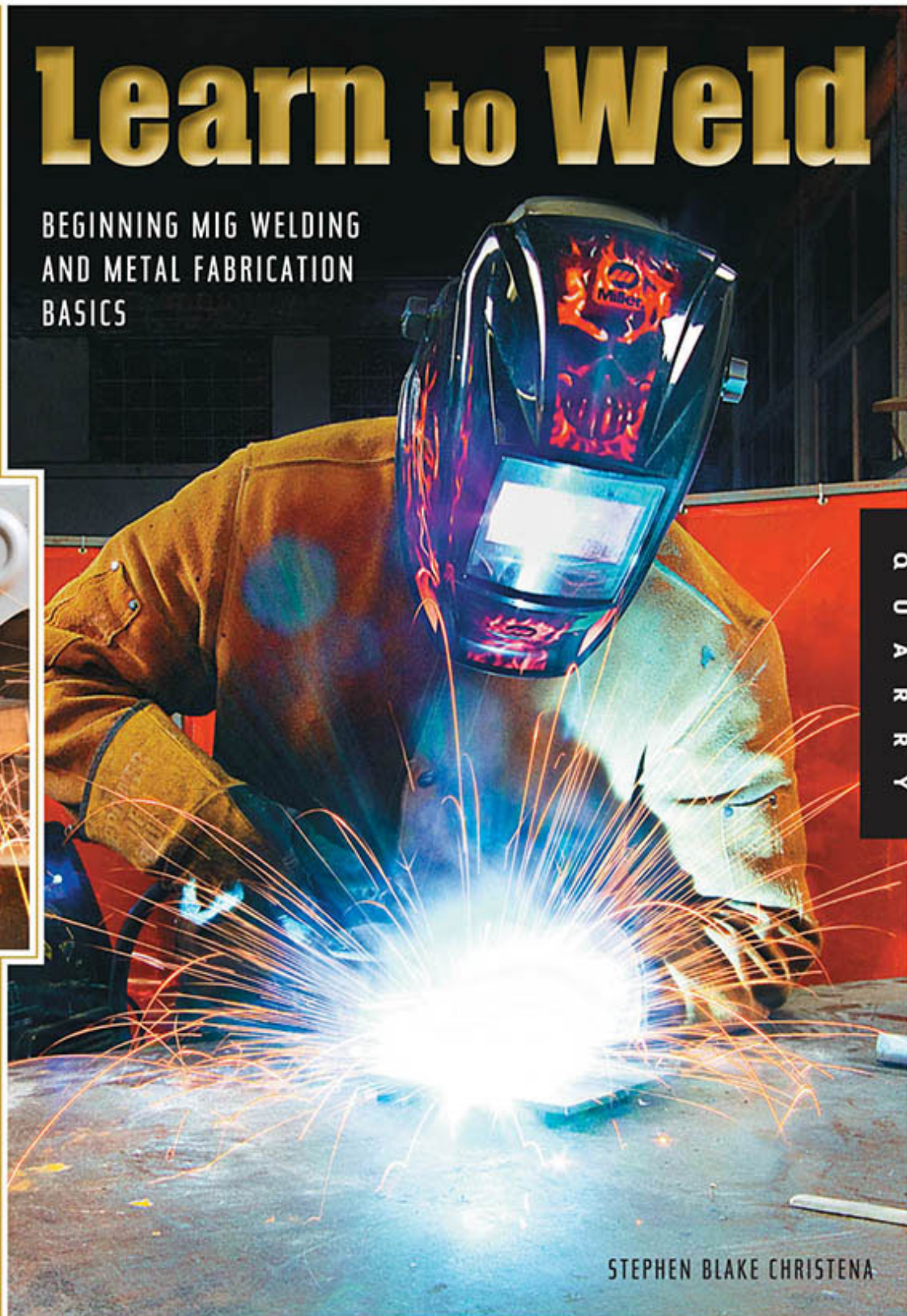


# Learn to Weld

BEGINNING MIG WELDING  
AND METAL FABRICATION  
BASICS



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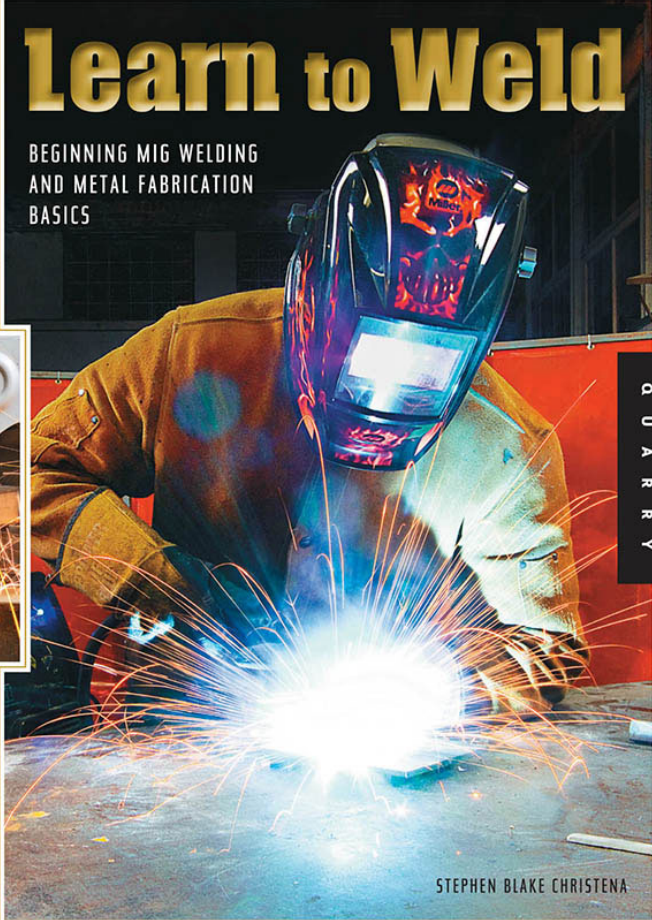
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**STEPHEN BLAKE CHRISTENA**



**Quarry Books**

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# Introduction

**W**hile I was growing up in Flint, Michigan, my dad, brother, and I would make and fix all kinds of things. My dad instilled his philosophy in me at a young age: “Why pay someone else to do something you can do yourself?” We enjoyed fixing everything from cars to bicycles, dishwashers, and TVs. We re-roofed houses and rewired radios. We built wooden tool chests, skateboards, snowboards, and hockey sticks. We were always working on a wide variety of projects using everything under the sun and all kinds of cold connections like nuts and bolts, screws, nails, glue, epoxy, fiberglass, solder, pop rivets—you name it; we used it. I grew up into a confident handyman and consummate tinkerer with an appreciation for three-dimensional construction.

By the time I started college I was no stranger to creating sculptures, furniture, art, and all sorts of other things using traditional woodworking and cold connection methods. But then in my first metal sculpture class, I cut into a piece of 11 ga mild steel with an oxy-acetylene gas torch and I was hooked. Metalwork and fabrication amazed me and became my passion. The way this cold, hard, and seemingly uncooperative material was so easily cut, formed, and manipulated still astounds me. As I learned how to weld, heat, bend, and cut various metals, I could not believe how these incredibly durable materials became as easy to work with as clay. Exploring the unlimited potential of metal work became the compass for the rest of my life.

I never stopped welding. After graduation, I moved to Chicago and set up my first shop on the south side, equipped with only a small 120 V Hobart MIG welder and grinder. Over the years, I moved my shop around a few times, expanded my gear, and worked in a wide range of fab shops, learning as much as I could along the way.

By the time I started my first fabrication company, I had worked for some of the top designers in the furniture industry and for world-class architects, and I’d worked side by side with amazing metal artists, fabricators, and sculptors. Each of them influenced my perspective and expanded my knowledge of metal work, for which I am grateful.



“Exploring the unlimited potential of metal work became the compass for the rest of my life.”

Then a few years ago some motorcycle friends approached me and asked about learning to weld and chop frames for their race bikes. After a few basic lessons in welding, they were asking me to teach them how to make their own bikes lighter, how to weld and fabricate new parts, and how to build custom components. Before I knew it I was teaching community welding classes at my metal studio, Midwest Metalworks.

