mass rather than weight. Within the context of the practical use of ASTM C 94/C 94M on earth, the user may substitute the concept of weight anytime the term mass is encountered.

Sentence one (**S1**) provides the basic method of checking the concrete yield as it has come to be called. Mathematically this can be stated as follows:

$$\text{Yield} = \frac{\text{Total mass (weight) of the batch}}{\text{Mass (weight) per unit volume of the concrete}}$$

The term in the denominator is the concrete density (mass per cubic foot or unit weight).

EXAMPLE 3.A—*Yield calculation.*

$$\frac{\text{Total mass of batch}}{\text{Density (Mass/unit volume)}} = \frac{32\ 000\ \text{lb}}{146\ \text{lb/ft}^3} = 219.18\ \text{ft}^3$$

$$\text{Yield} = \frac{219.18\ \text{ft}^3}{27.00\ \text{ft}^3/\text{yd}^3} = 8.12\ \text{yd}^3$$

The total mass (weight) of the batch may be determined by either of two methods. Sentence two (**S2**) describes these. The usual option is to begin with the sum of the masses (weight) of all materials in the batch including water from all sources. An alternate that is seldom used is to determine the mass (weight) of concrete as delivered. This option requires weighing the concrete and truck before delivery and weighing the empty truck after delivery. The difference is the net mass of the concrete as delivered. This option is very difficult to use because it involves accounting for fuel used between the truck scale site and the project site, water from the side tank used for washing out the truck, and any wash water remaining in the mixing drum as well as side tank water used to increase the slump of the concrete. This rather complicated method should be reserved for instances when it is suspected that the batch plant scales may be out of tolerance by a substantial amount.

The primary method of checking the concrete yield is by the use of the total mass (weight) of all the materials in the batch. This is determined from a computer printout for the batch plus water injected at the site or by a careful reading of plant scales plus water injected at the site.

S3 and **S4** provide specific instructions on the only acceptable method of determining the density (mass per unit volume) of the concrete. The specific rules set forth are sevenfold:

Rule 1: Obtain samples in accordance with ASTM Practice C 172.
Rule 2: Each sample shall be from the midpoint of load.
Rule 3: Use ASTM Test Method C 138/C 138M to determine the density.
Rule 4: Use a ½-ft³ [14 L] container to measure the density.
Rule 5: Each sample shall be from a different load.
Rule 6: Obtain samples from three or more batches.
Rule 7: Average all density measurements.

A complete example of the mathematics of the prescribed procedure with notes is demonstrated in Example 3.B.

Rules 1 and 2 dictate collecting two or more samples at regularly spaced intervals from the middle part of the batch during discharge with a maximum time interval of 15 min between obtaining the first and last sample. The portions of the sample from the same load shall be combined into a well-mixed composite sample and the density (unit weight) test begun within 5 min after obtaining the final portion of the composite sample. Some would debate the 5 min limit for the commencement of the density test, but a portion of what is being checked is the air content, which is the specific purpose for this time limit.

Rules 3 and 4 apply to the specifics of the test method. The minimum size of the unit volume shall be ½ ft³ [14 L]. This rules out smaller volume air meter bowls (pots) for yield checks or other small size containers based on the nominal maximum aggregate size described in ASTM C 138/C 138M. The reason for requiring the ½ ft³ [14 L] measure is for the improved accuracy of the density measurement compared to smaller size measures. ASTM C 138/C 138M provides criteria on when to consolidate by rodding and when to use a specific size of vibrator. ASTM Practice for Sampling Freshly Mixed Concrete (C 172) and ASTM Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete (C 138/C 138M) should be read carefully for details of procedures. For example, the scales used to weigh the empty density measure must be accurate to not less than 0.1 lb.

Very often when density tests of fresh concrete are taken and yields checked, there is a dispute concerning yield. When this is the case, it may be the expeditious procedure for both the supplier and purchaser to have qualified technicians, working in tandem and representing each of the parties, measuring the density on the same load or sample of concrete.

To obtain the yield, the information from each of the three batches used in the average density calculation is required. Those data are in Example 3.C on the next page.

Average relative yield of the three loads is 1.010. Any number equal to or greater than 1.0 indicates a satisfactory yield for the purchaser. ASTM C 94/C 94M does not offer any limits for acceptable relative yields or tolerances on the yield as ordered. It should be remembered that excessive yields without an increase in cementitious material can lower the concrete strength, or lower than design yields can be a result of low air content that may adversely affect the durability of the concrete.

Note 1*—It should be understood that the volume of hardened concrete may be, or appear to be, less than expected due to waste and spillage, over-excavation, spreading forms, some*

EXAMPLE 3.B—*Concrete density (unit weight) test.*

Load No.		2		3		5		7	
Tested by*		PT	RMT	PT	RMT	PT	RMT	PT	RMT
Conc. + Tare	lb.	87.64	95.33	87.21	95.28	87.83	94.64	86.87	95.39
Tare	lb.	18.47	19.33	18.47	19.33	18.47	19.33	18.47	19.33
Concrete	lb.	69.17	76.00	68.74	75.95	69.36	75.31	68.40	76.06
Tare Vol.	ft^3	0.48	0.53	0.48	0.53	0.48	0.53	0.48	0.53
Concrete Density	lb/ft^3	144.1	143.4	143.2	143.3	144.5	142.1	142.5	143.5
Difference	lb/ft^3	0.7		0.1		2.4†		1.0	
Remarks		OK		OK		Omit this set†		OK	

Load No.	Units	Purchaser's Technician	Ready-Mix Technician	Test Averages
2	lb/ft^3	144.1	143.4	143.8
3	lb/ft^3	143.2	143.3	143.2
5†		...	...	...
7	lb/ft^3	142.5	143.5	143.0
Avg. Density	lb/ft^3	143.3	143.4	143.3

* PT = Purchaser's Technician; RMT = Ready Mix Producer's Technician.

† The third set (load 5) is omitted from the calculations because the difference exceeds the ASTM C 138/C 138M acceptable precision for two properly conducted tests from the same sample. The allowable difference by two technicians is 2.31 lb/ft^3.

EXAMPLE 3.C—*Relative yield calculations.*

Line	Load No.		2	3	7
1	Load size	(yd^3)	10	10	8
2	1 in. coarse aggregate	(lb)	17 970	17 390	14 270
3	Sand	(lb)	13 500	13 260	10 760
4	Cement-Type I	(lb)	4 210	4 195	3 355
5	Fly ash	(lb)	930	910	740
6	Water	(lb)	2 350	2 360	1 900
7	Water on sand*	(lb)	400	429	355
8	Side tank water†	(lb)	83	50	0
9	Total mass (weight)‡	(lb)	39 443	38 594	31 380
10	Measured density§	(lb/ft^3)	143.8	143.3	143.0
11	Calculated yield (9 ÷ 10)	(ft^3)	274.4	269.4	219.4
12	Required yield, (27.0 × 1)	(ft^3)	270.0	270.0	216.0
13	Relative yield (11 ÷ 12)	(yd^3)	1.016	0.998	1.016

* Line 7 is actually weighed as a part of line 3 and is not a separate number from batch plant.

† Line 8 is measured in gallons and changed to pounds by multiplying gallons by 8.33 lb/gal.

‡ Line 9 is the total of Lines 2–8.

§ Line 10 is taken from the previous example of density measurements.

loss of entrained air, or settlement of wet mixtures, none of which are the responsibility of the producer.

This note is advisory to the producer and the purchaser on some of the items that can result in a discrepancy of yield as ordered. It informs the purchaser that when concrete hardens, its volume will be less than in its wet state. As mentioned before, this is due to the evaporation of water and reduction of volume when water chemically reacts with the cementitious materials. This change in volume will be approximately 2 % [18]. Part of the total group of losses includes a mortar coating inside the mixer drum, primarily on the fins. This mortar coating may amount to 400–600 lb (less than a wheelbarrow) and usually only affects the first load of the day [68]. Over-excavation or a low subgrade excavation needs no explanation, but a relatively small variation in the depth of a slab on grade will amount to a substantial difference in actual versus calculated volume of concrete. Spreading and bowing forms cause numerous complaints. The actual lateral pressure from fresh concrete can be 2000 lb/ft^2 in a wall and over 3000 lb/ft^2 in a column [45,52]. Pressures of these magnitudes will certainly stretch form ties and bow forming materials, thus increasing the quantity of concrete needed to reach the top of the structural element. On structural slabs the areas between supports will deflect under the mass (weight) of the fresh concrete, thus requiring a quantity greater than plan measurements to produce a level floor. The loss of entrained air by handling, such as through a pump, is going to reduce the concrete volume. Pump line coatings will also account for lost concrete. With wet mixtures there will be settlement as the excess water collects on the surface and evaporates or in trench or subgrade conditions as the concrete's excess water is absorbed by the earth.

There are so many scenarios that require ordering more concrete than plan quantities that knowledgeable contractors allow for concrete losses of 3–5 % [85] or sometimes where slabs on grade, unformed footings, or formed walls predominate, losses easily may be in the range of 5–12 % [23] or more. One estimating guide places waste (lost) concrete at 5–10 % [93].

Can a container 3 × 3 × 3 ft be constructed and one cubic yard of concrete be ordered to check the producers yield? The answer is simply no. Water losses may occur due to absorption by the box material, bowing of form materials will certainly occur, grout may escape the corner seams, entrained air may be lost, and the mortar coating on drum fins will be unproportionally excessive as compared to a full load, particularly for loads other than the first load of the day. A 3 × 3 × 3 ft box does not work. The concept advanced by ASTM C 138/C 138M of correctly checking a minimum of three loads for density (mass per unit volume) compared to the mass per batch does work and is the best method of solving questions or establishing the true yield of a mixture.

4 Ordering Information

4.1 In the absence of designated applicable general specifications, the purchaser shall specify the following.

This introduction to ordering information for concrete is intended to cover all situations. Either there are specifications that spell out specific requirements for the concrete, or the customer (purchaser) orders concrete with the minimum amount of information. The five items that follow need to be provided by an individual familiar with the project and cannot be the responsibility of the producer.

4.1.1 Designated size, or sizes, of coarse aggregate

The phrase "size or sizes" refers to one concrete mixture or multiple concrete mixtures, which may have varying top sizes of coarse aggregate. The order can be in terms of top size of coarse aggregate, such as ¾ in., or a size designation, such as Number 57. The coarse aggregate size normally is dictated by using the largest size that is readily available, but that is small enough that the nominal maximum size shall not exceed three-fourths of the minimum clear spacing between reinforcing bars, one-fifth of the narrowest dimension between sides of forms, or one-third of the thickness of slabs or toppings. Commonly, the readily available coarse aggregates will have nominal maximum sizes of ¾ in. up to 1½ in. in ¼ in. increments. Larger sizes are usually by special order and require large quantity orders to merit special production. A size of coarse aggregate that is smaller than the allowed maximum is often used for greater workability or for ease of finishing.

The term "nominal maximum size" of an aggregate is the smallest sieve opening through which the entire amount (100 %) of the aggregate is permitted to pass. A typical coarse aggregate grading specification that defines Size designations is in Table 2 Grading Requirements for Concrete Aggregates of ASTM C 33. This specification provides for up to 10 % of a sample to be retained on the smallest sieve through which all of a sample is permitted to pass. The discussion in ASTM Terminology Relating to Concrete and Concrete Aggregates (C 125) concerning the nominal maximum size reads as follows:

> "Discussion—Specifications on aggregates usually stipulate a sieve opening through which all of the aggregate may, but need not, pass so that a stated maximum proportion of the aggregate may be retained on that sieve. A sieve opening so designated is the nominal maximum size of the aggregate."

4.1.2 Slump, or slumps, desired at the point of delivery (see Section 6 for acceptable tolerances)

The slump for each different concrete mixture measures the consistency desired for each mixture. The slump measurement is described in ASTM C 143/C 143M as the vertical distance between the original and displaced position of the center of the top surface of the concrete compacted, by rodding, in a mold, which is then raised, allowing the concrete to subside. Specified slumps may range from zero-slump to 10+ in., but the most common range is 3–5 in. Slumps shall be specified for measurement at the point of discharge from the transportation unit at the job site. The discharge point, generally at the chute of the delivery vehicle, is the location where the producer ceases to have control over, or responsibility for, the mixture.

4.1.3 When air-entrained concrete is specified, the air content of the samples taken at the point of discharge from the transportation unit (see Section 7 and Table 1 for the total air content and tolerances) (Note 2)

If concrete is to be in a location that will be exposed to cycles of freezing and thawing while it is saturated or near saturated, or if it will be exposed to deicing salts, entrained air must be ordered for the protection of the concrete. In the late 1930s and early 1940s, the benefit of these tiny entrained air bubbles was discovered. Proper air entrainment in concrete, so exposed, in conjunction with other good concreting practices, will prevent surface scaling of the concrete. Microscopic air bubbles such as these are not visible to the naked eye. Readily available field equipment cannot measure the size or number of these air bubbles, but it can measure the total quantity of air in a concrete mixture. These tests will be discussed later. Experience and research has demonstrated that an air content of approximately 9 % of the volume of the mortar segment of the concrete is needed for adequate freeze-thaw resistance. Based upon customary mixture proportions of coarse aggregate/mortar ratio, the values of Table 1 will provide approximately 9 % air in the mortar fraction. Test methods to determine the total air content of the concrete rather than only the mortar fraction were developed. This concept of total air content has come to be the standard by which the air content is measured and also specified.

Table 1 recommends total air contents considering exposure conditions and the nominal maximum aggregate size of the concrete mixture. Note C to Table 1 identifies ACI 211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete as the source of definitions for mild, moderate, and severe exposure. Section 6.3.3 of ACI 211.1-91 provides the following definitions:

Mild exposure—When air entrainment is desired for a beneficial effect other than durability, such as to improve workability or cohesion or in low cement factor concrete to improve strength, air contents lower than those needed for durability can be used. This exposure includes indoor or outdoor service in a climate where concrete will not be exposed to freezing or to deicing agent.

Moderate exposure—Service in a climate where freezing is expected but where the concrete will not be continually exposed to moisture or free water for long periods prior to freezing and will not be exposed to deicing agents or other aggressive chemicals. Examples include: exterior beams, columns, walls, girders, or slabs that are not in contact with wet soil and are so located that they will not receive direct applications of deicing salts.

Severe exposure—Concrete that is exposed to deicing chemicals or other aggressive agents or where the concrete may become highly saturated by continued contact with moisture or free water prior to freezing. Examples include: pavements, bridge decks, curbs, gutters, sidewalks, canal linings, or exterior water tanks or sumps."

Note 2—$_{S1}$ *In selecting the specified air content, the purchaser should consider the exposure conditions to which the concrete will be subjected.* $_{S2}$ *Air contents less than shown in Table 1 may not give the required resistance to freezing and thawing, which is the primary purpose of air-entrained concrete.* $_{S3}$ *Air contents higher than the levels shown may reduce strength without contributing any further improvement of durability.*

The use of these criteria allows selection of the proper horizontal row in Table 1. Note that for a given size coarse aggregate, the recommended air content varies with each exposure condition. The severe exposure is based on an air content that will produce approximately 9 % air in the mortar fraction. The severity of exposure that includes the number of freeze-thaw cycles and length of cycles each affect the quantity of air needed for durability. Concrete placed in moderate exposure conditions needs approximately 7 % air in the mortar. Note that one of the differences between severe and moderate is the exposure of the concrete to the application of deicing salts.

The definition for mild exposure provides several advantages of using some entrained air, even in climates which do not produce freeze-thaw conditions. High air contents, however, will decrease the strength of moderate to high cement content concrete. This is reason enough to limit the air content to the recommended amounts of Table 1.

The concept of entrained air increasing the strength of low cement content mixes and decreasing the strength of high cement factor mixtures requires some explanation. Several independent factors must be considered, beginning with a reduced water requirement for an entrained air mixture compared to a non-air entrained mix for the same target slump. Entrained air provides increased workability and increases slump if water is not decreased. The decrease in mixing water to achieve the same slump is approximately 5 gal per yd^3. Example 4.A demonstrates the change in water-cement (w/c) ratio for two different cement contents and addresses the strength variation because of the addition of entrained air. The compressive strength versus water-cement ratios is interpolated from Table 6.3.4(a) of ACI 211.1. The mixture with 400 lb of cement/yd^3 will have a slight increase in strength due to the lower water content of the mixture caused by the addition of entrained air. The mixture with 600 lb of cement/yd^3 will have a decrease in strength because strength gained by the lower water content is of a smaller magnitude than the loss of strength due to the air entrainment. Because of the addition of air entrainment, these shifts in strength are limited to cementitious contents of approximately below and above 500 lb/yd^3 and to air contents in a normal range of less than 7.5 % [34].

EXAMPLE 4.A—*Strength changes with air-entrainment.*

	Without Air-Entrainment			With Air-Entrainment		
Cement, lb	Water, gal*	W/C ratio	Estimated Strength, psi†	Water, gal*	W/C ratio	Estimated Strength, psi†
400	36	0.75	2500	31	0.65	2600
600	36‡	0.50	4800	31	0.43‡	4600

* Mass of water is obtained by multiplying gallons times 8.33 lb/gal.
† ACI 211.1 values for estimated minimum strengths versus w/c ratio have been used.
‡ ACI 211.1 does not design for increased water contents being needed with greater cement contents, but the basic principle is demonstrated by the use of 36 gallons with each mixture.

Table 1 recommends lower required air contents as the aggregate sizes increase. This is due to the fact that concrete with larger size aggregates have a lower proportion of mortar. The only segment of the mixture being entrained with air is the mortar. Nine percent of a lower volume fraction of mortar translates to a lower total air content in the concrete. These changes in mortar fraction center around the fact that larger (well-graded) aggregates have a smaller percentage of voids between the aggregate particles than do mixtures of small sized (well-graded) aggregate. Fewer voids translate to less mortar per unit volume.

TABLE 1—*Recommended total air content for air-entrained concrete.*[A,B]

	Total Air Content, %						
	Nominal Maximum Sizes of Aggregate, in. [mm]						
Exposure Condition[C]	*3/8 [9.5]*	*1/2[12.5]*	*3/4[19.0]*	*1 [25.0]*	*1 1/2[37.5]*	*2 [50.0]*	*3 [75.0]*
Mild	*4.5*	*4.0*	*3.5*	*3.0*	*2.5*	*2.0*	*1.5*
Moderate	*6.0*	*5.5*	*5.0*	*4.5*	*4.5*	*4.0*	*3.5*
Severe	*7.5*	*7.0*	*6.0*	*6.0*	*5.5*	*5.0*	*4.5*

[A] *For air-entrained concrete, when specified.*
[B] *Unless exposure conditions dictate otherwise, it is permissible to reduce air contents recommended above by up to 1 % for concretes with specified compressive strength,* f'_c, *of 5000 psi [35 MPa] or above.*
[C] *For description of exposure conditions, refer to Standard Practice ACI 211.1, Section 6.3.3, with attention to accompanying footnotes.*

To illustrate an example of the use of Table 1, consider a northern state with exterior concrete usually being wet during freezing. The geographic area often uses deicing salts on the streets. The concrete is to be used in curb and gutter and will have a nominal maximum aggregate size of ¾ in. Severe exposure condition coupled with ¾ in. aggregate dictates a recommended air content of 6.0 %.

4.1.4 *Which of Options A, B, or C shall be used as a basis for determining the proportions of the concrete to produce the required quality, and*

The three ordering options (A, B, and C) divide the responsibilities for mixture proportions and related information into specific responsibility groups for the manufacturer and the purchaser. The division of responsibilities is listed in Table 4.A. The purchaser may select any one of the three and shall then furnish the specific information required based upon the particular option.

4.1.5 *When structural lightweight concrete is specified, the mass per unit volume as wet mass, air-dry mass, or oven-dry mass (see Note 3).*

Note 3—$_{S1}$ *The mass per unit volume of fresh concrete, which is the only unit mass determinable at the time of delivery, is always higher than the air-dry or oven-dry mass.* $_{S2}$ *Definitions of, and methods for determining or calculating air-dry and oven-dry masses are covered by Test Method C 567.*

The density (mass per unit volume) of structural lightweight concrete can vary substantially depending upon the aggregates used. The purchaser must provide the desired density and the test condition to be used to determine the specified density. The equilibrium density (air-dry density) of structural lightweight concrete can vary from approximately 90–120 lb/ft^3. The typical range is 100–115 lb/ft^3 with only the coarse aggregate being lightweight or 90–100 lb/ft^3 if both fine and coarse aggregate are lightweight. A good rule of thumb is the lower the specified density (unit weight), the higher the potential cost of the concrete. Equilibrium density is a standard way of defining the anticipated concrete density (equilibrium air-dry unit weight) of the concrete in the structure after some of the water has dissipated. The terminology of ASTM Test Method for Determining Density of Structural Lightweight Concrete (C 567) and test methods has changed considerably in recent years. If a user is not familiar with

TABLE 4.A—*Ordering options.*

Item		Option A	Option B	Option C
Maximum Nominal Aggregate Size	By	Purchaser 4.1.1	Purchaser 4.1.1	Purchaser 4.1.1
Slump at Point of Delivery	By	Purchaser 4.1.2	Purchaser 4.1.2	Purchaser 4.1.2
Air Content at Point of Delivery	By	Purchaser 4.1.3	Purchaser 4.1.3	Purchaser 4.1.3
Selection of Ordering Option "A", "B", or "C"	By	Purchaser 4.1.4	Purchaser 4.1.4	Purchaser 4.1.4
Density (unit weight) for Structural Lightweight Conc.	By	Purchaser 4.1.5	Purchaser 4.1.5	Purchaser 4.1.5
Mixture Proportions	By	Manufacturer 4.2.1	Purchaser 4.3.1	Manufacturer 4.4.1
Cement Content	By	Manufacturer 4.2.1	Purchaser 4.3.1.1	Manufacturer (above min.) 4.4.1
Compressive Strength Specified	By	Purchaser 4.2.1.1	...	Purchaser 4.4.1.1
Minimum Cement Content	By	...	...	Purchaser 4.4.1.2
List of Ingredients and Quantities of Each	By	Manufacturer 4.2.2	Manufacturer 4.3.2	Manufacturer 4.4.2
Proof of Mixture Strength	By	Manufacturer 4.2.2	...	Manufacturer 4.4.2
Proof of Material Quality	By	Manufacturer 4.2.2	...	Manufacturer 4.4.2
Proof of Other Concrete Qualities Specified	By	Manufacturer 4.2.2	...	Manufacturer 4.4.2
Maximum Water Content	By	...	Purchaser 4.3.1.2	...
Maximum Water-Cement Ratio	By	...	...	...
Required Admixtures	By	...	Purchaser 4.3.1.3	Purchaser 4.4.1.3
Aggregate: relative density (sp gr), gradation, sources	By	...	Manufacturer 4.3.2	...

the terms used above, it is recommended that a current copy of ASTM C 567 be consulted and the changes noted.

There is a limited range of density (unit weight) a producer can achieve with a given aggregate. It is in the specifier's best interest to determine what density is achievable with the commonly available lightweight aggregates before the design stage. The decision of the cost-effectiveness of specifying a concrete with a lower density (unit weight) that requires special and more expensive aggregates is then made. Any need to pump the lightweight concrete should be indicated during initial discussions. This need can affect the mixture proportions, density (unit weight), and cost.

Section 4.1.5 specifies that the method of measuring the density (mass per unit volume) is to be specified as wet mass (fresh or plastic concrete), air-dry mass, or oven-dry mass. The same concrete will have a different density at each of these conditions. ASTM C 567 is referenced in Note 3. ASTM C 567 specifies several test requirements for each type of density determination as shown in Table 4.B.

Freshly mixed concrete density (ASTM C 138/C 138M) is the only test that can be performed and completed in a timely manner to permit mixture adjustments the day of a concrete placement. All types of density are only determined well after it is too late to correct potential problems. ACI 301 Specifications for Structural Concrete requires proportioning lightweight concrete mixtures to meet the specified limit on maximum equilibrium density determined by ASTM C 567. It also requires correlating equilibrium density with the fresh bulk density of the concrete and using the fresh bulk density as the basis for acceptance during construction.

ASTM C 94/C 94M permits the purchaser to specify the maximum density of lightweight concrete to be measured by wet density (mass), air-dry density (mass), or oven-dry density (mass). The wet density (ASTM C 138/C 138M) is the only practical method of verifying the concrete density as delivered and is encouraged as the method of specifying and ordering.

Structural engineers need the equilibrium (air-dry) density for dead load design purposes. Note 1 of ASTM C 567 helps with this by stating that the equilibrium density will be approximately 3.0 lb/ft^3 greater than the oven-dry density. The oven-dry density can be determined in approximately one week or can be calculated from the mixture proportions of the concrete. This close correlation between oven-dry density and equilibrium density provides sufficient accuracy for the Architect/Engineer (A/E). The ASTM C 138/C 138M freshly mixed density can be determined when the cylinders for oven-dry density determination are made so that a correlation is established. A comparison between freshly mixed density and oven-dry density is then possible. Note 3 of ASTM C 567 cautions that fresh density tests made by using 6 × 12 in. cylinder molds rather than the prescribed 0.5 ft^3 measure will indicate a greater fresh density by approximately 2.5 lb/ft^3. Use the prescribed 0.5 ft^3 metal bucket for best results.

On average, a density variation between fresh lightweight concrete and equilibrium (air-dry) lightweight concrete of 3–12 lb/ft^3 should be expected [21,43]. For mixtures with both lightweight fine and coarse aggregate, a range of 6–12 lb/ft^3 is expected [21]. For mixtures with only coarse lightweight aggregate, the expected difference is only 3–6 lb/ft^3 [21].

Should time or circumstance prevent pre-construction testing, the ready-mixed concrete producer may have historical densities that will provide the needed comparisons. Another potential source of historical density data is the manufacturer of each lightweight aggregate usually available in the geographic location. ASTM C 567 provides a means to calculate the equilibrium density from the mixture proportions expressed on an oven-dry basis.

4.2 Option A

4.2.1 When the purchaser requires the manufacturer to assume full responsibility for the selection of the proportions for the concrete mixture (Note 4), the purchaser shall also specify the following:

Even though the purchaser wants the manufacturer (ready-mixed concrete producer) to accept full responsibility for the concrete performance, there are certain decisions the purchaser or his agent (A/E) must make before the proportioning process can begin.

4.2.1.1 $_{S1}$ *Requirements for compressive strength as determined on samples taken from the transportation unit at the point of discharge evaluated in accordance with Section 17.* $_{S2}$ *The purchaser shall specify the requirements in terms of the compressive strength of standard specimens cured under*

TABLE 4.B—*Lightweight concrete density testing procedures (ASTM C 567).*

	Freshly Mixed Concrete Density	Oven-Dry Density	Equilibrium Density	Air-Dry Density*
Method C 138/C 138M	Yes	No	No	No
Measure Size	0.5 ft^3	6 × 12 in. cyl	6 × 12 in. cyl	6 × 12 in. cyl
Concrete Sampling	C 172	C 172	C 172	C 172
Molding Field Cylinders	C 31/C 31M†	C 31/C 31M or C 192/C 192M	C 31/C 31M or C 192/C 192M	C 192/C 192M
Curing Time (Initial)	. . .	24–32 h	6 days	6 days
Curing Temperature (Initial)	. . .	60–80°F	60–80°F	60–80°F
Curing Time 2nd Period	. . .	72 h+	24 h	24 h
Curing Temperature 2nd	. . .	230°F	73.5°F	73.4°F
Curing Time 3rd Period	. . .	. . .	21 days +	21 days
Curing Temperature 3rd	. . .	. . .	73.5°F	73.4°F
Curing Humidity 3rd	. . .	. . .	50 % RH	50 % RH

* Air-dry density has been replaced in ASTM C 567 by equilibrium density.
† Not recommended for fresh density (unit weight).

standard laboratory conditions for moist curing (see Section 17). $_{S3}$ *Unless otherwise specified, the age at test shall be 28 days.*

The ordering information previously stated that the purchaser must furnish coarse aggregate sizes, slumps, desired air contents, and, if lightweight concrete is involved, the desired equilibrium or fresh density (mass per unit volume). If Option A is selected, the purchaser needs to additionally select the compressive strength. **S1** states that the specified compressive strength is to be based upon concrete sampled at the point of discharge from the truck mixer or other transportation unit. The reference to Section 17 identifies very specific sampling, molding, curing, handling, and testing procedures. **S2** verifies that requirements of the compressive strength are to be measured by standard specimens cured under the rigid requirements of Standard Curing defined in ASTM C 31/C 31M. Field curing for acceptance is not an option. The purpose of field curing is to obtain an estimate of the in-place concrete strength to schedule operations such as form removal or to verify if curing and protection afforded to the structure during construction was adequate. Placing cylinders indoors but without the benefit of a closely controlled temperature of 73 ± 3°F and a relative humidity of 95 % or more is unacceptable. By the same token, the temperature and humidity controls of the storage of cylinders during the period of initial curing in the field is critical to the measured strength and by extension to whether the concrete complies with the specified strength. The point to be considered is that the manufacturer (producer) has no control over the concrete after it leaves the transportation unit. The use of standard cylinders with standard curing conditions indicates the strength the manufacturer's product is capable of achieving, if properly handled and cured by the purchaser or purchaser's agent. If the actual field strength is needed, make some extra cylinders, but do not use them as the basis of acceptance of the quality of concrete delivered. Only standard cylinders as prescribed in Section 17 are allowed for acceptance or rejection of concrete.

S3 is used to set the age at which the specified strength should be attained. Concrete will gain strength daily for many months and often years. The rate of increase begins with a rapid change and then attains a pattern of a decreasing rate with each passing day. A typical strength requirement would be "Provide concrete with a compressive strength of 4000 psi at 28 days." Section 4.2.1.1 prescribes all the other particulars for testing the concrete and evaluating the strength.

Note 4—$_{S1}$ *The purchaser, in selecting requirements for which he assumes responsibility should give consideration to requirements for workability, placeability, durability, surface texture, and density, in addition to those for structural design.* $_{S2}$ *The purchaser is referred to Standard Practice ACI 211.1 and Standard Practice ACI 211.2 for the selection of proportions that will result in concrete suitable for various types of structures and conditions of exposure.* $_{S3}$ *The water-cement ratio of most structural lightweight concretes cannot be determined with sufficient accuracy for use as a specification basis.*

This note points out that the purchaser or his agent, in defining the various purchaser-specific information, should consider constructability (workability and placeability), life and use conditions of the structure (durability) and appearance (surface texture). The concrete density referenced in **S1** concerns the use of lightweight aggregates, heavyweight aggregates, or normal weight aggregates. Normal weight is assumed unless otherwise specified. **S1** also serves as a reminder that air entrainment affects the density of concrete, freeze-thaw durability, and texture.

S2 references the two ACI documents that are directed at proportioning normal weight, heavyweight, and lightweight concrete. ACI 211.1 provides detailed considerations and procedures for proportioning normal weight and heavyweight concrete. ACI 211.2 Standard Practice for Selecting Proportions for Structural Lightweight Concrete does the same for lightweight concrete proportioning.

S3 is a reminder that water-cement ratio versus strength curves is difficult to establish with adequate accuracy to be used as a basis for the strength design of lightweight concrete. Manufactured lightweight aggregates are commonly very porous, irregularly shaped, and rough textured, making it extremely difficult to separate absorbed water that is not available for reaction with cement and surface moisture, which may be hidden in open surface pores and is available for hydration reaction with the cement. The total cement content needed with each source of lightweight aggregate for a specific strength is a common proportioning procedure. In the absence of such data, ACI 211.2-98 provides design charts to estimate cementitious quantities for a first trial batch.

A potential change in this specification involves Note 4. There has been considerable interest within subcommittee C 09.40 to transfer a portion of the non-mandatory items of the note into the body of the specification, thus compelling the purchaser to assume responsibility for specifying requirements that will ensure that the structure will be durable in its intended application, when ordering the concrete and the subsequent mixture proportions to be furnished. The emphasis is expected to be on the purchaser or the design professional for a project to determine needs such as maximum water-cement ratios, special types of cement to combat sulfate attack, or the addition of supplementary cementitious materials to decrease the permeability of the concrete or other necessary specific requirements and then to communicate these needs to the manufacturer. The communication could be in the form of written specifications or orally in advance of a delivery order for the concrete.

It is not possible for every manufacturer to be a design professional with regard to each durability situation that may be encountered. All situations are different, and each needs a separate comprehensive evaluation whether the project is a sports stadium, a sanitary sewage treatment facility, a food freezer plant, or a hog house floor for the controlled production of pork. The issues often translate to the cost as a major component in the evaluation process, and ultimately the decision must be made by the purchaser.

Many manufacturers have personnel on staff or available to them on a consulting basis that are capable of assisting the purchaser with evaluations and potential solutions to a situation, but in the end the purchaser must be responsible for the decision and the ordering of the appropriate concrete. By extension, the purchaser should be aware of local code requirements for the structure being constructed and include specification requirements for the concrete that address those code requirements. Since the manufacturer seldom knows where the concrete will be placed, he is not in a position to make the judgment whether concrete furnished complies with the code.

Dr. Bryant Mather, former Director, Structures Laboratory, U.S. Army Engineer Waterways Experiment Station, proposed the best short set of instructions possible for durable concrete in a (1994) paper [50]: "Prepare specifications that require appropriate levels of relevant properties of concrete so that the concrete can resist the deteriorative influence it will encounter in service." The most important part of this statement is "require appropriate levels of relevant properties." In short, specify what you need, but not more than you need.

4.2.2 $_{S1}$ *At the request of the purchaser, the manufacturer shall, prior to the actual delivery of the concrete, furnish a statement to the purchaser, giving the dry masses of cement and saturated-surface-dry masses of fine and coarse aggregate and quantities, type, and name of admixtures (if any) and of water per cubic yard or cubic meter of concrete that will be used in the manufacture of each class of concrete ordered by the purchaser.* $_{S2}$ *He shall also furnish evidence satisfactory to the purchaser that the materials to be used and proportions selected will produce concrete of the quality specified.*

The purchaser is entitled to specific information about the mixture proportions and materials, but according to Option A they must be requested, otherwise they need not be furnished. **S1** very specifically spells out everything that goes into a concrete mixture and says the purchaser is entitled to the ingredients and quantities of each before any concrete is delivered. Some would argue that various cementitious materials such as pozzolans are not included, but they are wrong. ASTM Terminology Relating to Concrete and Concrete Aggregates (C 125) dispels any such notion to omit pozzolans.

> "admixture, n—a material other than water, aggregates, hydraulic cementitious material, and fiber reinforcement that is used as an ingredient of a cementitious mixture to modify its freshly mixed, setting, or hardened properties and that is added to the batch before or during its mixing."

Pozzolans are clearly included in this current definition as admixtures because they do not necessarily have cementitious value by themselves. The word cement, rather than cementitious material, may seem like a gray area, but when viewed as a whole, the intent is very clear. The term "cement" in this paragraph goes back to a time when it was unusual to have a cementitious material other than portland cement, but it now includes all hydraulic cementitious materials. The intent is clear that each and every cementitious material and admixture with its quantity is to be listed.

S1 calls for the disclosure of all mixture proportions in a customary format of dry masses (weights) of cementitious materials, saturated-surface-dry masses (weights) of each fine aggregate, and each coarse aggregate. The SSD mass (weight) of aggregates is the typical approach because the absorbed water in the aggregate pores does not usually react with the cement, but surface water on the aggregates constitutes a portion of the mixing water. Surface water is therefore included with the water quantity used for the manufacture of concrete. If any admixtures are used, solid or liquid, they shall be listed by type (water reducer, fly ash, etc.), name (brand or supplier), and quantity. Quantities for admixtures may be listed by mass (weight) or volume (oz/yd^3 or oz/cwt of cement). See Example 4.B.

EXAMPLE 4.B—*Satisfactory mixture proportion submittals.*

Item		Mixture ID	
		4000 psi	3500 psi w/Air
Cement (manufacturer A, Type I)	lb	470	440
Fly ash (Class C, supplier D)	lb	50	80
Coarse aggregate (No. 57 limestone) SSD	lb	1750	0
Coarse aggregate (5/8 in. gravel) SSD	lb	0	1850
Fine aggregate (washed sand), stream E	lb	1480	1155
Water, potable	gal	30	30
Water reducer (manufacturer B, Normal set)	oz/yd^3	14	14
Air entrainment (manufacturer C, AEA)	oz/yd^3	0	4

S2 is much more demanding on the ready-mixed concrete manufacturer than is the proportioning information of **S1**. Manufacturer shall furnish satisfactory evidence to the purchaser that "concrete materials" and "mixture proportions" will produce concrete of the quality specified. There may be special requirements by the purchaser, which both material suppliers and manufacturers need to consider. These could take the form of optional requirements for a special cement, test results on a 12-month long aggregate test, extraordinarily lightweight concrete to which the producer is not accustomed, or a myriad of other possibilities.

A purchaser may want nothing more than a recent grading test of the coarse and fine aggregate and the relative density (specific gravity) of each. The latter is presumably to check the yield of the mixture proportions submitted. A manufacturer should do much more than this for the protection of the customers and himself. Virtually every material used in concrete has some established written requirements that are set forth in an ASTM material specification. The manufacturer (ready-mixed concrete producer) should require copies of the certification tests from suppliers on a regular basis.

Cement properties are prescribed by ASTM Specification for Portland Cement (C 150), ASTM Specification for Blended Cements (C 595), and ASTM Performance Specification for Hydraulic Cement (C 1157). Cement manufacturers test each product on a regular basis and make these test results available to their customers. Suppliers of fly ash do tests prescribed in ASTM Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete (C 618). Such tests are typically available to customers on a regular basis of not less than once per month. The same is true for ground granulated blast-furnace slag which conforms to ASTM Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars (C 989); silica fume described in ASTM Specification for Use of Silica Fume as a Mineral Admixture in Hydraulic-Cement Concrete, Mortar, and Grout (C 1240) also has prescribed physical and chemical requirements which are tested often by their suppliers. Chemical admixtures are commonly placed through a series of physical certification tests, which are then available to users. The specifications for chemical admixtures are ASTM Specification for Air-Entraining Admixtures for Concrete (C 260), ASTM Specification for Chemical Admixtures for Concrete (C 494/C 494M), and ASTM Specification for Chemical Admixtures for Use in Producing Flowing Concrete (C 1017/C 1017M). These physical tests are not performed continuously to prove performance. Physical and chemical checks are performed regularly to ensure the consistency of the product. These tests include items such as pH, solids content, and specific gravity.

Aggregates are prescribed to meet ASTM C 33 or ASTM Specification for Lightweight Aggregates for Structural Concrete (C 330), depending on whether they are normal weight or lightweight. The list of tests prescribed for each product is rather lengthy, and unless a product is borderline, many of the tests are not performed more than annually, if that often. Many state highway departments require annual testing.

Should the purchaser desire material tests or material certification tests not older than a specific time period, such as one year or one month, it is best to provide such a request before issuing a purchase order. The information may not be readily available and for whatever reason may not be attainable prior to the placement date of the concrete. ACI 301 requires that all aggregate tests be not more than 90 days old at the time of submittal for approval of use.

As the era of using truck washout water, captured rainfall runoff water, and plant washoff water intensifies, certifications concerning batch water and submittal of batch water test results will become common.

S2 of 4.2.2 requires the manufacturer (ready-mixed concrete producer) to submit evidence that the proportions selected will produce the quality of concrete desired. When Option A is selected, this usually means historical data from one or more sets of concrete cylinders or trial mixture test results. Information commonly provided from the fresh concrete tests will be slump, air content, temperature, and often the density (unit weight). For projects utilizing the ACI 301 specification, this requirement is for at least ten consecutive sets of strength tests for the mixture and tests ranging over a period of at least 60 days. If such testing results are not available, ACI 301 has an alternate procedure for using two groups of compressive strength tests with different water-cement ratios to verify the strength versus water-cement ratio with the proposed materials. Another alternative within ACI 301 is to prepare at least three trial mixtures, each having a different cementitious material content. Compressive strength cylinders from each mixture are compared and a design mixture is prepared based upon the data and the appropriate safety factor to produce the required average compressive strength. The required average strength of the designed concrete mixture is greater than the specified strength to account for batching variations and cylinder strength variations and to maintain a satisfactory average project strength. Those not using ACI 301 may have different requirements.

On projects involving fewer statistical needs than incorporated in ACI procedures, it may be satisfactory to approach the strength submittal in a less sophisticated manner. The quickest approach would be compressive strength tests for the proposed mixture from a previous use, even though there are less than ten sets. A second possibility is to batch the proposed mixture and take test samples from the middle portion of the batch. This can be accomplished on a job or at the batch plant. The latter test site will require using a portion of the batch at the plant or off-loading a segment of the load to another truck at a high-low transfer station.

Both ACI 301 specifications and other specifications allow for laboratory mixing and confirmation cylinders. There are varying views as to the reliability of "labcrete" submittals, but it probably depends upon the experience, understanding of the problem, and care with which the laboratory operates.

Whatever the circumstances under which test cylinders are obtained, it is essential that slump, air content, and temperature determinations be performed and results be reported along with compressive strength test results.

4.3 Option B

4.3.1 *When the purchaser assumes responsibility for the proportioning of the concrete mixture, he shall also specify the following:*

Option B is the only one of the three ordering options that allows the purchaser to prescribe mixture proportions. Since the purchaser is assuming responsibility for proportioning the mixture, the manufacturer is thereby constrained in making adjustments or optimizing the mixture for any intended performance and therefore cannot be held responsible if the intended performance requirements are not satisfied. The purchaser should be aware of the limitations of local materials and common practice when choosing this option. When selecting this option, the purchaser must specify at least three specific items, if desired, as discussed below.

4.3.1.1 *Cement content in bags or pounds per cubic yard [kilograms per cubic meter] of concrete*

The cement content is a specific quantity and not a minimum quantity. This difference is very great and should not be confused. The purchaser in Option B states an exact quantity of cement, by mass, which is to be used. The allowance is made for the quantity to be specified in bags per cubic yard. Traditionally, if a 5 bag (5 sack) mix were specified, it means 94 times 5 (470 lb) per cubic yard. Note 10 of ASTM C 94/C 94M currently verifies this quantity, but this is changing. As cement specifications have converted to SI units or combined units, the quantity of cement in a standard bag has been questioned and has changed in ASTM C 150. The new quantity is 42 kg (92.59 lb) per bag. ASTM C 94/C 94M will soon follow ASTM C 150 and is expected to change Note 10 to conform to 92.6 lb per bag. With this change, the request for a "5 bag mix" will be specifying 92.6 times 5 (463 lb/yd^3).

Does the specified cement content mean portland cement? Not necessarily, because the blended cements contain pozzolans or other cementitious products. ACI documents often use the term cementitious materials, which includes cements, pozzolans, ground granulated blast-furnace slag, silica fume, and metakaolin. ASTM C 94/C 94M does not do this. In Section 5 "Materials," cement is confined to materials meeting ASTM C 150 portland cements, C 595 blended cements, and C 1157 hydraulic cements. The other cementitious materials are specified separately as "mineral admixtures"[3] or GGBF slag. The latter items do not yet count as cement without the purchaser's approval.

4.3.1.2 *Maximum allowable water content in gallons per cubic yard [liters per cubic meter] of concrete, including surface moisture on the aggregates, but excluding water of absorption (Note 4), and*

Part of the purchaser's obligation with Option B is to specify a maximum water quantity. The quantity described includes all water that affects cement hydration and workability of the concrete. This includes free water on the surface of the aggregates but excludes water the aggregates will absorb. The absorbed water is not available to the concrete for reaction with the cement and is therefore not included as a part of the prescribed maximum water content. The reference to Note 4 is a reminder that the water quantity must consider workability, placeability, durability, surface texture, and density in addition to strength. (See discussion of Note 4 following 4.2.1.1).

Note that C 94/C 94M does not provide for specifying a water-cement or water-cementitious materials (w/cm) ratio. It may be specified that way if there is a proper understanding how the w/cm ratio relates to the total quantity of cementitious materials allowed in the concrete. The water quantity must be a maximum due to the probabilities that aggregate grading variations will affect the water content needed to provide a specific slump value or workability the purchaser may desire. Some of the other variables that affect slump are changes in aggregate shape and texture, air content, temperature, minor variations in fine to coarse aggregate ratio with each successive load in addition to variations in cementitious materials, and minor differences in hauling equipment or conditions.

An example is that the purchaser may specify a maximum mixing water quantity of 32 gallons per cubic yard of concrete. The slump as specified in Section 4.1.2 is to be 4 in. Moisture conditions and water quantities are as shown in Example 4.C for an 8-yd^3 batch.

4.3.1.3 $_{S1}$ *If admixtures are required, the type, name, and dosage to be used* must be noted. $_{S2}$ *The cement content shall not be reduced when admixtures are used under this option without the written approval of the purchaser.*

[3] Mineral admixture, n—a deprecated term. Both ASTM and ACI are discontinuing use of the term "mineral admixture." The materials that were formerly grouped under the name "mineral admixtures" are actually supplementary cementitious materials (SCM) in the presence of cement [48,72]. These materials are now becoming identified as (SCM), although when possible it is deemed appropriate to use the name of the specific cementitious material referenced.

The use of admixtures is optional with the purchaser when Option B is used. Admixtures include both supplementary cementitious materials (SCM), solid, and chemical admixtures. The **name** refers to broad categories of admixtures, such as water reducer, fly ash, silica fume, accelerator, or other categories, such as color pigments or fibers. The **name** does not mean a brand name. In Section 13, the term "brand" is used when a brand name is desired. The imposition of a brand name by a purchaser is a rare circumstance that is usually not in the purchaser's best economic interest. **Type** further defines the admixture as to a grade, class, performance category, or other subgroup of the named admixture. Examples include class of fly ash, grades of slag, chemical admixtures by classifications defined in ASTM C 494, C 1017, or C 260, water reducer performance categories such as normal range, mid-range, high-range (superplasticizer), or description of the base, such as a lignin water reducer. It is recommended that the purchaser order the type of chemical admixtures by classification reference to the pertinent admixture specifications, such as ASTM C 494, Type A. **Dosages** are typically specified in either pounds or ounces per cubic yard or per hundredweight (cwt) of cementitious materials. There are no restrictions on dosage unit methods, with clarity and repeatability being the only criteria.

S2 confirms that the specified cement content of Section 4.3.1.1 is to be honored and cannot be reduced through the use of an admixture unless the purchaser provides a written approval for a specific reduction.

4.3.2 *At the request of the purchaser, the manufacturer shall, prior to the actual delivery of the concrete, furnish a statement to the purchaser giving the sources, densities, and sieve analyses of the aggregates and the dry masses of cement and saturated-surface-dry masses of fine and coarse aggregate and quantities, type and name of admixture (if any) and of water per cubic yard or cubic meter of concrete that will be used in the manufacture of each class of concrete ordered by the purchaser.*

This Option B requirement is identical to **S1** of Section 4.2.2 except for the addition of "sources, densities, and sieve analyses of the aggregates." When requested by the purchaser, the manufacturer of the concrete shall furnish mixture proportion information described in **S1** of Section 4.2.2 as well as the additional aggregate data. The prescribed aggregate data apply to each aggregate to be used in each specific class of concrete applicable to the project order. The **source** of each aggregate includes the name and location of a specific pit or quarry and, when appropriate, a ledge identification. In many cases, aggregate properties will vary significantly from ledge to ledge, necessitating a ledge identification (ID) to allow a specific concerning the aggregate quality to be used. River products should include the name of the river, processing plant ID, and specific river areas when aggregate properties tend to vary in accordance with original retrieval locations.

The **relative density** (specific gravity) and **grading** (sieve analysis) of each aggregate shall be furnished by the concrete

EXAMPLE 4.C—*Option B water computation.*

Water Source	Absorption	Total Moisture	Aggregate (lb) Oven Dry	Aggregate (lb) SSD	Water per yd^3 (gal)*	Water per 8 yd^3 (gal)*
Specified Mixture	. . .	. . .	. . .	. . .	32.0	256.0
Coarse Aggregate	0.8 %	0.6 %	1786†	1800†	−0.43‡	−3.5
Fine Aggregate (sand)	0.3 %	3.2 %	1396	1400	4.86§	38.9
Wash Water Remaining in Mixing Drum	. . .	0	. . .	. . .	0	0
Metered Water	. . .	. . .	. . .	. . .	25.0	200.0
Subtotal as Truck Departs Batch Plant					29.43	235.4
Allowable Water at Job Site if Slump is Less Than 4 in.					2.57	20.6
Mixing Water on Arrival at Job Site					29.43	235.4
With 3 in. Slump Add 10 gal from Truck Side-Tank System					1.25	10.0
Total Water in Mix is < 32 gal (OK)					30.68	245.4

* 8.33 lb of water per gal.
† 1786 lb (OD mass) × 1.008 (one plus absorption value) = 1800 lb (SSD mass).
‡ 1786 lb (1.006 − 1.008)/8.33 = −0.43 gal/yd^3 (minus sign indicates aggregate moisture less than absorption value).
§ 1396 lb (1.032 − 1.003)/8.33 = +4.86 gal/yd^3.

manufacturer. ASTM C 94/C 94M does not set the maximum age of these test results, in order to show that the information submitted must be representative of aggregates currently being used.

4.4 Option C

4.4.1 *When the purchaser requires the manufacturer to assume responsibility for the selection of the proportions for the concrete mixture with the minimum allowable cement content specified (Note 5), the purchaser also shall specify the following:*

The purchaser may require the concrete manufacturer to develop the mixture proportions and also may specify the minimum cement content for the mixture. The requirement for a minimum cement content is the primary difference between Option A and Option C. Be alert to the minimum cement content being a minimum value and not an absolute value. For example, the purchaser may specify a minimum of 470 lb of cement, but 500 lb may be needed to achieve the desired strength. The 470 lb is only a minimum and not a specified value.

It is the manufacturer's responsibility to verify that the most critical requirement in the specification is satisfied.

Note 5—$_{S1}$ *Option C can be distinctive and useful only if the designated minimum cement content is at about the same level that would ordinarily be required for the strength, aggregate size, and slump specified.* $_{S2}$ *At the same time, it must be an amount that will be sufficient to ensure durability under expected service conditions, as well as satisfactory surface texture and density, in the event specified strength is attained with it.* $_{S3}$ *For additional information, refer to Standard Practice ACI 211.1 and Standard Practice 211.2 referred to in Note 4.*

Minimum cement contents are usually specified to achieve durability or to enhance finishability. Often the strength level provided by the minimum cement content at the specified slump and approved water content is much greater than the specified strength. As soon as the first cylinders test well above the specified strength requirements, specification criteria are often relaxed, and water contents are allowed to be increased. Strength levels remain above that specified, but a portion of the cement is wasted due to an increase in the water-cement ratio. If specified strengths are compatible with minimum cement contents, the cement is used effectively. Another preferable option is to raise the specified strength levels to coincide with the minimum cement content desired for durability and to design for that strength level.

4.4.1.1 $_{S1}$ *Required compressive strength as determined on samples taken from the transportation unit at the point of discharge* is to be *evaluated in accordance with Section 17.* $_{S2}$ *The purchaser shall specify the requirements for strength in terms of tests of standard specimens cured under standard laboratory conditions for moist curing (see Section 17).* $_{S3}$ *Unless otherwise specified the age at test shall be 28 days.*

(See discussion under paragraph 4.2.1.1.)

4.4.1.2 *Minimum cement content in bags or pounds per cubic yard [kilograms per cubic meter] of concrete.*

(See discussion under paragraph 4.3.1.1.)

4.4.1.3 *If admixtures are required, the type, name, and dosage to be used* must be noted. *The cement content shall not be reduced when admixtures are used.*

(See discussion under paragraph 4.3.1.3.)

4.4.2 $_{S1}$ *At the request of the purchaser, the manufacturer shall, prior to the actual delivery of the concrete, furnish a statement to the purchaser, giving the dry masses of cement and saturated-surface-dry masses of fine and coarse aggregate and quantities, type, and name of admixture (if any) and of water per cubic yard or cubic meter of concrete that will be used in the manufacture of each class of concrete ordered by the purchaser.* $_{S2}$ *He shall also furnish evidence satisfactory to the purchaser that the materials to be used and proportions selected will produce concrete of the quality specified.* $_{S3}$ *What-*

ever strengths are attained, the quantity of cement used shall not be less than the minimum specified.

(See discussion under paragraph 4.2.2 concerning **S1** and **S2. S3** is clearly an admonishment that the minimum amount of cement in lb/yd^3 shall not be decreased from the specified quantity.)

4.5 $_{S1}$ *The proportions arrived at by Options A, B, or C for each class of concrete and approved for use in a project shall be assigned a designation to facilitate identification of each concrete mixture delivered to the project.* $_{S2}$ *This is the designation required in 13.1.7, and* it *supplies information on concrete proportions when they are not given separately on each delivery ticket as outlined in 13.2.* $_{S3}$ *A certified copy of all proportions as established in Options A, B, or C shall be on file at the batch plant.*

Ease of communication between the job and the dispatcher or batchman is greatly enhanced by an identification name for each concrete mixture. An order for a "3000 psi mix" may lead to the wrong mixture being delivered and the start of a problem. An order for "mix 30 ZT" is specific and identifies the quantity of each ingredient in the mixture to both the purchaser and the manufacturer. This is the same item addressed in Section 13.1.7 describing batch ticket information. The ID of the mixture batched should appear on the delivery ticket to enable both parties of the transaction to know what went into the concrete used in the project. Although it is not a part of this specification, it is a good practice for the purchaser's representatives to maintain a record of where the concrete is placed within the project, also including the mixture ID. **S2** also points out that the purchaser is permitted by Section 13.2 to request batch weights on each delivery ticket. **S3** requires the manufacturer to certify that the proportions for each concrete mixture for the project and on file at the batch plant are in accordance with the option selected by the purchaser and meet the purchaser's requirements.

4.6 $_{S1}$ *The purchaser shall ensure that the manufacturer is provided copies of all reports of tests performed on concrete samples taken to determine compliance with specification requirements.* $_{S2}$ *Reports shall be provided on a timely basis.*

The quality assurance testing for a project is furnished normally by the owner or the general contractor through the selection of a testing laboratory or inspection agency. It is the purchaser's responsibility to provide the manufacturer (ready-mixed concrete producer) with copies of all test reports of concrete or concrete materials tested for compliance with specification requirements. Who gets copies of the test reports and when they get them should be decided prior to the delivery of the first load to the job. The manufacturer will usually know, better than anyone, what results to expect on material tests, compression tests, or flexure tests. The manufacturer is therefore in the best position to spot potential trouble trends before anyone else and to offer suggested alterations to materials or mixture proportions to avoid or correct problems. ASTM C 94/C94M Section 4.6 does not address material samples directly, only concrete samples, but it is a good policy to furnish both to the manufacturer. **S2** demands reports on a "timely basis". ACI 301 requires reports of tests within seven days after tests or inspections are performed. It is always desired by all concerned to know of a problem or potential problem quicker than seven days, and a telephone call or e-mail concerning results may save others a lot of time and cost.

5 Materials

5.1 In the absence of designated applicable specifications covering requirements for quality of materials, the following specifications shall govern:

This sentence is an invitation to every specifier and purchaser to be explicit about the quality of raw materials desired or requirements for the use of specific materials or a particular brand of product. Without any such special or specific requirements or a complete list of material requirements, the ready-mixed concrete manufacturer is obligated to meet the requirements of Section 5. Note that it is not the manufacturer's obligation to determine the proper materials based upon a set of project criteria. It remains the responsibility of the purchaser or the designated agent to determine specific material criteria and to identify these specific criteria to the manufacturer (producer) in advance of pricing and ordering. Defaults are provided for some materials not covered by specific information from the purchaser.

The purchaser or specifier should be careful in planning for or ordering a material not in regular use by the producer or in the geographic area. Examples include specifying special cements not in regular use because this normally requires special dedication of a silo and very possibly extra transportation charges to bring the cement from a mill much farther away than the one whose products are in regular use. Exposed aggregate from a special source may entail significant additional freight charges. The use of a particular chemical admixture brand may be prohibitive if that chemical admixture manufacturing company is not active in the geographic market of the project. The use of a specific class of fly ash or grade of slag may be prohibitive in a region where it is not generally available due to transportation costs and the need for a dedicated silo. The use of any special cementitious material may be subject to the availability of a silo that can be dedicated to that product.

Concrete is normally produced using materials available in the geographic area of the manufacturer, and requests for major variations from these materials typically result in greater cost and, for a small project, may result in the purchaser not being successful in finding a willing manufacturer.

5.1.1 Cement—$_{S1}$ *Cement shall conform to Specification C 150, Specification C 595, or Specification C 1157 (see Note 6).* $_{S2}$ *The purchaser shall specify the type or types required, but if no type is specified, the requirements of Type I as prescribed in Specification C 150 shall apply.*

Cements acceptable under ASTM C 94/C 94M are quite varied, and although only three specifications are listed, each specification includes five or more specific types of cement. ASTM C 9 [80,89] was the "granddaddy" of these cement specifications. In 1940, the "Standard Specification for Portland Cement" was issued under the new designation, ASTM C 150. This specification, like all ASTM Standards, is now constantly reviewed and updated to keep pace with new technology and evolving needs.

Portland cement does not sound scientific, and, in fact, its origination is not, but it now occupies a special spot in cement terminology. The name portland cement originated in 1924 with John Aspdin, an English bricklayer, when he used it as a trade name for his new cement produced in England. He patented his new product, composed of limestone powder and argillaceous soil (clay), which included calcining (heated to a high temperature, but without fusion) [29]. Mr. Aspdin named his product, "Portland Cement," because its color was so similar to an oolitic limestone quarried as a building stone on the Isle of Portland, England. The Portland limestone (whitbed ledge) was a durable stone with excellent weathering qualities that placed it in high demand for government buildings [44]. The name portland cement stuck, even when the manufacturing process was modified by I. C. Johnson of Swanscombe, England in 1845. Mr. Johnson determined that heating to a much higher temperature resulted in semivitrification [11,48]. The material was then pulverized, and cement very similar to this material was produced in millions of tons per year for over the next 150 years.

Definitions as they appear in ASTM Terminology Relating to Hydraulic Cement (C 219) are:

> Portland cement, n—a hydraulic cement produced by pulverizing portland-cement clinker, and usually containing calcium sulfate.
> Portland-cement clinker, n—a clinker, partially fused by pyroprocessing, consisting predominately of crystalline hydraulic calcium silicates.

One of the features of portland cement is that it is a hydraulic cement, meaning it requires the presence of water to achieve a chemical reaction resulting in set (solidification), and that it is capable of doing so when under water. ASTM C 219 provides the remaining principles for the definition in terms of the clinker and the powdered product resulting from the pulverized clinker. The clinker, usually less than 2 in. in diameter, is formed at a temperature in the range of 2550–2900°F, which causes the various raw materials to have chemical reactions and form predominately calcium silicates. The tricalcium silicate (C_3S) and the dicalcium silicate (C_2S) compounds will total more than 70 % of the product we call portland cement, and, to be an effective cementitious material and to predominate, it must contain more than 50 % of these compounds. The third part of the ASTM definition states that the portland cement usually contains calcium sulfate (used to delay the time of set, typically in the form of gypsum).

The basic portland cement product being described contains four major constituents. The two largest components are identified as C_3S and C_2S. These chemical notations are industry abbreviations for lengthy chemical formulas. As the major constituent C_3S increases, the rate of hydration, resulting heat of hydration, and early age strength (28-day) all increase. The C_2S phase is responsible for the long-term (+28-day) strength development and, as expected, produces lower heat of hydration. A third major component in the cement is tricalcium aluminate (C_3A). The C_3A is responsible for starting the initial hydration process and contributes to the early age heat and strength at one to three days [3]. Even though C_3A aids the early strength, its content is often minimized due to unfavorable reactions with sulfates contained in soil, water, or possibly in sewage or industrial waste treatment plants. A typical quantity of C_3A is approximately 10 %; while in a sulfate resistant cement, the C_3A is held to a maximum of 8 % or less. The lower C_3A content also will lower the heat of hydration. The last of the four major constituents, by percentage, is tetracalcium aluminoferrite (C_4AF). This compound has little effect beyond its coloring influence on the finished cement product. The presence of this compound gives portland cement its gray color. The iron oxide in the raw feed also serves as a flux during manufacture and reduces the kiln temperatures during the manufacture of cement, thereby saving energy.