After a lesson recently, one of my students said to me, “You can pretty much make anything, knowing how to weld.” He had an amazed expression of bewilderment at the vast potential of this new medium that he had just learned. He had realized the fantastic new world of possibilities that I had discovered almost two decades before. Now you can too.

If you enjoy working with your hands, learning metalwork will give you a wealth of knowledge that will expand and challenge your ability to create. There are so many different techniques, styles, and methods to learn in welding, and in this book, I hope to introduce to you the enormous possibilities that come with each one.

The key place to start is learning the basics of Metal Inert Gas (MIG) welding, which we’ll learn in the following pages. You’ll learn the basic rules and principles of welding that can be applied to other processes such as Stick and Tungsten Inert Gas (TIG) welding. MIG is just the beginning.

It takes time and practice to become a good welder, but I hope through this text you will soon instinctively recognize a good weld that is laid properly. Just like an excellent musician knows when they are in tune or have played a bad note, an experienced welder understands their craft. The more arc time you log and the more projects you fabricate, the more the world of metalwork will open up to you.

—Stephen Blake Christena, Chicago 2013

# I

## Welding 101



# Welding: Start Here

I teach Metal Inert Gas (MIG) welding because it has become one of the most versatile methods of welding, it's easy to learn, and it's fun! It was originally developed for welding aluminum, but was quickly adapted to other metals such as mild and stainless steel. It has become extremely popular amongst all industries from hobbies to shipyard for its ease of use, versatility, and speed.

MIG welding is the focus of this book, but before we dive into it, I wanted to give you an overview of electrode arc welding and some insight into the readily available welding processes out there.

# How Welding Works

There are several different methods of welding. Today, the most common welding process is electrode arc welding. There are three types, or systems, of arc welding in this family: stick, MIG, and TIG. All three types of arc welding use the same three components. The first and most obvious is electricity, which creates the arc. Each type also uses a filler material, and the third component is flux. The differences between stick, MIG, and TIG arise in how the three of these elements are used to create a bead (a bead being the weld that is created); each type of welding has a different method of execution.

Before we talk about the differences in welders and the methods of execution, we should go over how arc welding works in general. The best way to explain this process is to clearly define the elements of welding and what they do.

## The Arc

Static shock, lightning, and spark plugs firing in a vehicle's engine are all examples of an electric arc. Not many people are aware of this, but an electric arc is actually a state of matter called plasma, which is similar to gas. The arc is created by an electrical current moving through the work piece from the welding machine's ground clamp to the electrode. The electrode is an electrical conductor used to complete the circuit, which allows the welding machine to create an arc. The arc is created by a breakdown of a gas that discharges plasma. Certain gases such as argon, carbon dioxide, and helium have a higher conductivity and ionization that assists in creating and maintaining the arc, making them candidates for a shielding gas.







Make sure to wear proper safety gear. Skin left exposed to the arc light can get a pretty bad sun burn. I don't recommend it.

In the stick and MIG welding processes, the electrode is also the filler metal. When the filler material comes into contact with the grounded piece of base metal, it completes a circuit that creates the electric arc. The arc forms at the very end of the filler material, which melts into the weld zone, creating the joint. In the TIG welding processes, the electrode is a rod of tungsten.

The arc temperature can range, depending on the welding process used and the setting of the machine or power supply, from around 5,000°F to around 18,000°F (2,760°C to 9982°C). Carbon steel, or mild steel, the most common form of steel you will be using, liquefies around 2,600°F (1,427°C). The arc's high temperature heats the base metal to the point at which it becomes liquid. This is known as the "puddle" or "pool".

## The Filler Metal

Appropriately named, the “filler,” or “filet,” metal is just that. It is a rod or wire of metal that is fed into the puddle that forms at the point where the arc makes contact with the base metal. It adds more material to fill the weld zone, feeding the puddle and creating the bead. The filler metal is usually the same type of metal as the type being welded, but in certain cases, it can be other metals. In the stick and MIG welding processes, it also acts as the electrode. Stick and TIG welding require the operator to manually feed the filler metal into the weld zone.

## Flux and Shielding Gas

The word *flux* comes from the Latin word *fluxus*, meaning to flow. That is exactly what flux does in welding. It helps stabilize the arc and keeps contaminants or oxides out of the weld zone. In stick welding, flux is a chemical coating over the filler rod that burns off, producing a shielding gas that prevents oxidation of the base and filler materials. Flux can be made from a wide variation of compounds depending on the application and material to be welded.

Flux is a component of welding with many jobs to do. The number one job of the flux is to protect the base and filler materials from oxygen and other ambient gases. It creates a barrier called the shielding gas, protecting the arc and metal from outside ambient gases that cause oxidation. It creates a purified environment for the arc to exist in. The flux keeps the liquid metal clean from impurities, also called inclusions, which would otherwise contaminate the metal. And last but not least, it controls the arc, helping the arc come up to a higher temperature to create the puddle of liquid metal.



et™

1-800-4-A-Miller  
MillerWelds.com

Set Voltage and Wire  
of metal being welded.

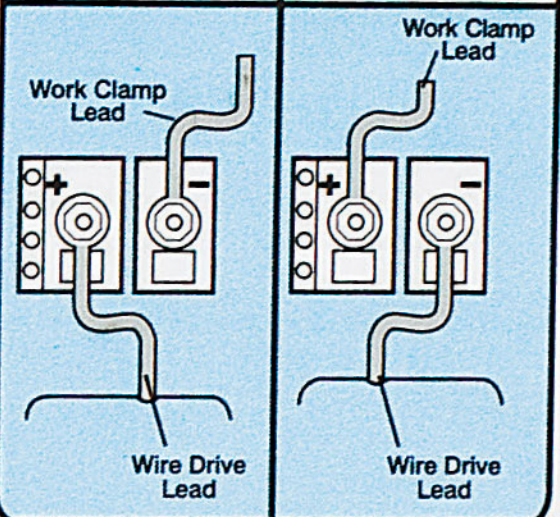
Number on right  
slash is Wire  
Speed Knob Setting.  
(Example: 4.5 / 65)

Number on left of  
dash is Voltage  
Knob Setting.  
(Example: 4.5 / 65)

**NOTE:** Settings are  
approximate. Adjust as  
required. “—” Means not  
recommended.

### CHANGING POLARITY

DCEP Electrode Positive For Solid Wire	DCEN Electrode Negative For Flux Core Wire
--	--



**230 Volt - 24 gauge to 3/8"**

Be sure to change the polarity from DC positive to DC negative when you're using flux-core wire in your MIG welder.

Flux is most commonly used in stick welding, where it coats the filler metal. When the filler metal arcs to the base material, the flux is engaged. As it burns, it creates a carbon dioxide semi-inert gaseous shield that protects the arc. Once the weld is laid, the bead is covered in a byproduct of the flux called “slag.” Agents that come from oxides in the molten metal are absorbed and removed by the flux, creating slag. This hard shell is usually removed afterwards with a chipping hammer and a wire brush.

Flux is also used in autofeed machines, similar to MIG welders, which take a spool called “flux core” wire. This wire has the same properties and behavior as a flux-covered stick welder electrode. These machines are not considered MIG welders because they do not have the hookup for a shielding gas. Most MIG welders can use flux core wire, but their polarity



needs to be switched over from DC+ to DC-. Some flux core processes can use a shielding gas in tandem with the wire.

Shielding gas is an inert gas that takes the place of a chemical flux. It does all the same duties as the flux. The first advantage of shield gas welding is that it has much better control over the arc. Just like blowing on the embers of a fire, the air pressure not only fuels the embers with gases, but also concentrates the direction of flow. Second, there is no slag byproduct. The shield gas process is cleaner. Third and most important, using a shielding gas makes it much easier to see the entire weld zone while welding. One drawback is that using shield gas outdoors has a tendency to not work very well. The pressure of the gas coming out of the nozzle can be easily blown away by the wind. Flux core and stick welding are the best options for outdoor welding.

The most commonly used shield gases are argon and a mixture of argon and carbon dioxide. Pure argon has great conductivity and heat transfer properties that will assist in creating a cleaner environment for the arc. And argon's ionization properties allow the arc to start and be maintained more effectively and efficiently. Pure argon is used in the MIG and TIG processes when welding on stainless steel and nonferrous metals (metals that do not contain iron) such as aluminum, titanium, or zinc. Hobbyist and beginning welders should focus on an argon/CO<sub>2</sub> gas mixture (75 percent argon, 25 percent CO<sub>2</sub>). This mixture is ideal for carbon steel and will be the focus of this book.