The raw materials used in the manufacture of cement are in the two basic categories of calcarious and argillaceous materials. The compounds previously described are formed primarily by combining lime (CaO), silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3). Lime is a calcarious material, and the others can all be found in argillaceous materials. The compounds described are formed primarily by combining limestone (CaO); clay or shale as a common source of silica (SiO_2); clay, shale, or fly ash as a source of alumina (Al_2O_3); and iron ore, clay, or mill scale as the iron oxide (Fe_2O_3) source.

Limestone as a primary source of calcium oxide (CaO) for the manufacture of cement is probably not a surprise to anyone. The use of clay or shale in the process may be unexpected by many. Every clay-like deposit is not suitable for commercial cement due to mineral impurities, the presence of other soil types, or perhaps excess excavation and transportation costs. All clay minerals, however, do contain silica and alumina, two of the minerals needed to manufacture cement. Kaolinite, which is the most prevalent clay mineral, is often used, but other forms of clay, such as illite, are usually desired [47] because of a higher silica to alumina ratio [51]. A potentially detrimental property of the illite is the presence of potassium when a low alkali cement is needed. It is not unusual for clay to contain iron oxide. The quantity of iron oxide often is approximately one-half that of alumina [24].

During the clinker grinding process, calcium sulfate (gypsum) is added to control the early reactions of C_3A and thereby delay set times of the finished cement. There are other raw materials that are used in the manufacture of cement, but the same basic chemical compounds must be formed. A comprehensive list of potential raw materials is contained in [48].

The raw materials will contain other constituents in addition to the primary oxides. These minor components make up approximately 5 % of the final product. Some can be quite important, such as the alkali oxides (sodium oxide (Na_2O)) and potassium oxide (K_2O), which usually total less than 1.3 % [87]. The difference between 1.3 % and 0.60 % could seem insignificant, but with the alkali oxides it is not. The 0.60 % alkali oxides, expressed as sodium oxide equivalent (Na_2O_e) in cement, is an arbitrarily assigned limiting value between high and low-alkali cements based on historical performance of cement. The appendix of ASTM C 150 suggests the use of the term "Equivalent Alkalies (%)" to provide the desired equivalent total alkali values on a Mill Test Report. Other abbreviations are often used in reports such as Na_2O, eq., but in all cases the desired value is equal to (Na_2O + 0.658 K_2O). A high-alkali cement combined with an alkali-reactive aggregate in concrete may create long-term durability problems. Aggregate containing certain forms of silica will react with alkalies to form products that cause expansive forces. These forces may be severe enough to cause cracking in the concrete. ASTM C 33 states that these reactive aggregates are not prohibited when used with cement containing less than 0.60 % alkalies calculated as sodium oxide equivalent (Na_2O + 0.685 K_2O). There have been cases of alkali reactive expansions occurring, even when the cement contained less than 0.60 % equivalent alkalies [72]. Specifications of some European countries take into account the total alkalies in the concrete mixture rather than placing limits on the cement alkali percentage. These specifications generally limit total alkali content to 3 kg/m^3 [5 lb/yd^3] [31,53,72]. Oberholster, van Aardt, and Brandt [76] do not suggest a specific alkali limit but do point out that the total alkali content of the concrete is determined by the total cement content. Their research demonstrated that the same total equivalent alkali content of two cements did not necessarily produce the same quantities of water-soluble and active-alkali contents. Further discussions of the raw materials or processes of cement manufacture are beyond the scope of this discussion of ASTM C 94/C 94M. There are numerous good publications on the subject available through the various societies involved with the manufacture or regulation of cement properties.

The selection of a cement depends on several factors, some of which are discussed in ACI 225R-99 Guide to the Selection and Use of Hydraulic Cements. The type of project may dictate a desired type of cement due to specific characteristics. The availability of that desired cement may become the deciding factor. Availability cannot be over-emphasized as a selection factor. The third factor is the manufacturer's ability to dedicate a silo to a special cement. Each of these factors should be considered in selecting and specifying a cement.

ASTM Specification for Portland Cement (C 150) is a combination prescriptive and performance specification. ASTM C 150 contains prescriptive requirements on the chemical composition for each of the eight types of cement included. ASTM C 150 also includes some performance requirements such as cube strengths and time of set. Each of these cements is classified as a portland cement as indicated by the specification title.

- **Type I—General purpose** cement is the cornerstone product for most cement mills. It is the cement commonly used for interior slabs-on-ground, interior structural slabs for low to moderate height multi-story buildings, pavements, sidewalks, curbs, box culverts, water reservoirs, bridges, building foundations, and precast concrete products. It can be used in any application where its normal heat of hydration is not a problem and where the concrete is subject to negligible sulfate quantities in the soil or water. If no other type of cement is specified, Type I is the default requirement in ASTM C 94/C 94M.

- **Type II—Moderate sulfate resistance** has an 8 % maximum limit on the tricalcium aluminate (C_3A) content and a mean value of 6 % according to ACI 225 [3]. Type II cement may be used in concrete for structures adjacent to soils or water that test in the moderate sulfate exposure range based on Bureau of Reclamation evaluation [18,86] and ACI 318-02 Building Code Requirements for Structural Concrete reproduced in Table 5.A. Type II[4] may be used as the cement when concrete is adjacent to seawater.

  Type II also may be used to reduce the heat of hydration if one of the optional requirements in ASTM C 150 is specified: Table 2, Optional Composition Requirements; or the heat of hydration limit in Table 4, Optional Physical Requirements. If one of the optional requirements is not specified, there is no guarantee that the concrete will have a lower heat of hydration. The lower heat of hydration aspect is desired for large foundations or piers, abutments or heavy retaining walls, or other mass concrete situations that make it desirable to reduce a temperature gradient between the surface and the interior mass where heat builds up. Type II may be used for general construction, although its strength gain is permitted to be somewhat slower than Type I.
- **Type I/II—General Construction** cement is not a separate type of product as defined by ASTM C 150. It is a cement that meets both Type I and Type II requirements (See Note 1 of ASTM C 150). This designation for portland cement is common in many geographic areas. It may be used in general construction and in situations requiring moderate sulfate resistance. The optional chemical requirement for moderate heat of hydration is not necessarily present in a Type I/II cement.

[4] A Type I cement alone is not recommended in these circumstances. Either a Type II cement or a Type I cement combined with a pozzolan that has been determined to improve sulfate resistance or a blended cement identified for this use should be utilized.

- **Type III—High early strength** cement is very similar to Type I cement in chemical composition. Some cement mills use modest increases of C_3S to help achieve higher early strengths. The primary difference, however, is physical in that Type III is ground to a much smaller diameter (finer), thus a greater surface area is available for hydration reaction when water is introduced. Type III is used when high strengths are needed at early ages, such as with slip-formed structures, precast concrete, cast-in-place concrete with an early form removal need, or any project with moderate dimensions needing quick strengths to allow early use.

  A separate use of high early strength concrete is to substitute it for Type I or Type II cement during cold weather, taking advantage of its early and increased heat of hydration, thus reducing the length of cold weather protection periods. High early strength also means a quicker time of set and shorter finishing time. The faster reactions also result in a cement that produces a higher heat of hydration than Type I and Type II cements.
- **Type IV—Low heat of hydration** cement was developed for use in massive structures where thermal cracking is a potential problem due to excessive heat when other ASTM C 150 portland cements are used. This product is not currently available in the United States. The demand became very low, and other more economical alternatives became available and acceptable to achieve the same effects. For example, a Type II cement with the moderate heat option and with a portion of the portland cement replaced by slag or pozzolans will reduce the heat of hydration at early ages of the concrete. Either method of reducing the heat of hydration also will severely reduce early and ultimate strengths and will slow the rate of gain in strength. The extent of strength rate retardation may need to be determined in the laboratory prior to commencement of a project.
- **Type V—High sulfate resistant** portland cement's primary use is for concrete exposed to severe sulfate conditions. These conditions may be from soil, ground water, or certain industrial waste waters. The improved resistance of this cement to sulfate attack is due to a 5 % limit on tricalcium aluminate (C_3A) in the Type V cement. Type V portland cement is not always readily available. There are other options to improve the sulfate resistance of concrete

TABLE 5.A—*ACI 318-02 building code requirements for structural concrete.**

Sulfate Exposure	Water Soluble Sulfate (SO_4) in Soil, Percent by Weight	Sulfate (SO_4) in Water, ppm	Cement Type	Maximum Water-Cementitious Materials Ratio, by Weight, Normal Weight Aggregate Concrete†	Minimum f'_c, Normal Weight and Lightweight Aggregate Concrete, psi†
Negligible	$0.00 \leq SO_4 \leq 0.10$	$0.00 \leq SO_4 \leq 150$	...	...	...
Moderate‡	$0.10 \leq SO_4 \leq 0.20$	$150 \leq SO_4 \leq 1500$	II, IP(MS), IS(MS), P(MS), I(PM)(MS), I(SM)(MS)	0.50	4000
Severe	$0.20 \leq SO_4 \leq 2.00$	$1500 \leq SO_4 \leq 10,000$	V	0.45	4500
Very Severe	$SO_4 > 0.10$	$SO_4 > 10,000$	V plus pozzolan§	0.45	4500

* Taken from Table 4.3.1—Requirements for Concrete Exposed to Sulfate-containing Solutions in ACI 318-02.
† When both Table 4.3.1 and Table 4.2.2 are considered, the lowest applicable maximum w/cm and highest applicable f'_c shall be used.
‡ Seawater.
§ Pozzolan that has been determined by test or service record to improve sulfate resistance when used in concrete containing Type V cement.

by using slag or pozzolans. It is therefore prudent to determine its availability prior to including it in a specification or an order for ready-mixed concrete. Most of the cement mills which produce Type V cement are in California or other western states. The northeastern United States has a moderate number of mills producing Type V. A good source of information concerning availability of a specific cement is the "U.S. and Canadian Portland Cement Industry Plant Information Summary" [82] published by the Portland Cement Association. This document contains a list of products produced by each mill. An inspection copy is usually available at the nearest cement mill.

- **Optional portland cement** properties can be specified by invoking Table 2 Optional Compositional Requirements or Table 3 Optional Physical Requirements. An optional requirement available for each of the five types is a maximum equivalent alkali content of 0.60 %. This restriction is one means of combating alkali-aggregate reactivity if the aggregates have been identified as potentially reactive when combined with a moderate or high-alkali level cement. At 0.60 % or less, the cement is identified as a low-alkali cement. As always, determine availability prior to specifying a low-alkali cement. If the cement types regularly available in a geographic area do not include low-alkali cements or sulfate resistant cements, care should be exercised in specifying such cements without the option of alternate cementitious materials that may offer the same safeguards. Special cements or special cementitious materials may involve greater costs, longer haul distances, and a dedicated silo or silos.

  There are Table 2 options for Type III portland cement that include resistance to high sulfate exposure or moderate sulfate exposure. A Table 2 option for Type II portland cement that limits the sum of C_3S and C_3A, intended to reduce the heat of hydration, was mentioned previously.

  An optional Table 4, "Optional Physical Requirements" is also available for the user to further modify the requirements for a cement. This addresses requirements to evaluate the false setting tendencies of a cement, heat of hydration, additional strength limits at 28 days, and sulfate resistance evaluation by testing. The user is advised to study all options closely, as Table 2 options and Table 4 options may not always be possible simultaneously.
- **Air-Entrained Portland Cement**—Types I, II, and III may be prepared by inter-grinding an air-entraining material. These cements are formulated to provide air-entrainment for concrete exposed to freezing and thawing conditions. Most air-entrained concrete is achieved by means of a chemical admixture, meeting ASTM Specification for Air-Entraining Admixtures for Concrete (C 260), placed in a batch of concrete during the mixing process using a non-air-entrained cement. The air-entrained Types IA, IIA, and IIIA make it impossible to accidentally omit air entrainment, but fluctuating air contents with slump and temperature changes cannot be controlled. Because of the limited demand, Types IA, IIA, and IIIA are not always available. When available in rural areas with small batching operations, a Type IA may be the only option for the purchaser. A one-silo operation may only stock air-entrained cement and no chemical admixtures. Nothing improves consistency more than limiting optional materials, and at some plants, each driver may batch his own load.

ASTM Specification for Blended Hydraulic Cements (C 595) is a combination prescriptive and performance specification. Each of the ASTM C 595 cements has specific compositional requirements, which account for the prescriptive portion of the specification, and each has specified physical requirements for items such as cube strength, autoclave expansion, time of set, mortar expansion, and more. There are six basic hydraulic cements included in this specification, plus an air-entrained (A) version of each, providing a total of 12 possible cement designations.

Most of these hydraulic cements use portland cement as one of the major components, but due to the differences in the finished composition, properties, and method of manufacture, they do not satisfy the definition of a portland cement. All are produced by blending a portland or other cement and slag or pozzolan, hence the name "Blended Cement."

None of the blended cements may be available in some geographic areas, and none of them should always be expected to be available in a specific area [82]. It is prudent to check on availability before specifying any of the blended cements. Availability will depend upon demand and transportation costs for the material being blended with portland cement. While the use of blended cement is more common in Europe, the general practice in the United States is that supplementary cementitious materials (SCM) are batched at the ready-mixed concrete plant. This system allows concrete for different purposes to have differing quantities of supplementary cementitious materials. The average quantity of blended cement used in the U.S. is less than 2 % of the total cement consumption according to a U.S. Geological Survey website: http://minerals.er.usgs.gov/minerals/pubs/commodity/cement/.

A very positive outlook on using blended cements is that the material being blended commonly has been processed from a product that otherwise would be wasted. Therefore, as a group, blended cements are environmentally friendly.

- **Type IS—Portland blast-furnace slag cement** is a blend of portland cement and finely ground granulated blast-furnace (GGBF) slag. The slag portion of the blended material is specified to be between 25–70 % of the total mass (weight) of the finished portland blast-furnace slag cement. The IS designation means a Type I portland cement plus slag (S). This is a cement suitable for the same general construction uses as Type I portland cement. The time of set for Type IS will be somewhat longer than for Type I, particularly in cooler weather, and the early age strengths will be somewhat lower. As the percentage of GGBF slag is reduced, the time of set also will be reduced. Research indicates the addition of GGBF slag to cement will probably increase drying shrinkage of the mortar. The shrinkage increase at 50 % GGBF slag replacement for portland cement ranged from 125 % to near 150 % in one test series [30].

  There are several very positive effects of combining GGBF slag with portland cement. Workability is improved, partially because the slag particles do not react with mixing water initially as much as portland cement. Also, when substituting GGBF slag for portland cement on a pound per pound basis, there is a greater paste volume due to the lower particle density (specific gravity) of the slag. Portland cement has a relative density of 3.15, and GGBF slag's density ranges from 2.85–2.94.[5] This relationship can easily increase the cementitious material volume by 5 % or more.

The permeability of concrete containing GGBF slag is improved. This produces a concrete that transmits less water and fewer chlorides. Resistance to sulfate attacks is increased by the substitution of GGBF slag for a portion of the portland cement. The optimum replacement ratio depends upon the chemistry of both the cement and GGBF slag, but typical replacements are in the 50 % range. Alkali-silica reactivity also is reduced by the use of GGBF slag as a component of the total cementitious material. Blends near the 50 % range usually are effective for reduction of the potential for both alkali-carbonate reactions and alkali-silica reactions. ACI 318-02 Building Code Requirements for Structural Concrete prohibits more than 50 % GGBF slag in concrete, which will be exposed to deicing chemicals. As an alternate to the use of an ASTM C 595, Type IS cement, the producer is likely to be able to use a portland cement and a GGBF slag conforming to ASTM C 989 as a separately batched material.

- **Type I (SM)—Slag-modified portland cement** has the same chemical and physical requirements as a Type IS. The difference is the greatly reduced GGBF slag quantity, which must be less than 25 % for the Type I (SM). This is a cement suitable for general construction use. It has better time of set characteristics than a Type IS, making it more suitable for cool weather. The lower GGBF slag content of the Type I (SM) reduces some of the major attributes of the Type IS. These include greatly reduced impermeability, resistance to sulfate attack, and resistance to alkali-silica reaction or alkali-carbonate reaction. Note the difference in the designations: S for slag and SM for slag-modified.
- **Type S—Slag cement** contains not less than 70 % GGBF slag plus a portland cement or hydrated lime or both. Type S is a hydraulic cement which will gain strength very slowly and will have a low heat of hydration. The primary use of this cement is to produce concrete for large dams and bridge piers. This is a cement that can replace ASTM C 150 Type IV portland cement.

  Type S also can be blended with various ASTM C 150 portland cements at the batch plant to reduce the overall GGBF slag content to a desired level for use in other projects requiring faster strength gains. This usage is dependent upon an available silo for each cement.
- **Type IP—Portland-pozzolan cement** is a blended cement containing between 15–40 % pozzolan by mass (weight) of the total cementitious product. Type IP is a cement that is suitable for general construction. Note that fly ash or other pozzolans are prohibited by ACI 318 from comprising more than 25 % of the cementitious material if the concrete is to be exposed to deicing chemicals. This restriction applies regardless of where or how the pozzolan is blended with the portland cement. A slower time of set should be expected with a Type IP than with a Type I portland cement. The Table 1 chemical requirements of ASTM C 595 apply, as do the Table 2 physical requirements. Pozzolan includes more than fly ashes. Natural pozzolans in current usage are processed, calcined, and ground clays of various compositions. These include calcined clays, calcined shales, and metakaolin (a high purity calcined kaolin clay). Calcining is the heating of the selected materials to a prescribed temperature below 2000°F to change the material's structure without causing fusion. The calcined materials are then ground to the desired fineness. Other natural pozzolans that may be used in the manufacture of portland-pozzolan cements include diatomaceous earth, opaline chert, tuffs, volcanic ashes, and volcanic pumicites [4]. Alternatively, pozzolans conforming to ASTM C 618 can be used as a separately batched material when concrete is produced.
- **Type P—Portland-pozzolan cement** is a blended cement containing between 15–40 % pozzolan by mass (weight) of the total cementitious product. Type P, unlike Type IP, has no requirements for a minimum three-day compressive strength and has a very low seven-day strength requirement. It is classified as a general construction cement, but it cannot be used in situations requiring even normal early strengths. The chemical requirements match those of Type IP, but not the physical requirements. Type P is available with a low heat of hydration by adding an (LH) suffix. It is then comparable to a Type IV portland cement for use in mass concrete.
- **Type I (PM)—Pozzolan-modified portland cement** contains a maximum of 15 % pozzolan by mass (weight) of the total cementitious product. The cement may be either portland cement or portland blast-furnace slag cement. The maximum pozzolan content is unchanged, regardless of which cement is used. This is a general construction cement with the same physical requirements as a Type I (SM), Type IS, or a Type IP. Because of a lower pozzolan requirement, it will probably have a faster set time than a Type IP. It will not have some of the advantages of pozzolans, due to the lower percentage allowed. Type I (PM) meets ACI 318 requirements for concrete exposed to deicing chemicals.

Suffix to base type designations are possible for each of the six blended hydraulic cements. The suffix (A) is used for each slag or pozzolan cement if direct air entrainment is desired in the cement. A moderate sulfate resistance, a moderate heat of hydration, or both may be ordered by adding the suffix (MS), or (MH) to any of the blended cements except a Type S. Other modifications are available upon request at specific mills.

General comments regarding ASTM C 595 blended cements are for the purpose of alerting users to batch plant possibilities and capabilities. ASTM C 595 places a ± 5 % variability on the pozzolan quantity in any of the portland-pozzolan blends. Variations of this extent are not expected due to possible customer complaints, but they are permitted. For cements blended with GGBF slag an allowable variation is not stated in ASTM C 595. Section 8 of ASTM C 94/C 94M,

[5] The units for density of cement or other cementitious materials are reported in Mg/m^3 or g/cm^3. Specific gravity = cement density/water density @ 4°C, which equals 1 g/cm^3. For purposes of calculating volumes for proportioning concrete, the density and specific gravity numbers are used interchangeably. (ASTM Test Method for Density of Hydraulic Cement (C 188)).

on the other hand, requires additions of pozzolan or GGBF slag to produce a batch within ± 1 % of the total desired quantity of both cement and cement with added cementitious materials. The idea that blended cement from the mill is more uniform than a batch plant produced mixture would therefore appear to be a myth. An advantage of the batch plant combination is the ability to alter the percentage of mixture components to meet the specific needs of the project or season. Some of the advantages of a mill-produced product are that the chemistry of the blend is optimized for improved performance with accompanying test data for the blended product, it permits faster batching, and it eliminates the need of one silo.

When a specifier desires a blended cement or has no objection to a blended cement, it will often be prudent for the specifications to spell out any desired limits for supplementary cementitious materials and to allow either appropriate ASTM C 595 cements or batch plant mixing of the cementitious materials.

ASTM Specification for Hydraulic Cement (C 1157) is a performance-based specification. The Scope of ASTM C 1157 reads "There are no restrictions on the composition of the cement or its constituents." The general requirements of the ASTM C 1157 hydraulic cements seem less restrictive than the ASTM C 150 requirements. There is no minimum fineness requirement, the allowable time of set range is broader than for ASTM C 150 portland cements, and the required compressive strengths of cubes are normally somewhat lower than for ASTM C 150 portland cements. These hydraulic cement requirements tend to be more focused on the long-range durability aspects and less on short-term time of set and early age strength characteristics than the ASTM C 150, Types I and II portland cements. The ASTM C 1157 hydraulic cements, however, can include the ASTM C 150 portland cements and ASTM C 595 blended hydraulic cements. For example, ASTM C 150, Type I meets requirements for ASTM C 1157, Type GU.

The minimum and maximum performance requirements are the only restrictions on materials used in the ASTM C 1157 cements. Analyses of chemical composition for both the individual constituents, which are either inter-ground or blended, and the finished product are required. This provides the user an opportunity to monitor consistency of the finished product through mill test reports. Trial batches are suggested to verify required compressive strengths being produced by the blended cement.

The ASTM C 1157 hydraulic cement types and their uses can be summarized by relating to ASTM C 150 type usages [48]. If restrictions are placed on the quantities of supplementary cementitious materials in concrete, the supplier of the cement can be asked to provide information on the general composition of a blended cement that conforms to ASTM C 1157, even though this is not part of the materials certification and reporting requirements in the specification.

- **Type GU—General Use** cement is for general construction as an ASTM C 150, Type I would be used.
- **Type MH—Moderate Heat** of hydration cement reduces the usual hydration rate and the resulting heat. Type MH compares to an ASTM C 150, Type II with moderate heat requirement.
- **Type HE—High early strength** hydraulic cement produces the highest one- and three-day strengths of the ASTM C 1157 cements. Its ASTM C 150 equivalent is Type III.
- **Type LH—Low heat of hydration** hydraulic cement is a replacement for ASTM C 150, Type IV. Its primary use is for very massive structures to reduce the potential for thermal cracking due to excessive heat of hydration. Early age strengths are very low.
- **Type MS—Moderate sulfate resistance** cement is comparable to ASTM C 150, Type II portland cement. The cement properties will provide resistance to moderate sulfate exposure when the concrete has a low water-cementitious materials ratio.
- **Type HS—High sulfate resistance** is provided by this cement with usages comparable to an ASTM C 150, Type V portland cement. Early age strengths are low.
- **Option R—Low reactivity with alkali-reactive aggregates** may be specified with any of the six basic types included in the ASTM C 1157 specification.
- **Strength options** are provided by the ASTM C 1157 specification to alter the standard requirements. Cements with these optional strengths may not be available at every mill.

With all of these cement options available, it is not necessary for the purchaser or the architect/engineer to specify any of them. If they do not specify anything **S2** clarifies, then an ASTM C 150, Type I shall be used. This includes the use of a Type I/II as previously discussed. The primary point of **S2** is that unless an ASTM C 595 blended cement or an ASTM C 1157 hydraulic cement is specifically requested, specified, or permitted, they shall not be used. Types of ASTM C 150 other than Type I or I/II are also prohibited unless specifically named. What is clear is that the selection of the type of cement used is the responsibility of the specifier or purchaser, not the manufacturer.

Note 6*—These different cements will produce concretes of different properties and should not be used interchangeably.*

Previous discussions on various cements clarify the purpose of Note 6. In addition to producing different strengths, each type of cement will also have varying times of set and durability properties.

5.1.2. Aggregates*—$_{S1}$ Normal weight aggregate shall conform to Specification C 33. $_{S2}$ Lightweight aggregates shall conform to Specification C 330, and heavyweight aggregates shall conform to Specification C 637.*

Aggregates comprise approximately 70 % of the concrete volume and can be the constituents with the greatest variability. It is essential that control be exercised over the quality of the aggregate, both fine and coarse. There are numerous quality tests with minimum requirements in each specification.

ASTM C 33 addresses fine aggregate properties of grading, organic impurities, soundness testing, and deleterious substances. ASTM C 33 provides the option of additional requirements in its Section 4 on ordering and specifying information. The specifier is afforded the opportunity to invoke a restriction on reactivity (alkali-aggregate reaction). Other choices consider which salt, sodium sulfate or magnesium sulfate, is to be used in the sulfate soundness test; what is the appropriate maximum limit for minus 75-μm (No. 200) material, if other than 3.0 %; and what is the appropriate maximum limit for coal and lignite, if other than 1.0 %.

Coarse aggregate, which is the ingredient that occupies the largest volume in concrete, has a lengthy list of requirements in ASTM C 33 and also presents some decisions to be made by the specifier. Coarse aggregate properties for which there are specific limits are clay lumps and friable particles, chert, minus 75-μm (No. 200) sieve material, coal and lignite, abrasion characteristics, and soundness test. Section 4 of ASTM C 33 assigns the responsibility to the specifier for several items including selecting a grading Size Number or nominal maximum size or a grading band from multiple size aggregates. Any desired grading may be specified, instead of selecting a standard size. The requirement for specialized grading often will become an economic issue because it will force suppliers to change screens and make special production runs.

The next critical item is the selection of a class designation relating to geographic weather conditions and the use of deicing chemicals. For example, the quantity of allowable chert (less than 2.40 sp gr SSD) changes due to these conditions. In severe weathering regions like Chicago or St. Louis, a retaining wall should have a 3S designation that limits the coarse aggregate to 5.0 % chert. Further south in Dallas, Texas, a 3M designation is appropriate for the retaining wall in this moderate weathering region. The chert limit for the retaining wall in Dallas is 8.0 %. In a negligible weathering region, such as Houston or New Orleans, the class designation becomes 2N, and there are no chert limitations. These class designations should not be overlooked. Coarse aggregate, like fine aggregate, may be a prime cause of alkali-aggregate reaction. Because of this possibility, ASTM C 33 offers the option of restrictions to mitigate these destructive chemical reactions. The available options actually permit restrictions on either the coarse aggregate or the cement.

A recent update of Appendix X1 of ASTM C 33 contains several pages of non-mandatory information concerning the available test methods for evaluating the potential for deleterious expansion of concrete due to alkali reactivity of an aggregate. Within the appendix is a list of several references that may help produce a better understanding of the alkali-silica and alkali-carbonate reaction process. The bulk of the appendix is devoted to a brief discussion of each test method currently available to assist in the evaluation of potential reactivity of an aggregate and test methods to assist in judging the effectiveness of a potential mitigation material.

An effective use of the material presented in the ASTM C 33 Appendix X1 is selecting the appropriate test method or methods to be included with a specification for the aggregate reactivity evaluation, including a service record evaluation. It is appropriate to name the specific test method that will be used within the project specification. These can be serious considerations that need to extend into economics to select the best mitigation strategy.

The last option of ASTM C 33 allows the specifier to select either sodium sulfate or magnesium sulfate for ASTM Test Method for Soundness of Aggregates by Use of Sodium Sulfate of Magnesium Sulfate (C 88). This test method for judging the quality of aggregates to be subjected to weathering action has proved to be beneficial, but it has a poor precision. The test may not be considered suitable for outright rejection of aggregates failing to meet specification values. A review of service records or other testing, such as freezing and thawing tests using ASTM Test Method for Resistance of Concrete to Rapid Freezing and Thawing (C 666), are encouraged. ASTM publication STP 169C contains a discussion of test methods available [33].

ASTM C 33 places specific requirements on aggregates without prescribing a testing frequency. The purpose of this approach is to send the message that any aggregate properly sampled by ASTM Practice for Sampling Aggregates (D 75) must meet the specified requirements. A suggested or accepted frequency of tests varies. ACI 301-99 Specifications for Structural Concrete requires all aggregate tests to be less than 90 days old when submitted for project approval. Quality control frequencies during the project are not mentioned in ACI 301. Many state highway departments require annual checks. Each agency or A/E firm will have varying specification requirements on this issue.

S2 identifies the specifications to be used for special type aggregates. Lightweight aggregates for structural concrete are specified by ASTM C 330. This specification includes the requirements for both fine and coarse lightweight aggregates. The key word is "structural." Insulating concretes, such as that made with vermiculite, are not covered by ASTM C 330. The lightweight aggregates for structural concrete are usually manufactured through the use of high temperatures to expand clay, shale, or slate. Slag, a byproduct from iron manufacturing, also is processed to produce structural lightweight aggregates. Natural materials such as pumice, scoria, or tuff may be processed to produce lightweight aggregates. All lightweight aggregate will not sustain applied loads and therefore do not qualify for use in structural concrete. ASTM C 330 contains requirements for minimum compressive strengths and splitting tensile strengths in three air-dry density categories. Lightweight aggregate producers should have this test data on file for submission to potential users. A critical criterion for lightweight aggregate is a maximum dry, loose, bulk density (unit weight) of 55 lb/ft^3 for coarse aggregate and 70 lb/ft^3 for fine aggregate. ASTM C 330 provides several grading requirements, which are tied to the nominal maximum size aggregate. As with normal weight aggregates, there are no specified testing frequencies. This is left to the discretion of the specifier. Due to limited demand for structural lightweight aggregates, there are a minimal number of suppliers. The specifier is advised to check for product and size availability prior to specifying these aggregates.

The third type of basic aggregate included for the manufacture of concrete is heavyweight aggregate. This special aggregate is specified by ASTM Specification for Aggregates for Radiation-Shielding Concrete (C 637). There are referrals within this specification to ASTM C 33 for such items as deleterious substances and the grading limits for conventionally placed concrete. ASTM C 637 is primarily concerned with radiation-shielding and heavyweight concrete. The special properties are high specific gravities or special composition, such as a high fixed-water content. For high-density materials, the relative density (specific gravity) will range between 4.0–7.5. Hydrous aggregates identified in ASTM C 637 have fixed water contents ranging from 8–13 %. Synthetic aggregates such as iron, steel, and boron compounds are also included within this specification. The specification is used primarily for coarse aggregate, but it encompasses both fine and coarse aggregates.

With either lightweight, heavyweight, or normal weight aggregates there is often confusion over what is meant by the terms maximum aggregate size and nominal maximum aggregate size. ASTM Terminology Relating to Concrete and Concrete Aggregates (C 125) separates these terms as having two different meanings:

> maximum size, n—in specifications for, or description of aggregate, the smallest sieve opening through which the entire amount of aggregate is **required** to pass.
> nominal maximum size, n—in specifications for, or description of aggregate, the smallest sieve opening through which the entire amount of the aggregate is **permitted** to pass.

An example of these two definitions can be demonstrated by a No. 57 size (1 in. to No. 4).

1 ½ in. sieve—100 % passing (All of the maximum size material is required to pass/be smaller than the 1½ in. sieve)

1 in. sieve—95–100 % passing (All of 1 in. nominal maximum size is permitted but is not required to pass 1 in. sieve. Up to 5 % may be retained on the 1-in. sieve.)

Therefore for a size No. 57 coarse aggregate, 1½ in. is the **maximum** size, and 1 in. is the **nominal maximum** size.

5.1.3 Water

5.1.3.1 $_{S1}$ *The mixing water shall be clear and apparently clean.* $_{S2}$ *If it contains quantities of substances which discolor it or make it smell or taste unusual or objectionable or cause suspicion, it shall not be used unless service records of concrete made with it or other information indicates that it is not injurious to the quality of the concrete.* $_{S3}$ *Water of questionable quality shall be subject to the acceptance criteria of Table 2.*

The initial statement addresses water that by appearance is considered drinkable (potable). **S2** addresses well water or surface supplies that are questioned because of a discoloration, smell, or taste that is not readily identifiable or attributable to a substance not harmful to concrete. A well water containing sulfur certainly smells and tastes bad, but it may be acceptable as mixing water. If the discoloration, smell, or taste is not so identifiable, or if its effect as mixing water in concrete is questioned, the first investigation may include documentation that it has been used successfully in concrete previously, and the condition of the concrete in which it was used has not been affected adversely. If several uses are known, concrete with the more severe environmental durability-challenged exposures should be inspected and judged. If the service record is nonexistent or is inadequate to make a judgment, the proposed water source must be tested in accordance with Table 2, as stated in **S3.**

TABLE 2—*Acceptance criteria for questionable water supplies.*

	Limits	*Test Method*
Compressive strength, min % control at 7 days	*90*	*C 109/C 109M*[A]
Time of set, deviation from control, h: min	*from 1:00 early to 1:30 later*	*C 191*[A]

[A] *Comparisons shall be based on fixed proportions and the same volume of test water compared to control mix using city water or distilled water.*

The Table 2 requirements for questionable water supplies include two tests. Compressive strength of cubes is tested at seven days using the test procedure of ASTM Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or 50-mm Cube Specimens) (C 109/C 109M). This is a test for hydraulic cement mortars using very specific quantities of cement, sand, and water. The compressive strength control samples using a city water supply or distilled water and the strength samples using the questionable water supply are to be compared. Table 2 states that from a strength standpoint, the questionable water may be used if it attains an average compressive strength of 90 % or more of the average strength of the control mixture cubes.

The use of mortar cubes rather than concrete cylinders for strength comparisons is sometimes questioned. The mortar cubes have several advantages beginning with mortar versus concrete. With mortar, the water content of a sample is approximately double that for concrete. This places more emphasis on the water quality, which is the subject of the test. The use of mortar also eliminates the coarse aggregate, which is typically the material with the greatest variability. Without the coarse aggregate, the test result differences are more apt to reflect the variation in water properties, which is the purpose of the test.

The second criterion is time of set variation between a control paste using cement and either city water or distilled water and the test paste using an equal quantity of the questionable water. The questionable water may have a Vicat needle time of set variation of up to one hour earlier than the control sample and as long as 1½ h later and be acceptable. Presumably, this means an evaluation of initial time of setting as this is typically the reported value for the time of setting determined by ASTM Test Method for Time of Setting of Hydraulic Cement by Vicat Needle (C 191) in the cement specifications ASTM C 150, ASTM C 595, and ASTM C 1157. Use the initial time of set as the criterion for Table 2.

A future revision to this specification is expected to permit tests using concrete samples rather than cement paste and mortar cubes.

5.1.3.2 $_{S1}$ *Wash water from mixer washout operations is permitted to be used for mixing concrete provided tests of wash water comply with the physical test limits of Table 2.* $_{S2}$ *Wash water shall be tested at a weekly interval for approximately 4 weeks, and thereafter at a monthly interval provided no single test exceeds the applicable limit (Note 7).* $_{S3}$ *Optional chemical limits in Table 3 shall be specified by the purchaser when appropriate for the construction.* $_{S4}$ *The testing frequency for chemical limits shall be as given above or as specified by the purchaser.*

***Note 7**—When recycled wash water is used, attention should be given to effects on the dosage rate and batching sequence of air-entraining and other chemical admixtures, and a uniform amount should be used in consecutive batches.*

Wash water disposal has become a major issue in some geographic areas due to restrictions on release of process waters from the batch plant site. Wash water is the water used to wash the inside of the mixing drum either between loads, at the end of the work day, or both. Water used to wash the exterior of the truck and drum also falls into this category, as does the water used to wash off the batching area pavements.

S1 is explicit that wash water may be recycled as concrete mixing water, but it must be tested and must meet the requirements of Table 2, which consists of two physical tests, compressive strength and time of set. According to **S2**, the wash water (washout water) should be tested weekly for a month and monthly thereafter, assuming all tests exceed the minimum limits of Table 2. One failed test takes the process back to testing weekly for four consecutive weeks.

Note 7 is a precaution that by replacing all or a portion of the mixing water with recycled wash water, the dosage rate requirements for chemical admixtures may change. This is particularly true for air-entraining admixtures, but the advice applies to all chemical admixtures. It may be found that a change in the batching sequence will affect the dosage rate and the consistency of achieving desired effects. Gaynor [38] cautions that it may be necessary to add air-entraining admixtures with the sand or with an increment of clean mixing water. Others believe that not permitting the use of wash water in air-entrained concrete without first having concrete laboratory checks is the prudent approach [42,73]. The properties and effect of wash water may not be as consistent as a potable water supply, so it is suggested to not alter dosage rates after one batch. Try the same dosage rate in consecutive batches, measuring desired effects for consistency. What may be found is that changes in admixture dosages are not necessary, even though recycled water is being used as batch water.

S3 moves into an area that optionally increases the limits for recycled wash water. If the requirements of Table 3 are to apply, the burden is on the specifier to require Table 3 chemical limits. These optional limits apply only to the total mixing water, which is generally a blend of tap or well water, aggregate moisture, and recycled wash water as indicated in Footnote B of Table 3. The testing frequency for Table 3 limits is the same as for Table 2 requirements according to **S4**.

Table 3 contains limits on chlorides, sulfates, alkalies, and total solids. Two different limits are established for chloride, with the most restrictive (500 parts per million (ppm)) being for pre-stressed concrete or bridge decks. These two areas of use are especially vulnerable to the corrosion of reinforcing steel. Such corrosion could cause a sudden failure with prestressed concrete, and bridge decks could deteriorate. The bridge decks also are susceptible to additional chlorides due to applications of deicing chemicals. The prospect of washing out concrete mixtures that contained chloride based admixtures, such as calcium chloride into washout pits should not be ignored. Table 3 takes this possibility into account.

TABLE 3—*Optional chemical limits for wash water.*

	Limits	*Test Method*[A]
Chemical requirements, maximum concentration in mixing water, ppm[B]		
Chloride as Cl, ppm:		*D 512*
Prestressed concrete or in bridge decks	*500*[C]	
Other reinforced concrete in moist environments or containing aluminum embedments or dissimilar metals or with stay-in-place galvanized metal forms	*1000*[C]	
Sulfate as SO_4, ppm	*3000*	*D 516*
Alkalies as (Na_2O + 0.658 K_2O), ppm	*600*	
Total solids, ppm	*50 000*	*AASHTO T26*

[A] Other test methods that have been demonstrated to yield comparable results are permitted to be used.
[B] Wash water reused as mixing water in concrete is allowed to exceed the listed concentrations if it can be shown that the concentration calculated in the total mixing water, including mixing water on the aggregates and other sources does not exceed the stated limits.
[C] For conditions allowing use of $CaCl_2$ accelerator as an admixture, the chloride limitation is permitted to be waived by the purchaser.

The higher chloride limit of 1000 ppm is implied to only be necessary for the following: other reinforced concrete that is going to be in a moist environment, concrete containing aluminum embedments, concrete with dissimilar metals, or concrete placed on stay-in-place galvanized metal forms (concrete on a metal deck). These are the locations and situations in which the presence of chlorides may accelerate the corrosion of reinforcing steel. Projects that do not contain these situations are not candidates to have the optional limits of Table 3 specified because of chloride concerns. These criteria reflect the limits on chloride ions in concrete for similar types of structures addressed in Chapter 4 of ACI 318-02 Building Code for Structural Concrete.

Footnote C to Table 3 makes it acceptable for the purchaser to waive the chloride requirements and to retain the other provisions of the table.

Sulfates as SO_4 have an upper limit of 3000 ppm in Table 3. The concern here is potential expansion of concrete due to cement aluminate compounds reacting with sulfates. Higher concentrations have shown satisfactory 28-day strengths followed by reduced strengths at an age of one year. The ultimate long-term deterioration question due to the presence of excessive sulfates in the concrete mixing water must be considered. The 3000 ppm is arbitrarily low but has proven successful. The prescribed test method to measure the sulfate content in water is ASTM Test Method for Sulfate Ion in Water (D 516).

Alkalies reported as (Na_2O + 0.658 K_2O) have a Table 3 limit of 600 ppm. Alkalies are of concern due to their possible reaction with potentially reactive aggregates and a subsequent alkali-silica reaction (ASR) and deterioration of the concrete.

Total solids are limited in Table 3 to 50 000 ppm. The prescribed test method is AASHTO T 26, "Method of Test for Quality of Water to be Used in Concrete." Footnote [A] permits other test methods to be used for each of the Table 3 tests if the substitute test has been shown to provide comparable results. In certain types of washout facilities, the potential exists for the solids content to change very frequently, and this needs constant monitoring, especially if this optional limit is invoked. Solids content is generally measured by a measurement of the density of the wash water, which is then correlated to the solids content by measurement or by calculation. Plants with an agitation system for wash water to maintain solids in suspension monitor the solids content at a minimum of once per day or have automated density measuring devices.

Footnote B to Table 3 is a very significant statement. Footnote B points out that the Table 3 limits apply to the total mixing water and not just wash water. Thus, if a plant has wash water that is found to contain 4000 ppm of sulfates as SO_4, and the city water supply has sulfates (SO_4) of 100 ppm, the 3000 ppm limit can be reached by limiting wash water to 74 % or less of the total mixing water.

The most common facility at ready-mixed concrete batch plants to collect washout water is a series of three or four small settling ponds or chambers. These are usually interconnected in a fashion that causes the wash water to take its longest possible route from truck discharge point to the outlet chamber for reuse or discharge after a 12–24 h minimum settling period. The route of movement is to induce the maximum possible settling time and to produce the clearest possible clarified wash water for that facility. Clarified wash water is that washout water allowed to remain in a settling basin a sufficient time period for aggregate particles and many cement particles to settle into the basin producing a water outlet color of clear greenish to somewhat cloudy. This clarified wash water may have dissolved solids in the 6000–8000 ppm range [69]. Earlier work indicated dissolved solids in clarified wash water of 2500–5000 ppm [55], but the water was not recycled as much in that earlier time period. Meininger indicated that without recycling the dissolved solids range dropped to 500–2500 ppm. After several hours of settling, the suspended solids content will drop well below the dissolved solids content with reported suspended solids contents of only 30–500 ppm [36] after minimum settling. A total suspended solids content plus dissolved solids of less than 20 000 parts per million (ppm), or < 2 % by mass is the usual result for wash water so clarified. Test results using clarified wash water have always been excellent to the point that regular testing of this water is no longer considered necessary. This is considerably cleaner water than permitted by the 50 000 ppm of Table 3. At 50 000 ppm of total solids, the water is more like a slurry and is distinguishable from clarified water. In a typical concrete mixture, this amounts to approximately 15 lb of solids per cubic yard that are composed of partially hydrated cement, aggregate fines, and fines washed into the pits by storm water. Current research is investigating the possibility of raising the limit of 50 000 ppm even higher and expanding the types of water permitted from washout water to any water collected at a concrete batch facility. The use of non-potable water as mixing water is to be applauded when it can be accomplished without putting the project or the public at risk. The disposal of wash water, storm runoff water, process water, and waste solids has become a major problem that must be accommodated. Evolving technology with computerized systems and admixtures is allowing the ready-mixed concrete producer to produce uniform quality concrete from batch to batch whereby potential effects of using wash water are not discernable to the purchaser.

At some ready-mixed concrete operations, various mechanical reclaim units are used to separate coarse and fine aggregates and a slurry composed of water and cementitious material. Depending upon the equipment, the slurry may be routed through settling chambers (ponds) as previously discussed or maintained as a slurry used as a portion of the concrete mixing water. This equipment allows reuse of virtually all of the returned concrete plus the drum washout water.

Possible areas of concern include oil and grease in storm runoff water and a resulting effect on bonding properties of the concrete. There has been little research regarding oil or grease in runoff water from shop areas, which drains into the wash water retaining basins. It has been suggested that limits of 2 % by mass (weight) will prevent excessive losses of strength. The German Commission for Reinforced Concrete [42] suggests only minimal traces are permitted. Minimal traces are not defined. The research basis for this statement is not provided.

Early research has indicated that fresh slurry water (high solids content) may provide better strengths than aged slurry water. Recent research at the National Ready Mixed Concrete Association [49] indicated a possible decrease in strength and accelerated time of set for concrete containing wash water slurries with high volumes (> 50 000 ppm) of solids aged as little as 1–3 days. One of the options available to producers is the use of hydration stabilizing admixtures (very potent retarders) whereby the hydration of cement is suspended. The NRMCA study demonstrated that it was possible to achieve similar setting times and strengths to concrete made with tap water when using mixing water at a higher solids concentration and a hydration stabilizing admixture. Research at The University of Toronto [90] also found an acceleration of setting time with high solids content in the recycled water. Greater water demands also were measured in this work. Using ASTM Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Salts (C 672/C 672M), increased scaling was observed on concrete slabs containing the high solids content recycled water. Field slabs using the high content solids recycled water have not been observed to have the increased scaling.

At many rural and small-town concrete batch plants and at portable facilities such as for highway, airport, or large industrial projects, the runoff water draining into the washwater chamber may contain considerable quantities of clay or silt which have been shown to affect the concrete, either in producing lower strengths (greater water requirements for same slump) or greater shrinkage. High quantities of silt or clay also can be obtained at any plant from product sand when the drum is washed out. ASTM C 33 permits as much as 3–5 % minus 75-μm material in specification sand. The portion of this high-fines sand that sticks to the blades is transferred to the drum wash water in the washout process. Assuming a washout quantity of 600 lb of mortar with 250 gal of water, the silt and clay fraction could amount to 5000–10 000 ppm. Excessive silts and clays, and particularly some clays, can greatly increase the water demand of the concrete. Literature currently reflects a limit of 2000 ppm for silt and clay. Each of these potential deterrents to good concrete strength may be checked by the cube and time of set tests of Table 2. It is prudent for a ready-mixed concrete producer to be aware of the characteristics of each material going into the product and to observe its use for potential problems.

As research progresses, major changes in allowable solids for mixing water are expected, and significant changes to Section 5.1.3 *Water* also are expected in the very near future. Sound research will allow "green" concrete to become even more environmentally friendly with new limits that keep concrete sound and that simultaneously dispose of unwanted waste water and solids.

The term parts per million (ppm) has been introduced here and needs to be related to other units of measure. Theoretically, ppm can be a measure of either mass (weight) or volume. The usual meaning is by mass (weight). With the solids in wash water or slurry having a relative density (specific gravity) in the range of 2.40–3.0, the relationships in Table 5.B are customary.

TABLE 5.B—*Wash water and slurry relationships.*

Solids Content by Mass (Weight) in Slurry (Wash Water)			
Solids Content			
ppm	%	Density of Slurry*	Solids†
10 000	1 %	1.01	3
20 000	2 %	1.01	6
50 000	5 %	1.03	15
100 000	10 %	1.06	30
150 000	15 %	1.10	45
300 000	30 %	1.23	90

* Assumes relative density of solids is 2.6.
† Assumes slurry is used as the total mixing water at 36 gal/yd^3.

The C 09.40 subcommittee has struggled for several years to improve the water quality requirements for water used as a component in concrete while encouraging the use of recycled wash water. "Do not lower the quality of the concrete," is the underlying theme in the overall endeavor. Research has shown that concrete can be manufactured using mixer washout water and storm runoff water in either a settled state or in a slurry state and sustain good quality concrete [15,55].

The current plan is to remove the actual requirements for water from Section 5 and write a separate ASTM "Standard Specification for Mixing Water Used in the Production of Ready-Mixed Concrete" with a reference to the Standard placed in Section 5. This approach parallels the one currently used for aggregates via a reference to ASTM C 33. It is expected that there will be a separate ASTM Standard providing a test method for the determination of the quantity of solids in the wash water or slurry. The actual property limits for the wash water and slurries are not expected to vary significantly from the current requirements. The required testing will probably have different test methods and different frequencies from the current specification. It is expected that concrete cylinders will replace mortar cubes for compression testing. There may be some standard mixtures prescribed using the wash water or slurry with control mixtures being made using potable or distilled water. An emphasis is expected to remain on testing the water, so some water-cement ratios or slump requirements with greater values than generally used for durable specification concrete may be prescribed for test mixtures. Changes are forthcoming, but with a consensus document such as ASTM C 94/C 94M, it is difficult to predict exactly what form the final changes will take.

***5.1.4 Mineral Admixtures**—Coal fly ash and raw or calcined natural pozzolan shall conform to Specification C 618 as applicable.*

Mineral admixture is a term that has lost favor in most circles of concrete experts. At the moment it remains a part of ASTM C 94/C 94M and is an easy term to understand and use. Mineral admixtures (see Footnote 3 of Section 4.3.1.1) are very small particles of inorganic materials that are added to concrete in significant quantities during the initial batching process and are ordinarily a substitute for a portion of the cement. A non-scientific, but thought-provoking view for deleting the term "mineral admixture" is provided by Neville [71], who takes the stance that the term admixture "conjures up, a minor component, something added to the "main mix," yet some of the supplementary materials (mineral admixtures) are present in large quantities." The emerging term to be used to describe a special group of materials that includes those now identified as "mineral admixtures" is "supplementary cementitious materials (SCM)." As used in ASTM C 94/C 94M, "mineral admixtures" is confined to materials that meet the requirements of ASTM Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete (C 618). The name of ASTM C 618 will soon be altered to remove the term "mineral admixture." Section 5.1.4 can then be changed to remove the phrase "mineral admixture."

ASTM C 618 divides the pozzolanic mineral admixtures (SCM) into three categories: (1) Class "C" fly ash, (2) Class "F" fly ash, and (3) Class "N" raw or calcined natural pozzolans that comply with specific requirements.

Class "C" fly ash is a product of coal-fired power generating plants. The ash is extracted from the exhaust gases created by burning sub-bituminous coal or lignite. The predominate sources of sub-bituminous coal and known reserves are Wyoming, Colorado, New Mexico, and Montana. Class "C" fly ash has cementing properties of its own due to a high lime content. Pozzolan is partially defined as a material, which in itself possesses little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide (lime) at normal temperatures to form compounds possessing cementitious properties. The key item is that Class "C" fly ash contains sufficient lime that it does not meet the little or no cementitious value requirement. It meets all the other criteria for a pozzolan, so it is sometimes identified as "pozzolanic" or "cementitious."

Fly ash as a substitute for a portion of the cement, commonly 15–35 % by mass of the cementitious materials, when used, produces many positive attributes for the concrete. Workability is improved due to the spherical shape of the particles. Fly ash provides higher long-term strength gains, lower permeability, often lower water requirements for the same slump, lower heat of hydration, and often a minimal decrease of drying shrinkage. A cost savings can usually be accomplished by substituting fly ash for cement, most often on a pound for pound basis.

Class "C" fly ash normally is not a good mineral admixture if mitigating alkali-silica reactivity (ASR) is the objective. The only alkalies in the fly ash that affect ASR are soluble alkali sulfates, which may be excessive in the high-calcium fly ashes. Table 3 Supplementary Optional Physical Requirements in ASTM C 618 limits expansion in a prescribed laboratory test. Fly ash is not a manufactured product however, and you get what the coal and its burning produce. Specifying Table 3 may eliminate some otherwise very good fly ashes. If the limitation on expansion is not necessary for the situation, it may not be cost effective to specify this option.

Class "C" fly ash is not a good choice for inclusion in concrete to be subjected to detrimental sulfate conditions. Because of its high calcium oxide content and potential formation of C_3A, the Class "C" fly ash will not improve the sulfate resistance of the concrete [72].

A property of Class "C" fly ash that is an attribute in hot weather can become a curse in cold weather. This fly ash results in a retarded time of set in concrete. In the summer it can be beneficial to offset faster setting characteristics, and in the winter it can keep a finisher up all night. Time of set will be proportional to the quantity used in the mixture. Stickiness is another physical property that can be a problem at higher substitution rates.

Class "F" fly ash is initially different only in its origin. This fly ash is produced by the burning of bituminous or anthracite coal. The major sources of this coal are Pennsylvania, West Virginia, Kentucky, Ohio, and Illinois. Almost all of these types of coal are found east of a North-South line located midway across North Dakota and extending due south through the mid-point of Texas. There are some scattered spots of bituminous coal across the western states and along the Pacific coast. As a general rule, Class "F" fly ash is found east of the Mississippi River, and Class "C" fly ash is primarily west of it [61].

Class "F" fly ash must be composed of a minimum of 70 % silicon dioxide (SiO_2) plus aluminum oxide (Al_2O_3) plus iron oxide (Fe_2O_3). It contains far less lime than Class "C" fly ash, giving it little or no cementitious value by itself. Class "F" fly ash is therefore a pozzolan in the true sense of the definition.

Class "F" fly ash has many of the same attributes as Class "C" fly ash. The spherical particles improve the workability, and it attains higher ultimate strengths, lower permeability, often lower water requirements for the same slump, lower heat of hydration, and typically a minimal decrease of drying shrinkage. Cost savings can often be accomplished by substituting fly ash for cement in a range of 15–35 %.

A major improvement to the concrete available from Class "F" fly ash as compared to Class "C" fly ash is that Class "F" is usually effective in reducing alkali-silica reactivity (ASR) because of higher silicon dioxide contents and lower lime contents [32]. When calculating the total effective alkali content of a concrete mixture, the total sodium oxide equivalent for the fly ash segment is limited to approximately 15–17 % of the fly ash's Na_2O equivalent [81]. Class "F" fly ash in the concrete mixture will also normally increase the resistance to sulfate attack.

Time of set can be a problem in cold weather when using Class "F" fly ash [79]. The time of set is typically slower than with Class "C" fly ash, but there also may be more variability in time of set with the Class "F" fly ash. Another problem with Class "F" fly ash is an increase and variability of carbon content as measured by loss on ignition (LOI). The carbon present affects the dosage requirements for air-entraining admixtures to produce the desired air content in the concrete. The fly ash may absorb the air-entraining admixture during mixing and delivery, thus reducing air contents as much as 60 % (2 or 3 % of air content) during the delivery process [41]. Stickiness with higher fly ash substitution rates is also a problem with Class F fly ashes. The usual substitution rates for Class "F" will be in the 15–25 % range.

Class "N" pozzolans include both raw and calcined natural pozzolans. The definition for a pozzolan was provided earlier but an explanation of where this name originated was not provided. A volcanic tuff from the Naples, Italy area was combined with lime and water many centuries ago to produce a cement-like product that would harden even under water. The best volcanic tuff (ash) came from the famous Vesuvius volcano near a village named Pozzuoli. The name given to the material was pozzolana [57]. Other natural pozzolans in addition to volcanic ash include pumicite, diatomaceous earth, opaline cherts, and opaline shales [4]. Natural pozzolans are available throughout the United States, but most of those testing satisfactory for use are located west of the Mississippi River [83]. Depending upon the particular material, it may or may not be necessary to calcine these pozzolans. These materials can be used in the same manner as fly ash and produce many of the same properties as a Class "F" fly ash.

Calcined clays and shales are the most frequently used natural pozzolans in blended cements. They are most frequently added at the mill rather than at the batch plant, where they are seldom available. These products are often effective in combating alkali-silica reactivity. Permeability of the concrete is lowered, reducing water penetration. Resistance to sulfates is increased irrespective of their source (water or soil) by the use of pozzolans. Pozzolans will decrease the heat of hydration and increase the time of set. The air-entraining admixture dosage to obtain a specific air content usually will need to be increased. The 25 % limit on pozzolan by ACI 318 for concrete exposed to deicing chemicals should be observed.

Metakaolin is a calcined kaolinite clay which has no special properties beyond those of other pozzolans. **High-Reactivity Metakaolin** is a calcined kaolinite clay that has been purified, has been bleached to appear white, has particles smaller in size than the average cement, and, because of its purification and processing, has attained properties that make it comparable to silica fume. Kaolinite is a very prevalent and very stable clay mineral. As compared to other clay minerals, kaolinite has little tendency to change volume when exposed to water. High-reactivity metakaolin is a Class "N" pozzolan but produces changes in the concrete at much smaller addition rates than a typical pozzolan.

As compared to concrete without any mineral supplements, concrete with 5–10 % high-reactivity metakaolin is expected to have higher early strengths and ultimate strengths. Drying shrinkage, chloride ion permeability, and risk of ASR damage are reduced with high-reactivity metakaolin. This can be a high-cost mineral admixture due to the processing involved, but it may be used in a ternary mixture (three cementitious materials) with cement and fly ash or slag to produce improved concrete at nominal overall cost increases. The product is available in bulk or bagged quantities. One of the pleasing features of the high-reactivity metakaolin is that its white color has little effect on the concrete color. The high-reactivity metakaolin particles are larger than silica fume particles and may produce a mixture that is not as sticky when finishing. There will be little bleeding when this mineral admixture is used. Close attention must be given to wind, humidity, and temperature to prevent plastic shrinkage cracks.

Rice-husk ash meets the requirements for a C 618, Class "N" pozzolan. It is a product produced by incineration of empty rice hulls. It has particle sizes similar to fly ash and produces the same concrete attributes as other pozzolans. Mehta [54] provides data revealing significant increases in compressive strength and reductions in permeability with the substitution of rice-husk ash for 15 % of the cement. Test results were good for both ordinary concrete mixtures and high-strength mixtures. The husks (hulls) are a waste product, but turning them into ash by means of controlled incineration is expensive so, as yet, this is not a widely distributed, cost competitive mineral admixture in the United States.

Silica Fume is a very finely divided pozzolanic material produced as a smoke byproduct from the production of silicon metal or ferrosilicon alloys. The smoke particles are approximately 1/100 the size of cement particles. Although silica fume is a pozzolanic material, it is not covered by ASTM C 618 because 1) it is not a coal fly ash, 2) it is not a raw or calcined product, and 3) it will not meet the maximum water requirement of ASTM C 618 Table 2.

ASTM Specification for Use of Silica Fume as a Mineral Admixture in Hydraulic-Cement Concrete, Mortar and Grout (C 1240) covers silica fume. The ASTM C 1240 specification is planned as a material reference in ASTM C 94/C 94M. It is a highly specialized product that requires special knowledge of handling, mixing, and use that may not be readily available to some producers. Bulk silica fume must be unloaded at lower pressures than cement and may require unloading times in the range of four hours. Mixing times may need to be extended and batch sizes reduced to achieve thorough mixing of the mixture [6]. It is therefore prudent to have project specifications with greater detail for silica fume than can be provided in ASTM C 94/C 94M.

Silica fume is used in typical dosages of 3–12 % of the cement mass, usually requiring a high-range water-reducer. It can be purchased in bags or bulk in the form of slurry or as a densified agglomerated product. The most notable attributes are high strengths, greatly reduced permeability, improved resistance to chemical attacks, reduced ASR expansion, and greater resistance to sulfate attacks. Silica fume is permitted to be batched in bulk quantities with the cement. Section 8.1 currently requires the cement to be batched first. The batching systems seek to achieve a target total after each material is batched, rather than a specific quantity of each material. Because small variations of silica fume have such a pronounced effect on the concrete, an alteration is expected soon in the specification with regard to batching bulk silica fume. The change is expected to assist in the endeavor to maintain tighter control on the silica fume quantity with each batch.

Silica fume has received several names over its history, such as microsilica or silica dust, but they are all the same product.

5.1.5 Ground Granulated Blast-Furnace Slag*—Ground granulated blast-furnace slag shall conform to Specification C 989.*

Slag is a waste product from the manufacture of iron in a blast furnace. The slag is in a granulated form that is later ground into a powdery substance. ASTM Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars (C 989) classifies ground granulated blast-furnace slag (GGBF slag) into three grades as determined by the average compressive strength of cubes. An ASTM C 150 portland cement is used for a control mixture for cubes, and the same cement is used with the GGBF slag on a 50/50 basis for cubes. The Grade 80 material has compressive strengths from the 50/50 cubes of not less than 75 % of control, but less than 95 % of control. Grade 100 GGBF slag has strengths comparable to the cement control cubes, and Grade 120 GGBF slag produces cube strengths equal to not less than 115 % of the cement control cubes. Therefore, a higher grade of slag has better strength producing properties.

GGBF slag is used in producing ASTM C 595 blended cements, ASTM C 1157 hydraulic cements, or as a cementitious component at the batch plant. Typical substitution rates can be from 25–70 % or more, but a range near 50 % is the most common. This is a bulk product that is not readily available in all areas due to transportation costs.