## **The Ground**

The ground is a crucial part of the power supply. All electric arc welders use one. In essence, you are creating a circuit, and without the ground, the circuit cannot be created. The ground clamp has to be clamped to the work piece or a conductive metal table that the work piece rests on or comes into contact with. The electrical current feeds through the ground and through the work piece, finding the shortest distance to the electrode as possible. The contact point between the ground and the machine's electrode is where the arc forms. If there is no ground, there is no arc.



Grounding to a conductive metal table allows you to manipulate the work piece easier. If you are going to be working on something large that has to remain on the floor, make sure to ground directly to the work piece.

# Spatter

MIG and stick welding, as well as welding with flux core, create “spatter,” small molten balls of metal that are ejected from the weld zone at the arc point. These small molten balls can fuse themselves to the work piece and to the gun’s tip and nozzle. Using nozzle spatter protection will help the tip and nozzle last longer and prevent double arcing.



Small molten balls of steel known as "spatter" are ejected from the weld in progress.

There is a variety of spray spatter protection that can be sprayed onto the work piece. These products help to protect the work piece from needing to have dozens of little metal balls ground off of the surface. They're



especially ideal for projects with moving parts or precision work; you don't want these little balls of metal inside a crank case or gear housing.



Stick welding is the best method to use when you're working outdoors or on thick plate metal. Use caution as the flux can create dangerous fumes and a byproduct known as "slag."



# Why Learn MIG Welding?

Shielded Metal Arc Welding (SMAW) is what is commonly referred to as “stick” or arc welding. When most people think of electric arc welding, they think of stick. This is a manual feed process in which the filler metal electrode is coated in a chemical flux. The arc forms after striking the electrode to the grounded base metal. As the filler material melts into the puddle, creating the bead, the flux burns off, producing a shielding gas to protect the arc. A byproduct of flux called slag solidifies over the freshly made weld. Stick welding can use a direct current (DC) or an alternating current (AC) power to create the arc.



TIG welding is clean and smooth, but can be difficult to master. It's a good idea to learn MIG welding first and work your way up to TIG.

Stick welding is popular in industrial applications for its versatility and ease of use. The use of a flux makes it ideal for outdoor heavy construction.

The wide variety of filler electrode sizes and metals allows quick transition to different thicknesses of material. And the high range of heat makes stick welding perfect for thicker materials.

Gas Tungsten Arc Welding (GTAW), or what is commonly referred to as Tungsten Inert Gas (TIG) Welding, is also a manual feed process: the operator is feeding the filler metal into the molten metal puddle. But in the TIG process, the filler metal is not the electrode.

TIG is a shield gas welding system in which tungsten is the electrode that produces the arc. The torch holds the tungsten rod, allowing the shield gas to pass over its tip through a nozzle. The arc is initiated when the control to the power source is activated, normally via a foot pedal controller. Much like the accelerator in a car, the pedal control allows the welder a range of amperage that creates the arc, giving more control over the heat going into the material. This control makes this method very popular for welding thinner materials and stainless steel.



MIG welding is easy to learn and fun to do. As soon as you pull and hold down the trigger you are welding. You just need to learn to control what you are doing.

TIG welding does not produce a spatter during welding, which makes it cleaner and more appealing to the automotive and motorcycle industries and to artists who would like their welds to be a part of the overall look of the piece. The operator has much more control over all the components than other systems.

Like its cousin the stick welder, TIG is a manual feed process with the ability to transition very quickly between metals. Pretty much all the operator has to do to switch from steel to stainless steel is to grab the appropriate filler rod. (Making sure you have prepped the metal and area around the piece for cross contamination is also recommended.)





All electrode arc welding systems need a ground to complete the circuit and create the arc. The ground needs to be clamped either directly to the workpiece or to a table made from conductive metal.

Most TIG machines are equipped with DC and AC power supplies that can be changed by the push of a button. Making a quick switch from steel to aluminum is as easy as switching the output from DC to AC and grabbing the correct filler rod, which makes it popular for welding aluminum and other nonferrous metals.