Attributes of GGBF slag include good resistance to sulfate attack, good ASR resistance with potentially reactive aggregates, improved workability, reduced permeability, and reduced chloride intrusion due to the decreased permeability [5]. The almost white color of the GGBF slag provides concrete with a lighter and brighter color.

The time of set with GGBF slag mixtures is usually longer than for portland cement mixtures, particularly in cold weather. Thus, in cold weather, GGBF slag percentages may need to be reduced and chemical accelerators considered. Concrete made with GGBF slag requires better attention to curing practices than portland cement mixtures. This is true of any combination of cementitious materials that lower both the heat of hydration and early strengths.

5.1.6 Air-Entraining Admixtures (AEA)*—Air-entraining admixtures shall conform to Specification C 260 (Note 8).*

There are numerous materials that meet the ASTM C 260 specification. It is a performance type specification requiring the admixture to meet specific physical requirement tests compared to non-admixture concrete, including time of set changes, maximum compressive and flexural strength changes, and maximum shrinkage changes. The specification does not distinguish between the use of a liquid admixture or a powdered admixture. The selection of an air-entraining admixture depends upon compatibility with cementitious materials being used, how well the air content holds on longer hauls, and good response to dosage changes of the admixture. Different cements will react differently with a specific AEA. Entrained air is generated by the mixing action when concrete is produced. Some air entraining agents need longer mixing time of concrete to generate a stable air entrained system than others.

A complete test series for an admixture shipment is a time-consuming endeavor. Three tests that can be performed rather quickly and without extensive laboratory facilities are density (specific gravity) of the product, pH, and percent solids (residue by oven drying). These values may be compared to design values supplied by the admixture manufacturer or to previous test data by the ready-mixed concrete producer.

The dosage rate needed to produce a desired air content will change with factors such as temperature, slump, types of cementitious materials, aggregate gradings, minus 75-μm (No. 200) material quantity, mixing time, other admixtures in the mixture, and the interior condition of the mixer. There are so many influencing factors that manufacturers typically will provide a wide range for possible dosage rates of the AEA. A stated range such as ¼–4 fl oz/100 lb (hundred weight) of cementitious material is common.

An example dosage range for a mixture with 540 pounds of cement plus fly ash would be: 5.4 × (¼ fl oz/100 lb) = 1.35 fl oz/yd^3 up to 5.4 × (4) = 21.6 fl oz/yd^3.

A good rule of thumb is to start low on the dosage rate and work up, not down, to attain the proper rate range. Excessive air reduces strength and it is much more difficult to remove than it is to increase the air in a batch of concrete.

5.1.7 Chemical Admixtures*—Chemical admixtures shall conform to either Specification C 494/C 494M or C 1017/C 1017M as applicable (Note 8).*

ASTM C 494/C 494M is a specification for chemical admixtures for concrete that has been in place for over 40 years. A chemical admixture is usually a liquid but also includes non-pozzolanic admixtures in suspension or water-soluble solids. There are seven types of admixtures within C 494 with seven types of end results being expected.

Type A—Water-reducing admixtures
Type B—Retarding admixtures
Type C—Accelerating admixtures
Type D—Water-reducing and retarding admixtures
Type E—Water-reducing and accelerating admixtures
Type F—Water-reducing, high-range admixtures
Type G—Water-reducing, high-range, and retarding admixtures

ASTM C 494/C 494M is a performance specification which includes a table (Table 1) setting forth a range of required test results, to be compared to a control mixture, for such properties as water requirements, time of set, compressive strength, flexural strength, shrinkage, and relative durability. The premise of this performance specification for product evaluation is to demonstrate that under standard conditions, the admixture will perform the function it is designed to perform while not causing any detrimental effects on the fresh and hardened concrete properties. The material is certified to comply with these minimum requirements. Actual performance in job concrete may differ due to the large number of other variables involved. These tests are normally performed only to test a new product and not on a regular basis, as are cement mill test reports.

Type C (accelerating) includes calcium chloride and chloride containing products unless chlorides are specifically excluded by the project specifications. Calcium chloride products, both flake and solution, are discussed in greater detail in Chapter 8, Section 8.4. Non-chloride accelerating admixtures are often specified when there is a potential for corrosion of reinforcing or pre-stressing steel. No water reduction is required for these admixtures.

Type B (retarding) does not require any water reduction, but commonly retarders include water reduction features. There are water reducers (Type A) available that will meet Type B requirements by using an increased dosage rate.

The other five types of chemical admixtures covered by ASTM C 494/C 494M all require a minimum water reduction of 5 % (A, D, & E) or 12 % (F & G). These admixtures may be used in either of two ways. Maintain a constant slump and decrease the water content, thereby lowering the water-cement ratio, or hold the water and water-cement ratio constant and increase the slump. Care should be observed in the second application that segregation does not take place by the production of excessive slumps.

ASTM C 1017/C 1017M is the specification for chemical admixtures for use in producing flowing concrete. The basic requirements set forth to define flowing concrete in ASTM C 1017/C 1017M are that it must have a slump greater than 7 ½ in., and it must maintain a cohesive nature. Physical requirements set forth within the specification (Table 1) require a minimum slump increase of 3 ½ in. while maintaining specified physical properties including time of set and minimal strength losses (10 % maximum) as compared to control mixtures.

The ASTM C 1017/C 1017M chemical admixtures include two types:

Type I—Plasticizing admixture
Type II—Plasticizing and retarding admixture

The only difference in requirements for these two types of admixtures is in the time of set window. The only significant difference in physical requirements between the ASTM C 1017/C 1017M chemical admixtures and the ASTM C 494/C 494M, Type F & G High-Range, Water-Reducing chemical admixtures is lower strength requirements for the former.

Note 8—$_{S1}$ *In any given instance, the required dosage of air-entraining, accelerating, and retarding admixtures may vary.* $_{S2}$ *Therefore, a range of dosages should be allowed, which will permit obtaining the desired effect.*

The initial statement here is that the three types of chemical admixtures named (air-entraining, accelerating, and retarding) will require varying dosages depending upon the ambient and concrete temperature, other weather conditions, concrete slump, and haul distances plus other factors. **S2** strongly recommends that mixture proportioning submittals and mixture proportioning acceptance or approvals recognize the need for dosage changes on a moment's notice. Submittals and acceptances or approvals should, therefore, be based on an acceptable dosage range rather than a specific dosage. For example, an air-entraining admixture dosage may need to be submitted as 0.6–1.2 fl oz/100 lb cementitious material (0.6–1.2 oz/cwt). Submitting a value of 0.9 oz/cwt is not recommended.

Chemical water-reducing admixture terminology is a subject not mentioned in ASTM C 94/C 94M and should not be because no specific definitions have been totally accepted by ASTM or the chemical admixture industry. The terminology alluded to involves the three groups of water reducers identified by most manufacturers as water reducers, mid-range water reducers and high-range water reducers. In terms of anticipated changes in slump, these categories are never defined. An approximation of what to expect is in Table 5.C.

The difference between an ASTM C 494/C 494M, Type A water reducer and an ASTM C 494/C 494M, Type A mid-range water reducer is generally the capacity of the mid-range reducer to be dosed at a higher variable rate and remain inside the time of set window of ASTM C 494/C 494M, Table 1. If a Type A, D, or E water reducer dosage rate reduces water to a range between 5–12 % without a major impact on the time of set, it is often termed a mid-range water reducer. Another benefit available with specific mid-range water reducing admixtures is an improvement in the ability to finish concrete in flatwork applications. Many older Type A, D, or E water reducers do not react well to increases in dosage rates. The increased dosage rate may increase the slump into the mid-range slump area, but a major increase in time of set also occurs. This increase actually can be measured in days rather than hours for some chemical admixtures. The user needs to investigate the specific product for dosage versus time of set characteristics.

At this time there is no specific specification addressing mid-range water reducers.

Other Materials

Other materials not specifically mentioned, both liquid and solid (including powders), but primarily solid, are products that are not a routine part of concrete mixtures and therefore are not mentioned within ASTM C 94/C 94M. Section 1.1 permits the purchaser's specification to include these specialty products. Included in this category are such items as:

- **polypropylene fibers** conforming to ASTM Specification for Fiber-Reinforced Concrete and Shotcrete (C 1116), Type III, for use as secondary reinforcement and as a possible deterrent to plastic shrinkage cracks, (solid).
- **steel fibers** meeting ASTM Specification for Steel Fibers for Fiber-Reinforced Concrete (A 820); special steels may also be available, and ASTM C 1116, Type I, for multiple uses and purposes as a steel reinforcement for concrete, (solid).
- **coloring admixtures** meeting ASTM Specification for Pigments for Integrally Colored Concrete (C 979) to produce integrally colored concrete, pigments that may be added to the concrete as powder or in a liquid form.
- **shrinkage-compensating expansive cements** governed by ASTM Specification for Expansive Hydraulic Cement (C 845), used to compensate for the early shrinkage tendencies of the customary cement products associated with concrete (powder).
- **shrinkage-reducing admixture,** a chemical formulation that is plant added to reduce the early shrinkage tendencies of the customary cement products (liquid).
- **calcium-aluminate cements** are used in non-structural concrete that will be exposed to high temperatures (up to 3400°F with correct aggregates and conditions) [3], strong sulfate attacks, very quick high strengths, resistance to weak acids at industrial plants, or other special uses (powder).
- **corrosion-inhibiting admixtures** are used to retard chloride induced corrosion of reinforcing steel (liquid).
- **hydration-control admixtures** used by purchasers for extended hauls by truck mixers or other situations, producing extended delays before placement after mixing (liquid).
- **anti-washout or viscosity modifying admixtures** used principally for underwater applications to resist segregation and promote stiffening under adverse conditions and in self consolidating concrete (liquid or powder).
- **foaming agents** for controlled low-strength concrete used to increase stable air, lower the density (unit weight), control strengths, and decrease shrinkage (liquid or powder).
- **water repellant admixtures** for lower permeability of concrete (liquid or powder).
- **polymer modifiers** such as latex additives for increased flexural strength, increased abrasion resistance, reduced permeability, or other properties (liquid) [79].
- **lithium-based additives** for the control of alkali-silica reactivity (liquid or powder).
- **bacteriocidal admixtures** providing toxic agents guarding against surface degradation by bacteria [84] (liquid or powder).
- **pumping aids** are used to enhance the pumpability of concrete mixtures that are marginally pumpable by improving viscosity and cohesion (liquid or powder).

This list is not complete, but it can be seen by the array of products listed above that a variety of effects on concrete is available by the use of other materials, both as primary cement and as admixtures. Some of these products have ASTM specifications governing their properties, and some do not. The purchaser is advised to include any relevant reference to the appropriate ASTM designation when ordering products not covered by ASTM C 94/C 94M. The purchaser also should be aware of any potential problems or secondary property changes that the proposed admixture or material may cause in the concrete. As the number of products attainable to enhance or alter specific properties of concrete increases, it becomes difficult, if not impossible, for the manufacturer to attain a technical knowledge of each admixture or material and the possible adverse affects of each. This type of knowledge is the responsibility of the purchaser and the project's design professionals to ascertain prior to specifying or ordering such products.

TABLE 5.C—*Slump changes expected using ASTM C 494 and C 1017 admixtures.*

Type	Slump Increase	Final Slump	ASTM Specification
Water reducer	±2 in.	3–5 in.	C 494, Types A, D, or E typically
Mid-range water reducer	3–4 in. ±	5–7.5 in.	C 494, Type A typically
High-range water reducer	min 3.5 in.	min 7.5 in.	C 494, Type F or G C 1017, Type I or II

6

Tolerances in Slump

SECTIONS 15 AND 16 REFERENCE or identify the use of the slump test, which has very specific procedures described in ASTM C 143/C 143M. The slump test was originally developed to provide a measure of consistency of freshly mixed concrete [77]. The basic test is performed by compacting a sample of concrete in a mold in the shape of a frustum of a cone with a height of 12 in. The concrete is compacted by tamping with a 5/8 in. smooth rod. The mold is raised vertically for removal. The slump measurement is the vertical drop of the concrete from its original height (12 in.) to the displaced position of the original center after removal of the mold.

A portion of Note 1 of ASTM C 143/C 143M provides a good overview of the original slump research and current technology. "Under laboratory conditions, with strict control of all materials, the slump is generally found to increase proportionally with the water content of a given concrete mixture, and thus to be inversely related to concrete strength. Under field conditions, however, such a strength relationship is not clearly and consistently shown. Care should therefore be taken in relating slump results obtained under field conditions to strength."

There are many potential causes of increases or decreases in the slump of a concrete mixture beyond a change in water content. Aggregate changes of grading, batch mass (weight) differences, surface texture, and surface area evaporation, and hydration rate. Variations in air content, either entrained or entrapped will alter the slump measurement. Cement will have variations in batch weights, chemistry, and fineness, each of which will affect slump to some extent. Fly ash, GGBF slag, or silica fume will, like cement, have variations in batch weights, chemistry, and fineness. Chemical admixtures can affect the slump due to varying dosage rates and varying times of introduction to the mix. Uniformity of mixing and total time of mixing will also affect the slump value. Concrete temperature and its effect on the water demand and rate of hydration (setting) of the concrete also will affect slump if measures are not used to offset these effects. Close scrutiny of each material or batching and delivery procedure will reveal other possibilities, but a major factor may be testing variations.

An important point to remember is that with the wide range of materials used in concrete and the factors that can affect slump, the measured slump should not be strictly related to the quantity of water in the mixture. There is guidance provided on establishing specification requirements for slump for different types of concrete applications in ACI 211.1. With the new self-consolidating concrete, the measurement of slump has no meaning, and the slump flow (horizontal spread) and the rate at which the concrete spreads is measured.

When two laboratories are performing tests from the same wheelbarrow sample, the standard deviation of slump measurements is approximately ⅜ in.

***6.1** Unless other tolerances are included in the project specifications, the following shall apply.*

The user is reminded by the phrase "Unless other tolerances are included" that this specification may be altered. If it is not, two types of criteria for slump tolerance are included for the specifier to choose from. These are "not to exceed" or a "nominal slump value." Tolerances for the delivered slump of the concrete are provided for each of the two specification types. Caution is urged in any consideration to reduce the slump tolerance.

Like all concrete properties, slump is subject to some variation in successive batches. Such factors as variations in aggregate gradings, batch mass (weights), air content, temperature, and aggregate moisture will each affect slump value. Not to be overlooked is the variation in slump value between two tests by the same technician. For example, at an average slump of 3.4 in., the acceptable range of two tests on the same concrete sample is 1.07 in. Testing variations are discussed in greater detail later. Coupling raw material variations and batching variations with testing variations, the allowable tolerances shown in Section 6.1.1 are actually quite limited and should be used unless there is a very compelling factor for a change.

***6.1.1** $_{S1}$ When the project specifications for slump are written as a "maximum" or "not to exceed" requirement:*

	Specified Slump:	
	If 3 in. [75 mm] or less	*If more than 3 in. [75 mm]*
Plus tolerance:	*0*	*0*
Minus tolerance:	*1 ½ in. [40 mm]*	*2 ½ in. [65 mm]*

$_{S2}$ *This option is to be used only if one addition of water is permitted on the job, provided such addition does not increase the water-cement ratio above the maximum permitted by the specifications.*

The purpose of specifying a "maximum" or "not to exceed" slump is to maintain tight control over the constructability of the concrete application. Examples include slip form construction such as curb and gutter or concrete pavements when it is important that the concrete in its plastic state does not change its shape when the placing equipment moves. This brief table provides the plus and minus tolerances for slump when the project specifications read "the slump shall not exceed ______ inches" or "the concrete slump shall have a maximum value of ______ inches." There are two categories of tolerance in the table. A tolerance of 1½ in. is set for specified slumps up to and including 3 in. For specified maximum slumps of more than 3 in., the tolerance is increased to 2 ½ in. The standard deviations shown in the ASTM C 143/C 143M precision statement clearly demonstrate that slump testing variations increase as slump increases. The standard deviations for single-operator and multilaboratory tests are as follows from ASTM C 143/C 143M.

	Standard Deviation [1s]	
Slump value	Single-Operator	Multilaboratory
1.2 in. [30 mm]	0.23 in.	0.29 in.
3.4 in. [85 mm]	0.38 in.	0.39 in.
6.5 in. [160 mm]	0.40 in.	0.53 in.

These values are the results of a series of tests utilizing 15 technicians, all performing tests on the same concrete samples.

Note that with "maximum" and "not to exceed" specifications, the plus tolerance is always zero. The slump is not allowed to exceed the specified maximum value. All of the specified tolerance is on the minus side. Several cases in Example 6.A will demonstrate the use of the "not to exceed" or "maximum" slump specification, tolerances, and subsequent field evaluation of the concrete based upon slump.

Concrete materials and concrete batching have not reached the level of an exact science. The slump will have load-to-load variations despite the best efforts of the concrete producer. When the specifications impose a maximum slump, the batchman will attempt to produce a slump near the middle to high end of the allowable tolerance range. A responsible batchman will not often send out a load with a slump above the maximum, unless it is a hot day and the haul time is extended.

In **Example 6.A, Case G,** a slump of 3–4 in. will be the target. Assume several loads have been batched, and the water is adjusted to 24 gal per cubic yard of concrete, producing a slump within the target range. New loads of coarse aggregate are unloaded and put into the overhead bin by the front-end loader operator without providing this information to the batchman. The coarse aggregate moisture has changed from + 0.2 % to −0.3 %. Coarse aggregate overhead bins usually do not have moisture probes. At 1900 lb of rock per cubic yard, the 0.5 % moisture swing amounts to a decrease of 9.5 lb (1.1 gal) per yd^3 of available water. The aggregate grading, unknown to anyone, happens to be gap-graded in this shipment and increases the water demand by another 0.5 gal per yd^3. The transit mix truck is delayed in traffic, causing a further loss in slump of ½ in. Just these three items change the water demand by 2.1 gal per yd^3 and will affect the slump by approximately 2 in. (1 in. of slump change per 1 gal of water change). The net result is a job site slump test of 2 in., which is lower than the 2 ½ in. lower limit.

The situation in this example dictates an examination of the allowable water content without violating the maximum specified water-cement ratio. The mixture submittal included 31 gal of free water per cubic yard. Example 6.B demonstrates the water situation with respect to the approved proportions, the last acceptable load, and the problem load, which has a 2-in. slump upon arrival at the job site. The total free water in the problem load is 28.3 gal. Therefore an addition of 2.7 gal (31.0–28.3) is permitted. This 2.7 gal will be more than enough to raise the slump above the 2 ½ in. minimum acceptable slump.

EXAMPLE 6.B—*Water management for slump control.*

Ingredient		Approved Mixture	Accepted Load	Problem Load
Cement	lb	520	. . .	. . .
Coarse Agg. (SSD)	lb	1900	. . .	. . .
Sand (SSD)	lb	1400	. . .	. . .
Allowable Water (Total)	gal*	31	. . .	. . .
Free Water on C.A.	gal*	. . .	0.5	−0.7
Free Water on Sand	gal*	. . .	5.0	5.0
Metered Water	gal*	. . .	24.0	24.0
Total Water at job arrival	gal*	. . .	29.5	28.3
Permitted Job Water	gal*	. . .	1.5	2.7
Slump	in.	5	4	2

* Water is presented in gallons rather than pounds due to the fact that most batch plants and all known transit-mix truck sidetanks measure in gallons. One (1) gallon of water = 8.33 lb.

The possible changes in a mixture affecting the slump greatly exceed the ones identified in Example 6.A, Case G. Each material or mixture property that affects slump has the capacity either to increase or decrease slump without a change in water content. Prudent ready-mixed concrete producers therefore do not attempt to batch at the maximum permissible slump but instead choose a target range below the maximum allowed. The need to have a slump value window dictates the need for the supplier to be able to add water at the job site, up to the limit permitted by the water-cement ratio.

Circumstances of Case G need some explanations. The example states that an unknown decrease in coarse aggregate moisture content helped create the problem slump. So, how did it become known that 2.7 gal of water per cubic yard could be added at the job site? A good driver keeps a close eye on testing procedures and test results. As soon as

EXAMPLE 6.A—*Slump values versus test results.*

Case	Specified Slump	Acceptable Slump Range (in.)	Test Value (in.)	Specification Compliance
A	3 in. maximum	1 ½–3	2 ¼	Meets specification
B	4 in. maximum	1 ½–4	3 ¾	Meets specification
C	Shall not exceed 4 in.	1 ½–4	4	Meets specification
D	Shall not exceed 2 in.	½–2	2 ¼	Fails (excessive)
E	3 in. maximum	1 ½–3	3 ½	Fails (excessive)
F	4 in. maximum	1 ½–4	1 ¼	Fails (low)
G	Shall not exceed 5 in.	2 ½–5	2	Fails (low)

the 2 in. slump result is suspected or known, the driver should radio this information to the batch plant. Typically moisture contents will be performed immediately on each aggregate used in the load. Quick results can be obtained by means of a microwave oven or a Speedy Moisture Tester. Calculations require another minute, and the information is transmitted by radio to the driver that an additional 2.7 gal/yd^3 is permitted in the load. Without a set of small scales, this quick adjustment is not possible. The microwave oven also is necessary, but this is an item commonly available for heating lunches. Remember that ready-mixed concrete manufacturers do not close for lunch, so facilities such as a break room are usually available.

6.1.2 *When the project specifications for slump are not written as a "maximum" or "not to exceed" requirement:*

Tolerance for Nominal Slumps

For Specified Slump of:	*Tolerance*
0–2 in. [0–50 mm]	*± ½ in. [15 mm]*
2–4 in. [50–100 mm]	*± 1 in. [25 mm]*
+ 4 in. [100 mm]	*± 1 ½ in. [40 mm]*

Nominal slumps are those specified as a 3 in. slump, a 4 in. slump, or some other target value. A typical specification might read:

Foundations	5 in. nominal slump
Grade beams	5 in. nominal slump
Floor slabs	4 in. nominal slump
Paving	2 ½ in. nominal slump

Slump values written in this manner have a permissible window of variation similar to that for maximum slumps. The tolerance for a nominal slump specification is plus or minus a value of ½ in., 1 in., or 1 ½ in., depending upon the numerical value of the specified slump. The target value for slump at the batch plant generally will equal the nominal slump specified unless the purchaser requests a target between the nominal value and the maximum allowable value. A comparison of several specified slumps and the acceptable tolerance for each follows in Example 6.C.

EXAMPLE 6.C—*Slump tolerance.*

Maximum Slump (in.)	Acceptable Tolerance (in.)	Nominal Slump (in.)	Acceptable Tolerance (in.)
6	3 ½–6	4 ½	3–6
5	2 ½–5	4	3–5
4	1 ½–4	3	2–4
3	1 ½–3	2 ½	1 ½–3 ½
2 ½	1–2 ½	2	1 ½–2 ½
2	½–2	1 ½	1–2

The option of one addition of water at the job site is not a requirement for a nominal slump specification, although it remains an excellent choice within the specification. There is no prohibition for a one-time job site water addition with this option since the ready-mixed concrete producer often "holds back" some water at the batch plant to accommodate a water addition at the job site by the contractor to achieve greater consistency. The target slump at the batch plant and the nominal slump specification usually will be identical, therefore the addition of water is needed only if the slump falls below the target value during transport. The tolerances for nominal slumps are narrower than those for maximum slumps, so the allowance for one water addition at the job site is a nice approach, especially in hot weather when the slump loss during transport is difficult to prejudge.

6.2 S1 *Concrete shall be available within the permissible range of slump for a period of 30 min starting either on arrival at the job site or after the initial slump adjustment permitted in 11.7, whichever is later.* S2 *The first and last ¼ yd^3 or ¼ m^3 discharged are exempt from this requirement.* S3 *If the user is unprepared for discharge of the concrete from the vehicle, the producer shall not be responsible for the limitation of minimum slump after 30 min have elapsed starting either on arrival of the vehicle at the prescribed destination or at the requested delivery time, whichever is later.*

The very nature of concrete's chemical reactions causes the slump to decrease with the passage of time. These reactions are accelerated by hot temperatures and slowed by cold temperatures, but the reactions and slump loss continue. Only the rate of slump loss varies. The question then becomes, at what point is it the concrete supplier's responsibility for the concrete to be within the tolerance and when does that responsibility transfer to the purchaser or designated agents? Slump increases are also possible if entrained air content increases with continued mixing.

S1 states that the supplier is responsible for the slump (maximum or nominal) for a 30-min period. The 30-min period begins either at the delivery vehicle's arrival at the job site or after the job site addition of water to the load. This one-time job site addition of water is for the purpose of increasing the slump to a point within the allowable tolerance. Neither a specified nor an approved maximum water-cement ratio should be exceeded during a slump adjustment. The details of this water addition are discussed in Section 11.7. Which governs, arrival at job site or job site slump adjustment? The latter of the two governs, and this will be the job site slump adjustment, unless there are some unusual logistics set up for a specific job. When does the 30-min clock begin when a Section 11.7 adjustment is made? The answer is when all the water is in the load.

S2 excludes the first and last ¼ yd^3 or ¼ m^3 from the slump requirements. The extreme ends of the load may not be uniform with respect to the remainder of the load. Two factors are important here: 1) do not test either fraction for slump, and 2) do not accept or reject the remainder of the load based on the appearance of these load portions.

S3 points out that after the 30-min period described in **S1** and **S2,** the user becomes responsible for the concrete slump, with one exception. If the delivery truck with the concrete is early, the 30-min clock of responsibility begins at the requested delivery time. Purchaser is not to be responsible for a mistake by the producer. By the same token, if the purchaser is not ready for the concrete when the truck arrives at the job site, the producer cannot be responsible for the slump at discharge if the delay is more than 30 min after the concrete was ordered, and the option to add water at the job site has been used.

EXAMPLE 6.D—*Slump responsibility.*

Time Criterion 1	A B	Arrival time at job site or After slump adjustment	Whichever is later
Time Criterion 2	A C	Arrival time at job site or Requested delivery time	Whichever is later

Case	Specified Slump	Delivery Time Specified C	Job Arrival Time A	Job Arrival Slump	Adjusted Slump	Time of Slump Adjustment B	Time to which Supplier is Responsible
1	4 in. max	9:00	9:12	3 in.	3 ½ in.	9:23*	9:53
2	4 in. max	9:20	9:15	3 in.	3 ½ in.	9:25*	9:55
3	4 in. max	9:40*	9:30	4 in.	...	...	10:10
4	4 in. max	10:00*	9:42	3 in.	3 ½ in.	9:55	10:30
5	4 in. max	10:20	10:23*	4 in.	...	...	10:53
6	4 in. max	10:40*	10:30	4 in.	...	...	11:10

* Controlling time element.

The three time criteria for transfer of responsibility of slump from producer to user are itemized as follows and are illustrated in Example 6.D.

Time criteria summary:

A. 30-min after arrival at job site.
B. 30-min after slump adjustment at job site.
C. 30-min after scheduled delivery time.

7

Air-Entrained Concrete

SECTIONS 15 AND 16 REFERENCE or detail the specifics of determining the air content of freshly mixed concrete. Three ASTM methods are available for the measurement of air in the concrete:

1. ASTM Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method (C 231)
2. ASTM Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method (C 173/C 173M)
3. ASTM Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete (C 138/C 138M)

Variations occur in air content for many reasons, including inaccuracies in testing methods. Time affects air contents, just as it affects slump, so multi-operator tests from the same sample appear to be the best comparison of tested air contents. The precision statement of ASTM C 173/C 173M is based upon multi-operator tests. The precision for ASTM C 173/C 173M (Roll-a-meter) varies with air content, but in the range of 5–6 % air, the standard deviation is approximately 0.5–0.7 %. Using the Type B pressure meter (most common device) of ASTM C 231, the standard deviation[6] reduces to approximately 0.4 %. The Type A pressure meter of ASTM C 231 has an even lower standard deviation of 0.28 % for multioperator precision. Test data concerning air content precision for the ASTM C 138/C 138M test method are not available. Making some assumptions, if the multi-operator precision of the density measurement is translated to the calculated air content, it amounts to a standard deviation of about 0.5 %. In summary, it is clear that testing precisions have reported standard deviations from 0.28–0.7 % air content.

Some of the other items that will cause variations in air content include variations in slump, changes in temperature, variations of batch masses (weights) of all materials, variations in air-entraining admixture (AEA), batch size as compared to mixer capacity, alterations in batching sequence, speed of mixing drum, haul time, sampling point, carbon content variations in fly ash, aggregate grading variations, quantity of fines attached to the surface of crushed coarse aggregate, use of water reducing chemical admixtures, and use of chemical accelerators or colored pigments. An increase in the alkalinity of the cement or the concrete will increase the initial air content at a constant admixture dosage, but some of this entrained air is apt to be lost in transit [27]. Even this long list does not include all factors that may affect the total air content and variations in the measured air value.

[6] ASTM Test Method C 231 does not yet address precision of the more common, shorter-necked Type B pressure meters. These were involved in a 1996 study conducted by the Portland Cement Association at their Skokie, Illinois laboratory. Fifteen Chicago area testing technicians assembled in Skokie to compare the results of Type B pressure meters when using the same concrete at three different ranges of air content. The unpublished test results indicated a standard deviation of approximately 0.4 % and an acceptable range of approximately 1.0 %, by volume of concrete, on consecutive tests on portions of the same sample.

7.1 $_{S1}$ *When air-entrained concrete is desired the purchaser shall specify the total air content of the concrete.* $_{S2}$ *See Table 1 for recommended total air contents (Note 8).*

The earlier discussion in Section 4.1.3 of the advantages of entrained air in concrete should be revisited. **S1** is a reminder to the specifier (purchaser or purchaser's agent) that it is the specifier's responsibility to determine the need for entrained air and the optimum amount desired. Note that the phrase "total air content" is used rather than "entrained air content." Each of the test methods available to measure air content measures the total air and cannot separate entrained air from entrapped air.

A moderate amount of air is entrapped in concrete during the mixing process. This normal air (entrapped air) typically occupies 0.5–2.0 % of the volume of the concrete mixture. The more typical range is 1.0–1.5 % for entrapped air. These air bubbles are usually 1 mm or larger in diameter and irregular in shape, while entrained air bubbles are predominately 0.1–0.05 mm (100–50 μm) with minimum diameters of approximately 10 μm [94,95]. One micrometer (μm) is one thousandth of a millimeter (mm), so entrained air is composed of very small bubbles, too small to be visible to the naked eye. The shape of these entrained bubbles is spherical and uniform.

S2 is a reference to Table 1 (see Ch. 4) for a recommendation to the specifier for a total air content. As discussed in Section 4.1.3, Table 1 makes recommendations on air content depending on the severity of exposure to freeze-thaw weather conditions and the nominal maximum aggregate size. In geographic areas where interior slabs are placed and finished in an exterior environment that is expected to freeze before enclosure, entrained air must be a consideration. If a dense, polished, machine-troweled surface is desired, entrained air may be detrimental to the desired surface texture and eventual durability. Entrained air in concrete tends to reduce the bleeding, and after the surface is sealed by trowelling, air and water are trapped below the surface skin, which may eventually pop off. In such cases, it may be necessary to schedule sequencing of an enclosure prior to slab placement. Several cases of Table 1 are demonstrated in Example 7.A.

Note 8, which was discussed in Section 5.1.6, is referenced in **S2** as a reminder that air contents are subject to many

EXAMPLE 7.A—*Recommended total air content using ASTM C 94/C 94M Table 1.*

Case	Environment of Concrete	Exposure Condition	Nominal Maximum Aggregate	Recommended Total Air Content
A	Pavement in a deicing salt location	Severe	1 in.	6.0 %
B	Interior slab placed in summer	N. A.	1 in.	none specified
C	Pavement in geographic areas exposed to occasional freezing but not deicing salts	Moderate	1 ½ in.	4.5 %
D	Basement wall in area exposed to freezing (wet soil)	Severe	¾ in.	6.0 %
E	Exterior beam not exposed to wet soil but exposed to periodic freezing	Moderate	¾ in.	5.0 %
F	Interior or exterior service without freezing exposure, but better workability desired	Mild	1 in.	3.0 %
G	Exposed gravel sidewalk in a deicing salt location	Severe	⅜ in.	7.5 %

variations. A predetermined dosage for an entire project is only a dream. Adjustments in the AEA dosage are common and necessary.

7.2 *The air content of air-entrained concrete when sampled from the transportation unit at the point of discharge shall be within a tolerance of ± 1.5 of the specified value.*

The tolerance from the specified air content is described as ± 1.5 % and is further defined as being the measured air content at the point of discharge from the transportation unit. This broad term "transportation unit" includes the customary ready-mixed concrete truck, an agitating delivery unit, or even an approved dump truck. There is no difference in entrained air requirements due to configuration of the delivery vehicle.

A second important aspect of this sentence is that the air content for the purpose of acceptance is to be measured at the point of discharge and not at some other location such as the point of placement. This distinction between measuring at the point of discharge (discharge from transportation unit) as opposed to measurement at point of placement is very critical and is crucial to the producer. This is an understandable problem because the A/E is concerned with the concrete as it becomes a part of the project, which is at the point of placement. The producers are concerned with the concrete only up to the point of discharge because that is where their control over the product ends. The typical intermediary is a concrete pump. It could be a conveyor, a power buggy, a concrete bucket, or some other movement device for the concrete. The pump arrangement of Fig. 7.A depicts the two potential sampling points.

The conflict with the needs of the A/E is that between the point of discharge and the point of placement, unpredictable changes in air content and slump often occur. The producer is not in a position to guarantee air content at a location other than the point of discharge. Changes occur to air content and slump in a pump line or other transporting method. The slump and air content will typically decrease, but how much of a decrease is unknown. The pump line losses are affected by the pump line diameter, pumping pressure, line length, and line configuration, which can change significantly even while placing the same load of concrete.

Who is responsible for predicting the changes in air content between the point of discharge and the point of placement? Candidates include the A/E, inspector, general contractor, concrete subcontractor, testing laboratory, and pumping contractor. Each of these has equal knowledge and greater control over the concrete after it reaches the job site than the ready-mixed concrete producer. It is best to assign responsibility among the candidate parties involved in the pumping process in the specifications, and to decide a process for ensuring that the correct quantity of air is achieved at the point of placement at a preconstruction conference. The ultimate goal is for the designated responsible party to direct the manufacturer to increase the slump and air contents by "X" in. and "Y" % to account for the job site transportation losses. These additions of "X" in. for slump and "Y" % for air may take the concrete out of specification range at the point of discharge, but if transportation losses are correctly assessed, the product will be correct at the point of placement. Losses of entrained air in the pump can be 2–3 % or may be considerably less. Losses on belt conveyors can be 1 % or more. Slumps also decrease during transport by these devices. Examples of handling such circumstances are shown in Example 7.B. A consequence of not losing the anticipated air content during the placement of the concrete is that the in-place concrete will be at a higher air content and a lower strength.

There is no disagreement that the A/E is best served by test results at the point of placement. There is also no disagreement that the producer has no control over the product beyond the point of discharge. The only disagreement seems to regard the placement of responsibility on knowledgeable persons having some degree of control.

The prudent approach on a project where the point of discharge and point of placement are different is for the purchaser's testing laboratory to initially evaluate air content and slump at both locations using what might be a typical pump line configuration. This will establish initial handling losses, thus assisting in adjustments at the batch plant as dictated by the testing laboratory or other responsible party. Do not be alarmed if changes occur later in the air content and slump, as the pump line configuration may change, temperatures may change, mixer waiting times may change, or the testing technician may change. If the trial or expected air content losses are not realized during the placement process, the additional air incorporated by the producer to account for placement losses may result in excessive air contents and a strength problem.

Some designers would like to reduce the ± 1.5 % specification window provided to the producer. In light of the many unpredictable changes in air content already discussed, including weather changes and testing variations, a reduction in the 3 % window is not prudent. If the specifier is nervous about the low side of the ± 1.5 % window providing inadequate air content for the project, a better approach is to increase the specified air content. Do not reduce the size of the specification window.

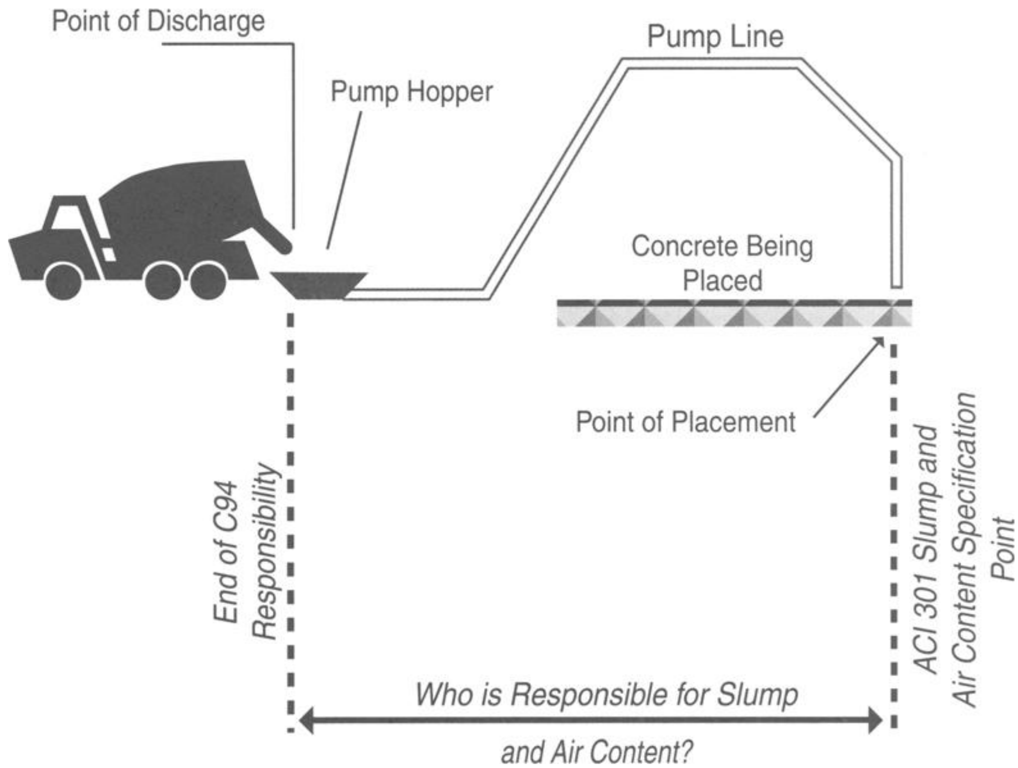


FIG. 7.A—*Sketch of ready-mixed truck unloading through pump line.*

EXAMPLE 7.B—*Air content specification compliance.*

Case	Specified Air Content (%)	Specified Test Location	Acceptable Range for Air Content (%)	Air Content at Discharge (%)	Air Content at Point of Placement (%)	Specification Compliance
A	6	at discharge	4 ½–7 ½	5.2	4.5	Yes
B	6	at placement	4 ½–7 ½	6.0	4.2	No
C	6	at placement	4 ½–7 ½	8.0	6.0	Yes
D	6	at discharge	4 ½–7 ½	8.0	6.0	No
E	6	at placement	4 ½–7 ½	7.0	4.0	No
F	6	at discharge	4 ½–7 ½	6.5	5.0	Yes

7.3 $_{S1}$ *When a preliminary sample taken within the time limits of 11.7 and prior to discharge for placement shows an air content below the specified level by more than the allowable tolerance in accordance with 7.2, the manufacturer may use additional air entraining admixture to achieve the desired air content level, followed by a minimum of 30 revolutions at mixing speed, so long as the revolution limit of 11.7 is not exceeded (see Note 9).*

Two references to Section 11.7 are stated within Section 7.3; the first of these is a reference to time limits. Section 11.7 includes a maximum mixing time of 1½ h unless waived by the purchaser. The second Section 11.7 reference is a maximum of 300 mixing drum revolutions unless waived by the purchaser.

S1 begins with reference to a "preliminary sample" taken "prior to discharge for placement." The preliminary sample is the same sample described in Section 6.3. It does not include the first ¼ yd^3 [1/4 m^3] but may then be taken to check air content or slump before any further concrete is discharged for the project. The sample must be taken prior to the 1½ h time limit and the 300 revolution limit or limits specified by the purchaser. If the specified time limit or number of mixing revolutions is exceeded, the air content becomes a moot point. The concrete may already be rejected. If not, the air content may be checked from a preliminary sample.

If the air content is below the specified minimum, the manufacturer may add some additional air-entraining admixture. The mixing drum is then turned a minimum of 30 revolutions at mixing speed to achieve adequate mixing and uniform air content throughout the load. The revolution limit of Section 11.7 remains in effect. As an example, if the batch has 280 revolutions at the time the AEA is added, it would have 310 revolutions after mixing is completed and

EXAMPLE 7.C—*Air content adjustments.*

Case	Specified Air Content (%)	Specified Range of Air Content (%)	Preliminary Air Content (%)	Adjusted Air Content (%)	Revolutions of Drum	Specification Compliance
A	5.0	3 ½–6 ½	3.0	4.5	200	Yes
B	6.0	4 ½–7 ½	4.0	5.0	310	No*

* Limit of 300 revolutions may be waived by purchaser (see 11.7).

would be rejected by the excessive number of revolutions, which again the purchaser can waive.

Two cases of using Section 7.3 are shown in Example 7.C.

The situation of an air content higher than the upper end of the tolerance may occur. While C94/C 94M is silent on this, there are means of using chemicals that remove some of the air in the concrete, and these same procedures might be permitted by the purchaser to allow for correcting this situation.

Note 9—*Acceptance sampling and testing in accordance with Practice C 172 is not obviated by this provision.*

ASTM Practice for Sampling Freshly Mixed Concrete (C 172) contains two specific provisions that are violated by the preliminary sampling process. ASTM C 172 requires sampling two or more portions of the load at regularly spaced intervals during discharge of the middle portion of the batch to obtain the sample for acceptance testing. The preliminary sample is one small segment of concrete after ¼ yd^3 has been discharged, so it clearly is not from the middle. Note 9 states that the preliminary sample cannot be used for strength testing and cannot be used as the reported acceptance test. The reported test results will still come from two or more combined portions of concrete taken from the middle portion (70 %) of the batch or load.

8

Measuring Materials

ONE OF THE CRITICAL FACTORS in producing consistent concrete is the consistency of batching materials in successive batches, on successive days, and throughout the course of the project. The required accuracy of these batching measurements is the primary focus of Section 8.

8.1 *$_{S1}$ Except as otherwise specifically permitted, cement shall be measured by mass. $_{S2}$ When mineral admixtures (including ground granulated blast-furnace slag, coal fly ash, silica fume, or other pozzolans) are specified in the concrete proportions, the cumulative mass is permitted to be measured with cement, but in a batch hopper and on a scale which is separate and distinct from those used for other materials. $_{S3}$ The mass of the cement shall be measured before mineral admixtures. $_{S4}$ When the quantity of cement exceeds 30 % of the full capacity of the scale, the quantity of the cement shall be within ± 1 % of the required mass, and the cumulative quantity of cement plus mineral admixtures shall also be within ± 1 % of the* required *mass. $_{S5}$ For smaller batches to a minimum of 1 yd^3 [1 m^3], the quantity of the cement and the cumulative quantity of cement plus mineral admixture used shall be not less than the required amount nor more than 4 % in excess. $_{S6}$ Under special circumstances approved by the purchaser, cement is permitted to be measured in bags of standard mass (Note 10). $_{S7}$ No fraction of a bag of cement shall be used unless its mass has been determined.*

Requirements for measuring cement and cementitious mineral admixtures (SCM) (see Footnote [3] in 4.3.1.1) are covered in Section 8.1. The section covers not only the method and required accuracy of material measurement, but it is explicit in which material is measured first.

S1 is clear that cement, and by extension, cementitious materials, will be measured by mass (weight), unless the specifications specifically permit otherwise. Alternative approaches to cement measurement could include measurements in bags of cement, shovels of cement, a meter such as in ASTM Specification for Concrete Made by Volumetric Batching and Continuous Mixing (C 685/C 685M) volumetric batching devices, or possibly as a slurry whose density is closely monitored. The typical mass (weight) measurements are in pounds or kilograms.

S2 concerns itself with mineral admixtures, which also are identified as supplementary cementitious materials (SCM) [3]. Specifically named are ground granulated blast-furnace slag, fly ash produced by burning coal, silica fume, and other pozzolans. Each of these mineral admixtures (SCM) can be substituted for a portion of the cement, under the proper circumstances. It is permissible for these supplementary cementitious materials to be weighed with the cement and the mass (weight) accumulated. The different materials cannot be released into the weighing apparatus simultaneously. They must each be weighed separately so that the individual weight of each material is known and may be recorded. The batching hopper for cement is not to be used for "other materials," meaning aggregates. **S3** stipulates that the cement will always be measured first when other cementitious materials are weighed in the same batching hopper. The requirement to weigh the primary cement first is a recognition that this quantity is critical to the intended performance of the concrete and also that it is most often the most expensive ingredient in the concrete, thereby protecting the purchaser. Minor deviations of the target mass of the supplementary cementitious materials (SCM) generally can be compensated for by adjustments in the aggregate measurements. Batching hoppers for the cementitious materials are also called cement weigh hoppers or cement scales.

The practical approach to configuring an apparatus to contain cement and to weigh the cement is to provide a container that is suspended from a separate support system. The container is to be attached to the support system by one of two methods: suspended from the support system frame by steel rods interconnected by intermediate load cells to measure the suspended weight or attached by means of a series of knife-edges and lever arms, which transmit the weight to a beam-and-poise type lever system. The scale capacity is related to the size of the container (cement weigh hopper). Cement traditionally is said to have a loose density of 94 lb/ft^3. In a weigh hopper it is not compacted but is in a partially aerated state with a density closer to 75 or 80 lb/ft^3 rather than 94 lb/ft^3. A typical assumption is that a cement weigh hopper with a volume of 3 yd^3 (81 ft^3) will hold three tons of cement (2000 lb/yd^3). The scale capacity can therefore be sized based on the size of the cement weigh hopper. The more common process for sizing weigh batchers is to provide sufficient capacity for the ingredient to produce a target minimum number of cubic yards of concrete in one batch. A manufacturer's approach is to provide a minimum of 9 ft^3 of batcher volume for each yd^3 of concrete, plus an additional allowance of 3 ft^3 for fluffing of cement [22]. Thus, for a batch plant rated at 10 yd^3, the cement batcher capacity must equal or exceed $(10 \times 9) + 3 = 93$ ft^3 of volume. The rated capacity of a cement batcher built to Concrete Plant Manufacturers Bureau (CPBM) standards is listed on a plate from the CPMB and affixed to the batcher. The dead load of the weigh container must also be considered in selecting the equipment, but this weight is zeroed or tared during the installation process.

S4 specifies the accuracy required when batching loads in which the cement quantity will be in the upper 70 % (30–100 %) of the cement scale capacity. The required accuracy in this range of use is ± 1 % for both cement and mineral

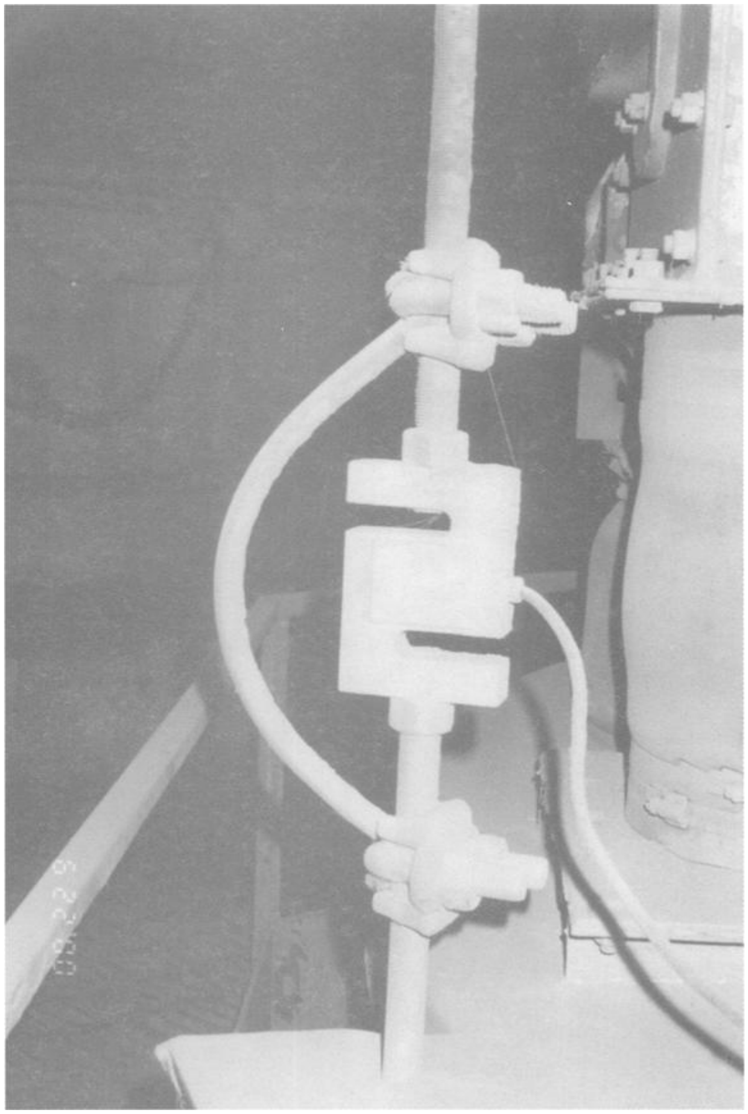


FIG. 8.A—*Photo of a load cell for scales.*

admixtures. An example on the required accuracy is demonstrated in Example 8.A.

S5 discusses the cementitious material batching accuracy for batches of 30 % or less of scale capacity. The required accuracy for the lower 30 % of scale capacity changes to −0 % and + 4 %. In the lower 30 % of the cement scale capacity, an underweight of cement is not permitted. Using our previous example of an 8000 lb scale capacity and a mixture utilizing 550 lb of cement per yd^3 for a batch of 3 yd^3, the required accuracy is as illustrated in Example 8.B.

S5 is explicit that these plus or minus tolerances only apply to batches of 1.0 yd^3 or larger. Batches of less than 1 yd^3 do not have a minimum or maximum tolerance and are discouraged due to the difficulties of accurate batching. Batching equipment available to the industry will not routinely batch less than 1 yd^3 within these narrow tolerances. A 1-yd^3 batch in the previous example of 550 lb of cement would have a tolerance range of 550–572 lb—a very narrow window!

A situation that may be confusing is one that straddles 30 % of capacity. Consider a scenario of a mixture with 400 lb of cement and 150 lb of fly ash and an order for 5 yd^3. The cement scale capacity remains at 8000 lb.

Which accuracy criteria governs this situation, the −0 %, + 4 % or the −1 %, + 1 %? Actually, **S4** handles this question in its opening phrase, "When the quantity of cement exceeds 30 %. . ." the cement shall be within ± 1 % of the required mass." In the example, the mass of the cement (25 %) is less than 30 %, and therefore the criterion related to operating at < 30 % of scale capacity governs for both the cement and the cement plus mineral admixtures. The tolerances for this example are −0 %, + 4 %. Current practice with most ready-mixed concrete producers is to read **S4** as "When the quantity of cementitious materials (cement plus mineral admixtures) exceeds 30 % of the full capacity of the scale. . ." Unfortunately, that is not what is stated.

Discussions at the subcommittee level are expected to produce a change in **S4** in the near future. The expected change

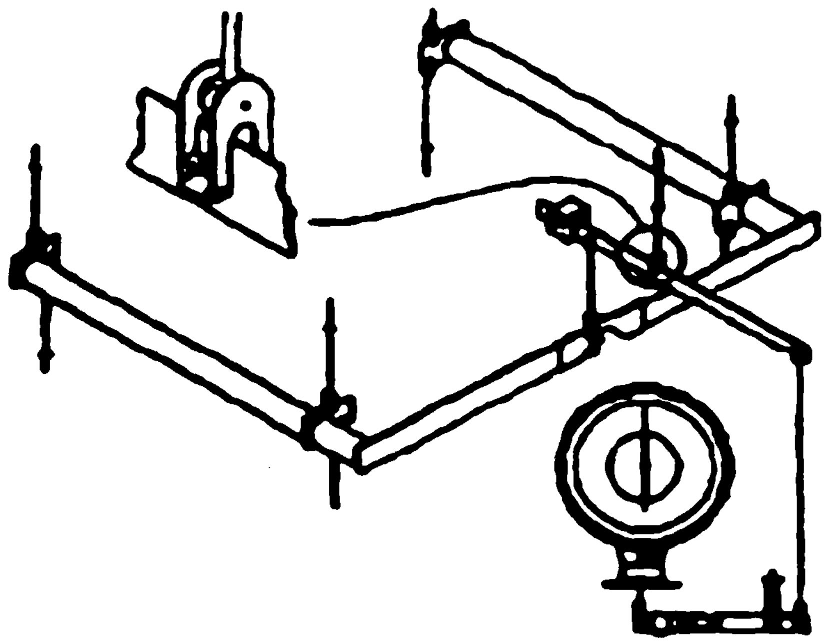


FIG. 8.B—*Schematic of scale lever system.*

EXAMPLE 8.A—*Required cement scale accuracy at greater than 30 % capacity.*

Cement scale capacity	=			8000 lb
Size of batch	=			8 yd^3
Cement per yd^3	=			550 lb
Total cement per batch	=	8 × 550	=	4400 lb
Percent of scale capacity used	=	4400 ÷ 8000	=	55 % > 30 %
Required accuracy (± 1 %)	=	4400 × 0.01	=	± 44 lb
Acceptable mass (weight) range	=	4356–4444 lb		

Tolerances are based upon Quantity of cement (not cementitious materials)	
Quantity of cement less than 30 % of scale capacity	Quantity of cement exceeds 30 % of scale capacity
−0 % + 4 % of cumulative total of cement and cementitious materials	± 1 % of cumulative total of cement and cementitious materials

would involve changing "cement" to "cementitious materials" exceeding 30 % of the full capacity of the scale. Another portion of the discussion will address having more than one tolerance range for one batch of concrete as currently exists.

EXAMPLE 8.B—*Required cement scale accuracy at less than 30 % capacity.*

Total cement per batch	=	3 × 550	=	1650 lb
Percent of scale capacity used*	=	1650 ÷ 8000	=	20.6 % < 30 %
Required accuracy (−0 % to +4 %)	=	1650 × 0	=	−0 lb
		1650 × 0.04	=	66 lb
Acceptable mass (weight) range	=	1650–1716 lb		

* Capacity of cement scale is 8000 lb.

A consequence to these two different tolerance brackets is that the cement scale should have its full-scale capacity limited to the minimum value that will allow it to batch the largest typical load. From the producer standpoint, a ± 1 % tolerance is more desirable than −0%, + 4 %, because the zero negative tolerance forces the batch target mass to be an over yield.

S6 is very straightforward in its requirement that bagged cement is only permitted when approved by the purchaser. The other requirement for usage of bagged cement regards special circumstances. Examples of special circumstances are running out of cement in a silo and trying to finish an order with bagged cement from the lumber yard or a small

EXAMPLE 8.C—*Required cement scale accuracy when cementitious materials straddle 30 % capacity.*

Total cement per 5 yd^3 batch	=	5 × 400	=	2000 lb
Cement as % of scale capacity*	=	2000 ÷ 8000	=	25 % < 30 %
Total fly ash per 5 yd^3 batch	=	5 × 150	=	750 lb
Fly ash as % of scale capacity	=	750 ÷ 8000	=	9.4 % < 30 %
Total cementitious material in batch	=	25 % + 9.4 %	=	34.4 % > 30 %
Acceptable mass (weight) range	=	2750 lb–2860 lb (−0 % to + 4 %)†		

* Capacity of cement scale is 8000 lb.
† Cement quantity controls allowable total tolerance.

order into the outback country and holding the cement out until the mixer reaches the job site. Another special circumstance can include a small job using white cement and a silo not being available or the order not large enough to require a full tanker load. A small job requiring a special cement such as a Type III can present the same scenario as the white cement.

S7 addresses the use of partial bags of cement. No partial bags of cement may be used unless scales are available to determine the mass of their contents. An example is an order of 1.5 yd^3 for a 5 ½ bag mix. This is 8.25 bags of cement, thus, necessitating scales to determine the accuracy of the ¼ bag. Many plants have platform scales available for such emergencies or in some localities a feed and grain store may not be far away.

Note 10*—In the United States the standard mass of a bag of portland cement is 94 lb [42.6 kg) ± 3 %.*

This note is for the purpose of advising the quantity of cement in a bag and the tolerances for a bag of cement. Traditionally the per bag quantity has been 94 lb, but the emphasis on metric (SI) units in the 1990s caused ASTM Specification for Portland Cement (C 150) to alter a standard bag to 42 kg, which is 92.6 lb. Note 10 of ASTM C 94/C 94M is expected to adopt the 92.6 lb bag standard to conform to ASTM C 150.

There are two significant reasons for manufacturers and purchasers to be advised on the mass (weight) and tolerances of a bag of cement. One relates to batching a mixer with bagged cement when proportions have been stated in pounds. Every bag does not need to have its mass determined (be weighed). The second reason encompasses Section 4 Ordering Information, Option B, 4.3.1.1, and Option C, 4.4.1.2, which allow the purchaser to state the desired cement content in bags per cubic yard or minimum cement content in bags per cubic yard. These options do not mean the manufacturer must actually use bagged cement. The intent is that the manufacturer must use a mixture proportion that includes a comparable cement content. When a purchaser says "It's cold today, send me a 6-bag mix," the order is for a mixture with a cement content of 564 lb (6 × 94 lb/bag) of cement per yd^3.

8.2 $_{S1}$ *Aggregate shall be measured by mass.* $_{S2}$ *Batch mass measurements shall be based on dry materials and shall be the required masses of dry materials plus the total mass of moisture (both absorbed and surface) contained in the aggregate.* $_{S3}$ *The quantity of aggregate used in any batch of concrete as indicated by the scale shall be within ± 2 % of the required mass when the mass is measured in individual aggregate weigh batchers.* $_{S4}$ *In a cumulative aggregate weigh batcher, the cumulative weight after each successive weighing shall be within ± 1 % of the required cumulative amount up to that point when the scale is used in excess of 30 % of its capacity.* $_{S5}$ *For cumulative weights for less than 30 % of scale capacity, the tolerance shall be ± 0.3 % of scale capacity or ± 3 % of the required cumulative weight, whichever is less.*

Aggregates, both fine and coarse, are measured by mass (weight). The weighing system is very similar to the arrangement for weighing cement and supplementary cementitious materials (mineral admixtures). The difference in the batching equipment for cementitious materials and aggregates is discussed in Section 9.

Like cementitious batchers, manufacturers of plant equipment provide for a minimum volume of the aggregate batchers and rate it based on the volume of concrete that can be produced. An aggregate batcher built to CPMB standards will have a plate issued by the Concrete Plant Manufacturers Bureau affixed to it that indicates its rated capacity. The standards [22] require 38 ft^3 of aggregate volume capacity for each cubic yard of concrete. Therefore an aggregate batcher rated to produce 10 yd^3 of concrete will have a volume equal to or greater than $10 \times 38 = 380$ ft^3. Assuming a loose density of 85 lb/ft^3 for the aggregate, this amounts to about 3300 lb of aggregate for each cubic yard of concrete.

S2 gets into the first difference between weighing cement and weighing aggregate, where aggregate moisture is weighed also. With cement, moisture is carefully excluded from the product until the time of mixing. With aggregates, this is not necessary. The only effect of aggregate moisture is the requirement to account for it in the total mixing water. **S2** is clear that batch weights for aggregates must include three components: dry aggregate mass, moisture absorbed by the aggregate, and surface moisture on the aggregate. It does not say that the aggregate must be dry, and it does not say that aggregate proportions are to be recorded as dry weights. The intent of the phrase "based on dry materials" is to ensure that the quantity of aggregate incorporated in the mixture is consistent with that of the mixture proportioning design and establishes that the batched weight is the sum of the dry mass of the aggregate and the total (absorbed and free) moisture within and on the aggregate. Aggregate moisture content typically is measured on the basis of its dry mass as described in ASTM Test Method for Total Evaporable Moisture Content of Aggregate by Drying (C 566).

S3 discusses tolerances for aggregate mass when each aggregate has a separate weigh batcher (scale hopper). Separate weigh batchers are referred to in **S3** as individual aggregate weigh batchers. This type of arrangement is present at high production rate plants because individual aggregate weigh hoppers allow each of the aggregates to be measured (weighed) simultaneously rather than consecutively, as in the more traditional batch plants. With individual aggregate weigh hoppers, the tolerance is ± 2 % of the target mass. If the target aggregate mass is 14 400 lb, the acceptable range for the target mass is 14 112–14 688 lb.

S4 discusses cumulative aggregate weigh batchers (scale hoppers), which take on a characteristic of a cement weighing system. The referenced characteristic is that allowable tolerances change at 30 % of scale capacity. **S4** addresses tolerances for batches in the plus 30 % of capacity range. The 30 % of capacity division is based on the total cumulative aggregate in the batcher being in excess of 30 % of scale capacity.

S5 describes the aggregate batching tolerances for cumulative mass scales at masses (weights) less than 30 % of scale capacity. The lesser of two criteria govern. The criteria are ± 0.3 % of scale capacity or ± 3 % of the desired weight at that point in the batching process. Compare the following values:

Assume there is an aggregate scale capacity of 30 000 lb. At 30 % capacity, the scale will read 9000 lb. From 9000–30 000 lb, the required accuracy is ± 1 % of the desired batch weight. At less than 9000 lb, the dual criteria are used. At 9000 lb, ± 3 % equals 270 lb. The ± 0.3 % of scale capacity criteria equals 90 lb. The latter value (90 lb) is the minimum accuracy required. The ± 3 % of load only governs at 10 % or less of scale capacity. The ± 0.3 % of scale capacity applies for loads between 10–30 % of scale capacity. Above 30 % of scale capacity, the ± 1 % of desired weight becomes the acceptable tolerance.

A typical aggregate scale capacity is 40 000 lb. The 30 % of capacity mark is then 12 000 lb. Assume a mixture composed of three aggregates with proportions of 37.5–19.0 mm (1½ in.–¾ in.) = 950 lb, 19.0–4.75 mm (¾ in. to No. 4) = 850 lb, and Sand 1400 lb. The customer's order is for 6 yd^3. Aggregate desired masses in a cumulative aggregate weigh batcher and allowable tolerances are shown in Example 8.D.

Note that the section does not require a particular sequence in which the aggregate is weighed. Producers choose the optimum sequence of batching aggregates in cumulative batchers based on the plant arrangement, tolerable noise level, and best sequence to prevent balling and to produce homogeneous mixtures in the shortest time.

8.3 **S1** *Mixing water shall consist of water added to the batch, ice added to the batch, water occurring as surface moisture on the aggregates, and water introduced in the form of admixtures.* **S2** *The added water shall be measured by weight or volume to an accuracy of 1 % of the required total mixing water.* **S3** *Added ice shall be measured by weight.* **S4** *In the case of truck mixers, any wash water retained in the drum for use in the next batch of concrete shall be accurately measured; if this proves impractical or impossible, the wash water shall be discharged prior to loading the next batch of concrete.* **S5** *Total water (including any wash water) shall be measured or weighed to an accuracy of ± 3 % of the specified total amount.*

Concrete mixing water comes from so many actual sources that it is difficult to precisely account for total water. Five water sources are named in Section 8.3, but there is one minor source of water that is not named and not specifically measured or accounted for. This is the water which is sprayed onto the mixing drum, mixing drum loading hopper, and the rear-mixing blade of the drum immediately after loading to wash down cement and sand adhering to the metal. There is no practical means of separating and measuring cleaning water going into the drum and that water which does not go into the drum, because it all comes from one source at one time. The quantity of this unmeasured mixing water is usually small and carries additional cement into the concrete.

S2 requires the primary source of water added to the batch to be measured before discharge into the load by metering the volume or weighing the water. The most common measurement is with a 2-in. or 3-in. turbine meter. These are good instruments but can get out of calibration due to temperature changes, variable water pressures, excessive repetitions of water hammer, and routine wear. These meters should have their calibration checked on a regular basis. Other types of meters, such as magnetic meters, are available and require fewer calibration checks due to the lack of moving parts in the water stream. Weighed water containers are almost all handled by load cells, which also require fewer calibrations than turbine meters. These factors are mentioned because the required accuracy is a relatively tight ± 1 %.

Each type of water measuring system has advantages. Turbine meters have the lowest initial cost. Magnetic meters do not require strainers, as do turbine meters, and will accurately meter recycled wash water. Weighed water has the advantage of production speed. The weighed water may be measured in its load cell supported holding tank while a mixing truck is maneuvering into its loading position. The usual arrangement for metered water is direct discharge into a mixing truck, and this operation cannot begin until the mixer is in the loading position. This delays the commencement of loading, thus increasing the loading time per truck and decreasing productivity.

There is a method by which it is possible to meter water while a mixing truck is maneuvering into the loading posi-

EXAMPLE 8.D—*Tolerances for cumulative aggregate batcher.*

Aggregate Component	Target Quantity for 6 yd^3 (lb)	Target Cumulative Mass for 6 yd^3 (lb)	Percent of 40 000 lb Scale Capacity¶	Controlling Tolerance	Tolerance Range (lb)
37.5–19.0 mm	5700	5700†	14 %	0.3 % Capacity*	± 120*
19.0–4.75 mm	5100	10 800§	27 %	0.3 % Capacity‡	± 120‡
Sand	8400	19 200‖	48 %	± 1 %‖	± 192‖

* 40 000 capacity × 0.3 % = 120 lb
† 5700 target × 3 % = 171 lb > 120 lb: use 120
‡ 40 000 capacity × 0.3 % = 120 lb
§ 10 800 target × 3 % = 324 lb > 120 lb: use 120
‖ 19 200 target × 1 % = 192 lb > 30 % of scale capacity: use ± 1 %
¶ The ± 3 % of the desired weight criterion does not become a factor until the aggregate weight drops below 10 % of scale capacity.

<table>
<tr><td colspan="3">Cumulative weight of aggregate as compared to scale capacity</td></tr>
<tr><td colspan="2">Cumulative aggregate weight to point in question is less than 30 % of scale capacity</td><td rowspan="2">Cumulative aggregate weight is now greater than 30 % of scale capacity</td></tr>
<tr><td colspan="2">Lesser of</td></tr>
<tr><td>± 0.3 % of scale capacity</td><td>± 3.0 % of cumulative aggregate total</td><td>± 1.0 % of cumulative aggregate total</td></tr>
</table>

tion. Rather than discharging metered water into the mixing drum, it is metered into a holding tank. Following positioning of the mixing truck into the loading position, the water is released from the holding tank into the mixing drum. The speed advantage is gained by a quicker release of water into the mixing drum. The slowest process of loading a mixing drum is often the metered mixing water. The holding tank allows this time constraint on production to be overcome. The integrity of this water system is protected by a sensor that prohibits the commencement of loading a new batch and more metered water into the holding tank when there is already water in the tank.

S2 states a required accuracy for the added mixing water equal to 1 % of the required total (metered or weighed) mixing water. Water meter calibrations are typically to a tolerance of ± 1 % of the actual water quantity going through the meter. This is a tighter tolerance than **S2** demands. The 1 % in **S2** is based on total mixing water and not 1 % of the metered mixing water. The difference is that aggregate moisture and retained wash water are not added water but are a part of total mixing water.

S3 requires ice to be measured by mass when it is used as a portion of the mixing water. The substitution rate is 8.33 lb of ice for each gallon of water removed from the batching process. Ice should be substituted for the water and not used as an addition. Ice is used to control concrete temperature in summer months when it is critical to meeting maximum specification temperatures, or to control the setting characteristics of the concrete. Ice is sometimes used in blocks that are crushed with a chipper that discharges the ice into the truck mixer. In smaller applications, bagged ice might be used. Larger projects more often use chilled water or liquid nitrogen for cooling rather than ice due to economics.

S4 requires that any wash water used to remove adhered mortar from the inside skin of the drum from a previous load be measured accurately. This water generally is from the side tank on a truck mixer when washing is done at the job site. This quantity of water is difficult to measure accurately because it depends on the habits of the truck operator. It is likely practical to quantify this quantity through the site gage, or a meter on the side tank, or "eye-balling" to the nearest 10 gal. The requirement in **S4** is that if this water source cannot be determined accurately, the water should be discharged before the new concrete batch is loaded.

Recognizing the various sources of water and the impracticality of accurately tracking and measuring each source, the tolerance for mixing water in **S5** is ± 3 % of the target water intended by the design of the concrete mixture or the specified total water amount including aggregate moisture and wash water.

8.4 $_{S1}$ *Admixtures in powdered form shall be measured by mass.* $_{S2}$ *Liquid admixtures shall be batched by mass or volume.* $_{S3}$ *Admixtures, except mineral admixtures (see 8.1), measured by either mass or volume, shall be batched with an accuracy of ± 3 % of the total amount required or plus or minus the amount or dosage required for 100 lb [50 kg] of cement, whichever is greater.*

Powdered admixtures include such items as flaked calcium chloride, coloring pigments, and lithium salts. Chemical admixtures, such as water reducers, retarders, and air-entraining admixtures are also available in powdered form in bags but are commonly only used for adjustments at the job site. Fibers, whether steel, polypropylene, polyethylene, glass, nylon, or some other material, are handled and dosed similarly to powdered admixtures. Each of these products is to be dosed by mass (weight). Many of these products are purchased in bags containing prescribed product masses. Some of the bags require opening and dumping the product into the mixer. Some bags dissolve in water or disintegrate by the mixing action, allowing both bag and contents to be placed into the mixer. Water-soluble bags containing 1.5 lb of polypropylene fibers are a common product. The 1.5 lb is a commonly specified fiber quantity per cubic yard, allowing the supplier to drop eight bags of fibers into an 8-yd^3 batch of concrete. No muss, no fuss, and the manufacturer and purchaser are both satisfied with the measure. When using powdered color products, pre-weighed bags are a popular method of measuring and dispensing. These bags are also available sized for one cubic yard of concrete. The only problem with 1 yd^3 sized product bags is the inaccuracies with orders involving fractional cubic yards, such as a 6 ½ yd^3 load to finish an order (the clean up load).

Powdered or fiber products may be purchased in larger containers and the mass determined (weighed) on scales such as bench scales or platform scales. Examples of this equipment are the scales normally used for density tests of concrete (bench) and feed store scales (platform). These weighing devices take more time but can be more accurate for fractional yd^3 orders, such as 6 ½ yd^3.

The most frequently abused powdered product is probably flaked calcium chloride. Bags of flaked calcium chloride ($CaCl_2$) may be opened and fed into a truck mixer by dumping onto the aggregate transfer conveyor. The $CaCl_2$ is proportioned by guessing at the fractional number of bags required to provide the $CaCl_2$ quantity ordered. No weighing is involved. Sometimes bags are strapped to the fender of the ready-mixed concrete truck and dumped into the concrete mixture at the job site using the same guessing method. An example of this poor practice is given in Example 8.E.

EXAMPLE 8.E—*Flaked calcium chloride bag proportioning.*
Concrete mixture contains 564 lb of cement
Order is for 2 % (by weight of cement) $CaCl_2$ in a 9-yd^3 load
Required $CaCl_2$ quantity = 564 × 2% × 9 yd^3 = 101.5 lb/load
Number of 80 lb bags required = 101.5 ÷ 80 = 1.27 bags

It is difficult to accurately discharge ¼ of a bag manually by feel and by eye. This is a bad practice that does not meet ASTM C 94/C 94M batching tolerances of ± 3 %. The primary problem is that inaccurate batching will produce varying times of set. A typical result of these variations is a slab that is not within the desired smoothness tolerances. Section 9 discusses allowable batching tolerances for the equipment.

The recommended method of using dry $CaCl_2$ is to place it in solution at the batch plant and introduce it at the plant in liquid measured quantities. A calcium chloride solution is obtained by placing approximately two-thirds of the ultimate

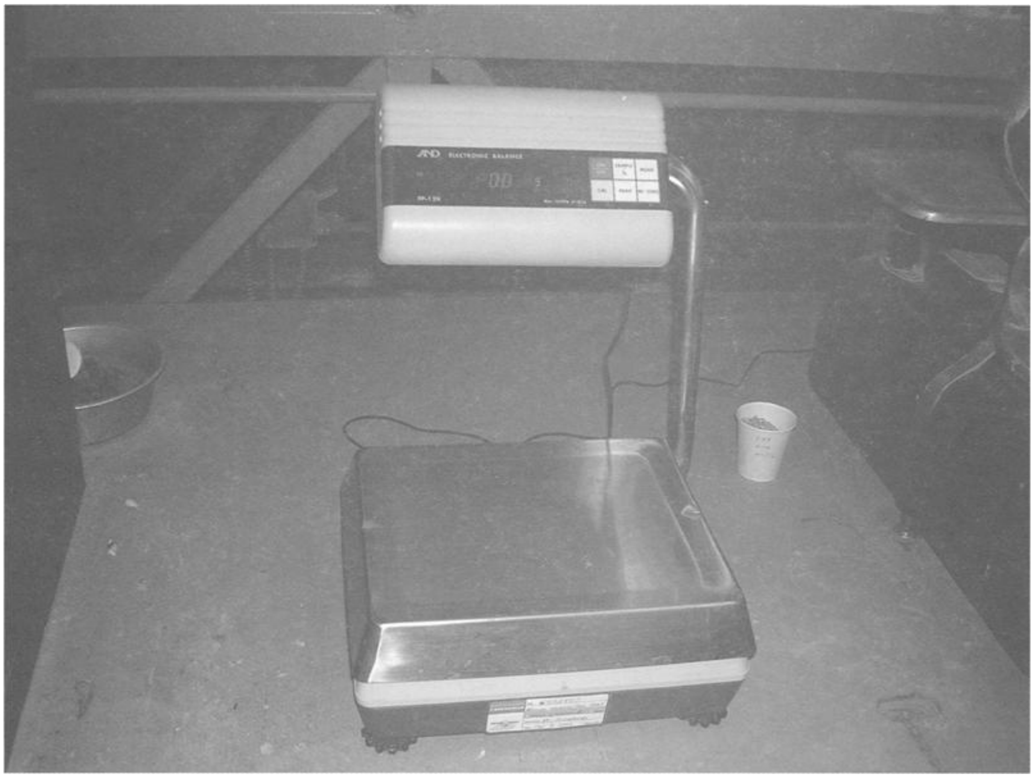


FIG. 8.C—*Photo of laboratory bench scales.*

water quantity in a tank. Dry $CaCl_2$ is then slowly added to the water while stirring the mixture. Quantities added vary with the form (flake or pellet) of the dry product. With a flaked product the usual addition rate is 4 lb per gallon of water. Thus, for a 500-gal tank, 2000 lb of $CaCl_2$ would be placed in solution before the final one-third of the water is added. Quantities of pellets will vary and are dependent upon the concentration of $CaCl_2$ in the pellet. The described mixture will produce a solution containing 1 lb of calcium chloride per quart (1 % per 100 lb of cement per cubic yard of concrete) [28]. For an 8-yd^3 load of concrete containing 500 lb of cement per cubic yard, the solution requirement is $(500 \div 100) \times 8 = 40$ quarts (two 5 gal buckets) per each 1 % calcium chloride needed.

A precaution to be taken with a calcium chloride solution is to subtract the $CaCl_2$ solution from the batch water quantity. The most important precaution is to not use calcium chloride if the concrete is to contain steel reinforcement and will not be in a dry or moisture protected service environment. Required limitations on the use of calcium chloride are given in ACI 301-99, Specifications for Structural Concrete[7].

A statement of importance in ACI 301 is that calcium chloride shall be added into the concrete mixture only in solution form. The most accurate means of meeting this requirement is for the ready-mixed concrete manufacturer to purchase the calcium chloride in a pre-mixed solution and to dispense it through a metered or weighing arrangement just as other chemical admixtures are measured.

In some large metropolitan areas where non-chloride accelerators (NCA) may be the rule, ready-mixed concrete producers may not stock calcium chloride products, but in most geographic areas where temperatures routinely drop below 60°F it is an in-demand product. The majority of ready-mixed concrete producers do not use a flake or pellet product but instead use a pre-manufactured solution of calcium chloride. The pre-manufactured solution will usually range between 28–42 % calcium chloride, with 32 % being the most popular, probably because of its low freezing temperature. Available solutions will depend upon the manufacturer and the geographic region. Each calcium chloride solution of a different percentage will contain a different quantity of calcium and chloride ions. It is important that a concrete producer be prepared to meet ACI 301 and ACI 318 maximum chloride requirements, when so specified by the purchaser. As a liquid admixture, the $CaCl_2$ solution is to be batched to the accuracies presented in **S3**.

With a variety of solution concentrations available to a ready-mixed concrete producer, there is a question of dosage calculations for each concentration. Early research was performed on the flake variety of calcium chloride that contained approximately 78 % calcium chloride, 17 % water, and 5 % of other products or impurities. It was research using the flaked product from which our current recommended restriction evolved, of not using more than 2 %

[7] The maximum chloride limits in ACI 301 are stated in terms of maximum water-soluble chloride ion (Cl^-) content in concrete, percent by weight of cement. The various limitations are on the chloride portion of the compound and not on the calcium chloride compound. The quantity of chloride ion in calcium chloride is approximately 48 % of the total product [37]. An order for 2 % calcium chloride only produces 1 % chloride ion.

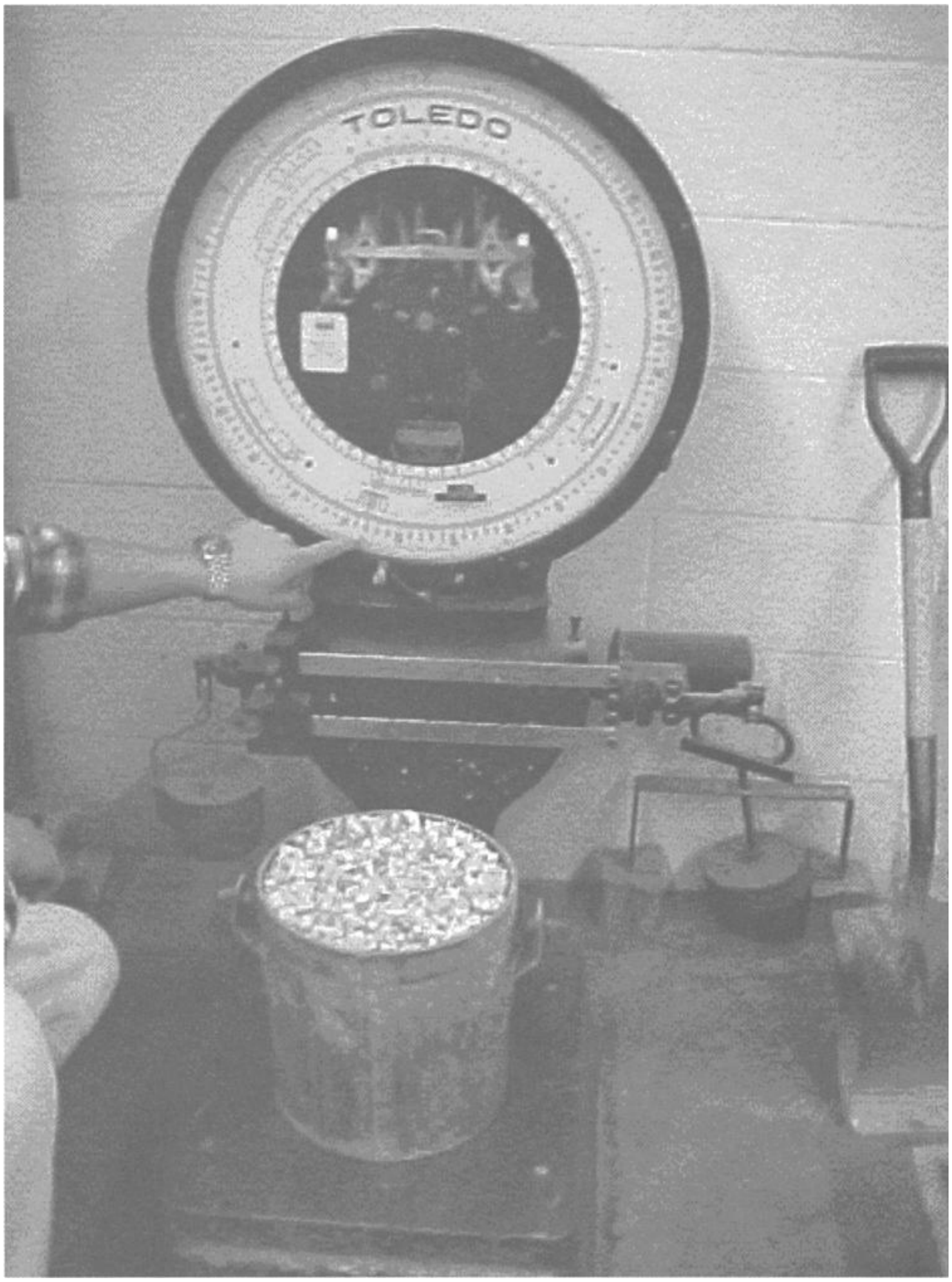


FIG. 8.D—*Photo of laboratory platform scales.*

$CaCl_2$ as an accelerator. Thus 2 lb of flaked $CaCl_2$ per 100 poundweight (cwt) of cementitious material is the traditional maximum dosage.

To obtain the same quantity of effective calcium chloride from a solution product, the 78 % $CaCl_2$ present in the flaked product must be considered. The other consideration is the strength of concentration. Each concentration of $CaCl_2$ solution will have a different density at various temperatures. Each $CaCl_2$ manufacturer has this data readily available. For the purposes of an example, a density of 10.99 lb/gal for a 32 % solution is assumed. Thus:

$$\frac{10.99\text{ lb.}}{\text{gal}} \times \frac{0.32}{0.78}$$

$$= 4.51\text{ lb of "Equivalent" } CaCl_2/\text{gal of 32 \% solution}$$

$$\frac{1.00\text{ lb "Equivalent" } CaCl_2/\text{yd}^3}{4.51\text{ lb "Equivalent" } CaCl_2/\text{gal}} \times \frac{128\text{ oz}}{\text{gal}} = 28.2\text{ oz/yd}^3$$

(dosage for 1 % "Equiv." flake $CaCl_2/yd^3/cwt$ of cement)

TABLE 8.A—*ACI 301-99 specifications for structural concrete.**

Type of Member	Maximum Water-Soluble Chloride Ion (Cl^-) Content in Concrete, Percent by Weight of Cement[7]
Prestressed concrete	0.06
Reinforced concrete exposed to chloride in service	0.15
Reinforced concrete that will be dry or protected from moisture in service	1.00
Other reinforced concrete construction	0.30

* Taken from Table 4.2.2.6—Maximum allowable chloride-ion content in ACI 301-99.

Sometimes it is necessary to know the amount of chloride ion in a cubic yard of concrete. Solutions of $CaCl_2$ are produced from a brine solution and do not have the impurities of the flake product. The $CaCl_2$ portion of the solution has a total molecular weight of ($2 \times 35.5 + 40 = 111$). The chloride portion is ($71 \div 111 = 64$ %). The most convenient method of comparison is to determine the amount of chloride ion in what has been previously described as 1 % equivalent $CaCl_2$. One pound of equivalent $CaCl_2/yd^3/cwt$ of cement only requires 0.78 lb of $CaCl_2$. Of the 0.78 lb, 64 % is composed of chloride ions ($0.78 \times 0.64 = 0.50$ lb). This is a 2:1 ratio of equivalent $CaCl_2$ to chloride ions. Another way to phrase the relationship is that 2 % equivalent $CaCl_2$ produces 1 % chloride ions.

S2 allows the concrete producer to choose between determining liquid admixture batch quantities by either volume (metering) or by mass (weighing). Pumping chemical admixtures through a miniature water meter and into a metal or plastic dispenser bottle is the most prevalent measuring method for liquid products. The weighing of liquid admixtures has been historically rare but accomplished by suspending a weighing pot from a load cell, which weighs the liquid product. The latest technology weighs the admixture by pumping it into the bottom of a vertical cylindrical tank. As the liquid rises in the cylindrical tank (dispenser), a load cell at the top of the dispenser measures the change in pressure, which is converted to mass (weight). Each of these measurement methods has proven effective and can be accurate if properly maintained and calibrated.

S3 requires admixtures to be batched to an accuracy of ± 3 % of the desired dosage or for small batches the requirement is ± the dosage per hundredweight (cwt.) of cement. The greater variation of the two criteria is used. For example, assume a water-reducing chemical admixture is dosed at 4 oz per cwt. of cement. An 8-yd^3 batch of a 5-bag mix is loaded. What is the permissible tolerance for the water reducer quantity?

FIG. 8.E—*Photo of admixture dispenser.*

- The first criterion is ± 4 oz.
- The second criterion is ± 3 % of (94 × 5 ÷ 100) × 4 oz/cwt × 8 yd^3.
- This result is ± 3 % of 150.4 oz equaling ± 4.5 oz.
- The 4.5 oz being greater than 4.0 oz is the allowable tolerance. The range of acceptable admixture dosage is 150.4 oz ± 4.5 = 146 to 155 oz.

Two questions are raised: Does "100 lb [50 kg] of cement" mean just cement, or does it mean "cementitious material"? Admixture dosages are often computed based upon a dosage per cwt. of total cementitious material rather than purely on the portland cement content, although some concrete industry professionals recommend using only the hydraulic cement content when computing the dosage of water reducers, retarders, and high-range water reducers. For air-entraining admixtures, the consensus is to always use the total cementitious material. The solution to the water reducer admixture question is for a producer to establish the dosage rate based on what is practical or technically sound to optimize the quantity of admixture required.

The water reducer dosage for a mixture comprised of 400 lb of cement plus 150 lb of fly ash and a dosage of 4 ounces/cwt. of cementitious material is 4 × (400 + 150) ÷ 100 = 22 oz/yd^3. The dosage tolerance for a 3-yd^3 batch is 22 × 3 × 0.03 = ± 2 ounces or ± 4 ounces (cwt. dosage). The latter value is greater and applies to this batch. The acceptable range of admixture is thus 62–70 oz.

The second question concerns the phrase "except mineral admixtures (see 8.1)." The mineral admixtures (SCM) discussed in Section 8.1 are a part of the cementitious material and are not considered admixtures under Section 8.4. The mineral admixtures of fly ash, silica fume, ground granulated blast-furnace slag, or other pozzolans are considered cementitious material and must be weighed within the same tolerances as established for cement in Section 8.1.

***Note 11**—Admixture dispensers of the mechanical type capable of adjustment for variation of dosage, and of simple calibration, are recommended.*

Several suggestions are packed into Note 11. The primary idea is that a reliable mechanical dispenser is superior to a calibrated beaker or 5 gal bucket for routine batching. Small variations in chemical admixture dosages can create noticeable changes in successive batches of concrete. This is particularly noticeable for workability and time of set.

Equipment that allows the admixture dosage to be input in terms of ounces per hundredweight of cementitious material (oz/cwt) can be the simplest to use. Input in terms of ounces per cubic yard is also very simple to use.

Good dispensers will be plumbed to provide a simple means of checking the calibration and making corrections when necessary.

9

Batching Plant

THIS IS AN OVERALL specification for a concrete batch plant. A wide range of plant types is covered within this section. The basic needs for producing consistent concrete are defined. Plant differences are brought about by factors such as increasing production rates, automating methods to replace personnel, and replacing human judgment with equipment operating on fixed parameters.

Why do we call a concrete manufacturing facility a batch plant? Webster defines batch as "the quantity of material prepared or required for one operation: a mixture of raw materials ready for fusion into glass." Webster uses the word glass rather than concrete, but the words are interchangeable in this instance. The materials are all proportioned for a specific volume and placed into a vehicle for delivery either in a mixed or unmixed condition depending upon the plant configuration and the delivery vehicle. The primary point here is that the plant produces one batch of proportioned material at a time and then starts over for another batch. It is not a continuous process such as you see at some asphalt plants.

Can concrete be produced continuously as asphalt is? Yes it can. Do we normally want to do this on a mass basis? Not often, because concrete users are more numerous with much broader needs than asphalt users. By using one batch at a time plants, rather than continuous flow type plants, each batch can be of the size and proportions desired by the specific customer. How can you serve a customer better than with individually, custom-proportioned concrete delivered to the chosen receiving point? Ready-mixed concrete is a service-oriented industry, and a "batch" plant is step one in this service. Continuous or volumetric batching of concrete can be accomplished by using ASTM Specification for Concrete Made by Volumetric Batching and Continuous Mixing (C 685/C 685M). At this time these continuous mixing units are truck mounted and are customarily used for very small projects or for extremely long hauls. Proportioning of materials and mixing takes place at the job site.

9.1 $_{S1}$ *Bins with adequate separate compartments shall be provided in the batching plant for fine and for each required size of coarse aggregate.* $_{S2}$ *Each bin compartment shall be designed and operated so as to discharge efficiently and freely, with minimum segregation, into the weighing hopper.* $_{S3}$ *Means of control shall be provided so that, as the quantity desired in the weighing hopper is approached, the material shall be shut off with precision.* $_{S4}$ *Weighing hoppers shall be constructed so as to eliminate accumulations of tare materials and to discharge fully.*

Aggregate storage, weighing, and discharge are the focus of Section 9.1. To the casual reader, it is easy to associate the term **bin** with overhead bin and jump to an erroneous assumption that overhead bins are required. This is not true. The definition of the word **bin** is: **a box, frame, crib, or enclosed place used for storage.** This can be a spot on the ground with large blocks of concrete or timbers separating areas as easily as it can be a steel compartment in the air. The word compartment does nothing to change the requirements. Compartment means: **a separate division or section; one of the parts into which an enclosed space is divided.**

S1 states very simply that "each"[8] fine aggregate and each size or type of coarse aggregate must be stored separately with each compartment of adequate size to prevent the different aggregates from becoming intermingled. As an example, assume a concrete plant uses six different aggregates. Each aggregate must have its individual compartment to prevent intermingling prior to entry into the weighing hopper. One final question regarding **S1** is: are visible physical walls required around each type and size aggregate, or may an open air space be used to separate piles? Open air spaces are satisfactory if they are maintained as open air spaces, and aggregate stockpiles are not permitted to "grow" together or intermingle. **S1** also includes such elaborate aggregate storage as compartmentalized concrete silos with complex overhead conveyor feeds and underground discharge systems. The ultimate emphasis of **S1** is that each aggregate must be stored separately without intermingling prior to transfer into the weighing hopper.

S2 discusses aggregate discharge into the weighing hopper. Does "designed and operated so as to discharge efficiently and freely" mean an overhead bin? No, it does not. Designed for efficient and free discharge can mean easy access by a front-end loader to scoop up large bucketsful of aggregate. Or it can mean a power-operated gate at the bottom of a bin that drops aggregate directly into a weighing hopper or takes a less direct route via conveyors and even an intermediate bin before reaching the weighing hopper. The real point of **S2** is that the aggregate gets from its storage space into the weighing hopper with a minimum of segregation. The terms efficiently and freely are a reference to not having spots or locations in which aggregate is trapped and interferes with movement of other segments of the aggregate supply. All aggregate control equipment (front-end loader or gates) and transportation conveyors shall be de-

[8] Section 9.1 does not use the term "each" with the fine aggregate, but it is implied by the "each" that precedes coarse aggregate. It is only in very recent years that blending of fine aggregates has come into prominence, while blending coarse aggregate is a long established practice. In either case, separate bins are needed to achieve a uniform product from batch to batch.

signed and operated to handle aggregate with a minimum of loss and segregation.

S3 requires a method of determining when the desired batch weight (mass) is being approached for each aggregate. Such an indication will make stopping the flow of aggregate into the weigh batcher more precise with respect to obtaining the desired aggregate mass. There are three basic types of scale indicators. Beam type scales with the long notched beams and poises have an over and under indicator atop the scales. These devices have very visible pointer arms that begin to move up toward a level position as the load in the weighing hopper approaches the desired load currently indicated on the active scale beam. Thus, the operator is warned that the cut-off point is approaching. With circular dial heads, the material quantity in the weighing hopper is constantly visible. Many dial heads have markers which can be pre-set to the desired load, thus, negating the operator's necessity of remembering what the cut-off load is for each batch. The third system is the more modern computer monitor that often shows a bar chart as the masses of materials are being weighed, and the actual scale values are displayed on the monitor.

S3 also requires the aggregate feed system to be capable of being consistently closed off with precision. Acceptable precision is identified by the tolerances of Section 8.2, Computer Controlled Batching, which considers the mass of aggregate suspended in air during the snapshot in time between aggregate gate closing and all aggregate entering the weighing hopper, plus the bounce of the weighing hopper due to the acceleration energy of the falling aggregate is currently the near ultimate in aggregate batching. These computers measure the change in mass in milliseconds of time and thus predict when to stop aggregate flow and act automatically on these data. Jogging the aggregate feed gates to get within the prescribed tolerance is a part of the computer software program.

Can non-computer plants operate within prescribed tolerances? Yes, it is possible, and it happens at numerous batch plants on a regular basis. Precision is accomplished by personnel pushing buttons or pulling levers to open and close gates on overhead bins while watching load indicators. At batch plants without overhead bins, the operator adjusts the aggregate flow by reducing the tip angle of a front-end loader bucket as the load indicator or dial head indicates the desired batch quantity is being approached. Many important and long lasting projects that we enjoy today were constructed in this fashion.

S4 is directed to assurance factors that all material weighed gets into the final batch, and a portion of the weighed material is not retained in the weighing hopper. Weighed aggregate remaining in the weigh hopper when the material is discharged affects the current batch by being short on aggregate and all subsequent batches until this aggregate is removed. The tare weight has been increased and the full quota of aggregate is not batched. Some of the tared aggregate may enter subsequent batches. Methods routinely used to ensure the complete discharge of aggregates are smooth sloping sides for the weigh hopper, no shelves in these sides (walls) upon which aggregate can be trapped, discharge gates occupying the entire bottom of the weigh hopper, and a vibrator attached to at least one wall of the weigh hopper. The location selected for the vibrator is typically the side with the flattest horizontal slope. At many batch plants, the weigh hopper vibrator is activated automatically during the discharge cycle. Most of the batching computers now available are interlocked to prevent the commencement of the next batch unless the scales return to zero within a small load tolerance such as 0.3 % of scale capacity. On older computers the batch man retains the responsibility of observing and ensuring a scale returns to near zero before commencing the next batch.

A relatively new approach to aggregate weighing hoppers is the weigh-on-the-belt configuration. This arrangement uses a conveyor belt assembly rather than metal gates on the bottom of what might otherwise pass for a weighing hopper. The entire system of side panels and conveyor belt assembly is suspended from load cells to measure the weight (mass) of aggregate being dropped on to the conveyor belt.

A decumulative batcher where a storage bin functions as a weigh batcher and discharged material is measured by the difference of the original mass and the final mass in the bin is usually confined to portable plants. This type of plant requires separate bins for fine aggregate and coarse aggregate.

9.2 S1 *Indicating devices shall be in full view and near enough to be read accurately by the operator while charging the*

FIG. 9.A—*Photo of scale dial head.*

FIG. 9.A.2—*Overhead aggregate bins with weighing hopper below.*

FIG. 9.B—*Photo of computer monitor.*

hopper. $_{S2}$ *The operator shall have convenient access to all controls.*

This is a very short and straightforward section. The clear intent is that the operators (batch men) have all batching controls at their fingertips and all weight (mass) or volume indicators for the current batch in full view so indicators can be read easily. The operator must know how much of each ingredient is going into the batch and be able to verify the ingredients that actually went into the batch. The target mass of each ingredient generally is displayed on monitors of computerized systems. One example of the extent taken to ensure this provision is the use of closed-circuit TV cameras on aggregate conveyors feeding mixer trucks when the aggregate transfer conveyor from weighing hopper to mixing drum is hidden from the operator's view. A second example is the use of TV cameras to transmit a view of remotely placed admixture dispensers. In each case, the operator has a TV monitor at his workstation providing a view of product movement.

9.3 *Scales shall be considered accurate when at least one static load test within each quarter of the scale capacity can be shown to be within ± 0.2 % of the total capacity of the scale.*

How accurate is accurate enough? The answer as defined here is ± 0.2 % of scale capacity. For an aggregate scale with a 40 000-lb capacity, 0.2 % is ± 80 lb. If the scale capacity is 30 000 lb, the allowable error when being calibrated is ± 60 lb. Cement scales are smaller, as is the allowable variance. A cement scale with a capacity of 7200 lb has an allowable calibration tolerance of ± 14.4 lb. Scales for concrete materials must be checked and must be accurate at all positions within the scale capacity. Concrete is batched in quantities from 12 yd^3 or larger down to 1 yd^3, or in some cases fractions of a cubic yard. Section 9.3 calls for scales to be checked within each quarter of the scale's capacity. This requirement may be satisfied by two additional test loads nearly equally divided between one calibration check at 24 % or less and one at 76 % or more of the scales' capacity.

The required scale accuracy (± 0.2 %) is less than required by the National Institute of Standards and Technology (NIST) Handbook 44 on Weights and Measures [64]. Handbook 44 accepts test loads, however, which only reach 50 % of scale capacity or the maximum load to which the scales will be subjected. Greater variations than described by Handbook 44 are permitted because concrete is sold by volume (see Section 3) and is not sold by mass, although the mass of the materials is what ultimately leads to the greater part of the volume. The variations described herein have been found to be acceptable in normal and high quality concrete without the additional costs necessary for minimal increases in scale accuracy. ASTM C 94/C 94M is currently silent as to procedures required to check the accuracy of the scales other than stating it should be done within each quarter of the scale capacity. All 50 states have adopted NIST Handbook 44 so scale calibration personnel in each state are familiar with the prescribed quantities of minimum certified test weights (usually 12.5 % of scale capacity). They are also familiar with the NIST procedure of using product load (e.g., aggregate) as a substitute for test weights (substitute loading) after the test weights have been used to check up to the minimum prescribed quantity of test weights. Exceptions to the NIST Handbook 44 procedures should be used only if the State DOT has lesser requirements, along with the requirement for the scale calibrations to be checked at intervals not exceeding six months. Under these conditions, a lesser requirement of a State DOT may be acceptable. Do not confuse scale equipment accuracy defined here with required batching accuracies described in Section 8.

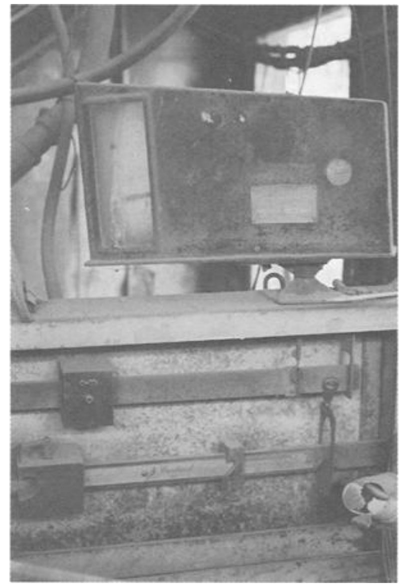


FIG. 9.C—*Over-under indicator for beam and poise weighing system.*

9.4 $_{S1}$ *Adequate standard test weights shall be available for checking accuracy.* $_{S2}$ *All exposed fulcrums, clevises, and similar working parts of scales shall be kept clean.* $_{S3}$ *Beam scales shall be equipped with a balance indicator sensitive enough to show movement when a weight equal to 0.1 % of the nominal capacity of the scale is placed in the batch hopper.* $_{S4}$ *Pointer travel shall be a minimum of 5 % of the net-rated capacity of the largest weigh beam for underweight and 4 % for overweight.*

Standard test weights shall be used in the calibration of scales. This does not mean that the manufacturer must have these test weights, only that they shall be available and used when the scales are checked. The most common source of the test weights are companies regularly engaged in calibrating, inspecting, and performing preventive maintenance on the scales. Some ready-mixed concrete producers retain a set of test weights at the plant, which allows them to make quick checks and corrections if there is reason to believe that the scales are out of calibration. To be identified as "standard test weights," the test weights must be accurate within ± 0.01 % of the indicated weight [63]. To avoid decimal points, the allowable tolerance on 50-lb weights must be stated in grams (2 ¼ g).

Nothing in either Section 9.4 or 9.5 is written about how often scales or test weights must be checked. The attitude of ASTM C 94/C 94M is that the calibrations should be often enough to keep the scales within the prescribed accuracy. The NRMCA Plant Certification program [70] requires test weight certification at maximum intervals of two years. More is presented about scale calibration frequencies in the discussion of Note 12.

S2 is a gentle reminder of preventive maintenance that is needed to maintain accurate scales in a dusty atmosphere with equipment, which is abused every time it is used because several tons of material are suddenly dropped on the scales from a height of several feet. The weighing hopper jerks and jumps from this abuse, and wear on metal parts is the result. **S2** also means that just because cement dust and rock dust are a part of life at a batch plant, they are not an acceptable excuse for inaccurate scales. The working parts must be kept clean.

S3 addresses the sensitivity of the scales. There must be movement of the balance indicator when a load as small as 0.1 % of the scale capacity is placed in the weighing hopper. This is 30 lb in a scale with a capacity of 30 000 lb. Does this apply only to beam scales? The intention is to apply this criterion to any scale including the modern load-cell supported weighing hoppers, which activate numbers on a computer-controlled monitor. Scales must be sensitive to loads as small as 0.1 % of capacity. Thus, a 7200-lb capacity cement weigh hopper must be sensitive to a load as low as 7 lb.

S4 provides detailed requirements for the over-under indicator specified in Section 9.1 for beam scales. The load range for the over-under indicator shall be not less than 9 % of the rated load capacity of the largest weigh beam in the beam scale system. With a 20 000-lb maximum beam scale, the indicator must have a minimum range of 1800 lb. The indicator will become active when the load reaches a point 1000 lb (5 %) below the desired quantity and will continue to be active up to 800 lb (4 %) over the desired batch weight.

These criteria are applicable to beam scales used to measure any of the concrete ingredients.

9.5 $_{S1}$ *The device for the measurement of the added water shall be capable of delivering to the batch the quantity required within the accuracy required in 8.3.* $_{S2}$ *The device shall be so arranged that the measurements will not be affected by variable pressures in the water supply line.* $_{S3}$ *Measuring tanks shall be equipped with outside taps and valves to provide for checking their calibration unless other means are provided for readily and accurately determining the amount of water in the tank.*

The term "added water" is used to distinguish between water contained in and on aggregates plus retained wash water and the other water put into the batch. The added water is put into the concrete batch from an outside source such as a municipal water supply, a water well, approved river, creek, or pond supply, satisfactory wash water supply, or another approved independent supply. Added water is the quantity of water that is determined after adjusting the design mixing water for the free moisture on aggregates, water to be absorbed by aggregates, and other potential sources such as ice, large quantities of admixtures, etc. (see Section 5). Regardless of the source, the added water must be measured.

"Device" is the descriptive term used for the water measuring equipment, because it may be a volumetric measurement or a weighing system. Even the volumetric system may be a flow through meter, or it may be a calibrated tank resembling an over-sized calibrated flask. A turbine type meter has been the industry favorite for decades, but in the future a straight-through flowing meter capable of measuring wash water and slurry water is apt to become prominent in concrete batch plants.

Accuracy is defined as that required by Section 8.3. A measuring accuracy of ± 1 % of the **total mixing water** (not added water) is the requirement for this metered or weighed water. How that accuracy is obtained is not the concern of this specification. The total accuracy for all water in the mixture including all other water sources is ± 3 % of total mixing water.

S2 requires that the measuring device not be affected by changing pressures in the water feed line. Variable pressures in municipal water lines or water well pump systems are common. The primary thought being conveyed is that a timer cannot be used to open and close water valves. If a timer is used to control the flow of water, varying pressures will deliver varying quantities of water in a given time.

S3 provides specific guidelines for calibrated tanks used to measure the added water. They must have valves to draw water directly from the tank for calibration purposes or some other method that will allow an accurate check of water in the tank. The accuracy of Section 8.3 must be obtained. The most practical means of doing this is a cylindrical tank with the long axis upright. A cylinder lying down is very difficult to calibrate and mark within the required accuracy. It is also difficult to control the shape of a cubical tank when it is filled with water. Metal sides bulge as the square or rectangular plan view attempts to become a circle during the filling operation. The vertical cylindrical tank with a uniform calibration strip is the simplest method of meeting the requirements for a calibrated tank.

Do these requirements and suggestions for tanks apply to a container holding weighed or metered water? No, they do not, because for the latter applications, the tank is merely a holding vessel as opposed to a measuring vessel.

Note 12*—The scale accuracy limitations of the National Ready Mixed Concrete Association Plant Certification meet the requirements of this specification.*

The National Ready Mixed Concrete Association has a written program for the inspection and certification of concrete batch plants and their delivery fleets. The inspection program is designed to ensure that a batch plant is capable of producing quality concrete meeting all requirements of ASTM C 94/C 94M. It also covers some items that are addressed in the CPMB standards for concrete plant equipment [22], all of which are not addressed in ASTM C 94/C 94M. The inspection guidelines make some specific requirements in a positive attempt to ensure ASTM C 94/C 94M compliance. Some of the inspection procedures and manufacturer management commitments concern scale accuracy. For example, manufacturer (producer) management agrees that all scales will be checked (calibrated) at intervals of six months or less [70]. The same agreement binds producer management to check the calibration of volumetric admixture dispensers and volumetric water batching devices (meters or calibrated tanks) at intervals not exceeding 90 days. These time intervals between calibrations are short enough that it is rare for a plant to lose accuracy to the extent of product failure unless there is an actual failure of the proportioning equipment.

A close study of Section 9 "Batching Plant" reveals that the words cement or cementitious material or chemical admixtures are never mentioned. How can you have a concrete batch plant section and not discuss specifics for these materials, or has this been accomplished in other sections?

Section 8 calls for cement to be measured by mass and for it to be measured in a batch hopper separate from aggregates. Section 8 states that cement shall be measured before mineral admixtures (supplementary cementitious materials) when the same batch hopper is used. To do this, the cement and mineral admixtures (SCM) must be in separate storage bins or silos. One thing that is not stated is that the cement and mineral admixtures must be kept dry until the added water is introduced into the mix. Ordering and strength requirements, as well as batching accuracy requirements, take care of this potential problem. If the cementitious materials are pre-wetted, large lumps are formed, which make accurate batching impossible, and the early hydration adversely affects strengths. Not mentioning keeping your powder dry is akin to not saying delivery vehicles must have wheels. It is simply unnecessary.

Chemical admixtures are not a required part of a batch plant, although they are present in most plants today. The accuracy with which they are proportioned is discussed in Section 8. Visibility to plant operators of all proportioning indicating devices is stated in Section 9.2.

The plant certification program of the National Ready Mixed Concrete Association describes specific plant requirements, which ensure compliance with the broad requirements of ASTM C 94/C 94M. As an example, the NRMCA certification checklist commences with "Cement bins or silos tight and provide for free movement to discharge opening." The checklist also requires methods of ensuring that admixture dispensers are measuring chemical admixtures and not air, as can occur with turbine type meters.

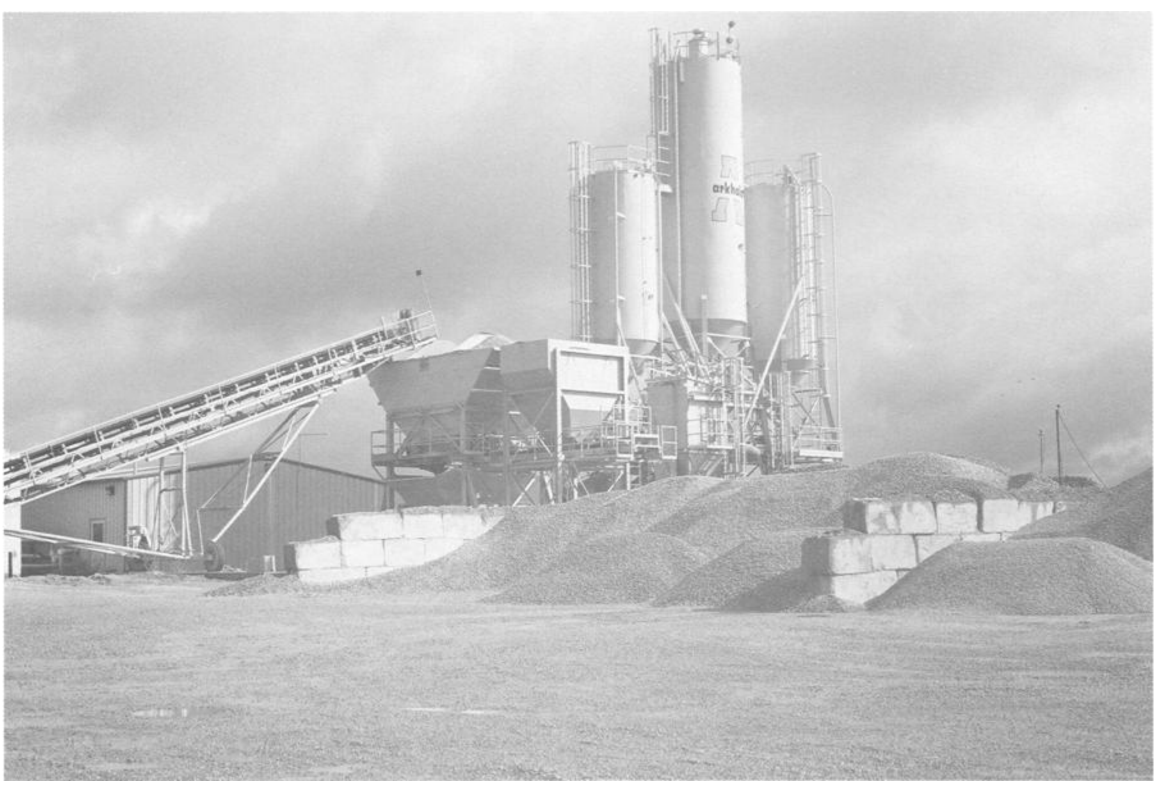


FIG. 9.D—*Concrete batch plant.*

10

Mixers and Agitators

THE BASIC REQUIREMENTS for mixers (stationary or portable) and for agitating transport equipment are described in this section. Mandatory nameplate data are listed for both mixers and agitators. Maximum capacities (mixed concrete volume) of the units in terms of their overall volume are stated. Uniformity of the mixed concrete occupies a major segment of this section. The importance of concrete homogeneity and uniformity is evidenced by the last five subsections, which reference Annex A1, "Concrete Uniformity Requirements."

10.1 $_{S1}$ *Mixers will be stationary mixers or truck mixers.* $_{S2}$ *Agitators will be truck mixers or truck agitators.*

A broad net is cast in describing equipment that may be used for mixing a concrete batch or for agitating a previously mixed batch. Stationary mixers consist of a variety of mixer types, which have one thing in common. They are a part of the batch plant, and after mixing the concrete is then transferred to a delivery vehicle. A common term used to describe a stationary plant is "central mix plant" or "wet plant," but "shrink-mix plants" are also stationary.

Truck mixers have only two basic types: rear discharge drums and front discharge drums. These units are the traditional concrete transit mix trucks seen on the streets. Materials are batched into them in an unmixed or partially mixed condition, and the mixing into a uniform mass occurs inside the revolving drum. Truck mixers are inclined with the charging and discharge end upwards. The higher point of the feed hopper allows materials to move toward the lower and closed end of the drum. The blades (fins) in the mixer are generally of two helixes. Clockwise drum rotation, when viewed from the high end, is in the charging and mixing mode, while counter-clockwise rotation causes the material to be lifted by the blades (fins) toward the discharge end.

S2 divides agitating units into two groups. The first of these is a conventional truck mixer, which is rotated at a slower speed than used for mixing concrete. Truck agitators may take a shape more closely resembling a dump truck than a truck mixer. Agitation of the concrete is provided by some type of moving paddle arrangement. The agitation is used to maintain the previously mixed concrete in a uniform fluid-like condition until discharge.

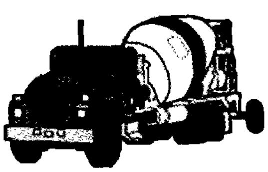


FIG. 10.A—*Drawing of rear discharge mixer.*

10.1.1 $_{S1}$ *Stationary mixers shall be equipped with a metal plate or plates on which are plainly marked the mixing speed of the drum or paddles, and the maximum capacity in terms of the volume of mixed concrete.* $_{S2}$ *When used for the complete mixing of concrete, stationary mixers shall be equipped with an acceptable timing device that will not permit the batch to be discharged until the specified mixing time has elapsed.*

S1 is a very direct statement concerning two pieces of information that need to be attached to a stationary mixer: the maximum speed in rpm at which mixing should take place and the maximum capacity of the mixer as reported in yd^3 [m^3] of mixed product. The placement by the manufacturer of this information on a metal plate attached to the equipment ensures availability to both operators and inspectors. ASTM C 94/C 94M does not impose a limit on the capacity of a stationary mixer with regard to volume of the mixer. Limitations are imposed by the manufacturer based upon uniformity performance and desired time of mixing. The rated capacity of stationary or plant mixers is addressed by the standards of the Concrete Plant Manufacturer's Bureau [22]. The rated capacities for member manufacturers require a minimum specific volume in cubic feet for a rated capacity as a mixer in cubic yards. The minimum volumes for a particular rated capacity of concrete vary depending upon the type of stationary mixer. Five types are defined by CPMB with accompanying tables for minimum volume capacities.

S2 addresses the use of stationary mixers to do the complete mixing of the concrete batch. This is the true intent of the term "central mixing." The requirement is for inclusion of a timing device that will prevent mixer discharge before a predetermined amount of mixing time. The determination of the length of mixing time is discussed under Section 11.3 and its subsections. This is the specified mixing time addressed in **S2**. The purchaser seldom specifies a mixing time, but such a requirement is not unusual for concrete paving jobs.

10.1.2 $_{S1}$ *Each truck mixer or agitator shall have attached thereto in a prominent place a metal plate or plates on which are plainly marked the gross volume of the drum, the capacity of the drum or container in terms of the volume of mixed concrete, and the minimum and maximum mixing speeds of rotation of the drum, blades, or paddles.* $_{S2}$ *When the concrete is truck mixed as described in 11.5, or shrink mixed as described in 11.4, the volume of mixed concrete shall not exceed 63 % of the total volume of the drum or container.* $_{S3}$ *When the concrete is central mixed as described in 11.3, the volume of concrete in the truck mixer or agitator shall not exceed 80 % of the total volume of the drum or container.* $_{S4}$ *Truck mixers and agitators shall be equipped with means to readily*

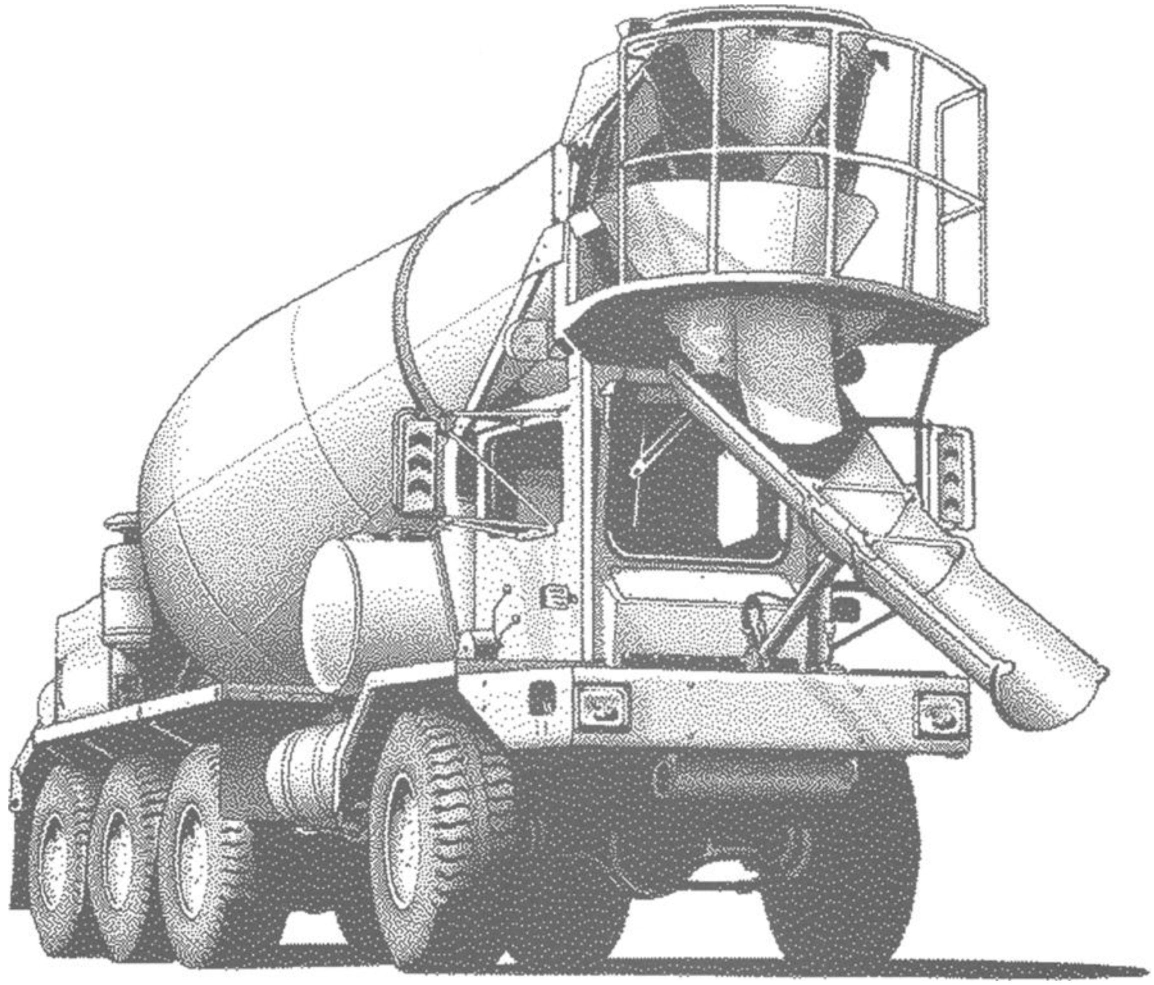


FIG. 10.B—*Drawing of front discharge mixer.*

verify the number of revolutions of the drum, blades, or paddles.

This subsection deals with specific requirements for **truck mixers and agitators.** Requirements for **truck mixers** get the first look. **S1** requires an attached metal plate or plates to indicate the gross volume of the mixing drum (usually in cubic feet). These plates usually are attached to a pedestal supporting the drum or are located on the inside of the driver-cab door. Also shown on the plates will be the approved capacity of the mixer (drum) in volume of mixed concrete (cubic yards are typical). The metal plate or plates shall also have inscribed the equipment manufacturer's recommended range for mixing speed of the drum in revolutions per minute. The Truck Mixer Manufacturers Bureau (TMMB) sets this range at 6–18 rpm of the drum for mixing concrete [91]. Tests by both drum manufacturers and the NRMCA have shown that mixing speeds up to 25 rpm will produce good mixing of the concrete [67]. The only potential problem with mixing at speeds between 18–25 rpm is equipment fatigue. The specific equipment that may be jeopardized by high speeds is the direct-drum drive, which experiences tremendous torque loads while turning large volumes of low-slump concrete. Truck engine sizes have been minimized for weight and environmental protection purposes, and new mixers are often unable to exceed a speed of 20 rpm.

S2 states a maximum approved capacity of a drum used for mixing (truck mixed or shrink mixed) is 63 % of the total drum volume. If the total inside volume of a drum is 352 ft^3, what is the allowable capacity for mixing concrete? Using $(352 \times 0.63) \div 27 = 8.2\ yd^3$, the answer is that this is an 8-yd^3 mixer.

The 63 % of total volume allows adequate vacant space for the concrete to mix as the mixing blades (fins) pick the materials up inside the drum, move them forward to the drum head, and return materials back up the central axis toward the discharge end during each revolution [14] and minimizes concrete spillage from the discharge end. There must be adequate space for these movements, or the required mixing time will increase. The 63 % of total drum volume also allows adequate volume to get all the materials in the drum before they are completely mixed. Mixing drums have had this requirement by the NRMCA since 1957 [66]. The standard size for mixing drums evolved from extensive 1952 research by the NRMCA [92] in cooperation with the TMMB. Do not forget that the mixing blades form a dam near the discharge opening to help retain concrete in the drum.