The disadvantages of TIG welding include the fact that it does take a lot of time and practice to master before one can produce a good weld. It is also a slower process that takes much longer to produce a weld. And a decent TIG system has a tendency to be much more expensive than its cousins stick and MIG.

A well-trained TIG welder can make welds that are not only structurally ideal but nice to look at as well. The expressions “stack of dimes” or “nickels on the side” stem mostly from TIG welding; they refer to the look of the surface of a bead that resembles a stack of coins lying on its side. Using various control techniques, a skilled electrode arc welder can create patterns on the surface of the weld that resemble coins, ripples, waves, etc. This comes in handy when welds are exposed and on display, such as on motorcycle frames, sculptures, and furniture.

Gas Metal Arc Welding (GMAW), or what is commonly referred to as Metal Inert Gas Welding (MIG) and sometimes also referred to as Mechanized Inert Gas, is an automated process in which all three components initiate at the same time once the trigger on the gun is pulled.

The filler metal for a MIG welder is a wire that comes on a large spool. Just like in stick welding, the filler metal is also the electrode. The machine has a motor that feeds the wire through a hose to the gun. The power supply that creates the arc is fed through the same hose as the shield gas and wire. A direct current (DC) is most commonly used in MIG welding. A nozzle covers the gun tip where the wire comes out. Under the nozzle are a series of uniform holes that deliver the shielding gas evenly over the arc point. Once the trigger is engaged, all three elements activate simultaneously and feed continuously as long as the trigger is depressed.

The rate at which the wire is fed through the gun and the amount of electricity used is determined by the settings of the machine. You set the voltage and the wire speed in relation to the thickness of the metal to be welded. The shield gas pressure is set using the regulators that are attached to the tanks of gas. The pressure setting for the shield gas is determined by the manufacturer of the machine, normally anywhere between 20 and 30 cubic feet per hour (commonly referred to as CFH). (Note: In countries using metric measurements, the common terminology is cubic meters per hour, or CMH.)





The wire on a MIG welder feeds through the tip of the nozzle.

Flux-core can be used in most MIG welding machines. Flux-core is an automated wire feed process just like MIG, but it does not commonly use a shielding gas. Instead, a chemical flux that produces a  $\text{CO}_2$  gas when burned is mixed in with the core of the metal wire. Very similar to stick, it also produces a slag coating. Always work in a well-ventilated area when working with flux to avoid breathing the flux fumes.

MIG welding is one of the simpler methods of welding. It is easy to learn and has a wide variety of applications. It has also become the most common form of welding, not only in the arts and hobbies world, but in the professional metal working world in general.

What you will need to begin is the MIG unit, a grinder, and a chop saw. All the techniques in this book will focus on these three tools.

If you want to learn to weld, this is where you start. The automated process will allow you to learn all the basic principles and techniques of welding by eliminating some of the controls that are normally affiliated with manual feed methods like stick and TIG.

Becoming a skilled MIG welder will allow you to create art and furniture or repair pretty much anything in steel. MIG welding and simple fabrication will be the focus of *Learn to Weld*. This book will provide you with all the basic information and tools you need to begin your own projects and build your interest in metal work and welding.

My approach to this book is going to be a little unconventional. It seems that most DIY books give you a laundry list of materials and equipment to buy that may or may not pertain to the beginning stages of the learning process. My approach will be to give you the proper tools and materials list that you will need for each chapter as you need them. It is not necessary to go out and purchase a full metal fabrication shop of tools and equipment right out of the gate.





Always have lots of clamps available to lock down the metal as you tack and weld.

One thing that I have learned over the years, especially if you are going to be welding a lot or turning this into a profession, is to only buy out of necessity. You don't want to go out and buy a \$2600 plasma cutter when a grinder and a chop saw will work just fine for the needs of that job. Even though plasma cutters give you much more control and options for cutting, it's an investment for down the road. Let's start by teaching you how to weld and fabricate a few simple things. What you will need to begin is the MIG unit, a grinder, and a chop saw. All the projects and techniques in this book will focus on these three tools.

## Buying Tools and Equipment

One of the most common questions I'm asked by my students after their first class is "What kind of MIG should I buy?" Well, there really isn't a straight answer to this question. As it goes with many tools, the longer a person welds, the more preferences they develop. Welders have a tendency to be very loyal to their brands.