FIG. 10.C—*Photo of agitator truck.*

FIG. 10.D—*Copy of mixer plates for rear discharge.*

S3 allows a truck mixer (truck-mounted mixing drum) to have a load of 80 % of its total volume if the concrete is completely pre-mixed in a true central-mixed stationary plant. Shrink-mixed concrete (Section 11.4) requires mixers that will be filled to no more than 63 % of their capacity. The mixing of shrink-mixed concrete can be completed by mixing in the truck mixer using full mixing speed either in the batch-plant yard or after arrival at the job site. Usually the truck mixer-agitator must not exceed the minimum nominal agitating speed during transit to the job site because of potential truck stability problems. Mixers for central-mix operations (Section 11.3) may be filled to the greater capacity because the materials have already been combined, thus minimizing their volume and because now all they need is agitation, not mixing. As an agitator, the 352-ft^3 drum volume looked at earlier produces the following numbers:

$(352 \times 0.80) \div 27 = 10.4$ yd^3, so for agitation this is a 10-yd^3 drum.

The 80 % of drum volume is an investigated capacity [65] that is seldom used by transit-mix trucks being used as agitator trucks. When loaded to this capacity, a portion of the load is subject to spillage on hilly terrain, especially with higher slump concrete, and could exceed the local weight regulations for travel on roads and bridges.

S4 requires a counter on all mixing drums to record the number of drum revolutions. Mechanical counters are mounted at the front of the drum, usually on the driver's side. The newer electronic counters with proximity switch sensors often have the revolution read out in the truck cab, thus allowing the driver to be better informed. The number of revolutions by the drum is related to three primary requirements:

1. Section 11.5 requires complete mixing within 70–100 revolutions at mixing speed.
2. Section 11.7 requires a minimum of 30 revolutions at mixing speed when additional water is injected at the job site.
3. Section 11.7 allows a maximum of 300 revolutions for discharge of the concrete unless this requirement is waived by the purchaser.

Requirements from 10.1.2 for **agitators** are similar to those for drum mixers, except as a transport vehicle, the purpose differs. Mixing is already completed in a "central-mix plant," and the agitator's only purpose is to maintain a cohesive mixture during transport and to prevent premature setting in the drum.

S1 requires a metal plate or plates attached to indicate the gross volume of the agitator container. These plates are typically attached to the supporting frame or may be located on the inside of the driver's side door. The plates also will display the approved capacity of the container or mixing drum when used to agitate pre-mixed concrete. The volume is typically displayed in cubic yards to coincide with the sale units of concrete. **S1** also requires the metal plate or plates to have inscribed the equipment manufacturer's recommended range for agitation speed of the drum or blades or paddles (agitating mechanism). The Truck Mixer Manufacturer's Bureau [91] sets this speed at a maximum of 6 rpm, leaving any minimum speeds to the individual manufacturer.

FIG. 10.E—*Copy of mixer plates for front discharge.*

FIG. 10.E.2—*Truck mixer loading at batch plant.*

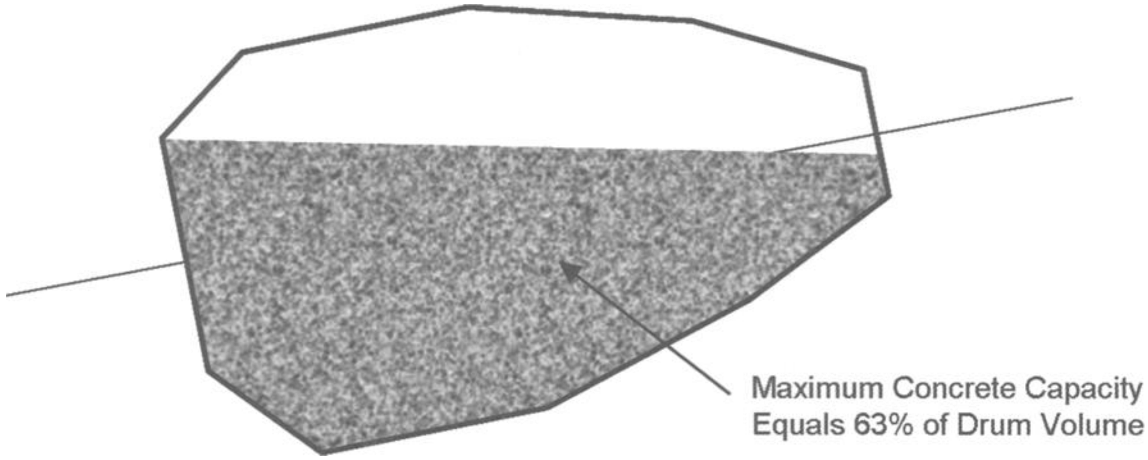


FIG. 10.F—*Sketch of mixing drum filled at 63 % of volume.*

S2 contains no requirements for agitator units.

S3 increases the maximum approved capacity of an agitator container, be it open topped or a mixing drum to 80 % of its total volume. A sample computation is a 405-ft^3 container × (0.80 ÷ 27) = 12-yd^3 agitator.

S4 requires agitators to be equipped with counters just like the requirement for mixers to have counters. The number of revolutions of a drum or paddles pulled through the concrete must be known, because the limit of 300 remains in effect unless waived by the purchaser.

10.2 All stationary and truck mixers shall be capable of combining the ingredients of the concrete within the specified time or the number of revolutions specified in 10.5, into a thoroughly mixed and uniform mass and of discharging the concrete so that not less than five of the six requirements shown in Table A1.1 shall have been met.

The reference to time concerns stationary central-mix plants as specified in Section 11.3 and its subsections. The reference to number of revolutions concerns transit-mix trucks, which perform the mixing operation and must do so within the 70–100 revolutions prescribed in Section 11.5.

Table A1.1 is in the A1 Annex to ASTM C 94/C 94M and sets forth the uniformity requirements for concrete as mixed and as discharged (see Table 20.A). The criteria set forth in Table A1.1 provide six measurable values to enable checking for "thoroughly mixed and uniform mass." Each of the values can assist in assessing the uniformity of the concrete. The concrete is to be tested and judged when discharged from the mixer.

Section 11.5.1 describes the obtaining of two separate samples from a single load of truck-mixed concrete. Sections of 11.3.3 provide a description of acceptable sampling from a stationary plant. Each procedure yields two samples, each from different segments of the batch. Each of the two samples is tested for six fresh and hardened concrete properties, and the test results compared for uniformity with acceptable differences defined in Table A1.1.

The six test values to be obtained for each of the two samples are as follows:

1. **Mass (weight) per cubic foot** calculated to an air-free basis in lb/ft^3, based on density test (unit weight) and test for air content
2. **Air content** (% of concrete volume)
3. **Slump** (in.)
4. **Coarse aggregate content,** portion by mass (weight) retained on 4.75 mm (No. 4) sieve (% of sample that is coarse aggregate)
5. **Mass (weight) per unit volume of air-free mortar** calculated from test results of density test (unit weight), measured air content, wet-sieve analysis on 4.75 mm (No. 4), and predetermined relative density of coarse aggregate (specific gravity, SSD)
6. **Average compressive strength** of not less than three seven-day cylinders

Values for each of the six test results are compared between the concrete sample from each end of the load. Acceptable test comparisons are set forth in Table A1.1. For a mixer to be acceptable it must satisfy any five of the six test requirements. The discussion of Table A1.1 in Chapter 20 (Annex to ASTM C94/C 94M) includes a numerical example and a discussion of the physical tests and information needed for each of the six values.

A common practice when checking transit mixers for uniformity compliance is to check one mixer of each drum manufacturer and size of drum. If the chosen mixer from a group meets the "mixer performance test," it can be reasonably assumed that identical mixers of the same size, blade design, and overall condition also will perform satisfactorily. Each mixer that is not tested should be inspected for blade wear, concrete or mortar build-up, and for missing blade sections. The latter should be repaired. For excessive build-up or excessive wear, the truck mixer may receive a uniformity performance test or be arbitrarily sidelined by the producer. Mixing uniformity evaluation requires considerable effort and a full load of concrete. It is not reasonable to require mixers to be tested for mixing uniformity on a regular basis. Factors that affect mixing are generally visually checked. These include the wear on the blades inside the drum barrel, especially at the section of the largest diameter, and the occurrence of build-up of hardened concrete inside the barrel.

These items are part of the inspection process for truck mixers in the NRMCA plant certification program.

Note 13—*The sequence or method of charging the mixer will have an important effect on the uniformity of the concrete.*

Studies performed by the National Ready Mixed Concrete Association beginning in 1969 and published in phases beginning in 1969 [14] and concluding in 1975 [39] are probably what prompted this note. The studies concluded that several loading sequences could be used satisfactorily, but that the batching sequence was an important factor in producing homogenous concrete. The point of water injection seemed to be an important component of several batching procedures. A desired sequence of batching was some form of ribbon loading in which the ingredients were placed into the mixer simultaneously.

A frequently used ribbon-loading batching sequence is to batch 50 % or more of the batch water followed by part of the coarse aggregate. The remaining coarse aggregate, the sand, and the cementitious materials are then added simultaneously to the batch preceding the last portion of the mixing water (tail water). Loading of cementitious materials should be completed before the last of the aggregates enters the mixer. The combination of initial water (head water) and a portion of the coarse aggregate as the first ingredients to be batched usually avoids head packs. A combination of sand or sand and cement packed against the head of the mixing drum is identified as a head pack. This material may reach a thickness of a foot or more and often does not drop into the remainder of the load until the unloading (discharge) process.

Other batching sequences may provide excellent uniformity of the concrete depending upon the actual materials, mixing equipment, and plant configuration. If a proven procedure suddenly seems to go bad, the first place to begin looking for a solution is a change in the water addition sequences or proportions. Countless other possibilities exist, but water is the most common culprit.

10.3 *The agitator shall be capable of maintaining the mixed concrete in a thoroughly mixed and uniform mass and of discharging the concrete with a satisfactory degree of uniformity as defined by Annex A1.*

The same parameters as discussed in Section 10.2 for mixers apply to agitators. The concrete as discharged from the agitator must meet a minimum of five of the six comparison values of Table A1.1.

If an agitator fails the uniformity test, it may be appropriate to perform a uniformity test on the stationary mixer feeding the agitation unit. The agitator is only expected to maintain a mixture in the state that it was received and is not expected to supplement the mixing.

10.4 $_{S1}$ *Slump tests of individual samples taken after discharge of approximately 15 % and 85 % of the load will provide a quick check of the probable degree of uniformity (Note 14).* $_{S2}$ *These two samples shall be obtained within an elapsed time of not more than 15 min.* $_{S3}$ *If these slumps differ more than that specified in Annex A1, the mixer or agitator shall not be used unless the condition is corrected, except as provided in 10.5.*

A quick check on a mixer or agitator may be made at any time by using the slump test. Samples are taken and slump tests performed after discharge of approximately 15 % of the load and after discharge of approximately 85 % of the load. The discharge of the load shall be fast enough that not more than 15 minutes elapse between taking the two samples and between the two slump tests. The difference between the two slump test results should not be greater than the limit in Table A1.1 of Annex A1.

A mixer or agitator failing the slump test portion of the uniformity test may be disqualified from use until the mixing uniformity problem is corrected. Section 10.5 provides some specific exceptions by which the unit may continue to be used.

If one or both of the slump tests appear to have a possible error, it is permissible to rerun the test, if done so immediately. The tolerance limits are small, and equipment should not be penalized by an erroneous test result.

Note 14—$_{S1}$ *No samples should be taken before 10 % or after 90 % of the batch has been discharged.* $_{S2}$ *Due to the difficulty of determining the actual quantity of concrete discharged, the intent is to provide samples that are representative of widely separated portions, but not the beginning and end of the load.*

S2 states "the intent" is to obtain samples that are representative of the load, but which are widely separated. Stay away from both ends of the load because they will not always be representative of the majority of the load. Sometimes it may be rock content or slump or one of the other factors, but the very ends of the load are not always representative of the delivered concrete.

S1 is explicit that the first and last 10 % of a load should not be tested. Section 10.4 states to obtain a concrete sample

EXAMPLES 10.A and 10.B—*Table A1.1 slump requirement excerpt.*

Slump Range of concrete by test	Requirement, Expressed as Maximum Permissible Difference in the Two Results of Tests
If average slump is 4 in. or less	1.0 in.
If average slump is 4 in. to 6 in.	1.5 in.

EXAMPLE 10.A—*Slump uniformity test.*

Truck No. 41
Slump one = 5.25 in. and Slump two = 6.50 in.
Average slump = 5.88 in.
Allowable difference in two slumps = 1.5 in.
Measured difference in two slumps = 1.25 in. < 1.5 in. OK

EXAMPLE 10.B—*Slump uniformity test.*

Truck No. 53
Slump one = 3.0 in. and Slump two = 4.25 in.
Average slump = 3.63 in.
Allowable difference in two slumps = 1.0 in.
Measured difference in two slumps = 1.25 in. > 1.0 in. Fails

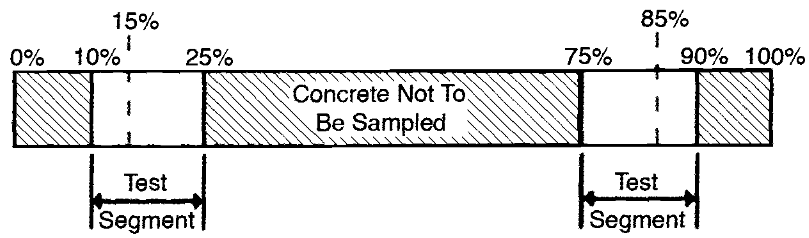


FIG. 10.G—*Drawing of test segments of concrete.*

at approximately 15 % and 85 % of the load. No limits are ever stated, but it is reasonable to assume that the center 50 % of the load does not meet the criterion of "widely separated portions."

How can the discharge points be measured? The most accurate method is to use a stopwatch to clock the actual discharge time of a couple of trucks prior to sampling the chosen mixer or agitator. Note that the discharge rates should be similar if this technique is used. Many drivers will have an excellent idea of the portion of a load that has been discharged.

10.5 *Use of the equipment is permitted when operation with a longer mixing time, a smaller load, or a more efficient charging sequence will permit the requirements of Annex A1 to be met.*

Alternatives are presented here that may make it possible to keep the equipment in service either temporarily or permanently depending upon the problem that has prevented it from meeting the Annex A1 uniformity criteria. Section 10.5 is applicable to both full uniformity criteria, and the quick check allowed in Section 10.4.

10.6 $_{S1}$ *Mixers and agitators shall be examined or their mass determined as frequently as necessary to detect changes in condition due to accumulations of hardened concrete or mortar and examined to detect wear of blades.* $_{S2}$ *When such changes are extensive enough to affect the mixer performance, the proof-tests described in Annex A1 shall be performed to show whether the correction of deficiencies is required.*

The interior of mixer and agitator containers must be inspected by responsible persons on a regular basis. The terms "as necessary" and "regular basis" mean that inspections shall be often enough to prevent build-ups of concrete or mortar that would cause the mixer or agitator to fail a mixing uniformity performance test. It is virtually impossible to prevent some build-up and completely impossible to prevent blade wear. As these items occur they should be corrected via a regular maintenance program prior to causing a performance test failure.

There are no specific criteria in Section 10.6 because the quantity of build-up that might be considered unacceptable will vary with size of drum or container and with blade configurations. Many producers weigh their delivery fleets on a regular basis and establish limits for concrete build-up. Limits of between 500–2000 lb are common. The middle of this range, somewhere between 1000–1500 lb, is the most often used limit before chipping and cleaning a drum.

A quick look into the mixer from the charging hopper may not reveal the extent of build-up. The routine build-up on blades occurs on the side facing the head of the drum and thus is not readily visible from the rear of drum. These build-ups can be observed via a mirror on a pole or by removing the drum inspection hatch.

Allowable blade wear has been quantified by the NRMCA in its plant certification inspection instructions [70]. The

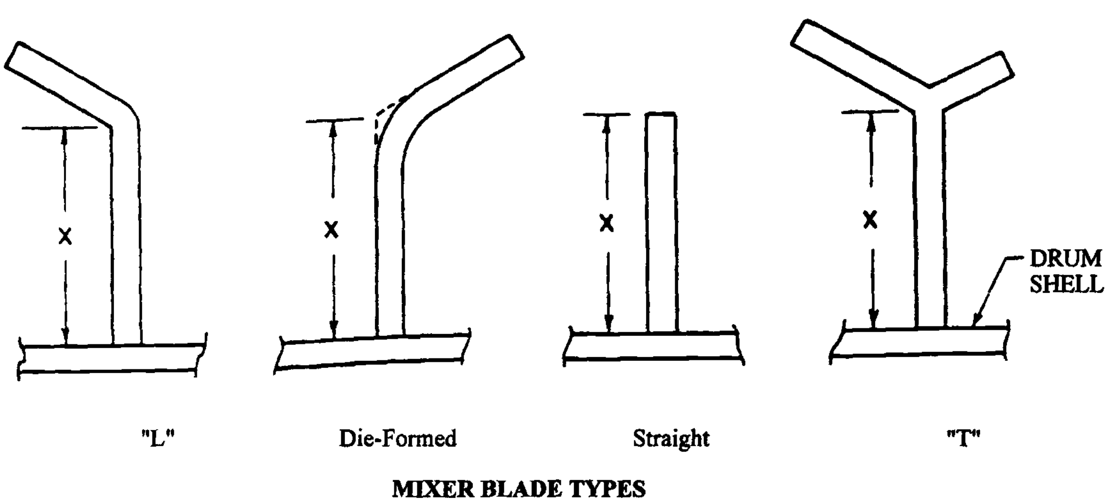


FIG. 10.H—*Mixer blade types from NRMCA plant certification checklist.*

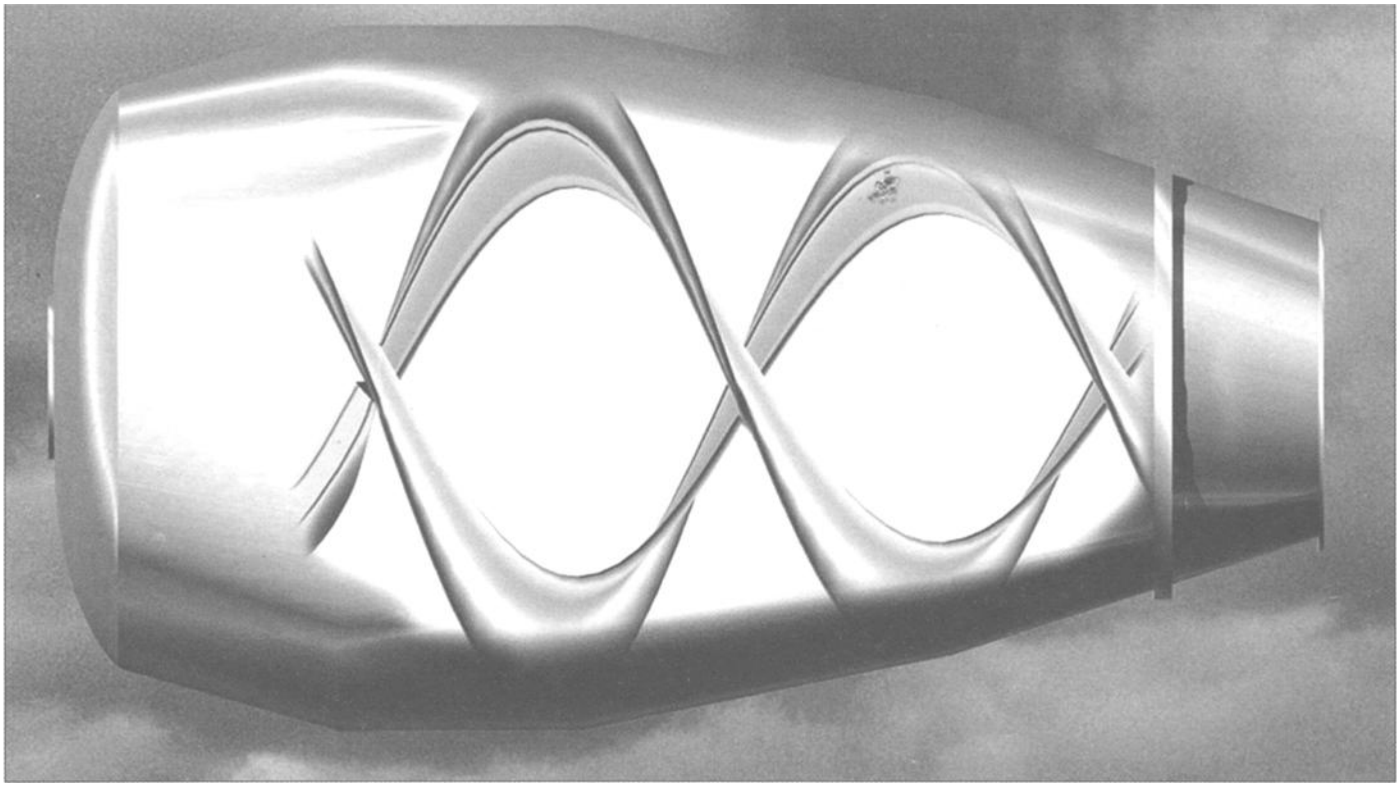


FIG. 10.I—*Drawing of inside of mixing drum depicting mixer blade configuration for truck mixers.*

NRMCA recommendations are not a part of this specification but may be used as guidance for an inspector. NRMCA identified four blade types as shown in Fig. 10.H. The internal configuration of the mixing drum blades needed for the mixing and discharge of concrete is shown in Fig. 10.I.

NRMCA criteria state that when the height of the blade at the point of maximum drum diameter nearest to the drum head is less than 90 % of the original radial height (dimension "X" in Fig. 10.H of applicable blade type), the blade is considered excessively worn and should be repaired or replaced. For blades with a lip, a view from the charging hopper may reveal if all of the lip has been worn off. Mixer manufacturers also provide guidance on the level of wear that may adversely affect mixer performance. A good rule of thumb is to perform a uniformity test if all of the lip is gone. If circumstances do not permit uniformity tests, the need for an extended mixing time and a longer time requirement to discharge low-slump concrete is usually an indicator of excessive blade wear or blades with excessive hardened buildup. A non-uniform slump or air content of the concrete throughout the discharge is also a sign of poor mixing due either to worn lips or blades or to excessive buildup of hardened concrete inside the drum. Slump variations will usually be visible without test measurements.

11

Mixing and Delivery

11.1 Ready-mixed concrete shall be mixed and delivered to the point designated by the purchaser by means of one of the following combinations of operations:

11.1.1 Central-Mixed Concrete

11.1.2 Shrink-Mixed Concrete

11.1.3 Truck-Mixed Concrete

There are several ways to mix concrete, beginning with a wheelbarrow, a shovel for measuring, and a garden hoe for mixing, but there are currently only four methods of furnishing commercial concrete in accordance with ASTM specifications. The less common of these methods is hauling raw materials on a truck and mixing them volumetrically at the job site. This method of producing concrete is covered by the ASTM Specification for Concrete Made by Volumetric Batching and Continuous Mixing (C 685/C 685M). This method has some benefits whereby concrete can be produced and delivered in small quantities and on demand such as for small residential addition applications and overcomes some issues related to long haul situations and delays on the job site. It is also used in situations where it is preferred not to use the regular ready mixed truck mixers due to the nature of the materials used in the concrete. These applications include latex-modified or rapid setting concrete for transportation infrastructure projects.

By definition, ready-mixed concrete is concrete that has been proportioned, mixed, and transported to the place of discharge. There are three viable methods, covered in ASTM C 94/C 94M, for accomplishing this task. The methods each use mass (weight) to proportion solid materials and either mass (weight) or volume for liquid components.

Central-Mixed concrete (11.1.1) consists of a batching facility and a stationary plant mixer which **completely mixes** the concrete before discharging it into a dump truck, agitator truck, mixer truck, conveyor, or some other means of transporting the finished product to the point of use.

Shrink-Mixed concrete (11.1.2) consists of a batching facility and a stationary plant mixer, which **partially mixes** the concrete (shrinks individual volumes to a mixed volume) before discharging the product into a truck mixer for completion of mixing the material into a homogeneous material and simultaneous transport to the point of use.

Truck-Mixed concrete (11.1.3) consists of a batching plant facility without any mixing capability, which deposits proportioned individual materials into a **transit mix truck for complete mixing** and transport to the point of use.

11.2 Mixers and agitators shall be operated within the limits of capacity and speed of rotation designated by the manufacturer of the equipment.

Each manufacturer of mixers (stationary or transit) and agitator equipment shall label their equipment with capacities and speeds of rotation. The ready-mixed concrete producer shall utilize this information in providing ready-mixed concrete.

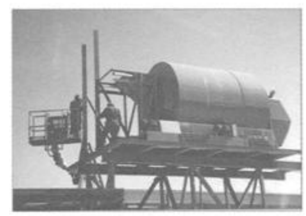
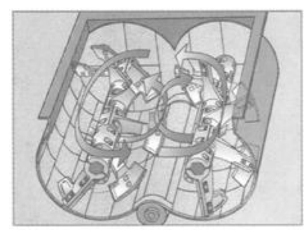
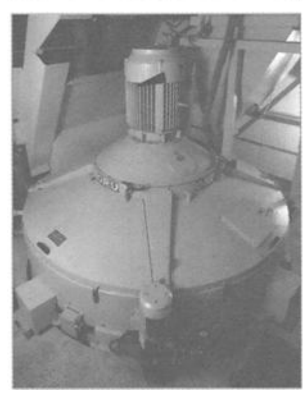
For central-mix stationary mixers, ASTM C 94/C 94M does not list specific ratios of concrete volume to mixer volume. There are five basic types of stationary mixers at this time. Each type has its own unique style of mixing, but each must meet the uniformity requirements of Section 11.3. Mixing uniformity combined with mixing time to achieve the uniformity are coupled with marketplace demands to achieve realistic production times for each type of mixer. Even though ASTM C 94/C 94M does not place specific volume restraints on the various types of mixers, an organization of stationary mixer manufacturers has established standards on each type. The Plant Mixer Manufacturers Division (PMMD) of the Concrete Plant Manufacturers Bureau (CPMB) places volumetric requirements on stationary mixer units manufactured by its membership [22]. The mixer-related concrete capacities versus mixer volumes differ with each type of mixer and are based upon research by equipment manufacturers. Rotating drum type (tilting or non-tilting) mixers contain approximately one-half the occupied volume of a mixer utilizing rotating shaft supported paddles or blades.

The rotating shaft types perform mixing by pulling paddles or blades through the materials and not by the folding and dropping process of the rotating drum type. Mixers manufactured by members of the PMMD carry a mixer capacity plate and identify the mixer as meeting PMMD standards. A brief description of each type of plant mixer is provided in Table 11.A.

***11.3 Central-Mixed Concrete*—**$_{S1}$ *Concrete that is mixed completely in a stationary mixer and transported to the point of delivery either in a truck agitator, or a truck mixer operating at agitating speed, or in nonagitating equipment approved by the purchaser and meeting the requirements of Section 12, shall conform to the following:* $_{S2}$ *The mixing time shall be counted from the time all the solid materials are in the drum.* $_{S3}$ *The batch shall be so charged into the mixer that some water will enter in advance of the cement and aggregate, and all water shall be in the drum by the end of the first one-fourth of the specified mixing time.*

At a central-mix plant, all of the required mixing of the concrete materials is accomplished at the plant. Uniform

TABLE 11.A—*Stationary mixer types.*

Type of Mixer	Description	Picture
Tilting Mixer w/15° Mixing Angle	A rotating-drum mixer that discharges by tilting a drum opening downward when the drum is tilted about a horizontal axis at right angles to the drum axis. The drum axis shall be inclined @ 15° with horizontal while mixing.	
Tilting Mixer w/Horizontal Mixing Axis	A rotating-drum mixer that discharges by tilting a drum opening downward when the drum is tilted about a horizontal axis at right angles to the drum axis. The drum axis shall be horizontal while mixing.	
Non-Tilting Mixer	A rotating-drum mixer that charges, mixes, and discharges with the drum axis horizontal. Drum typically reverses in manner of truck mixer to discharge.	
Horizontal Shaft (One or Multiple)	A mixer with one or more rotating horizontal shafts holding mixing paddles or blades, which are pulled through the concrete materials. The mixer shell has a cylindrical lower interior shape coinciding with each rotating shaft.	
Vertical Shaft (Pan Mixer)	A mixer with a vertical cylindrical shape. Paddles are mounted on a vertical shaft or annular ring. Charge at top and discharge from bottom.	

mixing and the correct consistency of concrete before discharge are essential. No further mixing either in transit or at the site is required, although it is not prohibited. If nonagitating equipment is used, it is not possible to have a water addition or other adjustments to the mixture at the job site. Section 12 describes the requirements for nonagitating equipment. The description of satisfactory delivery vehicles for central-mixed concrete includes "nonagitating equipment **approved by the purchaser.**" The purchaser must approve the use of nonagitating equipment (typically dump trucks) for several reasons. The haul time may require some transit mixing to avoid premature setting of the concrete, or the prescribed slump may be high enough that separation of the mixture will occur in transit without some agitation. The discharge situation may preclude the use of nonagitating equipment that typically discharges very low and very close to the transportation unit. Perhaps waiting times at the site will vary enough that job site added water will be necessary. If economic factors are involved, the planned use of nonagitating equipment should be made known and approved prior to the pricing of a project.

The use of agitating equipment including transit mix trucks is possible when approved by the purchaser. The approval of drum-type delivery units is needed because both loading and unloading are slower than conventional nonagitating delivery units. Some mixers and agitator units will have trouble handling very low-slump concrete. These units also require extra cleaning time during the workday as compared to open top dump truck or trailer units.

S2 defines the beginning of the mixing time, which is usually started automatically in modern central-mix plants. While the mixing in a transit mixer is usually defined by the number of revolutions of the mixer drum, time is generally used to control the amount of mixing in stationary plant mixers. Individual materials do not appear instantly in a mixer. Some amount of time measured in tens of seconds up to one or two minutes is required to get all the materials for a batch into the mixer. When all of the solid materials are in the mixer, the clock begins measuring the mixing time. Note that "solid" materials are used to differentiate sand, rock, and cementitious materials from water. All the water does not have to be in the mixer for the mixing timer to commence.

S3 requires some head water (initial water placed at front of drum) in the mixer prior to cement and aggregates. All of the scheduled mix water must be in the drum by the time one-fourth of the mixing time has elapsed. Thus, during at least three-quarters of the mixing time, all of the ingredients shall be in the mixer.

11.3.1 $_{S1}$ *Where no mixer performance tests are made, the acceptable mixing time for mixers having capacities of 1 yd^3 [0.76 m^3] or less shall be not less than 1 min.* $_{S2}$ *For mixers of greater capacity, this minimum shall be increased 15 s for each cubic yard [cubic meter] or fraction thereof of additional capacity.*

The reference to mixer performance tests is a reference to Section 11.3.2, which describes testing to demonstrate that a stationary mixer properly performs mixing in a shorter time period than the minimum time required in Section 11.3.1. If the mixer has a rated capacity of 1 yd^3 (0.76 m^3) or less, the minimum mixing time shall be one (1) min. If the mixer is larger than 1 yd^3, **S2** requires an increase in mixing time of 15 s for each 1 yd^3 of rated capacity above the original 1 yd^3. No distinction is made for mixer types in this requirement. Thus, a 10 yd^3 mixer would have a minimum mixing time of $[1 + (9 \times 15 \div 60)] = 3.25$ min., and a 4 ½ yd^3 or 5 yd^3 mixer's minimum mixing time is $[1 + (5 \times 15 \div 60)] = 2.25$ min. Each of these time periods may be shorter if the mixer performs well as tested and has been qualified to produce a homogeneous mixture as per the requirements of Section 11.3.2.

11.3.2 $_{S1}$ *Where mixer performance tests have been made on given concrete mixtures in accordance with the testing program set forth in the following paragraphs, and the mixers have been charged to their rated capacity, the acceptable mixing time is permitted to be reduced for those particular circumstances to a point at which satisfactory mixing defined in 11.3.3 shall have been accomplished.* $_{S2}$ *When the mixing time is so reduced, the maximum time of mixing shall not exceed this reduced time by more than 60 s for air-entrained concrete.*

To reduce the mixing times of Section 11.3.1, the central-mixer (stationary mixer) must be loaded to its rated capacity during tests to qualify the mixer for reduced mixing time requirements. What constitutes satisfactory mixing is defined in Section 11.3.3 and more specifically in Table A1.1 of Annex A1. There are no specific requirements for the type of mixture used for this qualification, but they should be representative of the concrete that will be produced by the concrete plant. It would be inappropriate to test a mixture with 1800 lb of sand rather than 1300 lb of sand if the latter was representative of the typical mixture from the plant. It would be inappropriate to use a mixture with only cement, if the typical mixture contains 25 % fly ash. The purpose of the tests is to determine required times to produce typical concrete and ensure that it is mixed uniformly.

S2 is a precaution against excessive mixing times for air-entrained mixtures. There is sometimes a tendency to increase the mixing time to that qualified by testing as a safety factor to ensure the proper development of air content and uniformity. Excessive mixing, however, may increase the entrained-air content of the concrete. The restriction imposed here is to not increase the mixing time by more than 60 s for air-entrained mixes. The reference time here is the mixing time that has been qualified by testing to produce a homogeneous mixture. This requirement would apply to all air-entrained mixtures considered similar enough that a separate mixing time test is not required. A short established mixing time for some mixtures may provide uniformity, but it may not be adequate to fully develop the air content that additional mixing time would produce. Thus there is a 60-s maximum for additional mixing time to prevent the possibility of excessive entrained air.[9]

11.3.3 Sampling for Uniformity Tests of Stationary Mixers—*Samples of concrete for comparative purposes shall be obtained immediately after arbitrarily designated mixing times, in accordance with one of the following procedures:*

When the minimum mixing time for a central-mix plant is being established for a specific mixture, the arbitrary mixing times must be timed very carefully and shall meet the requirements of Section 11.3 regarding the starting time. It is also prudent to record the time from the commencement of material charging to the beginning of mixing time.

[9] Gaynor, Richard D., former V. P. of Engineering at National Ready Mixed Concrete Association, 2003, personal communication via note concerning the origin of a maximum of 60 s additional mixing time beyond the approved time for central-mixed concrete.

The sampling for uniformity testing shall take place immediately after the mixing time is reached. There are two acceptable procedures, which are described in Sections 11.3.3.1 and 11.3.3.2.

11.3.3.1 Alternative Procedure 1*—The mixer shall be stopped, and the required samples removed by any suitable means from the concrete at approximately equal distances from the front and back of the drum or*

11.3.3.2 Alternative Procedure 2*—$_{S1}$ As the mixer is being emptied, individual samples shall be taken after discharge of approximately 15 % and 85 % of the load. $_{S2}$ The method of sampling shall provide that the samples are representative of widely separated portions, but not from the very ends of the batch (Note 14).*[10]

Section 11.3.3.1 involves sampling concrete from a drum or mixer that is stopped while being sampled. Due to the many differences in mixing chambers, no specifics are detailed except to direct that the two samples shall be taken from opposite ends of the batch, and each shall be taken from approximately equal distances from the batch ends with regard to discharge position. Any method possible may be used to sample the concrete, including the use of manual labor and shovels. A caution is issued here that a mixer is considered an enclosed or confined space and should be treated as such during the sampling process. Lock-out and tag-out precautions shall be utilized by personnel entering halted rotating equipment.

Alternate procedure No. 2 (Section 11.3.3.2) provides for taking concrete samples while the mixer is discharging. Therefore no one needs to enter the mixer, and this should be the safer sampling method for most equipment. Depending upon the specific method used for sampling, it may also be the most wasteful. Choose the sampling procedure considering safety, sample accuracy, and economy of product. **S1** requires the two uniformity samples be taken near the discharge points of 15 % and 85 % of the batch (load). This means a gap representing approximately 50–70 % of the load between samples. **S2** cautions not to sample the very ends of the batch. Mixers currently available will not consistently produce batches that are 100 % uniform, particularly at the ends of the batch. Some believe the segregation that occurs at the end of the batch is primarily the result of slow or intermediate discharge speeds at this point.[11]

Note 14 is discussed in Section 10. It states that samples should not be taken prior to 10 % of the batch being discharged, and samples should not be taken after 90 % of the product has been discharged.

The standard does not require continuous discharge. The lack of such a requirement greatly simplifies the sampling process of Procedure No. 2.

[10] The reference to Note 14 was erroneously a reference to Note 13 for several years. The corrected reference to Note 14 took place with the 2003 edition of ASTM C 94/C 94M.

[11] Gaynor, Richard D., former V. P. of Engineering at National Ready Mixed Concrete Association, 2003, personal communication via a note concerning one explanation for segregation of the last few cubic feet of discharge from a truck mixer.

Time a couple of discharges for maximum load sizes, and use these data to measure the 15 % and 85 % discharge points, or allow a batchman with adequate experience to estimate the 15 % and 85 % points of discharge.

EXAMPLE 11.A—*Sampling for mixing uniformity test.*

One satisfactory sampling procedure for a mixer uniformity test requires a front-end loader and a delivery vehicle plus a nearby testing station. Assume a 10-yd^3 (270 ft^3) batch is to be sampled. A minimum sample size of approximately 2–3 ft^3 is desired for each sample. This is almost a full wheelbarrow. Fifteen percent off each end of the batch is approximately 40 ft^3 (1 ½ yd^3). Discharge the load as follows:

1. Discharge 1.5 yd^3 into the delivery vehicle.
2. Temporarily halt the discharge without any remixing, and move the delivery vehicle a few feet out of the discharge spot, replacing it with a front-end loader with its bucket raised.
3. Discharge a sample into the loader bucket.
4. Move front-end loader to testing station, briefly remix sample in loader bucket using a shovel, and unload loader bucket into a sample container or onto a piece of visqueen, dampened plywood, or some other non-absorbing surface.
5. Simultaneously with Step 4, discharge the middle portion (6 ½ yd^3) of the batch into the delivery vehicle, and pull it out of the discharge spot.
6. Discharge a second sample into the raised loader bucket, and move to the testing station. Remix this sample, and hold it in the loader bucket until it can be tested. It is best to hold the sample in the loader bucket until testing and to cover the sample with visqueen to maintain moisture and slump.
7. Finish loading the remaining 15 % of batch into the delivery vehicle, and use the concrete in a manner appropriate with the general appearance, consistency, and strength of the concrete.
8. Test the two samples of concrete for uniformity as described in Annex A1. Consult the appropriate ASTM test methods for allowable times between sampling and performance of specific tests. Because concrete properties change with time, it is required by ASTM Practice for Sampling Freshly Mixed Concrete (C 172) to begin testing several of these properties within 5 min of obtaining each sample.

11.3.3.3 *$_{S1}$ The samples of concrete shall be tested in accordance with Section 17, and differences in test results for the two samples shall not exceed those given in Annex A1. $_{S2}$ Mixer performance tests shall be repeated whenever the appearance of the concrete or the coarse aggregate content of samples selected as outlined in this section indicates that adequate mixing has not been accomplished.*

Most of the test procedures are identified in Section 17 by means of reference to ASTM C 31/C 31M, which lists slump, density, air content, and molding of compressive strength specimens as companion procedures. The exception is the coarse aggregate content, identified and discussed in Annex

A1. Table A1.1 of the Annex also sets forth the specific requirements needed for the two batch samples to be considered uniform. **S2** removes any thoughts of accepting a uniformity test using a fixed time period as unchallenged proof of good mixing. Visual inspection of batches and samples for apparent consistency and uniformity should be a continual process. Should the appearance of the concrete or something else suggest non-uniformity of the mixture, one of the uniformity tests usually will answer the question of bad perception or poorly mixed concrete. Obtain two samples of the concrete as described previously, and check each sample for the coarse aggregate content as discussed in Annex A1. If the coarse aggregate uniformity criterion is not met, it is a good indication that proper mixing is not being achieved. Increase mixing time, or alter the charging sequence.

11.4 Shrink-Mixed Concrete—$_{S1}$ *Concrete that is first partially mixed in a stationary mixer, and then mixed completely in a truck mixer, shall conform to the following: The time of partial mixing shall be the minimum required to intermingle the ingredients.* $_{S2}$ *After transfer to a truck mixer, the amount of mixing at the designated mixing speed will be that necessary to meet the requirements for uniformity of concrete as indicated in Annex A1.* $_{S3}$ *Tests to confirm such performance shall be made in accordance with 11.3.3 and 11.3.3.3.* $_{S4}$ *Additional turning of the mixer, if any, shall be at a designated agitating speed.*

The volume occupied by the individual materials for a cubic yard of concrete is much greater than one cubic yard (27 ft^3). Consider the comparison of individual materials for a basic mix as shown in Table 11.B.

These individual materials occupy 166 % of the volume of the mixed concrete. Shrink mixing is employed to use a stationary mixer to get the materials mixed sufficiently to shrink the volume of a batch close to the final 27 ft^3 per cubic yard. The mixture is not expected to be uniform upon discharge from the stationary mixer into the truck mixer. The mixing time in a stationary mixer is typically 60 s or less. Note that discharge must be into a mixing drum because the concrete is not yet a uniform mixture. Shrink mixing affords some efficiencies to the ready-mixed concrete producer in terms of shorter times for loading mixers and reduced wear of the fins in the truck and the stationary mixer.

How long is the concrete mixed in a truck mixer? Long enough to obtain the uniformity designated in Annex A1. Once the concrete is discharged into a truck mixer, the additional mixing required is measured in revolutions of the mixing drum, not in time as it is in the stationary mixer. The required mixing in a truck mixer will be at the equipment manufacturer's recommended mixing speed or a speed approved for the specific truck mixer drum.

Tests are needed to determine the number of revolutions a truck mixer drum requires to complete the two stage mixing cycle. These tests are the same tests prescribed for the central-mix plant to check uniformity; however, the sampling process from a truck mixer drum is simpler. The procedures outlined in Sections 11.3.3 and 11.3.3.3 still apply.

S4 refers to the drum revolutions following the completion of the mixing revolutions. Some revolutions of a truck mixer are necessary to prevent the formation of flat spots on the drum rollers, and on a long haul a stiff mix may require some agitation to prevent premature stiffening. These revolutions should be at agitating speed, which should be posted on a plate attached to the drum frame or the truck (usually cab door). ASTM C 94/C 94M is silent on a limit for the number of revolutions in a truck mixer for shrink-mixed concrete, but the maximum limits for truck-mixed concrete discussed in Section 11.5 will apply.

11.5 Truck-Mixed Concrete—$_{S1}$ *Concrete that is completely mixed in a truck mixer, 70–100 revolutions at the mixing speed designated by the manufacturer to produce the uniformity of concrete indicated in Annex A1.* $_{S2}$ *Concrete uniformity tests shall be made in accordance with 11.5.1 and if requirements for uniformity of concrete indicated in Annex A1 are not met with 100 revolutions of mixing, after all ingredients including water are in the drum, that mixer shall not be used until the condition is corrected, except as provided in 10.5.* $_{S3}$ *When satisfactory performance is found in one truck mixer, the performance of mixers of substantially the same design and condition of blades are permitted to be regarded as satisfactory.* $_{S4}$ *Additional revolutions of the mixer beyond the number found to produce the required uniformity of concrete shall be at a designated agitating speed.*

Truck-mixing concrete is the most common procedure used for producing ready-mixed concrete. NRMCA estimates that approximately 80 % of the ready-mixed concrete produced in the United States is truck mixed. It is also called dry batch or transit-mixed concrete, due to the mixing drum continuing to turn and mix while the truck is in transit to the project site. The specification is that 70–100 revolutions of the drum are needed for completion of the mixing. It is also explicit that these 70–100 revolutions need to be at mixing speed. The most common mixing speed of truck mixers is in the range of 6–18 rpm. The fast revolution speed for mixing accomplishes two things: 1) it does a better job of moving the materials due to the centrifugal forces and blending action involved, and 2) it gets the job done quickly (approximately 4–6 min). Some mixers are designed for a faster rate of revolution, but when speed of mixing exceeds about 24 rpm, the intended folding action for blending materials may be lost.

TABLE 11.B—*Volumetric comparison of loose and combined ingredients.*

Material	Relative Density (sp gr)	Loose Density (lb/ft^3)	Quantity (lb)	Volume in Mixed Concrete (ft^3)	Loose Volume of Ingredients (ft^3)
Cement	3.15	75	500	2.55	6.67
C. Agg.	2.69	92	1850	11.04	20.11
Sand	2.61	90	1463	9.00	16.26
Water	1.00	62.3	258.2	4.14	4.14
Air (1 %)	...	...	...	0.27	—
Total				27.00	47.18

The uniformity of the concrete should meet the requirements of Annex A1. **S2** provides clear directions on when the count for the 70–100 revolutions begins. The rules differ from those for a central-mix plant. The count for mixing revolutions does not start for truck-mixed concrete until all materials, including tail water, are in the drum.

Section 11.5.1 discusses the uniformity tests for truck-mixed concrete. If the mixer does not produce the required uniformity of the concrete within 100 revolutions at mixing speed, it is considered to have failed the uniformity test, and the situation should be corrected, or the mixer shall not be used, unless it can be qualified by one or more of the provisions of Section 10.5. Section 10.5 gives options of performing uniformity tests on the mixer using a longer mixing time (more revolutions), using smaller batches such as 6 or 7 yd^3 rather than a full load of 8, 9, or 10 yd^3, or changing the sequence for loading materials, which may offer better mixing in a shorter time. Other options available are to inspect the mixer and correct any equipment problems. Concrete build-up on the blades and drum walls, worn-out blades, or inadequate mixing speeds will all affect mixing uniformity, and all are correctable. If the truck is to be used, it must be tested based upon the selected strategy and must meet the uniformity requirements of Annex A1 prior to further use.

S3 is meant to reduce the work of uniformity testing, which can require considerable time. Assume a mixer is tested and meets the mixing uniformity test. Inspect the blade conditions for wear and concrete build-up. All mixers of the same brand, with the same blade configuration, and with the same interior condition or better may be assumed to be satisfactory. Not all of these drums need to have the same capacity rating. Different drum manufacturers will have different characteristics for their drums, thus negating the idea that all 10 yd^3 drums by different manufacturers are the same. They are not, unless uniformity tests on two different brands (drum manufacturers) prove they are in fact quite similar for future evaluations.

S4 is a reminder that after the mixing of the concrete is completed, additional revolutions of the drum should be at the much slower agitation speed. This is usually between 2 and 6 rpm. Section 11.6 addresses some of the reasons for this limitation.

11.5.1 $_{S1}$ ***Sampling for Uniformity of Concrete Produced in Truck Mixers****—The concrete shall be discharged at the normal operating rate for the mixer being tested, with care being exercised not to obstruct or retard the discharge by an incompletely opened gate or seal.* $_{S2}$ *Separate samples, each consisting of approximately 2 ft^3 [0.1 m^3 approximately] shall be taken after discharge of approximately 15 % and 85 % of the load (Note 14).*[12] $_{S3}$ *These samples shall be obtained within an elapsed time of not more than 15 min.* $_{S4}$ *The samples shall be secured in accordance with Practice C 172 but shall be kept separate to represent specific points in the batch rather than combined to form a composite sample.* $_{S5}$ *Between samples, where necessary to maintain slump, the mixer shall be turned in mixing direction at agitating speed.* $_{S6}$ *During sampling the receptacle shall receive the full discharge of the chute.* $_{S7}$ *Sufficient personnel must be available to perform the required tests promptly.* $_{S8}$ *Segregation during sampling and handling must be avoided.* $_{S9}$ *Each sample shall be remixed the minimum amount to ensure uniformity before specimens are molded for a particular test.*

[12] The reference to Note 14 was erroneously a reference to Note 13 for several years. The corrected reference to Note 14 took place with the 2003 edition of ASTM C 94/C 94M.

Obtaining a concrete sample from a truck mixer is much simpler than from a stationary mixer. The batch size should be the maximum that will be hauled by the mixer type being tested. The larger the batch is with respect to drum volume, the greater the challenge of producing a uniform product. The discharge rate from the drum shall be the normal rate for the mixer (drum) that is being checked. For example, paving mixers discharge low slump concrete (1–2 in.) much faster than general-purpose mixers. **S1** cautions against obstructing or retarding the discharge by a gate or seal that is not completely open. This is a reference to mixers 30 or more years ago, which had a horizontal axis, rather than an inclined axis as is common today. The horizontal axis mixers had variable discharge openings. The admonition not to obstruct or retard the discharge remains valid. An extraordinarily rapid rate of discharge can represent a safety hazard to the technicians obtaining the samples, so it is advisable to adjust to a slower rate of discharge during the tests, if necessary, and not to vary the rate while the samples are obtained.

S2 declares that samples should be taken after the discharge of approximately 15 % and 85 % of the load. This can be accomplished by timing the discharge of full loads, maintaining the same discharge rate, and using a stopwatch to obtain the two distinct samples for evaluating mixing uniformity. If you have doubts about where the 15 % and 85 % of load really are, it is best to err slightly toward the middle of the load on both ends. Note 14 advises against obtaining samples before 10 % or after 90 % has been unloaded. A sample size at each location of approximately 2–3 ft^3 is recommended. A sample that is too large is difficult to work with, and a sample too small will be insufficient to conduct all the required tests.

Two samples are to be taken in a span of not more than 15 min **(S3)**. The two samples shall be obtained in accordance with ASTM C 172, except the samples shall be kept and tested separately **(S4)**. A segment of ASTM C 172 that is critical to these samples reads as follows:

> "Sample by repeatedly passing a receptacle through the entire discharge stream or by completely diverting the discharge into a sample container. Regulate the rate of discharge of the batch by the rate of revolution of the drum and not by the size of the gate opening."

If the concrete is to be used in a project, the testing must be done very near the discharge point. Within a 15 min. period allowed between the two samples, the truck movements are very limited, and the test itself places practical limits on moving the truck. Each situation will dictate what to do with the concrete that is not sampled. Several methods of sampling and complying with ASTM C 172 are available. Two wheelbarrows, one for each sample, may be used, and the discharge chute may be completely diverted over the wheelbarrow as quickly as possible when sampling is appropriate. An alternate to wheelbarrows could be two sheets of visqueen or two wash tubs. Hand sampling by repeatedly passing a shovel through the discharge stream is not satisfactory, because a representative sample will not be obtained unless a large shovel such as a scoop shovel for grain is used, and it is entered and retracted from the discharge parallel to the axis of the chute. Such a method of sampling requires a very strong man and also may require a method of suddenly blocking off the concrete at the end of the chute to prevent an overflow of the shovel. Give two wheelbarrows further consideration.

S5 is a reminder that the concrete already has received all of its mixing revolutions, but that turning the drum in agitation speed between sampling is allowed to help maintain the slump. Consider not discharging the middle 70 % of the load until the personnel are almost in position to obtain the second sample. A good procedure (but not required) is to discharge the middle portion of the load and, without stopping the drum, obtain the second sample in the same manner as used for sample one.

S7 is a requirement for adequate personnel, but what constitutes adequate personnel? It is virtually impossible for one technician to meet all the specified time constraints for testing two samples, which must be obtained within a 15 min. interval. By careful preplanning, two technicians can accomplish the testing by working as a team. It is very helpful if a third person is available to assist with obtaining the second sample, washing tools between uses, wetting slump cones, and keeping up with the elapsed time for the various tests.

S8 is a further warning about the integrity of the sample. Remix the remaining sample minimally after each test to retain uniformity. **S9** admonishes against too much remixing, which may change (reduce) the slump and air contents. A partial sheet of visqueen or plywood placed over each sample during any periods in which test materials are not being taken will also assist in maintaining a representative sample.

The discussion in Section 17.1 of this text will assist in meeting the uniformity test time schedules. The test to be performed last is the coarse aggregate content because this value will not change and has no time limit. An example of the mixing uniformity test procedures is provided in the discussion on Annex A1.

11.6 *When a truck mixer or truck agitator is used for transporting concrete that has been completely mixed in a stationary mixer, any turning during transportation shall be at the speed designated by the manufacturer of the equipment as agitating speed.*

For concrete mixed in a central-mix facility that is not operating in a shrink-mixing mode, there is no need for additional mixing during transit of the concrete. Additional revolutions at mixing speed can cause heat build-up in the concrete plus a reduction in both slump and air content. Confine any additional mixing speed revolutions to a few turns immediately before discharge to enhance uniformity after a long or bumpy trip from plant to discharge point. The drum should be turned at the manufacturer's drum plate stated agitating speed during transit and waiting times.

11.7 $_{S1}$ *When a truck mixer or agitator is approved for mixing or delivery of concrete, no water from the truck water system or elsewhere shall be added after the initial introduction of mixing water for the batch, except when on arrival at the job site the slump of the concrete is less than that specified.* $_{S2}$ *Such additional water to bring the slump within required limits shall be injected into the mixer under such pressure and direction of flow that the requirements for uniformity specified in Annex A1 are met.* $_{S3}$ *The drum or blades shall be turned an additional 30 revolutions or more if necessary, at mixing speed, until the uniformity of the concrete is within these limits.* $_{S4}$ *Water shall not be added to the batch at any later time.* $_{S5}$ *Discharge of the concrete shall be completed within 1½ h, or before the drum has revolved 300 revolutions, whichever comes first, after the introduction of the mixing water to the cement and aggregates or the introduction of the cement to the aggregates.* $_{S6}$ *These limitations are permitted to be waived by the purchaser if the concrete is of such slump after the 1½-h time or 300-revolution limit has been reached that it can be placed, without the addition of water, to the batch.* $_{S7}$ *In hot weather, or under conditions contributing to quick stiffening of the concrete, a time less than 1½ h is permitted to be specified by the purchaser.*

This subsection concerns the job site addition of water to a batch of concrete and the maximum limits on time and drum revolutions before the concrete must be discharged. Therefore, it is primarily about **slump and workability.**

S1 is a reminder that truck mixers and agitators are subject to inspection and approval or rejection. The truck water system shall not be used to inject water at the plant, in transit, or even at the job site unless the slump is less than specified upon arrival at the job site. As it is stated, the first impression may be that the job site water addition must occur immediately upon arrival. Section 6.2, however, makes a clear distinction between two criteria: "arrival at the job site" and "initial slump adjustment." In **S1**, the intent is not to mean "immediately" upon arrival. The "job site addition only" limitation is to permit an inspector to be present for all additions of water, should the purchaser so desire. Even then there are restrictions, which must be followed. The truck water system has two (2) functions. The most important is actually providing water to clean the drum and truck after batching and after delivery. The second is to make water available to adjust the slump when it is specified or permitted. Section 6, "Tolerances in Slump" alludes to the purchaser's right to prohibit any water additions at the job site. Such a prohibition is not usually a wise choice because it could detract from the placeability and finishability of the concrete, but it is nevertheless a purchaser's choice. The other limit and possible restriction to job site added water is a maximum water-cement ratio.

S2 discusses the injection of permitted water into the load of concrete. The water system shall not leak, shall be pressurized, and shall have a flow direction to assist with achieving a uniform mixture. The water is injected at the discharge end of the drum, causing it to be carried to the nose of the drum during the mixing rotation. When transit–mix drums are inspected, a check of the truck water system should include the end of the water injection outlet. These outlets are somewhat hidden from drum cleaning operations and will often become partially blocked by hardened concrete. This blockage will prevent a strong flow of water toward the nose of the drum, resulting in a poor distribution of added water.

For most concrete mixtures, it requires approximately 3 gal of water per cubic yard to lose the strength overdesign for the specified strength. A common practice is to use a portion of this water for retempering the load to overcome slump losses. There are also implications on the durability of concrete. When a specification calls for a maximum water-cement ratio, water that exceeds that amount should never be added. A maximum water-cement ratio is often a major component of a concrete specification and is closely related to the expected concrete durability and sometimes the expected strength. Does all of any added water count in the water-cement ratio? Probably not, according to Neville [72]. Neville states that there is considerable evidence that water lost by evaporation should not be counted, while water used in early hydration should be counted. When a maximum water-cement ratio is not an issue, minor additions of water for restoration of workability are often the most practical approach to good concrete but will lower the concrete's compressive strength. Burg [19] found that retempering with up to 8–10 % of the total water content was acceptable and maintained desired qualities in a properly proportioned mixture using chemical admixtures. It is the practice of many ready-mixed concrete manufacturers to design their mixture proportions for a late addition of job site water and to batch concrete at the plant with some of the design mixing water held back to allow for the job site addition. Research by Anderson and Carrasquillo [10] indicated strengths were not affected by adding withheld water at the job site. The ultimate water-cement ratio has a greater effect on the concrete properties than does the time of water addition. Withholding some plant water until slump losses during delivery have occurred is a common practice. The slump loss and water quality required for retempering vary with each individual mixture depending upon cement content, chemical admixtures, temperature, haul time, and other factors [40]. Even when there are water-cement ratio limitations, it is wise to check the total plant water versus the allowable water before disallowing a job site addition.

S3 gives instructions for 30 or more drum revolutions at mixing speed after job site water is added. These revolutions are intended to uniformly distribute and mix the added water into the entire load. **S4** in effect says this is a one time and one time only addition of water. This should be considered in evaluating when to add water and to what slump the adjustment should be made, assuming a maximum water-cement ratio is not exceeded. Subsection 6.1.1 uses the phrase "one addition of water." Does this mean if 10 gal are added and mixed into the load and the resulting slump remains low that more water cannot be added at that time? It does not mean this. If the water-cement ratio is not exceeded, more water may be immediately added and mixed into the load at this point. What is prohibited is the second addition of water at a later time frame when the slump has been allowed to decrease, due to the passage of time and the heat of hydration. The prohibition of a second water addition applies regardless of the water-cement ratio. Example 11.B provides three examples of adding water. Water should not be added once a significant quantity of concrete, more

EXAMPLE 11.B—*Evaluations for job site water additions.*

Example No.	(1)		(2)		(3)	
Process Step	gal	in.	gal	in.	gal	in.
Allowable water in mixture	36	...	36	...	no limit	...
Free water on aggregate	4	...	4	...	4	...
Batch water	23	...	23	...	23	...
Allowable job site water	9	...	9	...	as needed	...
Specified slump (maximum)	...	4	...	4	...	4
Slump upon arrival at job	...	3	...	3	...	3
Water added upon arrival	5		7	...	5	...
Slump immediately after water addition	...	3 ½	...	4	...	3 ½
Additional water added immediately after slump determination	4	...	0	...	as needed	...
Additional water permitted now	0*	...	0†	...	as needed	...
Additional water permitted later	none	...	none	...	none‡	...

* Maximum water-cement ratio has been reached. (5 + 4 = 9 gal allowable.)

† Maximum water-cement ratio has not been reached (2 gal permitted), but the maximum slump has been reached. (7 gal added is less than 9 gal allowable.)

‡ Maximum water-cement ratio is not specified, but any additional water desired should have been added after the 3 ½ in. slump was measured. A later time counts as a second addition and is not permitted.

than about 10 %, has been discharged, since the quantity of concrete remaining in the drum cannot be estimated accurately, and the effect of the water added on the water-cement ratio cannot be determined.

S5 begins the discussion of discharge limits. The specified time limit is 1 ½ h for **completion of discharge,** not the start of discharge. A second criterion is 300 drum revolutions. A drum must have an operating revolution counter to verify the number of revolutions. The controlling factor between 1 ½ h and 300 revolutions is **whichever comes first.** The clock and the revolution counter begin when the mixing water contacts the cement and aggregates (usual case) or when cement is added to the aggregates (unusual case). The water, cement, and aggregates case is very typical and readily understood because cement hydration has now begun.

Just adding cement to the aggregates is a bit harder to understand as a trigger to the clock. This is a situation typically reserved for a long haul, and the batch water is added at the job site. Aggregates will usually contain free moisture, which will commence hydration of the cement without the presence of batch water.

There are a couple of scenarios that would be excluded from commencing the hydration process. One is to batch the aggregates in the usual manner and then to load the cement on top of the aggregates and not rotate the drum until the water is added at the job site. Getting the cement in may require a smaller than desired load, and without drum rotation in transit, the drum rollers may acquire flat spots. The second scenario would be to dry aggregates in an asphalt plant or some other means prior to batching.

The reasons for these limits are generally understood. The time limit is because of a concern with excessive hydration of cement or loss of slump that might require an excessive water addition to achieve the desirable consistency. The limit on the number of revolutions has historically been in the standard due to a concern of breakdown of aggregate due to attrition and possibly detrimental effects of excessive mixing on entrained air content. If the purchaser believes that exceeding any one of these limits is not of concern to the concrete quality, the option to waive these limitations is provided.

S6 makes provisions for waiver of the time or revolution restriction by the purchaser. This waiver would extend to the purchaser's agent. The waiver is conditioned upon the slump being satisfactory for placement without more water being added to the concrete. The use of chemical admixtures may be permitted to achieve the required workability for placement. Admixtures meeting ASTM C 494/C 494M, Type B or Type D, High-Range Water-Reducers with or without retarding effects or approved two component admixtures, which stop the hydration process until reactivation at the will of the producer, may all be used to extend the life of the concrete beyond 1 ½ h and 300 drum revolutions. The waiver based upon these methods is the purchaser's decision. When possible, an agreement prior to the concrete placement time on when these waivers might apply is a good practice.

S7 allows the purchaser to reduce the allowable truck time to less than 1 ½ h in hot weather. This time reduction must be stated prior to pricing due to the possible effect on cost and price. When less than 1 ½ h, the selected truck time should be stated sufficiently in advance to allow both planning and price negotiations or adjustments. The term "specified" implies advance notification via a specification as opposed to a spontaneous decision.

11.8 *S1 Concrete delivered in cold weather shall have the applicable minimum temperature indicated in the following table. S2 (The purchaser shall inform the producer as to the type of construction for which the concrete is intended.)*

Minimum Concrete Temperature as Placed

Section Size, in. [mm]	*Temperature, min, °F [C]*
< 12 [< 300]	*55 [13]*
12–36 [300–900]	*50 [10]*
36–72 [900–1800]	*45 [7]*
> 72 [> 1800]	*40 [5]*

S3 The maximum temperature of concrete produced with heated aggregates, heated water, or both, shall at no time during its production or transportation exceed 90°F [32°C].

Good temperatures for concrete are from approximately 60°F up to the 80–85°F range. In this 20–25°F temperature window, the concrete has good time of set characteristics and requires little special attention. At lower temperatures and particularly with certain chemical admixtures or cementitious materials, it wants to lie quietly and not set up and get hard. One rule of thumb is that for a particular concrete mixture, a change in the concrete temperature by 20°F will change the setting time by a factor of 2, for example, a concrete that sets in 4 h at 70°F will take 8 h to set at 50°F and 2 h to set at 90°F. Another such approximation is that setting time can be anticipated to change approximately 30 % for each 10°F change in temperature from a base temperature of 73°F [20]. The estimated times of set for the previous example change to 2 ⅓ h at 90°F and 6 ¾ h at 50°F from the 4 h at 70°F base. When the temperature of the concrete drops to somewhere in the mid 20s, it does not set, but it will freeze. When the concrete thaws, the hydration process begins anew, although the concrete should not be expected to reach its potential strength or to achieve the original durability that may have been expected. All of these factors are a function of items such as the length of freeze and the temperatures experienced by the concrete during the freeze. To assist the concrete in attaining final set properties during cold weather, concrete temperatures should comply with the data shown in the table "Minimum Concrete Temperature As Placed." This table was extracted from ACI 306R, "Cold Weather Concreting" [8].

TABLE 11.C—*Concrete temperatures for cold weather construction (ACI 306R).*

	Section Size, Minimum Dimension, in. (mm)			
Air Temperature, °F (°C)	<12 (300)	12–36 (300–900)	36–72 (900–1800)	>72 (1800)
Minimum concrete temperature as placed and maintained, °F (°C)				
	55 (13)	50 (10)	45 (7)	40 (5)
Minimum concrete temperature as mixed for indicated air temperature,* °F (°C)				
Above 30 (−1)	60 (16)	55 (13)	50 (10)	45 (7)
0 to 30 (−18 to −1)	65 (18)	60 (16)	55 (13)	50 (10)
Below 0 (−18)	70 (21)	65 (18)	60 (16)	55 (13)
Maximum allowable gradual temperature drop in the first 24 hours after end of protection				
	50 (28)	40 (22)	30 (17)	20 (11)

* For colder weather a greater margin in temperature is provided between concrete as mixed and required minimum temperature of fresh concrete in place.

The table from ACI 306R, shown here as Table 11.C, defines minimum concrete temperatures at placement in terms of the narrowest dimension of the concrete element. ACI 306R instructs the contractor to maintain these same temperatures until the concrete has attained a compressive strength of at least 500 psi. This will often occur in the first 48 h after placement.

> ACI 306R defines cold weather "as a period when, for more than 3 consecutive days, the following conditions exist: 1) the average daily air temperature is less than 40°F (5°C), and 2) the air temperature is not greater than 50°F (10°C) for more than one-half of any 24-hr period".

A practical approach is that if the temperature is below 50°F consider it cold weather from a producer's standpoint. Some producers automatically use hot water in cold weather, adding a fixed winter-price surcharge. Other plants use hot water upon request for a cubic yard charge, and some plants simply do not have this capability. In addition to using methods to change the temperature of the concrete, chemical admixtures or different cements or cementitious material combinations may be employed to affect the time of set characteristics of concrete in cold or hot weather conditions.

S2 places the **burden on the purchaser** to order concrete with hot water, hot water and heated aggregates, or concrete at a minimum temperature. The purchaser should either order by the minimum placement temperature or by the minimum dimension of the concrete being placed. **S2** does not preclude the producer from asking the purchaser about cold weather concrete characteristics desired, if any.

The table of Section 11.8 describes concrete temperatures, as placed, not as batched. The "as batched" concrete temperature must allow for heat losses during transit, anticipated job site waiting times, and any delays for preliminary slump or air-content testing. ACI 306R reports a formula developed by Petersons in Sweden [78]:

$$T = 0.25\ (t_f - t_a)$$

where:

T = approximate temperature drop of concrete during 1 h of agitation in revolving drum mixer.
t_f = desired concrete temperature at placement, degrees F or C.
t_a = ambient air temperature, degrees F or C.

EXAMPLE 11.C—*Estimated temperature loss after batching.*

Assume the air temperature is 23°F, and the concrete is to have a thickness of 15 in. From the temperature table, the "as placed" concrete temperature should be 50°F or more. The approximate temperature loss during a one hour delivery and standby time is calculated as:

$$T = 0.25\ (t_f - t_a) = 0.25\ (50 - 23) = 0.25 \times 27 = 7°F$$

The concrete temperature at completion of mixing should not be less than (50 + 7) = 57°F.

There are numerous means of combating low-concrete temperatures. Most of them begin with hot water being substituted for all or a portion of the mixing water added to the batch. Hot water also can be carried in the side tank of the delivery vehicle. Heating of aggregates through the use of steam or hot air is the most common secondary method available to produce concrete with a higher temperature. Steam is used to heat aggregate stockpiles, storage bins, transfer hoppers, or other aggregate storage locations. Often hot air is circulated in or around enclosed aggregate containers, such as overhead bins or underground storage units, with an enclosed chamber surrounding the bins that will accommodate the hot-air ducts.

Aggregates should not be frozen at the time of batching. The use of frozen aggregates may lead to frozen lumps in the discharged concrete and an excess of water due to thawing of lumps at a point in the mixing process after the slump has been adjusted.

A formula for predicting the temperature of the concrete is available in ACI 306R and "Design and Control of Concrete Mixtures" by the Portland Cement Association [48]. Each publication contains the same formula, which is based upon the temperature and quantity of each raw material at the time of batching and the specific heat of each material. Specific heat is a numerical ratio that compares the heat required to raise the temperature of a material 1°F to the heat required to raise an equal mass (weight) of water 1°F. Water requires approximately five times the heat required for aggregates or cement for the same temperature rise. Approximate specific heat is assumed to be 0.22 for the solid ingredients and since water is the reference, its specific heat is 1.00. The formula does not consider any frozen materials because all materials should be thawed prior to batching. Note that the free moisture on aggregates will be at the same temperature as the aggregates. **S3** limits the maximum temperature of cold weather concrete to 90°F. The concern is an excessively rapid loss of temperature after placement will result in excessive cracking of the concrete due to a temperature differential between a cool surface and the interior at a much higher temperature. Another benefit of cooler concrete temperature is a lower rate of slump loss and a higher ultimate concrete strength. Concrete at a higher temperature will also cause the need for additional water to attain the desired slump. Determine the expected concrete temperature (T) in accordance with Example 11.D.

EXAMPLE 11.D—*Estimated concrete temperature.*

$$T = \frac{[0.22(T_sW_s + T_aW_a + T_cW_c) + T_wW_w + T_sW_{ws} + T_aW_{wa}]}{[0.22(W_s + W_a + W_c) + W_w + W_{ws} + W_{wa}]}$$

Where:		Example
T	= final temperature of concrete mixture (°F or C)	Desired value
T_c	= temperature of cement	60°F
T_s	= temperature of fine aggregate (sand)	38°F
T_a	= temperature of coarse aggregate	40°F
T_w	= temperature of added mixing water	140°F
W_c	= mass (weight) of cement	514 lb
W_s	= mass (weight) of SSD sand	1350 lb
W_a	= mass (weight) of SSD coarse aggregate	1800 lb
W_w	= mass (weight) of added mixing water	258 lb
W_{ws}	= mass (weight) of free water on sand	30 lb
W_{wa}	= mass (weight) of free water on coarse aggregate	9 lb

$$T = \frac{[0.22((38 \times 1350) + (40 \times 1800) + (60 \times 514)) + (140 \times 258) + (38 \times 30) + (40 \times 9)]}{[0.22(1350 + 1800 + 514) + 258 + 30 + 9]}$$

$$T = \frac{[0.22(154140) + 37620]}{[0.22(3664) + 297]} = \frac{71531}{1103} = 65°F$$

65°F > 55°F OK and < 90°F OK

Note 15—$_{S1}$ *When hot water is used rapid stiffening may occur if hot water is brought in direct contact with the cement.* $_{S2}$ *Additional information on cold weather concreting is contained in ACI 306R.*

Note 15 cautions about placing hot water and cement together immediately. Boiling water (212°F) is seldom used, otherwise flash setting may occur upon direct contact of cement and water. To avoid this possibility some plants limit the hot water temperature to approximately 180°F. Another method of avoiding a potential problem is a batching sequence of head water, aggregates, cement, aggregates, and tail water. This avoids batching cement and water simultaneously. Such a batching sequence allows the initial aggregates to temper the temperature of boiling water before the introduction of cement.

S2 of Note 15 references ACI 306R [8] as a good source of information for cold weather concreting.

11.9 $_{S1}$ *The producer shall deliver the ready-mixed concrete during hot weather at concrete temperatures as low as practicable, subject to the approval of the purchaser.*

High temperature concrete requires more water to attain the same slump when compared to low or moderate temperature concrete. A Bureau of Reclamation study indicated that for a typical concrete mixture, the change in water for a constant slump is approximately 0.8 gal (6 ⅔ lb) per 10°F temperature change [18]. The producer should take reasonable precautions to hold the concrete temperature down. There are no specific requirements, and depending upon the particular ready-mixed concrete operation, some or all of the following suggestions may not be available without an additional charge or an additional cost to the producer:

1. Do not batch earlier than necessary to meet delivery schedule.
2. Paint transit-mix drums a light color, preferably white.
3. Sprinkle coarse aggregate stockpiles with water to provide evaporative cooling. (Sand can also be sprinkled, but it is difficult to maintain a uniform moisture condition of the sand).
4. Store aggregates in a location protected from direct sunlight.
5. Keep cement silos full to allow as much cooling time for cement as possible.
6. Reduce mixing revolutions to the minimum number necessary to achieve a uniform mixture.
7. Re-proportion the mixture to replace portions of the cement with fly ash, ground granulated blast-furnace slag, or natural pozzolans.
8. Design and batch mixture for the maximum allowable slump.
9. Use chemical retarders to reduce temperature rise during transit due to reduced hydration rate. (Retarders do not cool concrete.)
10. Cool concrete via chilled batch water.
11. Cool concrete via replacing water with chipped or shaved ice.
12. Cool concrete via injection of liquid nitrogen into mixer.

Approval of the purchaser is needed for any of these methods or others which affect price of concrete or a change in approved or requested mixture ingredients or proportions.

Note 16—$_{S1}$ *In some situations difficulty may be encountered when concrete temperatures approach 90°F [32°C].* $_{S2}$ *Additional information may be found in the Bureau of Reclamation Concrete Manual and in ACI 305R.*

Note 16 directs attention to possible difficulties with higher temperature concrete. These include lower strengths with higher water contents for constant slump, potential for increased shrinkage, higher potential for plastic shrinkage cracks, faster set times that make placement and finishing difficult, and decreased durability. Current knowledge of available materials including supplementary cementitious materials (SCM), chemical admixtures, and concrete proportioning for hot weather makes it possible to batch and deliver quality concrete at temperatures above 90°F, 95°F, or even 100°F. Research by Mittelacher [58,59] and Gaynor, Meininger, and Khan [40] plus the current ACI 305R [7] each indicate concrete can be successfully placed at temperatures up to and even in excess of 95°F. **S2** references the Bureau of Reclamation Concrete Manual plus ACI 305R, "Hot Weather Concreting" as good sources for additional information.

Time of Set for concrete is not a topic in C 94. A list of factors which affect time of set is very long and often includes specified conditions that may be counterproductive to a desired range for time of set. This property can be so variable that if the need exists for close control, a negotiation process may be appropriate sufficiently in advance to allow trial mixtures.

Cold Weather slows down the hydration rate of cement, and thus the time of set is lengthened. The primary constituents of cement affecting time of set are Tricalcium Silicate (C_3S) and Tricalcium Aluminate (C_3A). The heat rise in concrete is proportional to the quantity of these two compounds and the fineness of the cement as it affects the rate of hydration. The heat of hydration directly affects the time of set. Each brand of cement from each mill will have different time of set characteristics.

The use of calcium chloride has been the primary time of set acceleration source for many decades. Research has now substantiated that chloride ions in concrete exposed to moisture will also accelerate corrosion of any reinforcing steel. ACI 318 places restrictions on the use and quantity of any chloride compound including the usual form, which is calcium chloride. In reading ACI 318, remember that adding 2 % calcium chloride dihydrate ($CaCl_2 \cdot 2H_2O$) as an accelerator will increase the chloride ion content 1 %. When using a purchased preconditioned solution of liquid calcium chloride, rather than a flake product, the proportion of chloride ion content may increase. Detailed data concerning the composition and use of calcium chloride are available from the product manufacturer.

Common practices to accelerate the time of set during cold weather include the following:

- Addition of calcium chloride ($CaCl_2$) at a rate not to exceed 2 % by mass of cementitious materials.
- Hot water as mixing water.
- Lower slumps at point of discharge.
- Heated aggregates.
- Increase the quantity of cement by 100 lb or more per cubic yard of concrete.
- Chemical accelerating admixtures containing some form of chlorides.
- Chemical accelerating admixtures without any chlorides. These are called Non Chloride Accelerators (NCA).
- Decrease the quantity of supplementary cementitious materials such as fly ash, natural pozzolans, and ground granulated blast-furnace slag while maintaining the required total cementitious materials to obtain desired strength and durability.
- Decrease the use of lignosulfonate-based and hydroxylated carboxylic acid-based water reducers.
- Substitute Type III for the general use cement if permitted by the specification.

Hot Weather also can produce time of set problems. Retardation can be accomplished by several methods, some of which are:

- Cooling the individual ingredients of the concrete, thus lowering the concrete temperature.
- Chemical retarding admixtures meeting ASTM C 494, Type D—Water-reducing and retarding admixtures or Type G—Water-reducing, high range, and retarding admixtures.
- Reduce the amount of cement when feasible and permitted.
- Reproportion the mixture to increase the quantity of supplementary cementitious materials such as fly ash, natural pozzolans, and ground granulated blast-furnace slag when permitted.
- Sprinkle coarse aggregate stockpiles.
- Shade aggregate stockpiles.
- Batch with chilled water.
- Substitute ice for a portion of the batch water.
- Change to a Type II cement or a blended cement when permitted.

12

Use of Nonagitating Equipment

12.1 $_{S1}$ *When the use of nonagitating transportation equipment is approved by the purchaser, the concrete shall be manufactured in a central mix plant.* $_{S2}$ *The proportions of the concrete shall be approved by the purchaser, and the following limitations shall apply:*

It is not the intention of ASTM C 94/C 94M to require the use of nonagitating equipment when the mixing is accomplished in a central-mix plant. It is the intention of ASTM C 94/C 94M to require the purchaser's approval to use nonagitating equipment as a delivery vehicle. The question to be answered is if the purchaser will allow the concrete to be hauled by nonagitating equipment, or if agitating equipment will be required or permitted.

S2 requires the purchaser to approve the proportions because of the possibility of segregation during transit. Also with nonagitating equipment, there is no possibility of adding water at the job site or any job site adjustments, such as additional air-entraining admixture. In effect, what you see coming out of the central-mixer is what you get, so it had better be what you want. Nonagitating delivery units are common on concrete paving projects where a portable central-mixing plant is set up close to the paving project, the concrete slump is low, and the haul distance is short.

Restrictions on the use of nonagitating equipment are necessary because of the no remixing, no tempering, and no addition of admixture limitations.

12.2 $_{S1}$ *Bodies of nonagitating equipment shall be smooth, watertight, metal containers equipped with gates that will permit control of the discharge of the concrete.* $_{S2}$ *Covers shall be provided for protection against the weather when required by the purchaser.*

Watertight containers are required so that any water or mortar, which may separate in transit, is not lost. Metal is required as the base container material for rigidity and nonabsorptive characteristics. A non-watertight rigid container can be used if it has a liner that is slick, non-absorbent, and watertight. The shape of the container must be such that all of the transported concrete is discharged. The best method of achieving this is to use a container (trailer or other unit) that has a smooth radius joining the container floor (bottom) and the side walls. A sharp edge at this junction of the floor and side is apt to collect a build-up of non-discharging concrete. The NRMCA Plant Certification program requires this rounded connection along the container sides [70]. The front of the container (often a dump trailer) has no such requirement. The concrete discharges away from the front trailer wall and not parallel to it as occurs along the sides.

The discharge gate shall control the concrete discharge rate. In its simplest form, this may be a material trailer gate with the discharge opening of the gate regulated by chains. Any device that is more sophisticated and that effectively controls the discharge rate is acceptable.

S2 concerns the purchaser's option of requiring the loads to be covered when open top containers are used for delivery. Weather conditions forcing consideration of covers include rain, very hot clear days for sun protection, or very windy days requiring protection from evaporation or even blowing dust. The typical scenario is that the trip length with nonagitating units is too short for covers to be effective, especially if they do not unroll and re-roll automatically. It does behoove the purchaser to require a specified number of covers at the site in the event of a breakdown or weather condition that halts work. There may be several nonagitating delivery units stranded and unable to discharge their load immediately. Covers to protect these loads are appropriate and may save the concrete.

12.3 *The concrete shall be delivered to the site of the work in a thoroughly mixed and uniform mass and discharged with a satisfactory degree of uniformity as prescribed in Annex A1.*

The use of nonagitating delivery equipment does not exempt the concrete from having to be mixed uniformly upon discharge at the job site. The uniformity requirements at discharge are stated in Annex A1 to ASTM C 94/C 94M. The requirements are identical to those for concrete delivered in a truck mixer. To meet this requirement the producer and purchaser must consider the length of haul, road conditions, and selected mixture in the deliberations concerning the use of nonagitating delivery vehicles.

12.4 $_{S1}$ *Slump tests of individual samples taken after discharge of approximately 15 % and 85 % of the load will provide for a quick check of the probable degree of uniformity (Note 14).* $_{S2}$ *These two samples shall be obtained within an elapsed time of not more than 15 min.* $_{S3}$ *If these slumps differ more than that specified in Table A1.1, the nonagitating equipment shall not be used unless the conditions are corrected as provided in 12.5.*

The slump test on two samples is the preliminary check for uniformity of concrete. This is the quickest of the Annex A1 tests. Samples for the slump test are taken at locations representing the load at a point approximately 15 % from each end. ASTM Practice for Sampling Freshly Mixed Concrete (C 172) is not cited, but adhering to its requirements is recommended. Note the variable sampling styles allowed by ASTM C 172 for nonagitating equipment.

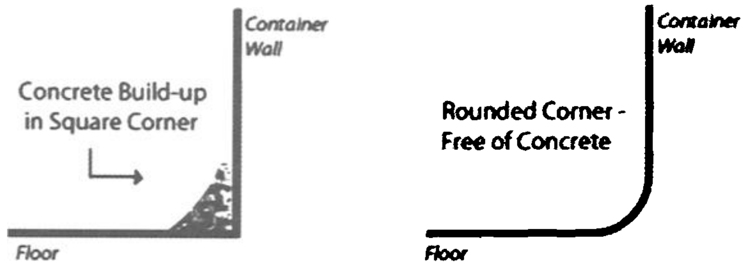


FIG. 12.A—*Nonagitating delivery unit wall and floor junction.*

The sampling is the difficult portion of this operation. With a full width tailgate discharge, sampling the full width of the discharge stream is difficult. ASTM C 172 permits nonagitating equipment to be sampled in the manner of paving mixers. One of the approved methods of ASTM C 172 is to place shallow containers at predetermined locations on the subgrade and discharge the concrete across the containers. The containers shall have sufficient capacity to provide samples of adequate size based upon the tests to be performed and maximum aggregate size. The 15 min. time limit is extremely important for the comparison of two slump tests. During hot weather, an unprotected sample can lose 1 in. of slump during the 15 min. period.

Note 14 is discussed in Section 10.4.

S2 and **S3** are discussed in Section 10.4. The only additional comment for nonagitating equipment is that "the conditions" can be taken to mean rough roads causing segregation of the concrete as well as the condition of the equipment. The equipment problems to be suspected are areas of hardened concrete within the trailer bed (container) not being discharged and growing in size with each load.

With nonagitating equipment, the specified slump will probably be less than 4 in. The allowable slump difference between the two samples will then be 1 in.

12.5 $_{S1}$ *If the requirements of Annex A1 are not met when the nonagitating equipment is operated for the maximum time of haul, and with the concrete mixed the minimum time, the equipment shall only be used when operated using shorter hauls, or longer mixing times, or combinations thereof that will result in the requirements of Annex A1 being met.*

Annex A1 requires six tests and that five of the six have results meeting the requirements of Table A1.1. The same tests and requirements of Annex A1 apply to transit mixers, stationary mixers or nonagitating units. The tests for nonagitating units are to be performed after undergoing the most severe conditions expected for the project. Two conditions present the worse situation and promote the most severe conditions with regard to uniformity of the delivered mixture. These are the stationary mixer operating for the minimum acceptable mixing time and the haul unit moving the maximum expected time at the anticipated delivery speeds. If a nonagitating haul unit fails to meet the uniformity test under these conditions, it shall only be used when haul times are shorter and mixing times longer and a satisfactory uniformity test is achieved using a prescribed combination. Tests may show that a longer mixing time achieves the desired results or that it is only necessary to shorten the haul time.

It is also possible that a satisfactory test is not achieved with any available nonagitating haul unit. The mixture proportions may need adjustment or the haul road repaired. If none of these solutions solve the problem, it may be necessary to switch to truck mixers or agitators for the long hauls. Annex A1 tests can then be used to determine an approved haul time or distance for the nonagitating haul units.

13 Batch Ticket Information

13.1 The manufacturer of the concrete shall furnish to the purchaser with each batch of concrete before unloading at the site, a delivery ticket on which is printed, stamped, or written, information concerning said concrete as follows:

Delivery tickets are business items that are critical to the ready-mixed concrete industry. Without tickets, who could remember at day's end if 14 loads were delivered, or was it 15, and was the last load 6 ½ yd^3 or 7 yd^3? The signed delivery ticket (batch ticket) is a major component of a business transaction. For small projects, the delivery ticket is essentially the contract between the purchaser and the manufacturer of the concrete. It is usually only on larger projects that a purchase order or subcontract is used as a contract. The delivery ticket also can become a major part of a forensic investigation if problems develop. The need for many of the items on the ticket is self-evident and will not be discussed.

13.1.1 *Name of ready-mix company and batch plant, or batch plant number*

The specific plant ID isolates the origin of a load for inhouse bookkeeping and for the source of materials, equipment, etc., in the event of a concrete problem.

13.1.2 *Serial number of ticket*

This identifies an individual load. This is particularly important on a project with multiple loads by several mixer trucks.

13.1.3 *Date* (Self-evident)

13.1.4 *Truck number*

The truck number on tickets is helpful in attempts to isolate problems.

13.1.5 *Name of purchaser* (Self-evident)

13.1.6 *Specific designation of job (name and location)*

A purchaser may have more than one project under construction, making this additional information important for bookkeeping purposes as well as for providing evidence that the load is at the correct job site.

13.1.7 *Specific class or designation of the concrete in conformance with that employed in job specifications*

Section 4.5 requires an identification (ID) designation for each of the concrete mixtures to be furnished to a project. It is helpful to all concerned if the concrete is ordered using this ID, and if the designation on the ticket is checked at the time of delivery. With literally hundreds of mixtures available to the batchmen, mistakes will occur, but they can be identified before the problem becomes worse. IDs are very helpful in forensic investigations. It is the responsibility of the entity placing the order to ensure the mixture ordered meets the job specification, is the proper job mixture for the segment of the project to be placed with a specific load, and that the delivery is discharged into the proper location.

13.1.8 *Amount of concrete in cubic yards (or cubic meters)*

The basis of purchase is volume measured in cubic yards as discussed in Section 3.

13.1.9 *Time loaded or of first mixing of cement and aggregates, and*

The time loaded (or first mixing of cement and aggregates and the aggregate moisture) is related to Section 11.7 and the 1 ½ h allowable time lapse before the concrete has been discharged.

13.1.10 *Water added by receiver of concrete and his initials.*

The delivery ticket must have a location to indicate the quantity of water added at the job site. This value relates to strength, durability, time of set, shrinkage, and other potential problems that develop after the concrete is actually placed. The initials of the purchaser's representative indicate receipt of the concrete and acknowledgment of the job-added water quantity. If water is not added at the job, this fact should be indicated on the ticket with a "zero." Although not required, many producers have drivers note the measured slump or estimated slump on the delivery ticket (producer's copy) as useful information in the event of unexpected problems.

13.2 *Additional information for certification purposes as designated by the purchaser and required by the job specifications shall be furnished when requested; such information as:*

The data listed under Section 13.1 are all mandatory. The data listed under Section 13.2 are all available to the purchaser by prior request. These items may each be requested or specified individually or as a total unit. Some of these items are not verifiable without a full-time inspector. For that reason, it is specified that the information provided be certified by the manufacturer, thereby saving the expense of an inspector. A couple of examples are brand of cement and reading of revolution counter during batching. Neither of these items can be verified by a third party at a later date.

Many of these optional items concern the composition of the mixture. Note that reporting the mixture composition is not mandatory. There are many cases where a producer, as a matter of prior agreement, may choose not to report the composition of the mixture, as it may represent proprietary information to the company that has a cost associated with its development. The purchaser, however, has the right to request such information according to ASTM C 94/C 94M. Identification of the mixture ID may suffice, however, to ensure the correct mixture is being delivered and placed. Practices for reporting mixture composition information varies by company, and ASTM C 94/C 94M does not dictate how this is reported, whether by cubic yard or total batch, or whether the ingredient quantities are reported by actual recorded weights or that intended in the mixture design. In computerized plants, recording devices record actual scale readings when concrete ingredient materials are batched. This recording cannot be tampered with and is linked to the delivery ticket ID in the event this information is needed for a forensic investigation.

13.2.1 *Reading of revolution counter at first addition of water*

It is unreasonable to expect the revolution counter to be zeroed at the instant of the first addition of water to the batch. It is not unreasonable to expect the driver to read the counter when the first water is batched. This number becomes important when the mixer approaches 300 revolutions and the determination of compliance with Section 11.7 and 300 maximum revolutions is at issue. The best place to retain the initial number of revolutions is on the delivery ticket. Note that Section 13.1.9 (mandatory information) has already requested the time of batching. Section 13.2.1 is simply the other shoe dropping to provide a complete picture for both time and revolutions.

13.2.2 *Type, brand, and amount of cement*

The brand of cement may be important if the Architect/Engineer (A/E) has specified that all cement shall be from one source. Brand name also provides the purchaser the contact information should additional information on the product be desired. The type of cement to be used includes data such as ASTM C 150, Type I/II, or a ASTM C 595, Type IP, or maybe an ASTM C 1157, Type GU. The purchaser is entitled to know what type of cement is being used on the project. Providing good historical records is one reason for such a request. Another reason would be a project utilizing more than one type of cement. The quantity of cement in each load may be of interest to the purchaser. This and other values regarding the concrete mixture may be reported as the actual batched quantity in the complete load, but more commonly it is reported as the quantity per cubic yard as indicated in the purchase order or the mix design.

13.2.3 *Class, brand, and amount of coal fly ash or raw or calcined natural pozzolans*

Brands and classes of pozzolans and pozzolanic materials are of interest to purchasers for the project record, for comparison to mixture submittals, for potential changes in expected time of set or finishing characteristics, for a forensic investigation of a problem, or for other unnamed reasons. These same concerns are valid for every component of the concrete mixture. The list of items to be shown on the delivery ticket, both mandatory and optional, first appeared in the late 1960s. One of the items on the list was "type and name of admixture and amount of same." In ASTM C 94 – 69 under the Materials section, the heading "Admixtures" included both chemical admixtures (ASTM C 260 and ASTM C 494) and mineral admixtures (ASTM C 618, for Fly Ash and Raw or Natural Pozzolans). In Section 13.2.3, the term "admixtures" has been recently changed to pozzolans including fly ash and admixtures relocated to Section 13.2.6.

The brand of pozzolan or fly ash optional requirement is satisfied by naming the supplier who handles the product. The class is a name such as "Class C fly ash" as defined in ASTM C 618. Disclosure of the class of the material provides additional information that may reveal important characteristics due to differences between these materials. The amount is typically shown in total pounds per batch, matching the presentation method used for cement.

13.2.4 *Grade, brand, and amount of ground granulated blast-furnace slag*

The grade of ground granulated blast-furnace slag (80, 100, or 120), defined in ASTM C 989, will affect the early strength and bleeding characteristics of the concrete. Each brand or manufacturer will produce variations of material because of differing chemical contents of raw materials and different grinding finenesses. These differences will affect the handling and time of set characteristics of the concrete. GGBF slag is a product that has influences on bleeding rates, time of set, workability, and rate of slump loss. An alteration in the amount of GGBF slag will affect each of these properties and thus affects the contractor. As always, knowing what the components of the concrete are provides historical value.

13.2.5 *Type, brand, and amount of silica fume,*

Silica fume is a critical cementitious material component. Variations in the quantity and type of silica fume will affect the ability to place the concrete and perhaps the intended functional purpose for which it was used in the concrete.

13.2.6 *Type, brand, and amount of admixtures,*

This section now refers only to non-cementitious admixtures. Principally it refers to chemical admixtures, but it also refers to such items as coloring pigment (liquid or powdered). The record keeping value cannot be underestimated, but the different affects of different admixtures cannot be overlooked. Types of chemical admixture can be satisfied by a simple C 494, Type A, or the brand name may be used. Amounts may be stated in oz/yd^3, oz/hundredweight (cwt), or ounces per load although the first method is more common. Solids may have quantities stated in either lb/yd^3 or lb/batch. The change in types of chemical admixtures, quantity, or brand can have influences on the time of set, workability, finishability, and early strengths. The issue in this section is clarity of type of product and the quantity used.

13.2.7 *Type, brand, and amount of fiber reinforcement,*

Fibers include many varieties from steel to polypropylene. There are varieties within each group concerning length, size, shape, and other property selections. They may be measured by various methods, but each is expected to meet the tolerance criterion of ± 3 % of the total amount required or plus or minus the amount or dosage required for 100 lb of cement, whichever is greater as established in Section 8 for admixtures. Fibers bagged for one cubic yard quantities may have their quantities stated in a manner of 1.5 lb/yd^3 or 15 lb/load for a 10-yd^3 batch. Clarity of the units being reported is important when a prescribed method is not set forth.

13.2.8 *Source and amount of each metered or weighed water or recycled slurry*

The primary consideration for this section is to keep a record of the quantity of wash-out water or wash-water slurry used in the concrete. A record of wash water or wash-water slurry test properties is expected to be on file at the manufacturer's office to allow computation of total water properties. Section 5 requirements for water are all based upon the total water and not the wash water or wash-water slurry. This is the reason for recording the quantity of each type of water used within a batch. The presence of the prescribed information on the ticket will allow anyone to check for specification compliance in such circumstances.

13.2.9 $_{S1}$ *Information necessary to calculate the total mixing water.* $_{S2}$ *Total mixing water includes free water on aggregates, batch water (metered or weighted) including ice batched at the plant, wash water retained in the mixing drum, and water added by the truck operator from the mixer tank*

The intent here is to measure and record the total water in the load. The source of the water is not really that important, if each source is correctly measured, recorded, and totaled. This information is needed to enable job site personnel to know how much water can be added at the site without violating the maximum permitted quantity of water. The maximum permitted water may be a specification item or may be a part of the concrete mixture submittal.

Aggregate moistures may be determined by several methods. Moisture probes are often present, particularly in the fine aggregate (sand). Aggregate samples may be checked for water content by being weighed moist and then drying on a hot plate, in a microwave, or in an oven. Another satisfactory method of moisture determination is a Speedy Moisture Tester. All of these moisture-measuring methods, including the probe, determine total moisture in and on the aggregate. The moisture probe indicators can sometimes be adjusted to report free moisture rather than total water if the aggregate absorption value is known and is relatively constant. This type of moisture probe reading makes it difficult to change overhead bin usage to a different aggregate. It is important to know what moisture value (total or free) is being reported by the probe. The water to be accounted for on the ticket is only the free water on the aggregate, which is a portion of the net mixing water that reacts with the cementitious materials. The absorbed water will not and should not enter into the total mixing water. See Example 13.A for types of calculations.

As Section 13.2.4 is written, the various calculations are not necessary, only the raw data are necessary to make the calculations including aggregate absorption values and total

EXAMPLE 13.A—*Total mixing water calculations.*

An 8 yd^3 load of concrete has an allowable mixing water content of 266.6 lb/yd^3 (32 gal/yd^3). Aggregate moisture properties and desired batch quantities (SSD) follow:

	Absorption, %	Total Water Content, %	Quantities lb/ yd^3		Quantity per 8 yd^3 (SSD)
			Oven Dry	SSD	
Coarse Aggregate	2.6	2.1	1852	1900	15 200
Fine Aggregate (sand)	0.4	3.2	1295	1300	10 400

a. Moisture calculations for coarse aggregate indicate a deficiency of water.
1852 × 8 yd^3 × (1.021 − 1.026) = −74.1 lb ÷ 8.33 lb/gal = −8.9 gal

b. Moisture calculations for fine aggregate indicate free water on the sand.
1295 × 8 yd^3 × (1.032 − 1.004) = +290.1 lb ÷ 8.33 lb/gal = +34.8 gal

c. Ice is used to replace a portion of the batch water (assume 100 lb/yd^3).
100 lb/yd^3 × 8 yd^3 = +800 lb ÷ 8.33 lb/gal = +96.0 gal

d. Water placed in mixing drum through water meter (or weighed water).
15 gal/yd^3 × 8 yd^3 × 8.33 lb/gal = +999.6 lb = +120.0 gal

e. Wash water in drum from last load was discharged prior to batching current load. = 0.0 gal

f. **Plant water subtotal** placed on delivery ticket = **+2015.6 lb** = **+242.0 gal**

g. Allowable water in load
32 gal/yd^3 × 8 yd^3 = **+ 2132.5 lb** = **256.0 gal**

h. At the job site it is estimated another 1.5 gal/yd^3 is needed for the slump to reach the desired range.

i. Water added from side tank is
1.5 gal/yd^3 × 8 yd^3 = = **12.0 gal**

j. This quantity is placed on the ticket as water added.

k. Total water in load is now 254.0 gal (2115.8 lb) and is 2.0 gal (16.7 lb) less than the allowable 256.0 gal (2132.5 lb).

Load meets allowable water requirements.

Control No.: 2453456

ABC
Ready-Mixed Concrete Co.

Ready Mixed Concrete
Concrete Products
Aggregates

Your Town, USA
Plant No. 2
Office: (222) 333-4444
Fax: (222) 333-5555
Visit us at: www.abcconcreteco.com

CAUTION

FRESHLY MIXED, UNHARDENED PORTLAND CEMENT CONCRETE MAY CAUSE EYE OR SKIN INJURY, MATERIAL SAFETY DATA SHEETS ARE AVAILABLE FROM DRIVER AND CONTAIN PRECAUTIONS FOR SAFE HANDLING AND USE

REMARKS:

JOBSITE TEST RESULTS

SLUMP 3 3/4 AIR 5.3 CYLINDERS TAKEN 3

UNLOADING

Drivers are prohibited from delivering concrete except under the truck's power, and where site conditions permit the safe and proper operation of equipment. Drivers are not permitted to add water to the mix to exceed the maximum slump nor to go beyond the curb line, except upon the authorization of the customer and their acceptance of risk for any loss of strength

Water Added: 5 Gallons. To 8 Yards — Customer Representative × RPG

CUSTOMER ID	P.O. NUMBER	JOB NUMBER	TIME LOADED	DATE	TICKET NUMBER	TIME ON JOB
			6:10 a.m.	11-18-03	2453456	7:00 a.m.

SOLD TO: Great Construction Company, Any Town, USA

DELIVER TO: 2200 Industrial Parkway

START POUR:
FINISH POUR:
DEPART JOB: 7:35 a.m.
TIME AT PLANT:

QUANTITY THIS LOAD	QUANTITY ORDERED	QUANTITY DELIVERED	PRODUCT CODE	PRODUCT DESCRIPTION	UNIT OF MEASURE	UNIT PRICE	EXTENDED PRICE
8 yd.	25 yd.	–	F4050A.	4000 psi w/air.			

TRUCK	DRIVER	SLUMP	DUE AT JOB	USE OF CONCRETE	
156	Sean	4″	7 am.		SUB TOTAL TAX ADDITIONAL CHARGE TOTAL
OFFICE USE			× RPG		

DELIVERY INSTRUCTIONS
SPECIAL INSTRUCTIONS

CUSTOMER AGREES TO ABOVE UNLOADING CONDITIONS AND TERMS AND CONDITIONS ON THE BACK

FIG. 13.A—*Sample of an acceptable delivery ticket.*

aggregate water (percentages), ice in pounds, added water in gallons or pounds. The batchman has more experience than anyone at making these calculations however, and is the least apt to make a mistake.

***13.2.10** Maximum size of aggregate,*

This will usually be a nominal maximum size. Some specifications will require the size to be a maximum size. The nominal maximum and maximum differences are examined in Section 5.1.2, Aggregates. If ASTM C 33 gradings are being used, those size numbers may be used, such as, "No. 57" or "Size No. 67."

***13.2.11** Mass (amount) of fine and coarse aggregate*

These are the batched masses (weights) of the aggregates. A computer printout listing the total mass (weight) of each aggregate or an alternate method is acceptable. One alternate includes listing the total for the initial aggregate, and the total of both aggregates is then recorded. These two quantities provide the required data. Clarity is needed in what is presented, such as:

# 57 Rock	19 090 lb	or	#57 Rock	19 090 lb
Sand	12 920 lb		Total Agg.	32 010 lb

Each of these provides clarity of what the quantities represent.

***13.2.12** Ingredients certified as being previously approved, and*

The request for a certification of materials presupposes that a list of ingredients was requested in the Ordering Information of Section 4 and that the purchaser responded with a written approval. Otherwise, it is not possible to certify the ingredients have been previously approved. This ingredient certification means sources, sizes, and types of materials have not been changed from those previously approved. The coarse aggregate for example was listed on mixture submittals as being a size No. 57 from Quarry A. The aggregate size cannot change to a size No. 67 without approval, and the aggregate source cannot change to Quarry B without approval.

13.2.13 *Signature or initials of producer's representative.*

The initials of the producer's (manufacturer's) representative are the certification that the delivery ticket information is correct. The initials (or signature) will usually be those of the batchman because this is the person knowledgeable with what actually went into each batch (load), plus each ticket will normally be available for certification.

14 Plant Inspection

14.1 $_{S1}$ *The manufacturer shall afford the inspector all reasonable access, without charge, for making necessary checks of the production facilities and for securing necessary samples to determine if the concrete is being produced in accordance with this specification.* $_{S2}$ *All tests and inspection shall be so conducted as not to interfere unnecessarily with the manufacture and delivery of concrete.*

This is a very encompassing two-sentence specification clause. It places burdens and responsibilities on both the concrete manufacturer and the inspector. **S1** makes it very clear that the concrete manufacturer (producer) must provide access to the inspector, who presumably represents the purchaser or the purchaser's agent. One interesting aspect of this section is that it places access responsibilities directly on the concrete producer, who is not a direct party to the contract between Owner and Contractor. It is unusual for a specification, but concrete is a rather unique product and therefore demands unusual stipulations.

S1 is unmistakable in that the inspector is allowed access without charge. It is just as clear that the access must be reasonable. Reasonable is defined as not extreme or excessive, having the faculty of reason, and possessing sound judgment. Unreasonable is not governed by or acting according to reason, or absurd. Reasonable is to schedule an inspection time while the plant is operating at less than peak capacity. This usually occurs in the afternoon when some jobs are finished and others are finishing. Reasonable access is to observe how the plant operates and to review calibration certificates. Reasonable is for the inspector to confine his activities to portions of the plant where his safety can be assured. Unreasonable is to expect to go into confined spaces. Reasonable is to confine questions of producer employees to time periods when their attention is not diverted from critical operations.

S1 also allows for sampling by the inspector. This includes both concrete and raw materials. Sampling concrete at the plant from a truck mixer generally means using the first concrete discharged for testing. It is not reasonable to expect a producer to discharge and waste 2 or 3 yd^3 of concrete to reach the middle portion of the batch. The inspector is advised to follow the mixer truck to the job to get a proper representative sample as per ASTM C 172. Sampling from a stationary mixer can usually be arranged by the use of a front-end loader. Is it reasonable for the inspector needing samples of raw materials to seek assistance from plant personnel? It is very reasonable as long as such assistance is requested through the person responsible for the plant operation. Assistance of the loader operator or other plant person will usually shorten the sampling time, produce more representative samples, and protect the safety of all concerned.

Many plants have safety rules that all visitors must follow, as well as company policies concerning the disposition of information to visitors. Reasonable access is typically readily attainable by open communication, scheduling in advance, a clear understanding as to what is to be inspected, what documentation is desired for review, and what safety rules are to be observed.

S2 has been discussed somewhat in the above discussion of reasonable access. One particular point to consider is that the vast majority of plants do not produce concrete for only the client represented by the inspector. The inspector's right to interfere with production or delivery is totally confined to the client represented. An inspector halting production of concrete for others while making an inspection is unreasonable. For example, an inspector may be sent to the batch plant to obtain samples of raw materials for quality control (QC) tests. If the (QC) sampling can be safely accomplished without delaying the product flow to others, there should be no problem. Other customers should not be affected by the actions of an inspector.

What types of duties do inspectors have? This is totally dependent upon the agency, Architect/Engineer, or Owner directing their work. It can be as simple as collecting aggregate samples once a day for moisture content determinations. It may entail notation of truck numbers versus time of loading and ticket numbers. Preliminary checks of air content and slump prior to leaving the batch plant yard may be needed. The most intensive inspection is checking every aspect of a batch plant and delivery fleet using the NRMCA Plant Certification Checklist [70]. A more significant item that is not very practical would be performing uniformity tests on each mixing drum built by a different manufacturer or of a different style. Typically an inspection of a rating plate and an observation of the condition of the fins and occurrence of hardened concrete buildup is sufficient to ensure that mixers can perform to produce homogeneous mixtures. The NRMCA inspection of plant and delivery fleet does not guarantee good concrete, but it can ensure that the plant is capable of producing and delivering good concrete, and it verifies that the production facility complies with all the pertinent requirements of ASTM C 94/C 94M. Under this program, each delivery vehicle, as well as the plant, is inspected. This inspection program requires the leader of the inspection process to be a licensed engineer with knowledge of concrete plants. Requesting an NRMCA certification of compliance should be adequate to suit the needs of most plant inspection requirements.

Practices, Test Methods, and Reporting

15

15.1 Test ready-mixed concrete in accordance with the following methods:

The purpose of the opening statement in Section 15.1 is to prohibit the reporting of test results or rejection of concrete on the basis of any test method not included in the subsections of 15.1. Each of these test methods has prescribed equipment and procedures to produce as much uniformity and repeatability as possible in the test results. Other test methods or deviations from the prescribed test methods or practice are not permitted.

15.1.1 Compression Test Specimens—*Practice C 31/C 31M, using standard moist curing in accordance with the applicable provisions of Practice C 31/C 31M.*

Compression test specimens are generally molded at the job site for the purpose of determining whether the concrete as delivered complies with the acceptance criteria. For that purpose it is important that standard procedures are followed. Standard curing is defined in terms of temperature and moisture when the cylinders are stored at the job site and after they are transported to the laboratory. Cylinders that have just been molded are very sensitive to the method of handling and storage conditions during the first few hours. Most deviations from standard procedures will result in a lower measured strength of the strength specimens and might cause perfectly acceptable concrete to be rejected due to no fault of the concrete producer.

Two of the most abused practices in concrete testing occur when compression test specimens are molded. The samples are often taken improperly such that they are not representative of the load. More discussion on this is in Section 15.1.6 "Sampling Fresh Concrete."

The other often abused criteria are the procedures for initial curing, which are explicit in ASTM C 31/C 31M. Any movement of cylinders to a storage area must take place **immediately after finishing**. Merriam Webster defines immediately as "without interval of time." The initial curing period is allowed to extend up to 48 h, but no longer. The cylinders must not be moved from the storage area until at least 8 h after final set of the concrete. An acceptable scenario is to transport the cylinders from job site curing to the laboratory on the day following molding. The initial curing environment shall be maintained at a temperature between 60–80°F plus protection against moisture loss from the specimens. Specimens shall not be exposed to direct sunlight or radiant heating devices. The storage temperature shall be controlled by use of heating and cooling devices, as necessary, to maintain the moist environment and the temperature. Record the temperature using a maximum-minimum thermometer. **Note 7 of ASTM C 31/C 31M provides some excellent suggestions on good curing practices.** One note of caution is that if the concrete has a specified strength of 6000 psi or greater, the allowable initial curing temperature limits are tighter at 68–78°F.

On initial curing some people will say "I want the cylinders cured like the structure so I will know how strong the structure gets." This is accomplished by molding an extra set of cylinders to be cured as prescribed for "field curing." The **acceptance cylinders** are for the purpose of determining how good the concrete can be, if handled and cured by standard procedures.

Final curing in the laboratory at 73 ± 3°F with free water on the cylinder surface at all times is equally important. Most laboratories are conscientious about maintaining this prescribed environment, so laboratory curing does not present the challenge associated with initial curing.

15.1.2 Compression Tests—*Test Method C 39/C 39M*

Initial curing of cylinders does not always take place in a level spot as required, and if the ends of compression cylinders are not prepared properly for testing, the test results are often lower than what they should have been. Another problem that sometimes arises, especially with pad caps, is an edge breaking off the cylinder, a sudden drop in the load, and an overzealous technician shutting off the compression machine to control the debris in and around the testing machine. Many times the load on the cylinder will immediately recover after the momentary drop and continue to a higher load at true failure. Compression cylinder tests must be carried to complete failure to identify the type of failure as required by ASTM C 39/C 39M.

Note in Section 17 that the average of at least two compression tests of specimens obtained from the same sample at the same age is required to represent one strength test. This is because it is rare for two specimens, even from the same sample, to have identical compressive strengths. There is a limit to such differences, however, and these are provided by the precision statement in ASTM C 39/C 39M. For cylinders molded in the field, the coefficient of variation is 2.87 % of the average compressive strength. Statistical procedures developed by ASTM Committee C 09 establish an acceptable range between two companion cylinders as 8.0 % of their average strength. If there are three companion cylinders, the acceptable range expands to 9.5 %. The acceptable range in this context means that when compressive strengths of companion sets of cylinders are observed, the range or difference between the highest and lowest strength in a set should not exceed the acceptable range more often than one time in 20. ACI 214R Evaluation of Strength Test Results of Concrete provides some additional information on the acceptability of test results and provides typical numbers that show how good or bad a particular laboratory performs in testing cylinders [1].

EXAMPLE 15.A—*Acceptable range of compressive strengths.*

Assume a set of two 28-day cylinders tested at 3360 psi and 3600 psi.
Average strength is 3480 psi.
The acceptable strength range is 3480 × 0.08 = 278 psi.
The actual range is 3600–3360 = 240 psi < 278 psi, OK.

If the range of the compressive strength of companion cylinders exceeds the ASTM C 39/C 39M criterion in several sets of results, an investigation should be undertaken.

15.1.3 Yield, Mass per Cubic Foot—*Test Method C 138/C 138M*

Test Method C 138 has a new designation and a new title: ASTM Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete (**C 138/C 138M**). The test method for density (unit weight) is used as a component in the determination of concrete yield. Section 3 of ASTM C 94/C 94M requires a ½ ft^3 container rather than the smaller ones allowed by ASTM C 138/C 138M for routine density tests. The larger sample bucket increases the accuracy of the measurement, and accuracy is critical in a yield test. Using a ½ ft^3 container to determine what a 27-ft^3 (1 yd^3) volume of concrete should weigh introduces a multiplier of 54 for any error in the test result, thus demanding careful and accurate test procedures. The calibration of the sample bucket should be accomplished to three decimal places. ASTM procedures do not require duplicate calibrations of a sample bucket, but it can increase the accuracy and confidence in the resulting bucket volume. Divide the mass of the concrete in the bucket by the known volume of the bucket to obtain the mass per unit volume.

Again from Section 3 of ASTM C 94/C 94M, density (unit weight) samples for yield determinations must come from the middle portion of three different loads and the concrete densities averaged. Again, accuracy and uniformity are prime considerations.

The most common source of error with the concrete density test is in the strike-off procedure. Inadequate work with the strike-off plate results in a reported density that is too high and a yield value that is too low. Improper strike-off procedures may compress the concrete rather than trim the top. The use of a field technician certified by ACI or an equivalent certification program is essential to this yield computation procedure.

15.1.4 Air Content—*Test Method C 138/C 138M; Test Method C 173/C 173M, or Test Method C 231.*

Each of these test methods presents a different procedure and different equipment for measuring the air content of concrete, and each will provide a slightly different result.

The ASTM C 138/C 138M test procedure begins with recording the batch masses (weights) of the load to be tested for air plus the moisture contents of the aggregates for greater accuracy. Step 2 is to determine the relative densities (specific gravities) of each material in the batch. The manufacturer usually will have this information. Step 3 is a density (unit weight) determination from combined samples taken from the middle portion of the load of concrete. Example 15.B demonstrates a gravimetric air content determination.

EXAMPLE 15.B—*Gravimetric air content determination.*

Material		Mass (Weight) lb/batch	Mass (Weight) lb/yd^3	Density[13] (sp gr)	Volume (air-free) ft^3/yd^3
Cement	(lb)	4210	421	3.15	2.14
Fly ash	(lb)	930	93	2.51	0.59
Coarse Agg. (SSD)	(lb)	17 970	1797	2.69	10.70
Sand (SSD)	(lb)	13 500	1350	2.62	8.26
Water (Total)	(lb)	2830	283	1.00	4.54
TOTALS			3944		26.23 ft^3

T (theoretical density) = 3944 lb ÷ 26.23 ft^3 = 150.36 lb/ft^3
D measured density (unit weight)* = 143.75 lb/ft^3
A (air content) = [(T − D) ÷ T] × 100
A = [(150.36 − 143.75) ÷ 150.36] × 100 = 4.4 %

* Value assumed to have been determined by field test.

How much does the calculated air content vary as differences in density (unit weight) determinations vary? The precision statement of ASTM C 138/C 138M states for a single operator, two properly conducted tests on the same sample may differ by 1.85 lb/ft^3, and for a multioperator test, the results should not differ more than 2.31 lb/ft^3. The standard deviations for these two cases are 0.65 lb/ft^3 and 0.82 lb/ft^3, respectively.

EXAMPLE 15.C—*Allowable variations in gravimetric air content.*

Assume a change in the measured concrete density of Example 15.B from 143.75 to 141.9 lb/ft^3 (difference of 1.85 lb/ft^3).
The new calculated air content becomes:

$$A = [(150.36 - 141.9) \div 150.36] \times 100 = 5.6\ \%$$

The allowable single-operator difference in measured concrete density accounts for an allowable reported difference of (5.6 − 4.4) = 1.2 % in air content. Had the test been a multioperator test, the allowable difference in air content for this example would be 1.5 % (5.9 − 4.4).

Note that 1.5 % is 50 % of the allowable tolerance for air as specified in Section 7.2. Testing errors (or inaccuracies) reduce the margin of error available for the producer. Correct and careful testing procedures are once again demonstrated to be essential.

[13] Two deprecated terms, weight and specific gravity, are contained in parentheses in this example. The scientifically correct terms, mass and density, are shown along with the deprecated terms. Other such pairs of terms or phrases are used throughout the text. The correct term for specific gravity of aggregates is now accepted to be "relative density." The accepted term for unit weight of concrete or mass per unit volume is "density."

FIG. 15.A—*Photo of equipment for density test.*

ASTM C 138/C 138M is seldom used as a field acceptance method for air content. It is more common in trial batch evaluation in the laboratory.

The ASTM C 173/C 173M test method is identified as the volumetric method for air content determination. It is more often referred to as a "Roll-a-Meter" test. Recent changes in the test procedure, including a large increase in the percentage of isopropyl alcohol to be used, have decreased the time requirement for this test, but it still needs some time and physical effort to ensure that all the air in the concrete sample is measured. This is the test method normally used for lightweight concrete due to the porous nature of lightweight aggregates. It is less involved than ASTM C 138/C 138M, has no requirements for additional information, and does not involve pressurized air as does ASTM C 231.

The testing work necessary for a completely new precision statement has not been accomplished. Perhaps the results will improve with the new procedures, but at the moment the reported multi-operator coefficient of variation is 11 % of the measured air content. "Results of tests by two different operators on specimens taken from a single concrete sample should not differ from each other by more than 32 % of their average air content" reports Section 9.1 of ASTM C 173/C 173M. Two items are noted here. The acceptable difference in two test results is approximately ⅓ of the test value, and the acceptable difference is measured by the coefficient of variation. The latter item indicates that the difference in tests is not a constant but becomes larger numerically as the air content becomes larger. Examples of the acceptable differences changing with varying air contents follow:

1. Measured air content = 4.4 % --- 0.32 % × 4.4 % = 1.4 %
2. Measured air content = 5.0 % --- 0.32 % × 5.0 % = 1.6 %
3. Measured air content = 6.0 % --- 0.32 % × 6.0 % = 1.9 %

The base of the roll-a-meter is too small to qualify as an acceptable measure for concrete density. ASTM C 138/C 138M does not permit the use of density measures with a volume less than 0.2 ft^3.

The ASTM C 231 test method uses air pressure to measure the air content in fresh concrete. A **Type A** meter uses a cylinder of water above a bowl of concrete. Applied air pressure on the water column compresses the air in the concrete sample, lowering the height of water in the cylinder. The measured drop of the water height provides a measure of the air content.

The precision statement of ASTM C 231 for the Type A meter has an upper limit of 7 % air content. The multioperator standard deviation is 0.28 % air, which translates to an acceptable difference in two tests of 0.8 % air by volume of concrete. With a measured air content of 4.4 % by Operator 1, the measured air content by Operator 2 can be as low as 3.6 % (4.4 – 0.8) and can be considered an acceptable test range.

A **Type B** meter uses a different approach of air pressure to make the air content measurement. A closed air chamber contains air pressurized to a predetermined level and is then released in the underlying bowl of concrete. The air pressures equalize in the concrete bowl and in the air chamber. The change in air pressure is calibrated to the air content of the concrete sample and is displayed on a pressure gage.

At this time, there is no published precision statement for Type B meters. Because of the similarity of the meters, the precision is expected to be similar to that of the Type A meter. Some unpublished tests indicate the standard deviation may rise to approximately 0.4 % for the Type B meter. Such a value would place an acceptable difference in companion tests at approximately 1.1 % as compared to 0.8 % for the Type A meter.

Each of these air meters is based on Boyle's law, which states, "If the temperature remains constant, the volume of gas (air) is inversely proportional to the pressure" [16]. Boyle's law is stated as $V_1 P_1 = V_2 P_2$.

The most commonly used instrument for the measurement of air contents for fresh concrete is the Type B pressure meter. The most common abuse of this measuring system is not calculating and using the required aggregate correction factor. This measured factor accounts for the air content indicated on the pressure gage by the pores within aggregate particles not filled with water. Since the air content of interest is that which is in the cement paste, the aggregate correction factor is subtracted from the measured air content. Because the test method measures the "air" within aggregate particles, it cannot be used for concrete containing very porous aggregate or lightweight aggregate.

The bowl in which the concrete sample is placed has a minimum capacity of 0.20 ft^3, and most Type B meters are 0.25 ft^3 in size. Thus, these containers are large enough to measure the concrete density according to ASTM C 138/C 138M when the concrete contains 1 in. nominal maximum size coarse aggregate or smaller. When the same exact sample is used for concrete density (unit weight) and air content, the density must be performed first, and the specimen top must be prepared with a strike-off plate, not just a strike-off bar.

15.1.5 Slump—*Test Method C 143/C 143M*

This measure of consistency of the concrete is somewhat crude, but quick. It remains a much specified test method. Chapter 6 of this text has a discussion of the test. The major performance problems with the test are improper measurement of the slump and non-uniform consolidation by rodding that will often result in a lopsided slumping of the concrete when the mold is removed.

After removal of the mold, the slump measurement is taken at the displaced original center of the top surface of the fresh concrete specimen and not from the low point of the original top or the high point of the original top. Improper selection of the point of measurement can lead to major errors in the slump value reported.

The precision statement of ASTM C 143/C 143M indicates an increasing range of acceptable test results between two tests as the slump value increases, but not to the extent that the coefficient of variation is a better measuring tool than the standard deviation. With a single operator and a slump between approximately 1–8 in., the acceptable range of two slump test results is between 0.65–1.13 in. For multiple operator test results, this range increases to between 0.82–1.50 in. Except for low-slump paving concrete, it is safe to say the typical range between acceptable slump test results is 1–1.5 in.

This range of acceptable test results uses up 50 % or more of the tolerance in slump permitted by Sections 6.1.1 and 6.1.2.

15.1.6 Sampling Fresh Concrete—*Practice C 172*

The proper sampling of freshly mixed concrete is the first step to meaningful test results for all test methods used to judge the quality of concrete, whether it is for quality control or for quality assurance. If the sample is not representative of the batch from which it came, conclusions regarding the quality of the batch will be in error, and this may create problems for someone, most likely the concrete producer.

The most common process of obtaining samples at the job site is from transit mixers being used as truck mixers or as agitators. The sampling procedure is one of the most common errors in testing conducted at the job site. ASTM C 172 requires that the concrete sample for testing should be a composite sample obtained by combining smaller portions from two or more locations within the load. This is to ensure that the sample tested has a better chance of being representative of the batch. Using a sample from just one location in the load rather than multiple portions to make up a composite sample representing the batch is common, and it is wrong. Major monetary amounts and time are involved, so unprofessional work by technicians is unacceptable. If concrete was entirely uniform throughout a batch, it would not be necessary to exclude the first and last portions discharged from the testing procedure. Neither would it be necessary to provide acceptable tolerances in Annex A1 for differences between samples taken from different segments of the load.

ASTM C 172 provides for sampling from a variety of mixing units and transport units, and all require multiple portions of concrete to be combined to make up the composite sample for testing. Mixing uniformity tests do not require composite samples. Three different scenarios are described in ASTM C 172 for sampling and then combining the portions of concrete into a composite sample within 15 min.

Concrete Unit Sampled	Number of Individual Samples to be Combined
Stationary Mixer, except paving mixers	2 or more portions of middle portion of batch
Paving Mixers	5 or more portions of batch after mixer discharge
Revolving-Drum Truck Mixer or Agitator	2 or more portions of middle portion of load
Open-Top Truck Mixers, Agitators, Nonagitating Equipment, or Other Types of Open-Top Containers	Sample according to the most appropriate of the three above procedures.

Note that no sampling procedure to determine compliance with the quality requirements of the specifications utilizes a single sampling point. The minimum number of portions of the load to make up the composite sample is two.

ASTM C 172 also specifies a procedure for the removal of large aggregate when the coarse aggregate contains particles larger than permitted for the applicable test method.