When it comes to welding machines, there are huge jumps in quality from brand to brand. This is the one piece of equipment that I do not compromise on. Like I said, "preferences". Grinders burn out all the time. Some last a few years or even a decade or so. Others burn out in weeks. I actually buy cheap grinders for on-site jobs so if anything happens to it I'm not out by much. But the right welder will last a lifetime and is worth the extra few hundred bucks.

The first few things to consider when buying a welder are how often you're going to be welding and the kind of electricity you'll have access to in the area that you're going to be welding in.

Both of these questions are important to any welding machine for one reason: the duty cycle. The duty cycle for any electrode arc welder is a 10 minute period of time where the welder can be running straight "arc on" and then has to rest in the ON setting to complete the full 10 minute block of time. It can be turned off if you don't intend to use the welder for a long period of time, but in its ON setting the internal fans will allow it to cool properly. For example, my welder has a 30 percent duty cycle when plugged into 230 V. That means this machine can run arc on for 3 minutes and then has to rest while still ON for 7 minutes to complete the full duty cycle. This ensures the machine does not overheat. When welding intermittently, the time at rest will factor into the duty cycle of the machine. It's best to monitor the usage referred to as arc time.

Other factors like ambient temperature can affect duty cycle. A pretty standard temperature duty cycle rating for most machines is between 68-82°F (20 to 28°C). If the overheated light comes on more than three or four times in the machine's life, it can seriously damage the machine. Don't stress about it too much, just make sure you are allowing the machine to rest.

Just a heads up, if you find that you can weld for three minutes straight, you may want to think about welding as a profession.

How does this answer our questions? If you plan on welding a lot, you will want a machine that has a higher duty cycle. Most machines with high duty cycles will normally plug into 230 V or higher. Do you have 230 V in the area where you will be welding? If yes and you are planning a major project after you learn how to weld, you may want to consider this type of machine.

The newer machines today have a lot of new features that allow quick transition between 115 V and 230 V. If you have access to 230 V in the work area, I would recommend taking a look at a few of these models. But for now, I would start small. There are a lot of great 115 V and 120 V machines out there that you can do a lot with.

The next question is how thick you'll be welding for most of your projects. The 230 V machines will allow you to weld thicker gauge materials, whereas 115 V machines start to max out at around  $\frac{3}{16}$  (5 mm)-to  $\frac{1}{4}$  (6 mm)-inch-thick material.

Look out for autoseed machines. Autoseed machines are not necessarily inert gas welders. The autoseed-only machines are for flux-core wire only and do not have a shield gas hookup. Most MIG machines can also use flux-core wire.

It is not always important to buy the top of the line tool for something you won't use that often. Always research the machines and tools you need before purchasing them. If you don't already have a welder and are looking to buy used, make sure you understand how the unit was used. For example, a hobbyist welder or a "fix-it-yourselfer" is going to have a lot fewer duty hours on their machine than, say, an auto-body shop or fabrication shop. The age of the unit is not as big of a factor as the actual arc time the welding unit has on it. The ideal used MIG welder is being sold by someone who bought it five years ago to learn how to fix stuff and is now selling it because they lost interest and are more than likely just trying to clean out the garage. That welder only has a few hours of duty time on it tops, and it is going cheap.

There is always a risk when buy anything used. So before buying a used machine, read the chapters that involve the machine. This will give you a better understanding of how everything is supposed to work. Look over the machine to make sure there isn't any damage to the terminals or any of the components on the inside. Turn it on; if the machine's fan turns on right away with out any struggle that is a good sign. Run some wire through it to



make sure the gun liner is not kinked and that the wire is moving freely to the gun. Check the ground clamp to make sure that the cable is secured correctly. Check the ground clamp cable for holes or cuts in the insulation. If the person selling it will let you, put your welding helmet on, put a piece of mild steel in the ground clamp, and make sure it arcs. Always check the exterior shell for damage as well.



Before you buy a MIG, consider how you'll be using it. If you don't plan on using it very often, you can skip the top of the line models and choose a more affordable one.