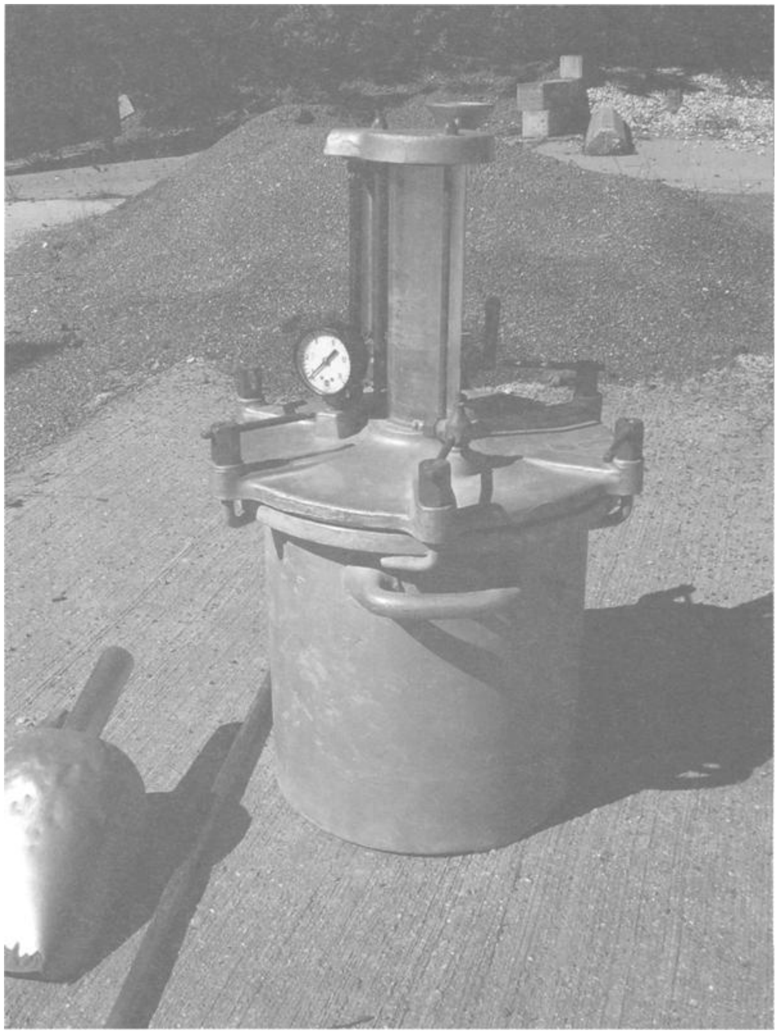


FIG. 15.B—*Photo of Type A meter.*

15.1.7 Temperature—*Test Method C 1064/C 1064M*

This test method, first published in 1986, became necessary because temperature of the mixture had become such a wide issue with regard to air content, slump, strength, and time of set, plus specification requirements for concrete temperature related to construction of massive or sensitive concrete elements. A couple of requirements are to maintain at least 3 in. of concrete completely around the temperature sensing element of the thermometer and to begin the test as quickly as possible after discharge from the transportation unit. The temperature desired for ASTM C 94/C 94M purposes is the temperature as discharged. It is not required to obtain a sample of concrete if temperature is the only test being conducted. The temperature of the concrete after placement in its forms is also permitted, provided sufficient volume surrounding the temperature probe is available.

One caution regarding temperature-measuring devices is that many of the concrete thermometers on the market do not meet the ASTM C 1064/C 1064M accuracy requirements of ± 1°F [± 0.5°C]. Do not use thermometers not meeting the accuracy requirements. When temperatures approach specification limits, it is in everyone's interests for measured and reported temperatures to be correct. At the time of measuring, it is seldom known that a temperature will later be the subject of an arbitration proceeding question. Purchase thermometers with a knowledge of their accuracy, and calibrate them often. Thermometers for use with concrete (temperature measuring devices) shall be calibrated in accordance with the procedures and at the minimum frequencies specified in ASTM C 1064/C 1064M.

***15.2** The testing laboratory performing acceptance tests of concrete shall meet the requirements of Practice C 1077.*

ASTM Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation (C 1077) identifies minimum technical requirements for testing equipment and personnel involved in testing concrete and concrete aggregates. The Practice sets forth specific criteria a laboratory must meet. ASTM C 1077 does not require approval of a laboratory, but instead sets up the criteria to be used by an accrediting agency or by other parties for approval, should that be desired. The

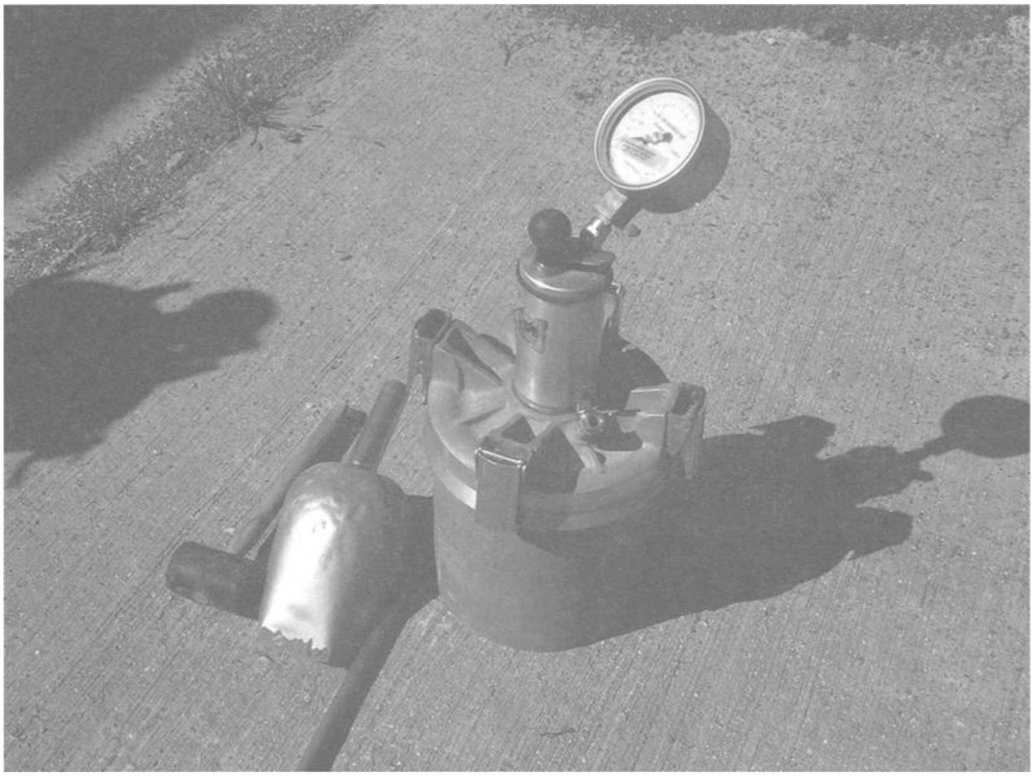


FIG. 15.C—*Photo of Type B meter.*

FIG. 15.D—*Photo of slump cone and tamping rod.*

Practice provides a qualification checklist for anyone inspecting a laboratory.

ASTM C 1077 sets maximum time intervals for the calibration of testing equipment and minimum relative experience levels for technician supervisors as well as a requirement for a registered professional engineer to oversee the laboratory's technical direction. These are all helpful features to all parties dealing with concrete produced under ASTM C 94/C 94M.

The requirements for technicians actually performing tests are spelled out in Sections 16.2 and 17.1 of ASTM C 94/C 94M. The technician performing the tests of Section 15.1

FIG. 15.E—*Photo of field thermometer.*

shall be a certified ACI Concrete Field Testing Technician, or equivalent, or ACI Concrete Laboratory Testing Technician—Grade I or Grade II or equivalent, as appropriate for the test involved. Equivalent certifications to ACI must include both written and performance examinations equal to or exceeding ACI requirements. See discussion in Chapter 16 for specific requirements.

15.3 $_{S1}$ *Laboratory reports of concrete test results used to determine compliance with this specification shall include a statement that all tests performed by the laboratory or its agents were in accordance with the applicable test methods or shall note all known deviations from the prescribed procedures (Note 17).* $_{S2}$ *The reports shall also list any part of the test methods not performed by the laboratory.*

Note 17—*Deviation from standard test methods may adversely affect test results.*

Note 18—$_{S1}$ *Deviation from standard moisture and temperature curing conditions is often a reason for low strength test results.* $_{S2}$ *Such deviations may invalidate the use of such test results as a basis for rejection of the concrete.*

Deviations from the prescribed procedures and equipment in each Test Method or Practice may be the cause of inappropriate test values. Statements of compliance by the laboratory regarding testing methods are as important in a forensic investigation as the manufacturer's certification regarding batch information on delivery tickets. It is important to know what factors should not have contributed to a problem, and which ones may have contributed. For example, if concrete sampling for strength tests only involved one portion of a load rather than a composite sample made from two portions, it should be stated on the cylinder report.

S2 concerns identifying any of the test procedures performed by others. For example, if the compression cylinders were molded, initially cured, and transported to the laboratory by the contractor, this information should be noted on the test report. If the Contractor reports a slump value, it should be noted if the value was measured or estimated.

Note 17 is a self-evident reminder of the importance of using prescribed test procedures.

Note 18 is an extension of Note 17 as a special precaution on the proper initial curing of concrete cylinders and the possible consequences of ignoring prescribed procedures. Field research has shown that improperly cured compressive test cylinders can produce compressive strengths well below the strengths of properly cured cylinders. A series of hot weather tests in New Mexico led to test values as much as 19 % lower for improperly cured cylinders, compared to those for properly cured specimens. The concrete being tested was designed to produce an averge strength of 4000 psi. With a 20 % loss due to improper curing, the result is a reported strength of 3200 psi [75].

Cold weather can be even harder on 28-day cylinders. Concrete cylinders that are allowed to freeze for as short a time as one or two nights before being removed and placed in laboratory curing conditions can lose 50 % or more of their potential compressive strength [60]. Prior to setting, the cylinders have all of the mix water available to freeze and expand upon freezing. This expansion in concrete that has not set or is just past the state of hardening will significantly damage the cylinder. The freshly molded cylinder does not have any strength to resist these forces and is immediately damaged. Field tests on a smaller scale indicated compressive cylinders stored outside in freezing temperatures for a weekend period (3 days) had even greater reduction of 28-day compressive strengths. These referenced test values resulted in a compressive strength at 28 days of 37 % of the strengths produced by standard cured 28-day specimens [26].

These data cover both ends of the temperature spectrum and show loss of strength for cylinders not properly cured. Improperly cured (non-standard) cylinders are a problem for all parties involved. Statistics are not available, but it is entirely possible, if not probable, that the majority of problems involving low-strength cylinders are the result of improper curing as opposed to all other problems combined.

16

Sampling and Testing Fresh Concrete

16.1 The contractor shall afford the inspector all reasonable access and assistance, without charge, for the procurement of samples of fresh concrete at time of placement to determine conformance of it to this specification.

Section 16 is very similar to Section 14, except that it addresses the contractor rather than the producer. The inspector must have the opportunity to sample the fresh concrete at the job site. The inspector will not be charged for the concrete, for the down time of the delivery vehicle, or for the idle time of the contractor's concrete crew while the concrete is being sampled and tested. The concrete itself is already being paid for by the Owner, so that is a non-issue. The idle time of the delivery vehicle and the crew is a contingency that should be considered in the pricing of concrete and the placement costs of concrete. What the "without charge" statement means is that "without direct additional charge" to others and "at no charge" to the inspector or the testing laboratory.

The question of reasonable access is raised again just as it was in Section 14. Reasonable access can depend upon the unloading circumstances. In the context of ASTM C 94/C 94M, it also revolves around two very specific concepts. The first of these concepts is that ASTM C 94/C 94M applies only to the point of discharge from the mixer or delivery vehicle at the job site. Reference **S4** of Section 1.1 states "This specification **does not cover the placement**, consolidation, curing, or protection of the concrete after delivery to the purchaser". Section 3.1 reads, "The basis of purchase shall be the cubic yard or cubic metre of freshly mixed and unhardened concrete **as discharged from the mixer**." These two statements make it very clear that ASTM C 94/C 94M and the producer's responsibility for the product quality end when the concrete is discharged from the delivery vehicle. Therefore, the concrete is to be tested at the point of discharge. The second specific item is that the concrete samples shall be obtained in accordance with ASTM C 172. This practice requires that two portions of concrete from the middle part of the load be combined into one test sample. ASTM C 94/C 94M makes exceptions for preliminary slump and air contents, but it makes no exceptions for strength tests and the related tests required when strength tests are made (see Section 16.4).

What does all of this have to do with reasonable access? The sampling must be done as the delivery vehicle is unloading. It is not difficult to divert the unloading chute away from the pump, power buggy, point of direct placement, concrete bucket, conveyor, or other point of discharge a couple of times and put some concrete in a wheelbarrow for the inspector and the concrete technician. If the mixer truck can reach the point of discharge, a wheelbarrow should also be capable of reaching it.

There may be times when the A/E desires some additional samples at the point of pump discharge or the point of remote placement, but these tests are not a part of ASTM C 94/C 94M and only affect the contractor and not the producer. Access for remote points of discharge is covered by other portions of the project specifications, because they are beyond the ready-mixed concrete producer's scope of control. This does cause problems as a practical matter because the A/E is interested in the concrete properties in the structure. A process needs to be established prior to the placement whereby the requirements for the concrete at the point of discharge are established, even if they are different from the specification requirements, such that the concrete at the point of placement complies with those requirements. The common problem elements are the air content and slump of the concrete, which can each change depending upon the placement method.

Section 16.1 states "reasonable access and assistance." What does assistance mean? There is no further explanation here, but it certainly seems to be coupled with the word "reasonable." This does not mean that the Contractor is expected to furnish people to carry testing equipment and cylinders, although there are times and places where this type of assistance is both helpful and appreciated. What reasonable assistance does mean is cooperation in diverting the discharge chute at the proper times to allow good sampling techniques, a clear working area near the curing box suitable for performing tests, a location for truck mixers to be spotted for preliminary tests, an electrical outlet for a temperature regulated curing box, and water to wash off testing equipment or to perform similar acts.

Cooperation between contractor, producer, inspector, and testing technician is the bottom line. All work for the Owner, and all want or should want a successful project.

This spirit of cooperation will assist in producing good samples to more accurately reflect the quality of the concrete being delivered by the producer. Without quality samples, any non-conforming test results will themselves become questionable.

16.2 *S1 Tests of concrete required to determine compliance with this specification shall be made by a certified ACI Concrete Field Testing Technician, Grade I or equivalent. S2 Equivalent personnel certification programs shall include both written and performance examinations as outlined in ACI CP-1.*

Some tests at the site may not be to determine compliance. For example, the producer may send a technician to measure slump or air content on several loads to adjust plant-added batch water or the air entraining admixture dosage. Anyone who can perform this duty to the producer's satisfaction is eligible, and certification requirements will not apply. When the tests are performed to measure specification compliance, a higher level of proven proficiency is required. Considering that a load of fresh concrete represents 500–700 U.S. dollars, the higher requirements are justified. Before a load is rejected due to non-compliant test results, everyone wants to be sure the tests are accurate and performed correctly. It is just as important to know that the concrete is of acceptable quality, through accurate testing, before it is permitted to be placed into the project structure.

Technicians certified to be ACI Concrete Field Testing Technicians, Grade I have been tested for a knowledge and proficiency of the following ASTM Test Methods and Practices.

C 1064/C 1064M	Temperature of Freshly Mixed Portland Cement Concrete
C 172	Sampling Freshly Mixed Concrete
C 143/C 143M	Slump of Hydraulic-Cement Concrete
C 138/C 138M	Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
C 231	Air Content of Freshly Mixed Concrete by the Pressure Method
C 173/C 173M	Air Content of Freshly Mixed Concrete by the Volumetric Method
C 31/C 31M	Making and Curing Concrete Test Specimens in the Field

The testing examination for these standards includes a closed-book written examination consisting of approximately 50 multiple choice questions to be answered in a 1-h period. A passing score is considered to be 60 % or more on each of the ASTM standards and an overall score of not less than 70 %.

To attain certification, the technician must also correctly perform each of six standards without notes, a book, assistance, or prompting, as verified by independent examiners. It is permitted for the examiner to ask a series of questions and accept oral answers on sampling procedures.

The examiner must meet certain criteria to be acceptable to ACI. The examiner must be a registered professional engineer with at least two years of recent experience in concrete construction, inspection, or testing and shall be unrelated professionally or personally to the technician being examined. The examiner must be thoroughly familiar with the current ASTM standards applicable to the field technician certification program including ASTM C 94/C 94M and should have obtained the same certification at some point in the past.

The ACI certification has a 5-year limit. After five years, the technician must once again take and pass the same examination program, again with a neutral PE examiner. This re-certification ensures that technicians are familiar with current standards, because they are revised frequently.

S2 references an examination not provided under the ACI umbrella. Such a program can be written by anyone knowledgeable about the specified tests. The five primary features to be observed in an equivalent program include:

1. All or more test procedures than covered by the applicable ACI program.
2. A closed book written (oral in special circumstances) and timed examination covering essential elements of each test procedure to be included in the certification. Scores shall be a minimum of 60 % on each individual test procedure and a minimum overall score of 70 %.
3. A performance demonstration of each test procedure to be included in the certification. This demonstration must be closed book and without coaching or assistance of any type. Each test procedure must be accomplished properly.
4. The examiner for the performance test must be a P.E. and must be an impartial observer without affiliation to the examinee or the examinee's employer or potential employer.
5. The certification must have a limited time period prior to re-examination, which does not exceed the ACI time period prior to re-examination for the specific program.

ACI publication CP-1 [9] provides detailed guidance on testing procedures, sample questions for each procedure, grading requirements, and some helpful supplementary information.

***16.3** Samples of concrete shall be obtained in accordance with Practice C 172, except when taken to determine uniformity of slump within any one batch or load of concrete (10.4, 11.3.3, 11.5.1, and 12.4).*

ASTM Practice for Sampling Freshly Mixed Concrete (C 172) is a two page document that is a must-read for every concrete technician. It is, without a doubt, the most commonly violated practice in the world of concrete testing. Whether the violations are due to ignorance of the standard or not knowing the easiest method to follow, violations still occur repeatedly, thus bringing test results into question.

The following statement within the Significance and Use section of ASTM C 172 speaks volumes:

> "This practice is intended to provide standard requirements and procedures for sampling freshly mixed concrete from different containers used in the production or transportation of concrete."

Why is obtaining a concrete sample so painstakingly described? Think in terms of a 10-yd^3 load of concrete as it arrives at the job site. This size load typically represents a 500–700 U.S. dollar investment. Furthermore, it may represent the acceptance testing for the day's pour, or at least 150 yd^3. A sample of 1–2 ft^3 in size is usually obtained in a wheelbarrow and tested to determine if the load is acceptable or not acceptable. A 10-yd^3 load has a volume of 270 ft^3. The fate of this load is thus determined by a sample that represents approximately 0.5 % of the total load. The worst-case scenario is if the load is placed, the 28-day strength test fails, work stops while in-situ testing or cores are taken, and these tests prove the problem was with the original tests and not the concrete. The total cost of such a scenario is unlimited.

The Scope of ASTM C 172 gets right to the point in the very first sentence:

> "This practice covers procedures for obtaining **representative samples** of fresh concrete as delivered to the project site on which tests are to be performed **to determine compliance** with quality requirements of the specifications. . ."

The key phrase here is representative samples. The sample must represent the entire load, not just an isolated segment. Everyone, from the raw material suppliers, to the producer, to the contractor, to the Owner, to the A/E, wants a representative sample. ASTM C 172 is really only about one thing, obtaining a representative sample. The first segment of the load is not reliable for a representative sample.

The initially discharged concrete may be affected by the loading sequences of materials, especially the cement and quantity of tail water (last metered or weighed water), plus the number of mixing and total drum revolutions. If the batching sequence places the cement at the end or near the end of the loading process, and only a small quantity of tail water is used, the initially discharged concrete may have a high proportion of cement and produce test strengths in excess of what is representative for the load. A series of unpublished tests by Daniel [25] compared compression tests of initial discharge concrete to tests on ASTM C 172 sampling procedures at the job site. The average compressive strength and standard deviation were both greater for the tests on the initial discharge samples. Approximately 75 % of the initial discharge samples had greater compressive strengths, and approximately 25 % resulted in lower strengths when compared to the ASTM C 172 mid-load, composite samples. The standard deviation for the compression test results of the initial discharged concrete was approximately 40 % higher than the standard deviation of the properly sampled concrete. These are significant differences that explain why preliminary samples are not permitted to be used for acceptance strength testing.

The Procedures section of ASTM C 172 discusses sampling from stationary mixers, paving mixers, revolving-drum truck mixers, revolving-drum agitators, open-top truck mixers, agitators, nonagitating equipment, and other types of open-top containers. The central theme in the procedure for each is collecting two or more distinct portions of the concrete and then compositing these into a single test sample. The most common of the sampling procedures is from a revolving-drum truck mixer, which reads **". . .by collecting two or more portions taken at regularly spaced intervals during discharge of the middle portion of the batch."** This instruction is amplified by a later caution of "do not obtain samples from the very first or last portions of the batch discharge." A note defines first and last portions as 10 % each. Technically, this means to sample from the middle 80 % of the load. Prudent practice is to focus on the middle two-thirds of the load. Do not forget a requirement to obtain the first and last portions of the sample within a 15-min. time span.

An exception to the "two portions makes one sample" rule is spelled out in the last part of Section 16.3 regarding preliminary tests for slump and air content prior to job site adjustments to the mixture. The details of preliminary samples are provided in Section 16.6. If a load is being tested for uniformity of slump or complete uniformity testing, the use of composite samples is also waived by ASTM C 172. The section references to specialized testing (not for acceptance of concrete testing) are as follows:

10.4	Slump test on mixer or agitator to determine the probable degree of uniformity
11.3.3	Sampling for uniformity tests of stationary mixers
11.5.1	Sampling for uniformity of concrete produced in truck mixers
12.4	Slump test on nonagitating equipment to determine the probable degree of uniformity

16.4 $_{S1}$ *Slump, air-content, density, and temperature tests shall be made at the time of placement at the option of the inspector as often as is necessary for control checks.* $_{S2}$ *In addition, these tests shall be made when specified and always when strength specimens are made.*

The tests discussed do not include strength testing itself. These are supplemental tests used to evaluate the concrete at the moment of discharge and not 28 days later when strength tests become available. What is the condition of the concrete at the time of discharge? If this can be determined accurately, potential problems can be overcome. Each of the tests named often have limits named within the specifications subjecting the concrete to possible rejection, and each are capable of sounding an alarm of potential or pending trouble, regardless of the lack of a specification requirement.

A review of the test procedure methods follows:

Slump	C 143/C 143M
Air-Content	C 231 (Pressure), C 173/C 173M (Volumetric), or C 138/C 138M (Gravimetric)
Density	C 138/C 138M (concrete density)
Temperature	C 1064/C 1064 (fresh concrete)
Temperature	Ambient (There is no requirement to check the ambient temperature, but it can be beneficial and prudent.)

The inspector may have each or all of these tests performed by the Owner's technician any time it is desired. Typically, all tests would not be performed on each load, but it is not uncommon for one of these to be targeted on each load. This is a very strenuous inspection of fresh concrete, and the question is whether it is ever justified. "At the option of the inspector" means justification is not necessary. This exercise can be costly to the producer by tying up trucks while inspections and testing take place, thus requiring extra trucks on a project. Delays in discharging the concrete during these tests may change the consolidation and finishing properties of concrete. If it is known that this type of scrutiny is needed, it is best to state it in the specifications.

What types of circumstances could lead to checking every load of concrete for a particular property of the fresh product?

1. Superflat floors require a consistent slump and no entrained air for the best results.
2. Pumping concrete, particularly with a high stone content, also requires a consistent slump.
3. Air-content can change dramatically after a long haul on a hot day. If traffic conditions, and therefore delivery times are variable, the air content also may be variable.
4. Temperatures can become particularly important if the project specifications contain specific temperature restrictions for either hot or cold weather concreting or mass concrete sections, and if conditions are borderline.
5. Density of concrete may be the acceptance criterion on a lightweight aggregate project. If the density of the fresh concrete is not consistent, it may be prudent to continue

to measure fresh densities until the condition is solved and densities are stabilized.

6. Highly variable slumps may lead to checking slumps on every load until the cause is determined. The cause often proves to be the same trucks with high slumps because wash water is not being discharged prior to batching concrete or otherwise controlled as required by Sections 8.3 and 13.2.9.

These are only some isolated examples of the inspector's need to check every load for a physical property. Such circumstances are actually somewhat rare, but this is an option that must be available to the inspector. Good inspectors and the testing technicians assisting them will work with a producer to isolate and solve any problem as quickly as possible, thus allowing the checking of every load to be discontinued as quickly as possible.

S2 provides no leeway for testing procedures when strength tests are made. Each of the physical property tests for fresh concrete is required. Tests are slump, air-content, temperature, and density in addition to the casting of cylinders or beams for strength determination. This is a lot of information, but should the strengths be lower than specified or exceedingly high, this information usually will offer clues to the reason and become the first step in correcting the problem.

16.5 $_{S1}$ *Strength tests, as well as slump, temperature, density, and air content tests shall generally be made with a frequency of not less than one test for each 150 yd³ (115 m³).* $_{S2}$ *Each test shall be made from a separate batch.* $_{S3}$ *On each day concrete is delivered, at least one strength test shall be made for each class of concrete.*

The initial part of the section is a restatement of the fact that when strength tests are made other tests are required. A rare statement in a specification is one such as "shall generally be made." Specifications by definition are explicit and demanding, and the word "generally" does not fit. So why is it used here? Testing of the delivered product is normally performed for the Owner and at the expense of the Owner. ACI 301-99, Specifications for Structural Concrete follows this path of responsibility and payment, of the Owner hiring, directing, and paying the testing laboratory, which performs the services for the project. ASTM Specification C 94/C 94M cannot demand that the Owner test the concrete every 50 yd³, or every 100 yd³, or even every 150 yd³. It can only suggest a frequency, thus the term "generally" to provide helpful guidance to the Owner or the Owner's representative. ACI 318-02 Building Code for Structural Concrete is frequently referenced in building codes applicable to local jurisdictions, including the relatively new, but widely used International Building Code. The testing frequency of not less than once for each 150 yd³ of concrete is a specific requirement of ACI 318. This minimum frequency thus applies by law to all structures, or portions thereof, that are covered by building codes containing or adopting ACI 318.

Some would argue that the Owner cannot be required to perform the physical tests that Section 16 demands be a part of any strength test. After all, the Owner is also the one paying for these extra tests. As stated, the Owner is not required to take any strength tests. However, note the responsibility of the Owner as it applies to conformance to the Building Code. What is required is that if the Owner elects to have strength tests made, the other tests must be made in support of the data gleaned from the strength test itself. This requirement is no different than requiring tests to be performed in a very specifically-prescribed procedure.

How can all of these tests be useful to anyone? Consider these possibilities. A high temperature on the concrete could indicate excessive mixing, traffic delays, or loading on top of some leftover concrete. Temperatures of concrete can be particularly useful if several are obtained during the day to watch for a trend. Simultaneous ambient temperatures are helpful in the evaluation of concrete temperatures. Was the air content high and the density (unit weight) low? This could indicate a problem with the presence of excessive air in the concrete. If the air content is at the proper level and the density (unit weight) is low, perhaps the wrong aggregate was utilized, or the wrong mixture proportions were batched. If the density is low, it may indicate that air content is high if it is not measured, and this serves as a check on a potential for low strength. Slump tests, while not the true indicator of excessive water, are nonetheless helpful as another tool in evaluating strength tests which provide unexpected results. These test results all work together to form probabilities of what may have caused an unexpectedly low-strength test. The evaluation of these other tests will sometimes point to improper testing as being a problem.

Even when every test has acceptable results, the testing program is helpful in achieving a successful project. Typically there will be test results that are near the borderline, and if these are promptly reported to the producers, adjustments can often be made to move the particular property closer to the middle of the specification window. Good testing and good communication can be a major part of a successful project.

S1 suggests that strength tests, along with the accompanying tests, be made at a frequency of "not less than one test for each 150 yd³." ACI 301 requires strength tests at least once for each 100 yd³ or any fraction thereof, for each concrete mixture placed in any one day. The suggestion of not less than one test for each 150 yd³ is directly in line with the ACI 301 specification requirement. As indicated above, ASTM C 94/C 94M reflects the minimum requirement in ACI 318-02. When these quantities are considered in terms of typical mixer truckloads (8–10 yd³), the spacing of tests (every 10–20 loads) is a compliment to producers that their product is usually consistent enough that it is sampled so seldom. Earlier it was pointed out that a test sample represents 0.5 % of a load, and now the specifications are only requiring a test every 10–20 loads. Thus, less than 0.05 % of the concrete is actually tested. Only a small portion of these tests ever fails, which is a tribute to the concrete being manufactured and to the technicians performing the tests.

S2 states that each test shall be made from a separate batch of concrete. If three strength tests are to be made today, the samples must come from three different trucks. Legitimately there is no reason to cast multiple sets of cylinders from the same truck or batch, except for uniformity testing. Each set of cylinders and thereby each set of tests must be made on separate batches.

S3 concerns testing different classes of concrete. Classes may mean different strengths, different air contents, different aggregates, or a multitude of possible differences. Class of concrete is used here to indicate different mixture proportions. The statement in **S3** then becomes, you should perform not less than one strength test per different mixture on each day the specific mixture is used, regardless of how many or how few cubic yards are placed. There is no indication of why this statement is made, but one very good reason is to ensure to the extent possible that the correct mix design is used. If a project places 200 yd^3 of a 3000 psi mixture today, and in the midst of this large concrete order, an order for 8 yd^3 of a 4000 psi mix with 6 % air is ordered, it is rather important to ensure this one load with different properties was furnished correctly. Accidents can happen in a busy day, and a small amount of testing is an excellent method of buying insurance.

16.6 *S1 If preliminary checks of slump or air content are made, a single sample shall be taken after the discharge of not less than ¼ yd^3 [¼ m^3]. S2 All other requirements of Practice C 172 shall be retained. S3 If the preliminary measurement of slump (11.7) or air content (7.3) falls outside the specified limits, address as indicated in Section 16.6.1 or 16.6.2, as appropriate.*

Slump or air content or both are often checked on a preliminary basis as alluded to in Section 6.2 (slump) and as specified in Section 7.3 (air content). These properties are always tested when strength test specimens are cast. **S1** concerns sampling for preliminary tests. A sample is permitted to be taken after the discharge of as small a quantity as ¼ yd^3. This is a preliminary sample that is to be used only for checks of slump and air content to determine specification compliance. The preliminary sample does not need to be very large, but there is a requirement to not use the first ¼ yd^3 discharged. This is a quantity approximately equal to the manageable mass of a couple of loaded construction grade wheelbarrows. One-fourth cubic yard is not a dribble, it is approximately 1000 lb of material, which must be discharged prior to taking the preliminary sample. Nothing prohibits this discharge into the project. One of the primary purposes of this preliminary sample is to avoid making adjustments on air content and slump when a significant portion of the load is discharged, as is true when an acceptance sample is taken in accordance with ASTM C 172. Because the quantity of concrete in the truck will be unknown, making adjustments at a later point during discharge will be purely guesswork.

The preliminary sample is not to be used for the molding of strength specimens. It is tempting to everyone to proceed with test specimens when slump and air content requirements are met, but do not succumb to temptation.

S2 cautions that all other requirements of ASTM C 172 shall be retained. This addresses the technique of obtaining concrete from the complete stream of discharge, allowing free flow of the discharge, handling of large maximum sized aggregate concrete, remixing of sample once in the sample container, and beginning the slump test and air content determinations within 5 min. after obtaining the sample. Nothing is waived beyond the early sampling point and the use of only one portion of concrete to make up the test sample.

S3 is an instruction concerning a slump or air content value from the preliminary sample that is outside the specification window of tolerance. If the slump or air content or both are greater than permitted, the requirements of Section 16.6.1 are to be followed. If the preliminary test results for slump or air content or both are less than the specified minimum, the requirements of Section 16.6.2 are to be followed. If both slump and air content meet specification requirements, the placement of concrete proceeds as planned.

16.6.1 *S1 If the measured slump or air content, or both, is greater than the specified upper limit, a check test shall be made immediately on a new test sample. S2 In the event the check test fails, the concrete shall be considered to have failed the requirements of the specification.*

This section is only applicable if the measured slump or air content or both is greater than permitted by project specifications. **S1** addresses the reality that a preliminary sample may not be satisfactory or that a test result can be in error and must be checked before a load of concrete is declared "out of specification." To fully satisfy both of these possibilities, a new (replacement) sample is taken. No mitigation procedures are currently addressed within ASTM C 94/C 94M for slump or air contents that are greater than desired. Thus, no mention is made of the possible use of air-detraining admixtures or slump reducing agents. Such mitigation products are available and may be desirable by both the producer and purchaser. ASTM currently takes no position on the use of these products.

The check test on the replacement sample is performed before any additional concrete is discharged for the purchaser's use. If the results of this second test are outside the acceptable limits for the project, the concrete shall be considered as failing the specifications and may be rejected for use on the project or otherwise handled in accordance with project requirements. The purchaser still has the ability to accept the concrete. The purchaser's representative on the job site with the appropriate authority needs to make the judgment as to whether the deviation from the specification requirement is of significance to the requirements of the project and whether the cost and delay associated with rejecting the concrete are justified.

Is it really necessary for a technician to check a test result by performing a second test? Can the same technician check the slump twice on the same sample and obtain identical results? Usually they cannot. Can two technicians check the slump on the same sample and obtain identical results? Usually they cannot. ASTM subcommittee C09.60 (Testing Fresh Concrete) has done everything possible to standardize the slump test, but every test is new and different and will normally give a different value for tests that are both well performed. The precision statement for slump (ASTM C 143/C 143M) was revised recently, based upon some closely supervised tests performed by certified field technicians. Both the standard deviation and the acceptable range of two successive slump test results by the same technician are shown in the Section 6.1.1 discussion.

Based upon 270 slump tests by 15 technicians all working with the same load of concrete, the acceptable range of

EXAMPLE 16.A—*Retest possibilities for slump and air content.*

Specified Item	Slump (in.)	Air Content (%)	Remarks
Specification	4 in. ± 1 in.	6.0 % ± 1.5 %	. . .
Test No. 1	3 ½ in.	4.2 %	Air Content Low
Test No. 2	. . .	5.0 %	Air Content OK

slump results is slightly more than 1 in. Section 6.1.2 allows a 4-in. nominal slump to range from 3–5 in. But is a 5 ¼ in. slump really a 5 ¼ in. slump, and does the 5 ¼ in. slump concrete fail the specification? No, not until the certified technician has performed a second slump test on another portion of a sample of concrete and the second sample has also failed by giving a second test result outside the specification window of acceptance.

Air content values also vary from test to test and are not absolute values. The precision statement for ASTM C 231 (Pressure Method) states that two tests properly conducted by different operators but on the same material should not vary by more than 0.8 % air by volume of concrete. Air contents obtained using a volumetric meter (Roll-a-meter) usually have a wider range of results than other test methods. The acceptable air-content range for two tests performed on different portions of the same sample is 1.6 % for an average air content of 5.0 % and 1.9 % for an average air content of 6.0 %. Both are very large values and demonstrate why a second test should be performed before declaring a load of concrete has failed to meet air content requirements.

Example 16.A demonstrates how a second test can benefit everyone, even though the second series of test results are within an acceptable variation of test series one. The concrete meets specifications and can be placed.

16.6.2 $_{S1}$ *If the measured slump or air content, or both, is less than the lower limit, permit adjustments in accordance with 11.7 or 7.3 or both, as appropriate, and obtain a new sample.* $_{S2}$ *If the sample of the adjusted concrete fails, a check test shall be made immediately on a new sample of the adjusted concrete.* $_{S3}$ *In the event the check test fails, the concrete shall be considered to have failed the requirements of the specification.*

When the slump is less than permitted, Section 11.7 permits a one-time addition of water at the job site. What Section 11.7 does not do is waive any project restrictions or mixture proportioning submittals that limit the total water content or prescribe a maximum water-cement ratio.

When an air content measurement is less than specified as a lower limit, Section 7.3 allows the manufacturer to use additional air entraining admixture to increase the air content. Section 7.3 does not place a one-time limit on such an increase.

The permitted adjustments apply to either or both, slump and air content, as appropriate and in accordance with other restrictions of the specifications, including additional mixing as specified in Section 7.3 and 11.7, maximum revolutions of the mixer, and time limits of Section 11.7. After the adjustments have been made and the additional revolutions of the mixer completed, a new sample is obtained for a second series of tests.

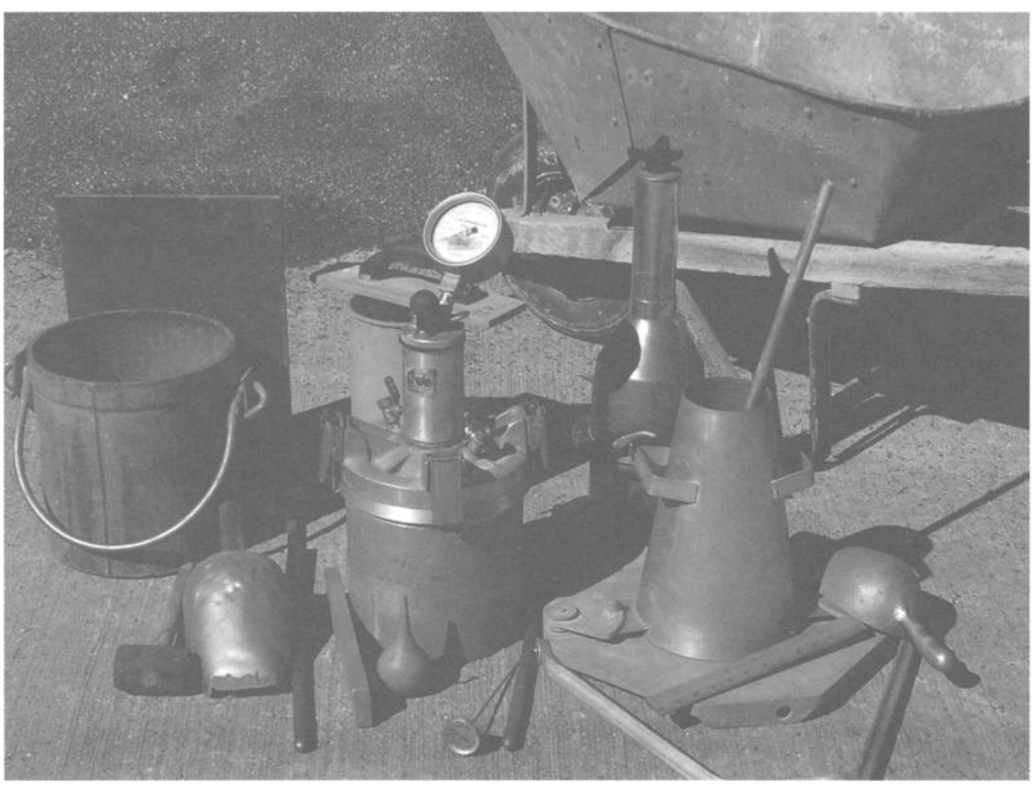


FIG. 16.A—*Group photo of testing equipment.*

S2 recognizes the possibilities discussed in Section 16.6.1 for two tests by the same technician or different technicians to produce differing test results. Therefore if a test on the adjusted concrete sample fails, a second test shall be made immediately on a new sample of the adjusted concrete. A new sample is considered important as a hedge against a problem sample initially, insurance that ASTM C 172 time constraints on beginning the tests will be met, and it affords the opportunity for using a second technician, if readily available to participate in checking the new sample (second sample of adjusted concrete).

S3 really needs no explanation beyond the specification statement. A failed slump or air-content test result on this second adjusted sample is grounds to reject the concrete as not meeting project specifications.

What then happens to this load of concrete is beyond the scope of ASTM C 94/C 94M. The immediate foreseen possibilities are:

1. Reject the load, and remove it from the job site.
2. Place the load in the project, and immediately call the batch plant for changes in the mixture proportions that are expected to correct the next load.
3. Make further corrections to the slump or air content with the permission of the Purchaser or Owner's representative as appropriate under the terms of the project specifications.

17

Strength

17.1 *S1 When strength is used as a basis for acceptance of concrete, standard specimens shall be made in accordance with Practice C 31/C 31M. S2 The specimens shall be cured under standard moisture and temperature conditions in accordance with the applicable provisions of Practice C 31/C 31M. S3 The technician performing the strength test shall be certified as an ACI Concrete Strength Testing Technician, Concrete Laboratory Testing Technician—Grade II or by an equivalent written and performance test program covering the relevant test methods. S4 If acceptance is based upon compressive strength test results, the certification requirement is satisfied by certification as an ACI Concrete Laboratory Testing Technician—Grade I or by an equivalent written and performance test program.*

Minimum strength requirements are the most common method of ultimate acceptance of concrete. Strength may be measured by either compressive or flexural methods. Even when a mixture has been proportioned to meet a criterion other than strength, such as a maximum water-cement ratio or a minimum cement content, there typically will be some minimum strength assigned to become the ultimate pass-fail judgment of the concrete.

All strength specimens shall be made (molded) in accordance with ASTM Practice for Making and Curing Concrete Test Specimens in the Field (C 31/C 31M). A study of ASTM C 31/C 31M is recommended, particularly for concrete with slumps of 1 in. or less and with approved cylinder molds different from 6 in. × 12 in. A brief summary of the primary considerations for proper strength testing procedures follows:

Sampling: ASTM C 172: Take two portions of concrete from middle portion of load separated by not more than 15 min., and combine into one composite sample.

Begin Tests: ASTM C 172: Time constraints for beginning strength tests and the specified companion tests are rigid and require good planning and execution when only one technician is available. One sequence of tests that permits compliance using a single accomplished technician and meeting the required starting times after obtaining the final portion of the composite sample follows (maximum starting times in parentheses):

1. Advance planning on where testing will take place.
2. Lay out and prepare equipment.
3. Obtain **two sample portions,** and mix into one composite sample.
4. Begin **temperature** determination, ASTM C 1064/C 1064M (5 min.).
5. Perform **slump** test, ASTM C 143/C 143M (5 min.).
6. Complete **temperature** determination ASTM C 1064/C 1064M.
7. Perform **air content** determination; ASTM C 231 or ASTM C 138/C 138M are the quickest. ASTM C 173/C 173M requires a second technician (5 min.).
8. Perform molding of cylinders or flexural beams, ASTM C 31/C 31M (15 min.).

   Cylinders

   a. Select method of consolidation (rodding or vibrator) from Table 2 of ASTM C 31/C 31M.
   b. Select number of layers and consolidation requirements from Tables 3 or 4 of ASTM C 31/C 31M.
   c. Tap outside of mold after rodding each layer.
   d. Smooth top of concrete with trowel or float.
   e. Move cylinders quickly to location of initial curing in the field while fully supporting bottom of cylinder mold.
   f. Cover top or otherwise prevent moisture loss.
   g. Cure in 60–80°F temperatures up to 48 h (68–78°F for specified strengths of 6000 psi or greater). Keep min-max thermometer with cylinders, and record curing temperatures.
   h. Move to laboratory, strip mold, cure at 73 ± 3°F, and maintain free water on surface as described in ASTM Specification for Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes (C 511).

   Beams

   a. Fill mold in 2 layers.
   b. Rod if slump greater than 1 in.
   c. Rod each layer at 1 rodding per each 2 in.^{2} of top surface area.
   d. Tap outside of mold 10–15 times with rubber or rawhide mallet after rodding each layer, and then spade the sides and ends of mold with a trowel after consolidating layer.
   e. Smooth top of concrete with float.
   f. Move quickly to field storage area.
   g. Cover top or otherwise prevent moisture loss.
   h. Cure in 60–80°F temperatures up to 48 h. Keep min-max thermometer with beams, and record temperatures during initial storage period.
   i. Move to laboratory, remove molds, cure at 73 ± 3°F, and maintain free water on surface as described in ASTM C 511, except the last 20 h or more prior to testing require submersion in water saturated with calcium hydroxide.
9. Perform **density (unit weight)** test last, unless it was the selected method for air content determination, ASTM C 138/C 138M (start and complete test expeditiously).

S3 makes the point that the technician performing the laboratory portion of the strength tests must be certified. This is not a field testing certification, it is a Laboratory Testing certification. The ACI Strength Testing Technician certification covers the testing of both cylinders and beams (flexural).

The ACI certification program Concrete Laboratory Testing Technician—Grade II covers both cylinders and beams (flexural). **S4** provides for the ACI certification Concrete Laboratory Testing Technician—Grade I covering only cylinders, when the project acceptance tests are compression cylinders.

Any of these ACI certification tests may be supplanted by a certification program that includes all the basic elements of the ACI program. The basis for an equivalent technician certification program is outlined in Chapter 16 in the discussion of Section 16.2.

17.2 $_{S1}$ *For a strength test, at least two standard test specimens shall be made from a composite sample secured as required in Section 16.* $_{S2}$ *A test shall be the average of the strengths of the specimens tested at the age specified in 4.2.1.1 or 4.4.1.1 (Note 19).* $_{S3}$ *If a specimen shows definite evidence other than low strength, of improper sampling, molding, handling, curing, or testing, it shall be discarded, and the strength of the remaining cylinder shall then be considered the test result.*

Compression cylinders or flexural beams whose test results are to be a part of the acceptance or rejection process shall be made such that the test made at the age designated for the acceptance has at least two or more specimens. One cylinder does not represent a test result. Even when strength specimens are molded from a well-mixed sample and by certified technicians the strength results of these specimens will not be identical. ASTM Test Method for Compressive Strength of Cylindrical Concrete Specimens (C 39/C 39M) contains a precision statement, which states that a pair of cylinders molded in the field may have a strength range as high as 8.0 % of their average and be acceptable. When three cylinders are tested to be averaged, the range can be as high as 9.5 %. This value (8.0 %) is based upon procedures adopted by subcommittee C 09.94 and approved by committee C 09 and published in ASTM Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials (C 670). Consider a compression test result of 4850 psi and a companion cylinder with a strength of 5250 psi. At an average strength of 5050 psi, 8 % is an allowable spread of 404 psi. The spread is acceptable, and the average is an acceptable 5050 psi for a 5000 psi strength specification.

A second example has a first cylinder strength of 3700 psi and a companion cylinder strength of 5250 psi. The ASTM C 39/C 39M precision statement suggests that there is a problem with a cylinder when the range is this large, 34 % of the average compared to 8 %, expected to be exceeded only 5 % of the time. From a practical standpoint there are long odds that the problem is with the low-test result (3700) rather than the high one (5250). Nevertheless, **S2** is explicit that "a test" includes all the cylinders or beams from a composite sample and that the reported test result is the average of these individual specimen strengths tested at the same age. These are just a couple of reasons for having more than one strength specimen to form a strength test. Three specimens is great, two is good, and one is unacceptable. **S3** provides for excluding bad cylinders or beams (strength test specimens) from the reported test results. When the difference between the strength of two specimens averaged for a test result is larger than the allowable range stated in the test method's precision statement, inspections and inquiries should be made for possible bad test specimens. If a problem is found, the low cylinder strength result may be excluded and the strength of the other cylinder reported as the test result. If a specific reason for a low test is not found, the average of both is reported. While the precision statement provides a basis for qualifying what might be a significantly high difference between specimens, it does not qualify whether the testing conducted is acceptable. ACI 214R-02 Evaluation of Strength Test Results of Concrete [1] is a document that provides greater detail on evaluating strength test results. It indicates that with reasonably good testing, the within-test coefficient of variation is around 3–4 % of the average strength. If it is higher, there should be concern about the testing procedures. Further, if the within-test coefficient of variation is too low, say in the range of 1–2 %, this should also be considered abnormal, and the procedures used at the lab should be reviewed. The relationship of the coefficient of variation and the standard deviation is that the standard deviation expressed as a percentage of the average strength is the coefficient of variation. If the standard deviation is 120 psi and the average strength of cylinders is 4000 psi, the coefficient of variation is 3.0 %.

The age for acceptance tests is 28 days unless otherwise stated in the project specifications. This age is spelled out in both Section 4.2.1.1, Option A Ordering Information and Section 4.4.1.1, Option C Ordering Information. It is not unusual for pavements to be based on 90-day acceptance testing or for tilt-up panels to require a very short acceptance strength period to permit lifting in 1 or 2 days. High strength concrete containing higher amounts of supplementary cementitious materials often have strength acceptance criteria at 56 days. Such deviations for acceptance testing, if desired, must be spelled out in the project specification, otherwise the default value of 28 days prevails.

Note 19—$_{S1}$ *Additional tests may be made at other ages to obtain information for determining form removal time or when a structure may be put in service.* $_{S2}$ *Specimens for such tests are cured according to the section on Field Curing in Practice C 31/C 31M.*

Note 19 points out that tests not used to judge the acceptability of the concrete as delivered may be tested at other ages. What it does not say is that for these non-acceptance tests, the curing conditions may also differ from standard curing conditions. These curing conditions may be tailored to the specific purpose and tested at selected ages depending upon the purpose. ASTM C 31/C 31M discusses field-cured cylinders. Field cured tests are for purposes such as when a structure may be put into service, determination of the adequacy of curing and protection from adverse weather conditions, when forms may be removed, when tilt-up panels may be lifted, or a comparison of standard test results and in-place test methods. These cylinders or beams are for the benefit of the contractor or owner and are not to be considered as acceptance test results. Field cured cylinders are addressed in ACI 318-02 Building Code Requirements for Structural Concrete for the purpose of judging whether the curing and protection afforded to the structure were adequate. In that instance, the purpose of the tests is to verify contractor's practices and comparisons of field cured tests to the standard cured cylinders to determine acceptability.

The New Mexico Ready Mix Concrete And Aggregate Association paper concerning non-standard curing versus standard curing conditions for cylinders indicates that not all professionals are aware of the differences in the curing requirements for acceptance cylinders and job-cured cylinders [75].

***17.3** The representative of the purchaser shall ascertain and record the delivery-ticket number for the concrete and the exact location in the work at which each load represented by a strength test is deposited.*

Section 16.5 recommends a strength test frequency of not less than every 150 yd^3. ACI 301 specifies a test set at least every 100 yd^3. With 9–10 yd^3 batches as the norm, testing occurs every 10–17 loads. In percentages, this translates to testing only 6–10 % of the placed product. It is extremely important to know where each tested load is within the project. In the event a test is low and the quality of a load of concrete is suspect, it is important to know exactly where both good and suspect loads are located. Knowing where the questionable load and acceptable loads were placed helps limit the area where the other 10–17 loads that were not tested may be located, because they too may be suspect. The cataloging process of load locations must include the number of the delivery ticket. An abundance of information is tied to the delivery ticket number beginning with the identification of the mixture batched and very often the quantities of each material batched for the suspect load. The delivery ticket should include the time loaded and the quantity of any extra water added at job site.

***17.4** To conform to the requirements of this specification, strength tests representing each class of concrete must meet the following two requirements (Note 20):*

***17.4.1** The average of any three consecutive strength tests shall be equal to, or greater than, the specified strength, f'_c, and*

***17.4.2** No individual strength test shall be more than 500 psi [3.5 MPa] below the specified strength, f'_c.*

Section 17.4 and its subparts are each derived from ACI 318-99, Building Code Requirements for Structural Concrete and Commentary, which establishes the pass-fail criteria for concrete compressive strength tests. The strength tests must meet both of the minimum criteria set forth in Sections 17.4.1 and 17.4.2 to be acceptable for a compressive strength requirement. The criteria of Sections 17.4.1 and 17.4.2 establish the necessity for maintaining a running average of strength tests for each different mixture on a project and simultaneously watching for an individual test result (which is averaged from two or more cylinders) to always exceed a value of the specified strength minus 500 psi. The criteria in Section 17.4.2 do not apply to single cylinders in that a proper strength test is the average strength of two or more cylinders. They apply to the test (test set) average.

With ACI 318-02 now published, the ASTM C 09.40 subcommittee is preparing revisions to Section 17.4 that will keep ASTM C 94/C 94M current with Concrete Building Code requirements. The revisions will be for specified compressive strengths (f'_c) greater than 5000 psi. Overdesign factors and pass-fail criteria will become more conservative for the higher strength (plus 5000 psi) concrete. Essentially, the 500 psi or 3.5 MPa in Section 17.4.2 will be replaced by (0.1 f'_c) when $f'_c > 5000$ psi. Table 4 will be replaced with a new table compatible with the new ACI 318-02 requirements.

The testing of flexural strength specimens (beams) is not currently included in ASTM C 94/C 94M, although some specifications use these tests as a basis for acceptance. For projects using flexural strengths, the specifications must include the applicable acceptance provisions. Sampling, molding flexure specimens, curing, handling, testing, and certifying field and laboratory technicians are each covered within the ASTM C 94/C 94M specification. Only the method of flexural testing (third-point or center-point loading) to be used and the method of evaluation with respect to pass-fail criteria are not included in ASTM C 94/C 94M and should be covered by the project specifications that invoke this specification by reference.

Several potential problems arise in Example 17.A and will be examined. The combined average of sets 3, 4, and 5 is less than the required 4000 psi (3973 psi). There are no major differences between cylinders within a set and no major low cylinder strengths. The within test acceptable range of 8.0 % of the test average is not exceeded (4.0 %, 2.0 %, and 2.5 %, respectively) in any of the cylinder sets, so results appear valid. None of the cylinder sets are more than 90 psi below specified strength and therefore do not approach the 500 psi value of Section 17.4.2. What happens with this close but technically low strength cylinder group? There is probably an increase in cementitious material or a decrease in

EXAMPLE 17.A—*Applied strength criteria of Sections 17.4.1 and 17.4.2.*

Assume a specified strength, f'_c, of 4000 psi.

Set No.	Individual Cylinder Strengths at 28 days (psi)		Average (Test Result) (psi)	Average of Last 3 Tests (psi)	Remarks
1	4310	4270	4290	. . .	OK
2	4670	4430	4550	. . .	OK
3	3960	4120	4040	4293	OK
4	3870	3950	3910	4167	OK
5	3920	4020	3970	3973	Avg. last 3—low
6	4310	4210	4260	4047	OK
7	4720	4680	4700	4310	OK
8	4670	4630	4650	4537	OK
9	4450	3770*	4110	4487	OK (Testing suspect)‡
10	3360	3540†	3450	4070	550 psi low
11	4410	4550	4480	4013	OK
12	4800	5060	4930	4287	OK
13	4260	4100	4180	4530	OK
14	5310	4810*	5060	4723	OK
15	4010	3610*	3810	4350	Less than 500 psi low
16	3810	3450*	3630	4167	See footnote§

* Outside the test range limit of 8.0 % specified by ASTM C 39/C 39M. In Example, this occurred on 25 % of the tests and suggests the possibility of sloppy testing.

† Nothing to directly imply bad cylinders. Individual cylinder test results support each other.

‡ Wide range of two compression tests from one concrete sample.

§ 3450 is OK because it is a single cylinder (1/2 a test), not a full test.

slump and water and a closer look at initial curing of cylinders at the job site. Any legal questions probably will be resolved in accordance with Section 18. Removing and replacing the concrete are probably not required. Nondestructive in-place tests with a rebound hammer or other methods may be warranted to verify the similarity of concrete strengths, but nothing further should be anticipated unless these tests show contradictory results. Remember these cylinders represent the 28-day strength and from a safety standpoint, the concrete strength is expected to increase between 10–18 % during the succeeding 28 days (56 day strengths). At 56 days, the 3973 psi average can be expected to reach 4300 psi or more depending upon the mixture materials and proportions.

Test set 9 has a wide spread (4450 − 3770 = 680 psi) between two individual cylinders within a test set. This is more than double the acceptable 8.0 % range variation of ASTM C 39/C 39M. Nothing is found to appear visually defective with the cylinders, and the average of 4110 is greater than the 4000 psi design strength, so typically nothing would be changed. If the 3770 psi cylinder revealed signs of being improperly molded, such as honeycomb, it would be discarded, with the average for set 9 recorded as 4450 psi.

Set 10 has an average of more than 500 psi below the 4000 psi design strength. Both cylinders tested low, so there is concern for the in-place concrete. Several factors will be investigated, beginning with a look at the test cylinders plus the molding, curing, and handling of test cylinders. The batch plant load print-outs will be examined for potential problems as will the delivery tickets for that day looking for excess water, excessive stand-by time, or some form of mishandling or change that may have affected the tests or the concrete. Many producers require a driver's log to note any changes or irregularities in the concrete, its testing, or its handling.

This is the type of situation which suggests the possible need to drill concrete cores. The plan for coring the concrete and handling the cores is discussed in ASTM Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete (C 42/C 42M) and ACI 318-02. There should be no less than three cores, and each should be carefully examined for acceptability. The cores should be obtained from random locations within the portion of the structure represented by the low strength cylinders, and for this purpose it is important to establish locations at which individual loads were placed. ACI 318-02 sets acceptance criteria based upon at least three cores at an average strength (corrected to L/D ratio of 2) equal to at least 85 % of the specified strength (f'_c) and no single core less than 75 % of the specified compressive strength, f'_c. An example of acceptable concrete strength for Example 17.A is shown in Example 17.B.

The provisions for core strengths are established primarily to determine if the concrete furnished for the job meets the requirements of the strength specification requirements. The provisions are established based on considerable research that compared core strengths to well cured cylinders [12,35,88]. Research by Meininger, Wagner, and Hall [56] established correction factors for use in ASTM C 42/C 42M to adjust compressive strengths to an L/D (length/diameter) ratio of 2:1. This was a necessary element to establish any relationship between standard cylinders and cores, which are often short, compared to their diameter. The 85 % factor is questioned occasionally, but this has proven to provide a reliable comparison between cylinders and cores. Cylinders provide a mortar coating outside all of the aggregate, and cores do not provide this protection. Cores by cutting through many pieces of aggregate along the core circumference may produce microcracking adjacent to the aggregate. Many cores do not have as smooth and uniform a surface as the cylinders will, and the curing conditions for the in-place concrete may not have been quite as good as that for the cylinders. The result is that 85 % of cylinder strength is all that is expected of cores, thus the 85 % and 75 % factors. Regarding the suitability of concrete strength in the structure, one needs to realize that the process of structural design applies several safety factors, in the form of load factors and reliability factors, ϕ, that ensure that the actual design stresses witnessed by the structure are significantly smaller than the design or specified strength, f'_c. While these core strength criteria are provided for determining the acceptability of concrete as delivered, the core strength data should not be used to determine the equivalent strength of standard cured cylinders or equivalent design strength, f'_c, by dividing the average core strength by 0.85 [88]. This is not an appropriate interpretation or use of these acceptance provisions.

EXAMPLE 17.B—*Sample evaluation of concrete cores.*

Specified compressive strength, f'_c = 4000 psi
Core test criteria:
Average of at least 3 cores > 0.85 (4000) = 3400 psi
Individual core > 0.75 (4000) = 3000 psi

Core No.	Compressive Strength * (psi)	Evaluation	Remarks
1	3750	> 0.75 (4000)	OK
2	3300	> 0.75 (4000)	OK
3	3650	> 0.75 (4000)	OK
4	3900	> 0.75 (4000)	OK
Avg.	3650	> 0.85 (4000)	OK

* Corrected for the L/D ratio of core as per ASTM C 42.

There are rational methods for calculating conservative estimates of the value of the compressive strength of concrete within a structure when investigating structural adequacy. ACI Committee 228 has a document ACI 228.1R-95 In-Place Methods to Estimate Concrete Strength, which addresses this issue. ACI Committee 214 has a recently approved document using core strength results for the same purpose. The document is ACI 214.4R-03 Guide for Obtaining Cores and Interpreting Compressive Strength Results [2]. Again these procedures should not be turned around to determine the acceptability of the concrete as delivered. These are two distinct and separate issues for different purposes that should not be compared or confused.

Cylinder set 15 is questioned because at 3810 psi it is less than the 4000 psi design strength, but everything is deemed to be satisfactory because it does not drop to more than 500 psi below design strength (4000 − 3810 = 190 psi), and the running average of the last three tests is 4350 psi and thus above the 4000 f'_c.

Set 16 may appear to be trouble because of the 3450 psi cylinder strength, but it is not a concern because the test result (average of two) is 3630 psi and only 370 psi low. The 500 psi low factor applies to a test result and not an individual cylinder strength.

Note 20—$_{S1}$ *Due to variations in materials, operations, and testing, the average strength necessary to meet these requirements will be substantially higher than the specified strength.* $_{S2}$ *The amount higher depends upon the standard deviation of the test results and the accuracy with which that value can be estimated from prior data as explained in ACI 318 and ACI 301.* $_{S3}$ *Pertinent data are given in Table 4.*

It is a known fact that the same concrete proportions in different batches will not produce identical strengths each time they are tested. The same is true for any other measured property of concrete. If the same results were the norm, companion cylinders would always have the same exact strength test result. If testing were not a factor, there would be no allowable difference between cylinders made by different technicians. Every effort is made to keep materials the same, to batch and mix precisely the same each time, and to test exactly the same each time, but it is never exactly the same, and therefore test results vary. Because of these differences, the average strength for which the concrete mixture is designed must be higher than the specified strength, f'_c. This reduces the probability that tests of concrete fail the acceptance provisions. **S2** relates the amount of increase needed above the average strength to the standard deviation of a series of compression test results.

Standard deviation is a statistical term often used in the analysis of concrete tests. Another such term is variance. Mean, the third term used in the statistical evaluation of concrete, is often referred to as the average. The mean is calculated as the sum of test values divided by the number of test results (observations). In Example 17.A, the number of test results (observations) is 16. The mean (average) of the cylinder strengths is 4251 psi (68 020 ÷ 16).

Variance is defined as the mean of the squares of the deviations of the observations (number of tests) from their mean. By squaring the difference between an observation and the mean of a group of numbers, all negative signs are voided. The variance (average of the squares) will be a positive number. This can be demonstrated by an expansion of Example 17.A into Example 17.C.

TABLE 4—Overdesign necessary to meet strength requirements. [A]

Number of Tests [B]	*Standard Deviation, psi*					
	300	*400*	*500*	*600*	*700*	*Unknown*
15	*466*	*622*	*851*	*1122*	*1392*	*C*
20	*434*	*579*	*758*	*1010*	*1261*	*C*
30 or more	*402*	*526*	*665*	*898*	*1131*	*C*
	Standard Deviation, MPa					
	2.0	*3.0*	*4.0*	*5.0*	*Unknown*	
15	*3.1*	*4.7*	*7.3*	*10.0*	*C*	
20	*2.9*	*4.3*	*6.6*	*9.1*	*C*	
30 or more	*2.7*	*4.0*	*5.8*	*8.2*	*C*	

[A] *Add the tabulated amounts to the specified strength to obtain the required average strengths.*

[B] *Number of tests of a concrete mixture used to estimate the standard deviation of a concrete production facility. The mixture used must have a strength within 1000 psi [7.0 MPa] of that specified and be made with similar materials. See ACI 318.*

[C] *If less than 15 prior tests are available, the overdesign should be 1000 psi [7.0 MPa] for specified strength less than 3000 psi [20 MPa], 1200 psi [8.5 MPa] for specified strengths from 3000 to 5000 psi [20 to 35 MPa] and 1400 psi [10.0 MPa] for specified strengths greater than 5000 psi [35 MPa].*

The standard deviation is a convenient measure of the dispersion of a group of numbers from its mean (average). Variance and standard deviation are terms used to mathematically describe how close together or how far apart a series of test results may be. Small numbers for either the standard deviation or the variance indicate close test results and good consistency of materials, batching, mixing, and testing. For example, a standard deviation of 500–600 psi may be considered good for a batch plant, and lower numbers such as 400 psi are considered excellent, while a 700 psi value represents poor control.

There is one minor point to note on the calculation of variance and standard deviation. What is normally calculated is the *sample* variance and the *sample* standard deviation because we are obtaining a measure of variability from tests of a portion (or samples) of the total concrete placed (*total population*). The sample variance is calculated by dividing the sum of the squared deviations by (n-1), rather than n, where n is the total number of tests or samples. The sample standard deviation is the square of the sample variance.

The mathematical expression for the computation of the variance and standard deviation actually comes in two forms (n) and (n-1). One form is the variance and standard deviation of the *population* (all the concrete). This form is appropriate when measurements are available for all possible items in an entire group that all characterize the property being measured, for example, the age of 20 people. In this case, the variance is calculated from the sum of the squared deviations divided by the number of measurements, (n). The other form is when only a sample of all possible items is measured to estimate the variance and standard deviation of the population. This sample (tested concrete) and the measured characteristics of the sample are used to estimate the mean, variance, and standard deviation of the population (all

EXAMPLE 17.C—*Statistical use of previous test results.*

Observation	Strength Test Result (psi)	Deviation $X - \bar{X}$	Squared Deviation
1	4290	4290–4251 = 39	1521
2	4550	4550–4251 = 299	89 401
3	4040	4040–4251 = −211	44 521
4	3910	3910–4251 = −341	116 281
5	3970	3970–4251 = −281	78 961
6	4260	4260–4251 = 9	81
7	4700	4700–4251 = 449	201 601
8	4650	4650–4251 = 399	159 201
9	4110	4110–4251 = −141	19 881
10	3450	3450–4251 = −801	641 601
11	4480	4480–4251 = 229	52 441
12	4930	4930–4251 = 679	461 041
13	4180	4180–4251 = −71	5041
14	5060	5060–4251 = 809	654 481
15	3810	3810–4251 = −441	194 481
16	3630	3630–4251 = −621	385 641
Totals	68 020		3 106 176

$$\text{Mean (avg.)}, \bar{X} = \frac{68\,020}{16} = 4251 \text{ psi}$$

$$\text{Variance} = s^2 = \frac{\text{sum of squared deviations from mean}}{(\text{number of observations} - 1)} = \frac{\sum (X-\bar{X})^2}{(n-1)} = \frac{3\,106\,176}{(16-1)}$$

Variance = s^2 207 078

Standard Deviation = s = square root of variance 455.1 psi of the concrete). In this case, in the formula used to calculate the variance and standard deviation utilizes Bessel's correction [46]. Bessel's correction involves using a value of one less than the total number of observations (n − 1) in the denominator for calculations. This is called the sample variance and sample standard deviation. In most cases in concrete testing, because we are using samples to estimate characteristics of a larger load of concrete, the sample variance and sample standard deviation form of the calculation is used. In this example, a set of 16 observations is being used to predict the standard deviation for hundreds of mixtures produced by this ready-mixed concrete plant. This applies to calculations on calculators and computer spreadsheets where different key functions are available for measures of dispersion of samples and population. The difference between sample and population standard deviation gets rather small when the number of samples gets large, say in the range of 15–30. A more detailed explanation of the mathematics of this correction is available in textbooks on statistics [46].

In Example 17.C the variance will equal 3 106 176 ÷ (16 − 1) = 207 078, and the standard deviation $(207\ 027)^{1/2}$ equals 455 psi.

The standard deviation of a set of strength test results is used to establish a safety factor to account for variability related to concrete production and testing and to establish a target value for average strength when proportioning mixtures for each class of concrete at a particular concrete batch plant.

S1 of Note 20 includes the term operations along with materials and testing as variables that will show up in the standard deviation for a plant. Operations include equipment and personnel. Equipment affects the variation in test results, and each plant is configured differently, which leads to differences between plants. Operations also include personnel, primarily the batchman, loader operator, and drivers. There remain some batch plants that batch by pulling levers on aggregate bins and cement silos. Even on computerized plants there often are no functioning moisture probes in the aggregate bins. Even when there are such advantages, there will be material variations, which bring about a need for batch water adjustments requiring the experience of the batchman. At plants, which transfer aggregates to overhead bins using a front-end loader, the operator's experience is instrumental in preventing aggregate segregation and maintaining uniform moisture contents. The effect of drivers is more visible through the care and cleaning they provide to their trucks and mixers. Little things such as a few revolutions at mixing speed and wetting the chutes immediately before discharge will aid the uniformity of the concrete product and subsequent test results.

ACI 318 provides requirements for overdesign of concrete strength that minimize the chances of failing the acceptance provisions in Sections 17.4.1 and 17.4.2 to a probability of less than 1 %. The following equations are used to establish the required average strength, f'_{cr}:

$$f'_{cr} = f'_c + 1.34\ ks$$

and

$$f'_{cr} = f'_c + 2.33\ ks - 500$$

where:

f'_{cr} = required average compressive strength;
f'_c = specified compressive strength;
k = factor for increasing the standard deviation if the total number of tests available to calculate the standard deviation is less than 30. (For 30 tests, k = 1.0; for 20 tests, k = 1.08; and for 15 tests, k = 1.16);
s = standard deviation from a test record of a previous mixture for a similar class of concrete from the batch plant.

Table 4 of ASTM C 94/C 94M and its notes may be used after the standard deviation is known to calculate the strength overdesign (safety factor) when proportioning the concrete mixture.

ASTM C 94/C 94M Table 4 contains three notes important to its use. **Note A** points out that Table 4 calculates the overdesign and that this overdesign for compressive strength must be added to the project's specified strength f'_c to obtain the required average strength f'_{cr} of the compression strength of the proposed mixture.

Note B involves the number of tests used to calculate the mixture overdesign (safety factor). The "k" factors presented earlier are directly related to the number of tests used to calculate the required overdesign. The test record from the mixture used to calculate the standard deviation for the concrete batch plant must have a specified strength within ± 1000 psi of the specified strength and shall use similar materials. The term similar materials refers to not using tests from a limestone coarse aggregate mixture to calculate the overdesign for a lightweight concrete mixture. Do not use a non-air-entrained mixture to establish the overdesign for an air-entrained mixture. It does not prohibit using a mixture containing 15 % fly ash to calculate the overdesign for a mixture containing 25 % fly ash. Every possible situation cannot be identified here, but the intent is to use reason when comparing the proposed mixture to the mixture from where the test record was obtained. For example, can the overdesign be calculated for a mixture with 60 % GGBF slag from a mixture with 30 % fly ash and 20 % GGBF slag? These are similar if the design strengths are within 1000 psi, if each is either air-entrained or non-air-entrained, and if each uses similar aggregates. A test here for similarity may be the cementitious weigh hopper arrangement. Typically the fly ash and slag will be augered into the cement weigh hopper for proportioning. If this is the case, these may be considered similar. If a separate weigh hopper was used for the fly ash, which has now been dropped out of the mixture, the equipment itself has changed, and a different mixture without fly ash could be used to calculate the overdesign.

Note C discusses the required overdesign if less than 15 test values are available to calculate the standard deviation for the concrete batch plant. In this event, the overdesign factor shall be as follows:

Specified Strength	Overdesign
< 3000 psi	1000 psi
3000–5000 psi	1200 psi
> 5000 psi	1400 psi

In the revision to this section in ACI 318, the required average strength, f'_{cr}, for a specified strength exceeding 5000 psi is $f'_{cr} = 1.1f'_c + 700$, and this will be incorporated in ASTM C 94/C 94M in a future revision. No provision is made for using a single mixture with less than 15 tests for the computation of the overdesign factor. ACI 318 does make provisions for combining the results of two groups of compression test results if the total number of tests is at least 30 and each set has at least 10 tests.

An example of determination of the required overdesign for a specified compressive strength considers the following relationships.

EXAMPLE 17.D—*Determination of required safety factor (overdesign).*

The proposed mixture for a project is to have a minimum compressive strength (f'_c) of 5000 psi. The mixture with test results shown in Example 17.A used similar materials and is within 1000 psi of the specified design strength. It will be used to compute the required average strength for the proposed 5000 psi mixture. The 16 tests of Example 17.A are less than the required 30 test results, but this can be handled by a correction factor "k" or proper use of Table 4 of ASTM C 94/C 94M.

In Example 17.C, the concrete plant's standard deviation from 16 test results was calculated as s = 455 psi

With a standard deviation value of 455 psi, the required overdesign may now be determined from Table 4. Select 15 as the number of tests (16 is the actual value, but if the actual value is not in the left hand column, select a lower value). Move horizontally in Table 4 to a standard deviation of 500 psi, and select an overdesign factor of 851 psi. The required average compressive strength target for a mixture with a specified strength of 5000 psi is 5851 psi based upon the test data used. If the historical test record was not available for this class of concrete from this concrete plant, Note C of Table 4 governs, and the required average strength for proportioning the mixture will be 6200 psi. This demonstrates the benefit of collecting strength test data to establish the strength variability from a plant and reducing the level of overdesign (safety factor) based upon past experience.

Could the 455 psi have been used by interpolation between 400–500 psi in Table 4 of ASTM C 94/C 94M? Interpolation is not wise with this table because the tabular values are the larger numbers produced by two separate calculations. The two equations which come from ACI 301, were presented earlier and will be used here to demonstrate the development of Table 4 and as an alternate procedure to Table 4.

The interpolated value will not always be larger than the solution using the calculated standard deviation because two different equations are involved. Note that the equation producing the larger required overdesign was different for s = 400 from the critical equation for s = 500.

Note that these differences in calculated values of f'_{cr} are small and not really distinguishable regarding the proposed mixture proportions. The intent is for the concrete producer to demonstrate to the A/E, typically in a pre-job submittal, that the proposed mixture will produce a strength equal to or greater than f'_{cr}. The producer does not have to achieve that average level of strength during the course of the job. All that governs during the job is that the strength tests comply with the acceptance provisions in Section 17.4.

EXAMPLE 17.E—*Demonstration of Table 4 development.*

All of the proposed mixture information and standard deviation data of Example 17.C will be used.

f'_c = 5000 psi; s = 455 psi
number of tests = 16, therefore k = 1.16 from Table 4.2.3.3.a of ACI 301 (one can also interpolate for the value of k between 1.16 for 15 tests and 1.08 for 20 tests)

Solution for s = 400

$f'_{cr} = 5000 + 1.34\ (1.16 \times 400) = 5622$ (larger value)
$f'_{cr} = 5000 + 2.33\ (1.16 \times 400) - 500 = 5581$

Solution for s = 500

$f'_{cr} = 5000 + 1.34\ (1.16 \times 500) = 5777$
$f'_{cr} = 5000 + 2.33\ (1.16 \times 500) - 500 = 5851$ (larger value)

Solution for s = 455

$f'_{cr} = 500 + 1.34\ (1.16 \times 455) = 5707$
$f'_{cr} = 500 + 2.33\ (1.16 \times 455) - 500 = 5730$ (larger value)

Interpolation from Table 4

$$f'_{cr} = \left[\frac{(455 - 400)}{(500 - 400)} \times (851 - 622)\right] + 622 + 5000 = 5748 \text{ psi}$$

18

Failure to Meet Strength Requirements

18.1 $_{S1}$ *In the event that concrete tested in accordance with the requirements of Section 17 fails to meet the strength requirements of this specification, the manufacturer of the ready-mixed concrete and the purchaser shall confer to determine whether agreement can be reached as to what adjustment, if any, shall be made.* $_{S2}$ *If an agreement on a mutually satisfactory adjustment cannot be reached by the manufacturer and the purchaser, a decision shall be made by a panel of three qualified engineers, one of whom shall be designated by the purchaser, one by the manufacturer, and the third chosen by these two members of the panel.* $_{S3}$ *The question of responsibility for the cost of such arbitration shall be determined by the panel.* $_{S4}$ *Its decision shall be binding, except as modified by a court decision.*

S1 addresses a possible adjustment or compromise process if strength tests do not equal or exceed the specification requirements. One scenario was suggested in Example 17.A. Other possibilities are the Owner's test laboratory has low cylinder test results, and the producer's test results indicate the design strength criteria of Section 17 were met. Other obvious situations are apparently low strength concrete was removed and replaced, and somebody must pay for the removal and second placement, or perhaps the design engineer decides that the apparently low strength concrete may be accepted due to its specific location, but the Owner still believes a reduced price is in order because the tests indicated the concrete was below the specification requirements of Section 17. All of these scenarios can and often do lead to resolution through the Section 18 arbitration process. Even arbitration is not inexpensive but almost always is cheaper than lawsuits and courtrooms. The preference for an arbitration process in ASTM C 94/C 94M is that it offers an opportunity to bring in professionals with knowledge or a systematic process of evaluation as opposed to the legal system where the judge and/or jury may not have the technical background that could be advantageous to come to an equitable decision.

S2 suggests the best way out of a disagreement. Get the purchaser who may be the Owner or a contractor together with the manufacturer (ready-mixed concrete producer), and perhaps they or some appointed representatives can work out an agreement that each feels is either equitable or the best he will ultimately achieve financially when considering the costs of arbitration or a courtroom battle. Typically the lawyers get the best of the latter scenario unless the dispute involves many tens of thousands of dollars.

If mutual agreement is not possible, **S2** directs an arbitration panel of three qualified engineers. Qualified can take on a broad meaning. The dictionary definition is: 1) "fitted (as by training or experience) for a given purpose: competent; 2) having complied with the specific requirements or precedent conditions (as for an office or employment): eligible." The implication is that the panel will be composed of three individuals who know something about concrete, concrete construction, and concrete testing, but they do not need to be an expert in each phase. As engineers, they should each have been trained in the assembly of facts and an orderly assessment of those facts to reach a logical conclusion. The greater knowledge they have of the key elements, the quicker the case may be presented, but a good mechanical engineer or geotechnical engineer, for example, may be perfectly competent or even desirable to sit on the panel. Competent and eligible do not necessarily mean a civil engineer. Arbitrating parties have the right to impartial and independent judgment. A neutral and unbiased arbitrator possessing the ability to understand a technical presentation, evaluate the facts as presented, and vote with conviction based upon these facts is an asset to any such proceeding. A civil engineer with limited field experience or considerable experience in only one aspect of concrete may have preconceived ideas that are detrimental to an unbiased examination of the facts presented. A prospective arbitrator, whether or not a civil engineer, should always abide by professional ethics to consider and decide if the knowledge and ability are present to allow for a satisfactory process and decision. A knowledge of concrete, concrete production, concrete construction, and possibly testing will be needed, but the arbitrators do not need to be experts in these fields. Lawyers usually remain involved, and it is their job to make sure the arbitration panel fully understands their client's view of the problem. Expert witnesses to explain specific facts and to advance their professional and personal views will often testify for each of the arbitrating parties. An ability to evaluate properly the testimony of expert witnesses is an important part of an arbitrator's job. The true expert witness is not an advocate but responds to questions with the entire truth; unfortunately this does not always occur. Neville [74] reports a judge once asking an expert witness, "Would you hold the same views if you were retained by the other side to the dispute?"

S2 further tells how the panel will be selected. The purchaser selects one panelist, individual A, and the manufacturer selects one panelist, individual B. Individuals A and B will now confer and mutually agree on a third panelist, individual C. Now, when A and B are selected, the purchaser and manufacturer are each hoping that their selected individual will favor their interests, but the intended purpose is that these friendships are put aside to rule based upon evidence and facts. Each arbitrator will in fact take an oath to act in this fashion.

S2 does not suggest arbitration; it commands arbitration if the dispute cannot be settled by the involved parties. "A decision shall be made by..." cannot be interpreted any other way but as a command.

Whether everyone is bound by the command is a legal question that will vary with circumstances. ASTM C 94/C 94M is typically a referenced document in an Architect/Engineer's (A/E's) specification. Thus, ASTM C 94/C 94M forms a portion of the contract documents binding the owner and contractor to Section 18. The manufacturer may or may not be bound to arbitration depending upon the agreement between contractor and manufacturer, be it a subcontract, purchase order, or verbal agreement. In most instances, the manufacturer will be bound in this situation.

When there is no contract for sales of concrete to knowledgeable contractors, it becomes an arbitration gray area that can certainly depend upon the circumstances and the background of both the manufacturer and the contractor.

If the purchaser is a consumer who has ordered concrete to be put in a paved driveway and parking space at his residence, it becomes doubtful if arbitration is binding. Even if the delivery ticket's small print involves the term ASTM C 94/C 94M, a user of this background is not expected to have advance knowledge of ASTM C 94/C 94M.

The best part is that arbitration is usually looked upon favorably as a means of settlement rather than a court proceeding. Arbitration is quicker, cheaper, and a means of deciding a dispute on the merits by knowledgeable professionals rather than a jury of virtual unknowns.

S3 states that the arbitrators have complete authority in deciding how the costs of arbitration will be assigned to the involved parties. These costs include fees and expenses for the panel of arbitrators, plus costs for hearing rooms, court recorders, and other expenses incurred in the arbitration process. The expenses considered by the arbitrators would not normally include the fees for attorneys hired by the involved parties.

S4 contains two parts. The arbitration is binding unless contested and overruled or modified in legal action. The arbitration usually does not preclude the possibility of court action if the losing party believes the judgment was wrong and desires to take the disagreement further; or if the winner received a monetary award for less than expected and believes a better judgment will be received in a civil court.

Legal action will not often prevail. Most states have adopted or adopted with modification, the Uniform Arbitration Act [62] or a previous version of this Act, which was promulgated in 1955 by the National Conference of Commissioners on Uniform State Laws. The Uniform Arbitration Act sets forth rules that encourage arbitration rather than lawsuits. These rules extend from compelling reluctant parties into arbitration when contracts contain language, such as in ASTM C 94/C 94M, to providing civil action subpoena power to the arbitrators, to defining the grounds for vacating or modifying an award.

Awards can only be annulled for such acts as corruption or fraud, evidence of partiality by an arbitrator or legal arguments, such as the arbitration panel refusing to hear evidence pertinent to the controversy or refusing to postpone the hearing when the reasons presented would normally be considered sufficient by legal standards. The rules set forth in the Uniform Arbitration Act tend to support the original award unless there is evidence the panel acted improperly. If the award is vacated, the rules tend to send the controversy back to a new arbitration panel if there was legal standing initially for arbitration, such as Section 18 of ASTM C 94/C 94M.

Modifications of arbitration awards have relatively short action periods, and again the court is limited in its action by the rules of the Uniform Arbitration Act. The action of modification is primarily directed at monetary values of an award. The modification may be appropriate for such items as mathematical errors in the written award or the arbitrators awarding upon a matter not actually submitted to them.

A few items have been presented that could cause binding arbitration to be modified or overturned but, as mentioned, the courts approve of arbitration. They are therefore reluctant to modify awards without very good reason.

19

Keywords

19.1 *accuracy; blended hydraulic cement; certification; ready-mixed concrete; scales; testing*

Keywords are significant words from the specification. These are used by ASTM and perhaps others in computer or subject searches regarding the content of this standard. As ASTM C 94/C 94M is periodically revised, the list of keywords may also be revised. The chosen keywords are believed by the C 09.40 subcommittee to best represent this specification for ready-mixed concrete in a keyword index.

An example of the use of keywords follows:

On the ASTM website: http://www.astm.org/, a menu is immediately displayed of over 12 subjects, of which one of the choices is "Standards".

1. Click on **"Standards"**.
2. Go to **Search Standards,** and locate space designated as **"Enter Designation or Keyword"**.
3. At **Keyword** → Enter one of keywords of 19.1, such as **"ready-mixed concrete"**.
4. Click on **"Designations, Titles, Scopes, and Terms"**.
5. Click on **Search**.
6. Select **C 94/C 94M** and click on it. A summary of this specification and documents referenced within ASTM C 94/C 94M appear on the computer monitor as do the price and instructions to obtain a complete copy of the latest standard. An option available on the ASTM website is suggested language to be used when citing ASTM C 94/C 94M in a project document. If you used a keyword such as "scales" which is common to many standards, a list of five matching results will appear. The one you want may not be among them.
   a. Click on "Show All Results" (A long list of possible standards will appear from which select and click on "C94/C 94M").

Annex (Mandatory Information)

20

A1.1 $_{S1}$ *The variation within a batch as provided in Table A1.1 shall be determined for each property listed as the difference between the highest value and the lowest value obtained from the different portions of the same batch.* $_{S2}$ *For this specification, the comparison will be between two samples, representing the first and last portions of the batch being tested.* $_{S3}$ *Test results conforming to the limits of five of the six tests listed in Table A1.1 shall indicate uniform concrete within the limits of this specification.*

When a batch or load of concrete is tested for uniformity, the properties tested from each of the two samples are not required to match each other exactly. The range between the high test value and the low test value may equal but not exceed the value indicated in Table A1.1. The language here is "the different portions of the same batch". The high and low test values do not allow testing three or four samples and tossing out the tests with undesirable results. Use the values obtained for each of the two samples. **S2** is very specific that two samples will be used—no more and obviously no less. Within ASTM C 94/C 94M, every reference to the uniformity test indicates that the two samples shall be taken after the discharge of approximately 15 % and 85 %. Note 14 (following Section 10.4) is explicit that none of the samples shall come before discharge of 10 % of the batch or after 90 % of the batch has been discharged. Mixing uniformity requirements are pertinent to truck mixers for both truck-mixed and shrink-mixed concrete or for plant mixers for central mixed concrete as discussed in Section 11, since these are the methods of mixing the raw ingredients to produce concrete.

S3 states the pass-fail limits for mixing uniformity. Pass any five of the six tests, and the equipment being checked is considered capable of producing a homogeneous batch of concrete. It does not matter which five tests of the six meet the requirements of Table A1.1.

A1.2 Coarse Aggregate Content, *using the washout test, shall be computed from the following relations:*

$$P = (c/b) \times 100 \qquad (A1.1)$$

where:

P = *mass % of coarse aggregate in concrete,*
c = *saturated-surface-dry mass in lb [kg] of aggregate retained on the No. 4 [4.75-mm] sieve, resulting from washing all material finer than this sieve from the fresh concrete, and*
b = *mass of sample of fresh concrete in mass per unit volume container, lb [kg].*

A1.3 Mass per Unit Volume of Air Free Mortar *shall be calculated as follows:*

Inch-pound units:

$$M = \frac{b - c}{V - \left(\frac{V \times A}{100} + \frac{c}{G}\right)} \qquad (A1.2)$$

SI units:

$$M = \frac{b - c}{V - \left(\frac{V \times A}{100} + \frac{c}{G}\right)} \qquad (A1.3)$$

where:

M = *mass per unit volume of air-free mortar, lb/ft^3 [kg/m^3],*
b = *mass of concrete sample in mass container, lb [kg],*
c = *saturated-surface-dry mass of aggregate retained on No. 4 [4.75-mm] sieve, lb [kg],*
V = *volume of mass per unit volume container, ft^3 [m^3],*
A = *air content of concrete, %, measured in accordance with 15.1.4 on the sample being tested, and*
G = *density of coarse aggregate (SSD).*

The size of each sample should be close to 2 cubic feet, which is about the manageable capacity of a wheelbarrow. The six test values stated in Annex Table A1.1 in the order of appearance within the table, plus some formula items, have been given shorter descriptions and letter designations for purposes of formulas, discussion, and example (Table 20.A).

The slump tests must be performed first in accordance with ASTM C 172 time limits for beginning tests. Assuming the air content determination will be accomplished by the pressure method, the air-meter base is filled next. Before the air content is determined, the concrete density (unit weight) test is performed. This concrete density (D) test is very critical, and extreme care is essential, especially in the use of the strike-off plate for surface preparation. Following careful surface preparation and cleaning off excess concrete, the air-meter base is weighed, and then the air-content test (A) is completed using the pressure method. The concrete compressive strength cylinders are then molded, and the sample from the concrete density test is washed over a 4.75-mm [No. 4] sieve as the last physical test. The Bureau of Reclamation [17] suggests the use of the ASTM C 231 air-meter base material for the coarse aggregate sieve analysis on the 4.75-mm (No. 4) sieve. By ASTM C 136 standards [ASTM Test Method

TABLE A1.1—*Requirements for uniformity of concrete.*

Test	Requirement, Expressed as Maximum Permissible Difference in Results of Tests of Samples Taken from Two Locations in the Concrete Batch
Mass per cubic foot [mass per cubic meter] calculated to an air-free basis, lb/ft^3 [kg/m^3]	1.0 [16]
Air content, volume % of concrete	1.0
Slump:	
If average slump is 4 in. [100 mm] or less, in. [mm]	1.0 [25]
If average slump is 4 to 6 in. [100 to 150 mm], in. [mm]	1.5 [40]
Coarse aggregate content, portion by mass of each sample retained on No. 4 [4.75-mm] sieve, %	6.0
Mass per unit volume of air-free mortar [A] based on average for all comparative samples tested, %.	1.6
Average compressive strength at 7 days for each sample, [B] based on average strength of all comparative test specimens, %	7.5 [C]

[A] "Test for Variability of Constituents in Concrete," Designation 26, *Bureau of Reclamation Concrete Manual,* 7th ed. (available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402).
[B] Not less than three cylinders will be molded and tested from each of the samples.
[C] Approval of the mixer shall be tentative, pending results of the 7-day compressive strength tests.

TABLE 20.A—*Discussion, abbreviations, and comments on tests.*

Item	ID	Units	Method of Determination
Concrete Density (unit wt.) (air-free)	$\mathbf{D_{af}}$	lb/ft^3	calculated
Air Content	**A**	%	measured
Slump of concrete 4 in. or less	$\mathbf{S_1}$	in.	measured
Slump of concrete 4–6 in.	$\mathbf{S_2}$	in.	measured
Coarse aggregate content	**ca**	%	measured
Mortar Density (unit wt.) (air-free)	**M**	%	calculated
Compressive strength (average 7 day)	$\mathbf{F_{avg}}$	psi	measured
Density (unit weight) of concrete*	**D**	lb/ft^3	measured
Volume of density bucket†‡	$\mathbf{V_D}$	ft^3	measured
Mass (weight) of density bucket†‡	$\mathbf{W_D}$	lb	measured
Air-free volume of concrete†	$\mathbf{A_V}$	ft^3	calculated

* Not a direct comparative value.
† These items are only used for calculations.
‡ Density bucket and air-meter base will sometimes be the same container and become interchangeable in computations.

for Sieve Analysis of Fine and Coarse Aggregates (C 136)], the coarse aggregate sample is somewhat small, less than 22 lb for a sample with a nominal maximum size of 1 in., but the standards actually set no minimum sample size for this coarse aggregate washout test. The Bureau of Reclamation has recommended the concrete sample from the ASTM C 231 air test be used, and it has stood the scrutiny of time [17].

Alternatively, it may be desirable to use a larger unit-weight container and possibly a different air content determination method such as ASTM Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method (C 173/C 173M). When a larger ASTM C 138/C 138M container is used for unit weight or the air is determined by ASTM C 173/C 173M, the air content is determined immediately after the slump test and then the cylinders molded before the ASTM C 138/C 138M density (unit weight) test. The coarse aggregate content of the sample is determined using the material from the ASTM C 138/C 138M measurement that is then washed on a 4.75-mm sieve.

The ASTM C 231 pressure air-meter base cannot be used for the density (unit weight) determination of concrete when the nominal maximum size of aggregate exceeds 1 in. (see Table 1 of ASTM C 138/C 138M). ASTM C 172 provides for removal by wet-sieving of larger aggregate from the mixture prior to testing, but this procedure is not recommended by ASTM C 231 for air content determinations, unless aggregates exceed a 2 in. maximum size. For a maximum aggregate size greater than 1 in. nominal maximum, the concrete density (unit weight) test can no longer be performed in the base of the ASTM C 231 air meter. A larger density (unit weight) bucket is required. It is also acceptable to take a separate portion of each sample that is not for the air content or density (unit weight) measurements to determine the coarse aggregate content. It is suggested that the weight of the portion of the concrete sample should be at least 25 lb before it is washed over the sieve.

The Bureau of Reclamation Concrete Manual, 7th and 8th Editions [17,18] each contain the same numerical calculation example when removing large aggregate by wet sieving for the mixing uniformity test. The presentation methods differ slightly, but each are identified as Appendix, Designation 26.

A1.2 and **A1.3** contain formulas which will be utilized in an example of uniformity testing.

Batch Characteristics

The batch size for either stationary mixers or truck mixers should be the maximum volume proposed for production and not necessarily at the maximum rated mixing capacity of the unit. It is a common practice, particularly in truck mixers located in hilly or mountainous terrain, to size mixers larger than the usual maximum load. The extra volume is needed to prevent spills on uphill pulls. Using a smaller than normal maximum batch size to have the two samples closer together does not provide proof of the mixing capabilities of the unit. Mixing times for stationary mixers should be carefully recorded on the uniformity test calculation sheet. The minimum time required to achieve uniformity is an important part of this test. With truck mixers, it is recommended that at least 70 revolutions, and preferably the full 100 mixing revolutions permitted, be used unless a special project will limit drums to fewer revolutions.

Unless the uniformity tests are strictly for a project or geographic area not requiring air entrainment, it is recommended that an air-entrained mixture be used because the ability to generate the required quantity of air throughout the mixed concrete is an important part of this evaluation.

EXAMPLE 20.A—*Uniformity test.*

Having just one person to do all the recording of test results and to maintain the timing for the testing schedule is helpful. Not less than two certified technicians are essential. If the testing technicians work as a team, the most efficient procedure is to allow each technician to perform the same tests on each sample and thereby remove the potential variance of different technicians producing varying test results.

Slump: This is the only one of the six tests which has a variable requirement depending on the level of slump. When the **average** value of the two slump tests is 4 in. or less, the maximum allowable difference between the test results is 1 in. When the average value of the two slump tests is 4–6 in., the allowable difference increases to 1.5 in. When the average slump value is greater than 6 in., the batch is not acceptable for uniformity testing. At the high slump, the concrete is beginning to get sloppy and difficult to sample properly for this critical uniformity test.

Test No. 1 slump = 3.00 in.
Test No. 2 slump = 4.25 in.
Average slump ($\mathbf{S_1}$) = 3.625 in. (3 ⅝ in.)
Difference = **1.25 in. > 1 in. NG**

The average slump value of 3.625 in. is less than 4 in., thus the uniformity requirement is a maximum difference of 1 in. (see Table A1.1). The measured difference is 1.25 in., meaning the slump difference is greater than permitted, and slump failed in this uniformity test.

Air Content: The pressure meter has been found to produce the most consistent results (lowest standard deviation) of any of the air content determination tests. Therefore ASTM C 231 is the preferred test method if the type of aggregate in the concrete permits it to be used. ASTM C 231 cannot be used to test the air content of concretes made with lightweight aggregates, air-cooled blast furnace slag, or aggregates of high porosity.

Example:

Test No. 1 air content = 4.5 %
Test No. 2 air content = 5.1 %
Difference = **0.6 %**

The difference of 0.6 % is less than the allowable difference of 1.0 %. The air-content test meets mixing uniformity requirements of Table A1.1.

Density of Concrete (Unit Weight): Using the base section of the pressure air meter, the density is determined by measuring the mass of (weighing) the meter base while empty and then again after being properly filled and the top surface prepared, but prior to completing the assembly of the top section for the air content determination. The air meter base will have a volume of approximately ¼ ft^3 and will weigh approximately 10 lb. The scales are required to be accurate to 0.1 lb or to within 0.3 % of the test load, whichever is greater, at any point within the range of use. For a 10-lb tare weight, this is 0.1 lb versus 0.03 lb. The 0.1 lb minimum accuracy is the control. Older field scales may not meet the accuracy criterion. Predetermine (calibrate) the volume of air meter base in accordance with procedures described in ASTM C 29/C 29M.

Example:

Item		Sample No. 1	Sample No. 2
Concrete + $\mathbf{W_D}$ (density measure)	(lb)	45.22	44.86
$\mathbf{W_D}$ (density measure) mass	(lb)	9.68	9.68
Concrete = **b**	(lb)	35.54	35.18
$\mathbf{V_D}$ = Volume of base	(ft^3)	0.25	0.25
Density of Concrete (unit weight)			
$\mathbf{D} = \mathbf{b} \div \mathbf{V_D}$			
D = 35.54 ÷ 0.25 (Test No.1)	(lb/ft^3)	**142.16**	
D = 35.18 ÷ 0.25 (Test No. 2)	(lb/ft^3)		**140.72**

Note: Scale readings in 0.1 lb increments are acceptable.

Density of Concrete (air-free): The air content of the two samples has already been determined. By calculating the concrete density of each sample on an air-free basis, the effect of the different air contents of each sample is removed from this calculation so that the composition of the samples in terms of density can be compared.

The density of concrete on an air-free basis can be calculated using:

$$D_{af} = \frac{D}{100 - A} \times 100$$

where: D_{af} is the density on an air free basis, D is the measured density, and A is the air content in percent.

From previous calculations:

		Sample No. 1	Sample No. 2
Density, **D**	(lb/ft^3)	142.16	140.72
Air content	%	4.5	5.1
Density on an air-free basis, $\mathbf{D_{af}}$		$\frac{142.16}{100 - 4.5} \times 100$	$\frac{140.72}{100 - 5.1} \times 100$
$\mathbf{D_{af}}$	(lb/ft^3)	148.86	148.28
Difference	(lb/ft^3)	148.86 – 148.28 = **0.58**	

A difference of only 0.58 lb/ft^3 is good. The allowable difference is 1.0 lb/ft^3. This is the second of three uniformity values that is within allowable tolerances.

Coarse aggregate content (%): Use the density (unit weight) sample to determine coarse aggregate content. It does not matter that the ASTM C 231 air test contaminated the sample with water because the washing process occurs before anything else is done to the sample. Wash the entire sample over a 4.75-mm [No. 4] sieve. The portion of the sample that is retained on the 4.75-mm sieve must be saved meticulously, while the portion passing the 4.75-mm sieve may be wasted. If the uniformity test is not a regularly performed test, it is usually accomplished by hand shaking the 4.75-mm sieve. For frequent uses or checking a large number of mixers, a large tray type mechanical shaker with a spray bar will speed up the process. Wipe the retained coarse aggregate surface dry, and then determine the mass in air. Alternatively, the wet material may be weighed while suspended in water and the saturated surface dry (SSD) mass computed using a previously determined SSD density (sp gr). The 4.75-mm sieve represents the separation point between coarse and fine aggregate. Annex section A1.2 provides the formula for this computation.

	Sample No. 1	Sample No. 2
Mass of SSD aggregate retained on 4.75-mm (No. 4) sieve (lb)	16.63	15.70
Percent Coarse Aggregate, P = c/b × 100	$\left(\frac{16.63}{35.54}\right) \times 100$	$\left(\frac{15.70}{35.18}\right) \times 100$
P (%)	**46.8**	**44.6**
Difference (%)	(46.8 – 44.6) = **2.2**	

The difference of 2.2 % is less than the allowable difference of 6.0 %. The coarse aggregate content meets the mixing uniformity requirements.

Mortar Unit Weight (air-free): This is a means of determining differences in mortar properties of the two samples. The coarse aggregate has been physically removed, and calculations have been corrected for the measured air content, leaving only cementitious materials, fine aggregate, and water. Tests by Bloem, Gaynor, and Wilson [13] at the NRMCA determined that differences of more than 1 lb/ft^3 in this test indicated substantial variations in the mortar proportions and recommended that a difference of 2 lb/ft^3 in the air-free mortar density value represented changes in mixture composition that are unacceptable.

The saturated-surface-dry relative density (specific gravity) of the coarse aggregate is a final test value needed to perform the mortar density (unit weight) calculations. This value may be predetermined in the laboratory by ASTM C 127 or by a submerged determination of the mass (weighing) of the coarse aggregate procured from the mixing uniformity test, percent coarse aggregate determination. This value may also be available from aggregate test data furnished by the aggregate supplier. Use the formula of Annex section A1.3 for calculations.

Relative Density of coarse aggregate is 2.60 as predetermined.

$$M = \frac{b - c}{V - \left(\frac{V \times A}{100} + \frac{c}{G}\right)}$$

$$\text{Sample 1: } M = \frac{35.54 - 16.63}{0.25 - \left(\frac{0.25 \times 4.5}{100} + \frac{16.63}{2.60 \times 62.3}\right)}$$

$$M = \frac{18.91}{0.25 - (0.0113 + 0.1027)} = \frac{18.91}{0.1360} = 139.04 \text{ lb/ft}^3$$

$$\text{Sample 2: } M = \frac{35.18 - 15.70}{0.25 - \left(\frac{0.25 \times 5.1}{100} + \frac{15.70}{2.60 \times 62.3}\right)}$$

$$M = \frac{19.48}{0.1403} = 138.85 \text{ lb/ft}^3$$

To view this formula in perspective, look at the parts as objects and volumes.

$$\text{Mortar (lb/ft}^3) = \frac{\text{Concrete mass} - \text{Coarse aggregate mass}}{\text{Vol. of density measure} - \text{Vol. of air} - \text{Vol. of coarse aggregate}} = \frac{\text{lb}}{\text{ft}^3}$$

The **alternate solution of determining the Mortar Density (Air-free)** using the field materials without a predetermined relative density (specific gravity) is now illustrated. The apparent mass of the Sample No. 1 coarse aggregate while submerged in water is 10.23 lb. Use the formula in ASTM C 127 to compute the Relative Density (Specific Gravity) (SSD) of the coarse aggregate:

$$\text{Relative Density (SSD)} = \frac{\text{Mass of SSD sample in air}}{\text{Mass of SSD sample in air} - \text{Mass of Sample when immersed in water}}$$

$$\text{Relative Density (SSD)} = \frac{16.63}{16.63 - 10.23} = 2.60$$

(Sample No. 1)

Proceed with the calculations for **M** without any predetermined values for specific gravity. For Test No. 2, the submerged mass of coarse aggregate from the field measurements will be used for computations. In practice, it is better to use the same method for both tests.

(Sample No. 2)

Mass of aggregate retained on the 4.75 mm sieve (SSD in air) = 15.70 lb.
Apparent mass of aggregate when immersed in water = 9.66 lb.

$$\text{Relative Density (SSD)} = \frac{15.70}{15.70 - 9.66} = 2.599 \text{ (Use 2.60)}$$

$$M = \frac{35.18 - 15.70}{0.25 - \left(\frac{0.25 \times 5.1}{100} + \frac{15.70}{2.60 \times 62.3}\right)}$$

$$= \frac{19.48}{0.25 - (0.128 + 0.969)}$$

$$M = \frac{19.48}{0.1403} = 138.85 \text{ lb/ft}^3 \quad \text{(Sample No. 2)}$$

The difference in Mortar Unit Weight computed on an air-free basis is (139.04 – 138.85) = 0.19 lb/ft^3.
The average of the two tests is **138.94 lb/ft^3**.
Percentage difference is (0.19 ÷ 138.94) × 100 = **0.14% < 1.6% (OK)**

TABLE 20.B—*Summary of uniformity test.*

Property Tested		Sample No. 1	Sample No. 2	Difference Between Samples	Maximum Permissible Difference	Remarks
Slump	in.	3.00	4.25	1.25 >	1.0 in.	Fails
Air content	%	4.5	5.1	0.6 <	1.0 %	Passes
Density of concrete (air-free)	lb/ft^3	148.86	148.28	0.58 <	1.0 lb/ft^3	Passes
Coarse aggregate in concrete	%	46.8	44.6	2.2 <	6.0 %*	Passes
Mortar density (air-free)	lb/ft^3	139.04	138.85	0.14 <	1.6 %†	Passes
7-day compressive strength	psi	5318	5117	3.85 <	7.5 %‡	Passes

* Allowable variance is a percent of coarse aggregate segment of sample.
† Allowable variance is a percent of air-free density of mortar.
‡ Allowable variance is a percent difference in compressive strengths.

Four of the five tests have met the mixing uniformity criteria. According to Note C of Annex Table A1.1, the approval of the mixer shall be tentative, pending results of the 7-day compressive strength tests. A tentative status is established in the event the 7-day tests do not meet mixing uniformity criteria: the mixer will not have met five criteria, only four, and will have failed.

7-Day Compressive Strength: Note B to Annex Table A1.1 requires that not less than three cylinders will be molded from each sample. More than three are permissible, but the same number must be molded from each sample. A different number of cylinders from each sample could unfavorably skew the test results because the allowable percentage of difference is based upon the average of all test results. These specimens shall be cured in accordance with ASTM C 31/C 31M. Just as important is that all the cylinders from each mixer tested shall be kept close together to ensure that cylinders from both samples receive identical curing. Identical curing is absolutely necessary.

7-day Compressive Strength Results	Sample No. 1	Sample No. 2
Cylinder 1	5473 psi	5006 psi
Cylinder 2	5118 psi	5137 psi
Cylinder 3	5364 psi	5209 psi
Average of 3 cylinder tests = f_{av} =	**5318 psi**	**5117 psi**

Difference (psi)	(5318–5117) = 201 psi
Average of **all** cylinder tests	5218 psi
% Difference	$\frac{201}{5218} \times 100 = \mathbf{3.85\ \% < 7.5\ \%}$ **OK**

The difference of 201 psi is used in conjunction with the average of all cylinders, 5218 psi to compute the actual percent difference of 3.85 %.

The mixer of Example 20.A—Uniformity test passes five of the six mixing uniformity criteria and meets requirements of uniformity test. This mixer can be approved for use.

Effective June 1, 2001, mixing uniformity evaluation became a requirement for new truck mixers of similar design for mixers manufactured by members of the Truck Mixer Manufacturers Bureau as addressed in their standard TMMB 100-01.

Due to the considerable time and effort and potential waste of concrete, mixing uniformity evaluations of individual mixer units is seldom performed. Visual inspection of the inside of a mixer will indicate if worn blades or build-up of hardened concrete are excessive and adversely impact the mixer's ability to function. The configuration of the batch plant and the sequence used to batch raw ingredients into the mixer also play an important role in the ability to obtain a homogeneously mixed concrete batch.

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A.S.T.M. Standard Specifications
FOR
Ready Mixed Concrete

ADOPTED, 1935

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260 S. BROAD ST., PHILADELPHIA, PA.

STANDARD SPECIFICATIONS
FOR
READY MIXED CONCRETE[1]

A.S.T.M. Designation: C 94 – 35

These specifications are issued under the fixed designation C 94; the final number indicates the year of original adoption as standard or, in the case of revision, the year of last revision.

ISSUED AS TENTATIVE, 1933; ADOPTED IN AMENDED FORM, 1935.

Scope

1. These specifications cover requirements for the materials, proportioning, mixing, delivery, quality, inspection, testing, and acceptance of ready mixed concrete for all purposes.

Ready Mixed Concrete

2. The term ready mixed concrete is used to describe mixed concrete delivered at the work ready for use.

MATERIALS

General

3. Ready mixed concrete shall consist of a mixture of portland cement, aggregates and water, proportioned in accordance with the requirements of these specifications. Admixtures may be included with these primary ingredients when specified by, or with the permission of, the purchaser.

Cement

4. (*a*) Portland cement shall conform to the requirements of the Standard Specifications for Portland Cement (A.S.T.M. Designation: C 9) of the American Society for Testing Materials.[2]

(*b*) High-early-strength portland cement shall conform to the requirements of the Tentative Specifications for High-Early-Strength Portland Cement (A.S.T.M. Designation: C 74 – 30 T) of the American Society for Testing Materials.[3]

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[1] Under the standardization procedure of the Society, these specifications are under the jurisdiction of the A.S.T.M. Committee C-9 on Concrete and Concrete Aggregates.

[2] 1933 Book of A.S.T.M. Standards, Part II, p. 3.

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 30, Part I, p. 1016 (1930); also 1935 Book of A.S.T.M. Tentative Standards.

Aggregates

5. (*a*) Aggregates shall conform to the requirements of the Tentative Specifications for Concrete Aggregates (A.S.T.M. Designation: C 33 – 31 T) of the American Society for Testing Materials.[1]

(*b*) Frozen aggregates, or aggregates containing lumps of frozen material, shall be thawed before use.

Water

6. Water shall be free from injurious amounts of impurities. Potable water shall be considered as meeting the requirements of these specifications.

COMPOSITION OF CONCRETE

General

7. The size and type of aggregate and the quality and consistency of the concrete required for the work shall be specified by the purchaser. The manufacturer of ready mixed concrete shall determine the quantities of materials for the batch to produce concrete of the quality and consistency specified. The consistency shall be determined by the slump test, referred to in Section 26 (*a*), unless another method is specified or permitted by the purchaser.

Proportions by Volume

8. When the quality of the concrete is specified in terms of the consistency and arbitrary proportions by volume, 1 cu. ft. of cement shall be considered to weigh 94 lb., and, unless another basis is specified by the purchaser, the weight per unit of volume of the aggregates shall be based on rodded weights determined on dry materials, in accordance with the Standard Method of Test for Unit Weight of Aggregate for Concrete (A.S.T.M. Designation: C 29) of the American Society for Testing Materials.[2]

Proportions by Weight

9. When the quality of the concrete is specified in terms of the consistency and arbitrary proportions by weight, the weights of the aggregates shall be stated in terms of dry materials.

Proportions in Terms of Quantity of Cement

10. When the quality of the concrete is specified in terms of the consistency and the quantity of cement per unit of volume of concrete, 1 cu. ft. of cement shall be considered to weigh 94 lb., and the ratio by weight of the fine aggregate to the fine plus coarse aggregate shall

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 31, Part I, p. 750 (1931); also 1935 Book of A.S.T.M. Tentative Standards.

[2] 1933 Book of A.S.T.M. Standards, Part II, p. 247.

be such as to produce a plastic and workable mixture and shall not be greater than shown in Table I, unless otherwise specified by the purchaser; except that this ratio may not apply to aggregates having specific gravities less than 2.2 or greater than 3.0. Under this clause the proportions of cement to aggregate shall not be stated.

TABLE I.—LIMITING RATIO OF FINE AGGREGATE TO FINE PLUS COARSE AGGREGATE.

MAXIMUM SIZE OF GRADED AGGREGATE, IN.	MAXIMUM RATIO OF FINE AGGREGATE TO FINE PLUS COARSE AGGREGATE
2	0.40
1½	0.45
1	0.50
¾	0.55
⅜	0.60

Proportions Based on Water-Cement Ratio

11. When the quality of the concrete is specified in terms of the consistency and the ratio of quantity of mixing water to quantity of cement, the water shall include that added to the batch and the surface moisture of the aggregates, and the ratio of fine to coarse aggregate shall be such as to produce a plastic and workable mixture. Under this clause the proportions of cement to aggregate shall not be stated, except that a minimum cement content may be specified.

Proportions Based on Strength

12. When the quality of the concrete is specified in terms of the consistency and the compressive or flexural strength, at an age specified by the purchaser, the ratio of fine to coarse aggregate shall be such as to produce a plastic and workable mixture. Under this clause the proportions of cement to aggregate shall not be stated, except that a minimum cement content may be specified.

MEASURING MATERIALS

Cement

13. Cement shall be measured by weight or, if permitted by the purchaser, in full bags of 94 lb. each. When the cement is measured by weight, it shall be weighed on a scale separate from those used for the other materials; the entire contents of the hopper shall be completely discharged. When the cement is measured in bags, no fraction of bags shall be used unless weighed.

Aggregates

14. Coarse aggregates shall be measured by weight. Fine aggregates shall be measured by weight or by inundated volume in a

device approved by the purchaser. Batch weights shall be based on dry materials and shall be corrected to take into account the weight of moisture contained in the aggregates.

Water

15. Water shall be measured by volume or by weight. The device for the measurement of the water shall be readily adjustable and, under all operating conditions, shall be accurate to 0.5 per cent or less of its maximum capacity.

Admixtures

16. Powdered admixtures shall be measured by weight and liquid admixtures by weight or volume.

Weighing Hoppers and Scales

17. Weighing hoppers and scales shall conform to the Specifications and Tolerances of the American Road Builders' Association for the Bin Batcher Type of Equipment for Weighing Concrete Aggregates.[1,2]

MIXING

General

18. The mixing equipment shall be capable of combining the aggregates, cement, and water within the specified time into a thoroughly mixed and uniform mass, and of discharging the mixture without segregation.

Central Mixing Plant

19. In the case of the stationary mixers, the mixer drum shall be of adequate size to accommodate the maximum batch, and shall be in accordance with the Concrete Mixer Standards adopted by the Mixer Manufacturers' Bureau of the Associated General Contractors of America. The mixer shall be rotated at the rate recommended by its manufacturer. Provision shall be made at the mixer to insure that the concrete is not discharged until the specified mixing time has elapsed. The mixing time shall be measured from the time that all cement and aggregates are in the mixer. The batch shall be so charged into the mixer that some water shall enter in advance of cement and aggregate, and shall continue to flow for a period which may extend to the end of the first one third of the specified mixing time. When the central mixing plant is depended upon for the complete mixing, the minimum mixing time for mixers of 1-cu. yd. capacity or less shall be not less than 1 minute; for larger capacities of mixers this

[1] Am. Road Builders' Assn., *Bulletin 15*, Section I, Part 1 (1931).

[2] The essential requirements outlined in *Bulletin 15* have been adopted by the American Association of State Highway Officials.

mixing time shall be increased at the rate of 15 seconds or more for each cubic yard, or fraction thereof, additional capacity. When the concrete is transported in an agitator, the size of batch shall not exceed the rated capacity of the agitator as stated by the manufacturer, and as stamped in metal at a prominent place on the equipment. When the agitator is provided with adequate mixing blades, the mixing time at the central mixer may be reduced to the minimum required to incorporate the ingredients of the mixture into a mass and the mixing completed in the agitator; under these circumstances all ingredients for a batch shall be in the mixer and properly incorporated before any concrete is discharged to the agitator and each batch of concrete shall be mixed in the agitator for 50 revolutions or more.

Truck Mixing

20. In the case of truck mixers, the size of batch shall not exceed the maximum rated capacity of the mixer as stated by the manufacturer and as stamped in metal at a prominent place on the mixer. The mixer shall be water-tight when closed. Each batch of concrete shall be mixed not less than 50 nor more than 150 revolutions of the mixer at the rate of rotation specified by the manufacturer as mixing speed. Additional mixing, if any, shall be done at a slower speed specified by the manufacturer for agitation. Except as subsequently provided, the truck mixer shall be equipped with a tank for carrying the mixing water; the water shall be measured and placed in the tank at the proportioning plant, unless the tank is equipped with an automatic measuring device of the required accuracy and capable of being locked. The mixing water may be added directly to the batch, except as limited by Section 22, in which case a tank shall not be required.

DELIVERY

General

21. Concrete shall be hauled in a water-tight container in which segregation will not take place and from which the concrete can be discharged freely and shall be delivered to the work at the consistency specified.

Time of Hauling

22. Concrete shall be delivered to the site of the work, and discharge from the hauling container shall be completed within a period of $1\frac{1}{2}$ hr. after the introduction of the mixing water to the cement and aggregates, or the cement to the aggregate when the fine aggregate contains moisture in excess of 6 per cent by weight and the coarse aggregate contains moisture in excess of 3 per cent by weight.

Temperature

23. Concrete delivered in out-door temperatures lower than 40 F. (5 C.) shall arrive at the work having a temperature not less than 60 F. (15 C.), nor greater than 100 F. (38 C.), unless otherwise specified or permitted by the purchaser.

INSPECTION

General

24. Proper facilities shall be provided for the purchaser to inspect ingredients and processes used in the manufacture of the concrete either at the mixing plant, loading plant or point of delivery. The manufacturer shall afford the inspector representing the purchaser, without charge, all reasonable facilities for securing samples to determine if the concrete is being furnished in accordance with these specifications. All tests and inspections shall be so conducted as not to interfere unnecessarily with the manufacture and delivery of the concrete.

Samples

25. (*a*) Samples of concrete taken for the purpose of determining if the concrete conforms to the requirements of these specifications shall be secured at the point of delivery during the discharge of the batch.

(*b*) Each sample of concrete for strength tests shall consist of not less than one cubic foot made up of portions obtained from not less than three points within the batch.

METHODS OF TESTING

Methods of Testing

26. Tests of the concrete shall be carried out in accordance with the following methods of the American Society for Testing Materials:

(*a*) *Consistency.*—The consistency of the concrete, unless otherwise specified or permitted by the purchaser, shall be measured by the slump determined in accordance with the Tentative Method of Test for Consistency of Portland-Cement Concrete (A.S.T.M. Designation: D 138 – 32 T).[1]

(*b*) *Compression Tests.*—Compression test specimens of concrete shall be molded, cured, and tested in accordance with the Standard Method of Making and Storing Compression Test Specimens of Concrete in the Field (A.S.T.M. Designation: C 31),[2] except that

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 32, Part I, p. 775 (1932); also 1935 Book of A.S.T.M. Tentative Standards.

[2] 1933 Book of A.S.T.M. Standards, Part II, p. 225.

Section 7 (*b*) shall not apply for specimens used as the basis for acceptance.

(*c*) *Flexure Tests.*—Flexure test specimens of concrete shall be molded and tested in accordance with the Tentative Laboratory Method of Making Flexure Tests of Concrete, Using a Simple Beam with Center Loading (A.S.T.M. Designation: C 78 – 30 T).[1] The samples of concrete shall be obtained and the specimens cured in accordance with the method described for compression tests in the Standard Method of Making and Storing Compression Test Specimens of Concrete in the Field (A.S.T.M. Designation: C 31),[2] except that Section 7 (*b*) shall not apply for specimens used as the basis for acceptance.

ACCEPTANCE AND REJECTION

Consistency

27. (*a*) The concrete shall be considered to have conformed to the consistency requirements of these specifications if the average consistency of three determinations of the slump on a single sample is within 20 per cent of the consistency specified.

(*b*) The slump test for consistency shall be made as often as required by the purchaser.

Strength

28. (*a*) Concrete shall be considered to have conformed to the strength requirements of these specifications if the average strength of all specimens tested is equal to or greater than the strength specified and if the number and concordance of the strength tests conform to the requirements of Paragraphs (*b*) to (*e*).

(*b*) The number of strength tests shall be determined by the purchaser, except that, if acceptance or rejection is based on Paragraph (*a*), not less than the number of tests shown in the following table shall be made:

Total Cubic Yards of Concrete Delivered on Job	Number of Strength Tests
0 to 100	One for each 50 cu. yd.
101 to 1000	One for each 125 cu. yd.
1001 to 2000	One for each 175 cu. yd.
2001 and over	One for each 250 cu. yd.

(*c*) A test shall consist of the average of two or more standard specimens made from a single sample. Results from obviously

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 30, Part I, p. 1027 (1930); also 1935 Book of A.S.T.M. Tentative Standards.

[2] 1933 Book of A.S.T.M. Standards, Part II, p. 225.

faulty, defective or improperly cured specimens shall be disregarded in determining the average.

(*d*) At least 90 per cent of all strength tests shall be equal to or greater than 90 per cent of the strength specified.

(*e*) The strength tests shall be carried out under the supervision of a qualified engineer mutually agreed upon by both the manufacturer and purchaser.

NOTE.—The question of payment for the strength tests shall form a part of the contract between the purchaser and the manufacturer.

Alternate Strength Basis

29. The provisions of Section 28 may be waived, at the option of the purchaser, if the manufacturer can produce evidence satisfactory to the purchaser that concrete of the proportions proposed for use will furnish the specified strength. Under this clause the concrete shall be considered to have conformed to the requirements for strength if these proportions are maintained throughout the work.

Retest

30. (*a*) When Section 28 is used as the basis for acceptance, if the concrete fails to conform to the requirements of that section, the manufacturer shall have the right to test specimens cut from the structure. Such specimens shall be obtained in accordance with the Standard Methods of Securing Specimens of Hardened Concrete from the Structure (A.S.T.M. Designation: C 42)[1] and tested in accordance with Sections 19, 20 and 21 of the Standard Methods of Making Compression Tests of Concrete (A.S.T.M. Designation: C 39) of the American Society for Testing Materials.[2]

(*b*) Specimens cut from the structure shall be obtained and tested within a period of 60 days after placing the concrete. The specimens shall be tested in a saturated condition and no correction shall be made for the age of the concrete.

(*c*) The tests shall be carried out under the supervision of a qualified engineer mutually agreed upon by both the manufacturer and purchaser, and the costs of the tests shall be borne by the manufacturer.

(*d*) The concrete shall be considered as conforming to the requirements of these specifications if the average strength of the specimens cut from the structure is equal to or greater than the specified strength, and at least 90 per cent of all tests are equal to or greater than 90 per cent of the specified strength.

[1] 1933 Book of A.S.T.M. Standards, Part II, p. 238.
[2] *Ibid.*, p. 230.

Measurement of Concrete

31. The basis of measurement of the concrete shall be the cubic yard. The quantity of concrete produced by a given combination of materials may be determined by measurement in a standard measure or may be calculated from the absolute volumes of the separate ingredients as determined from the weight of each used in a batch and its specific gravity. When the latter method is used, proper correction shall be made for the free and absorbed moisture content of the aggregate.

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