If you are buying a new welder, make sure it is a trusted brand such as Miller, Hobart, or Lincoln. It's a good idea to talk to someone you know or can trust in regards to the quality of a welder you're considering. There are a lot of welding manufacturers out there that don't have all of the safety

features you need. Some of the more inexpensive wire feed units on the market today don't have proper shut offs such as electric. When the trigger is released, the filler electrode can still arc if the nozzle touches the grounded base metal. This is extremely dangerous if you are not wearing the proper protection or if your welding helmet is up. If you find a great deal on a new welder, make sure you trust the brand.

Of course, there are the standard benefits to buying new, such as warranty. When buying new, it's not a bad idea to build a rapport with the closest welding supply store. Normally, the people that work at these businesses have an in-depth knowledge of welding, which is helpful if you are not sure which consumable products to purchase for your machine, such as contact tips and nozzles.

## Getting Started

Now that you've decided to learn MIG welding, the first things you'll need are a place to weld, the proper safety gear, and of course, the right equipment. Safety should always be your first consideration in choosing a location. As a welder, not only will you be working with extreme heat, but you'll also be working with compressed gases, vapors, fumes, materials, and chemicals that are harmful to you and others. A studio absolutely must have proper ventilation, exits, and electrical access suitable for the machines you use.



# Your Studio

Welding is a practice that involves high heat, lots of sparks and spatter flying around, and things that can cause fires. It's not a hobby to start in the home. A garage, shed, or some kind of detached structure would be ideal. Masonry structures made out of concrete, brick, or cinderblock work the best as long as they have good ventilation. Sheds with concrete floors and corrugated metal walls are great places to set up a welding shop.

A garage is also a decent place to set up a small welding area. Normally, garages are already fitted with concrete floors, so the rest of your fire prevention equipment can be pretty easy to install and not very expensive. Ventilation can be provided by simply opening the garage door and directing the air out with a box fan. You also have the ability to move your welder outside on nice days that aren't too windy. If you have an attached garage, you may want to consider using a work shed instead. But if you are set on using the garage, make sure the welding area is the furthest distance from the house as possible.

You don't have to set up a full metal fabrication shop right out of the gate. A 6-foot (1.8 m)-square corner should provide enough room to be comfortable and get started. If you are in a garage that has exposed wood surfaces or bare studs, they should be covered with a flame retardant material such as sheet rock or, even better, sheet metal screwed right to the studs. If the floors are not cement, they should also be covered with a mortar-style compound such as a flame-resistant epoxy mortar. Welding blankets and mattes should never be used as a permanent solution to protect floors from fire. These are for temporary protection for short projects; they aren't 100 percent resistant to flames.



Basements: These are not good! You are working with a process that produces all sorts of harmful byproducts. Basements don't normally have

the ventilation required for a safe welding environment. Also, shielding gas is roughly twice as heavy as air. This means that in small, confined areas, it will displace the air that you breathe and you will suffocate. Just like drowning in water or any other fluid, you will lose consciousness and die. And we don't want that. To make matters worse, whoever sees you on the ground will try to come save you, and they might be met by the same fate if the gas hasn't dissipated first. So don't do that.

## **Electrical**

The only drawback to a garage is that most household garages are not built with 220 V–240 V power outlets for larger machines. For the beginner, this shouldn't be a problem because you should be starting with a smaller 115 V to 120 V machine, which most garages should be able to accommodate. There are machines on the market today that convert from 120 V to 240 V simply by changing the plug, so you can always install 240 V later on.

When making the switch from 110 V to 240 V, have a licensed electrician install and upgrade the lines. If not done properly, bad wiring can lead to a damaged machine or worse. Always make sure the breakers are a match for the machines.

The location of the outlets is a good thing to consider when setting up a welding area. It's a good idea to start off by putting the welder and the welding table in close proximity to the outlets to be used. Multiple outlets may be needed depending on the electrical demands of the machine. Welders draw a lot of juice, so having a dedicated outlet just for the welder is recommend to avoid tripping breakers. If everything is wired properly, this shouldn't be an issue, but it never hurts.

## **Ventilation and Lighting**

Ventilation is key to setting up your studio. Not only will you be welding, you will also be grinding, cutting, and heating materials. These processes all produce different kinds of sparks and vapors that can be harmful, so proper ventilation is vital.

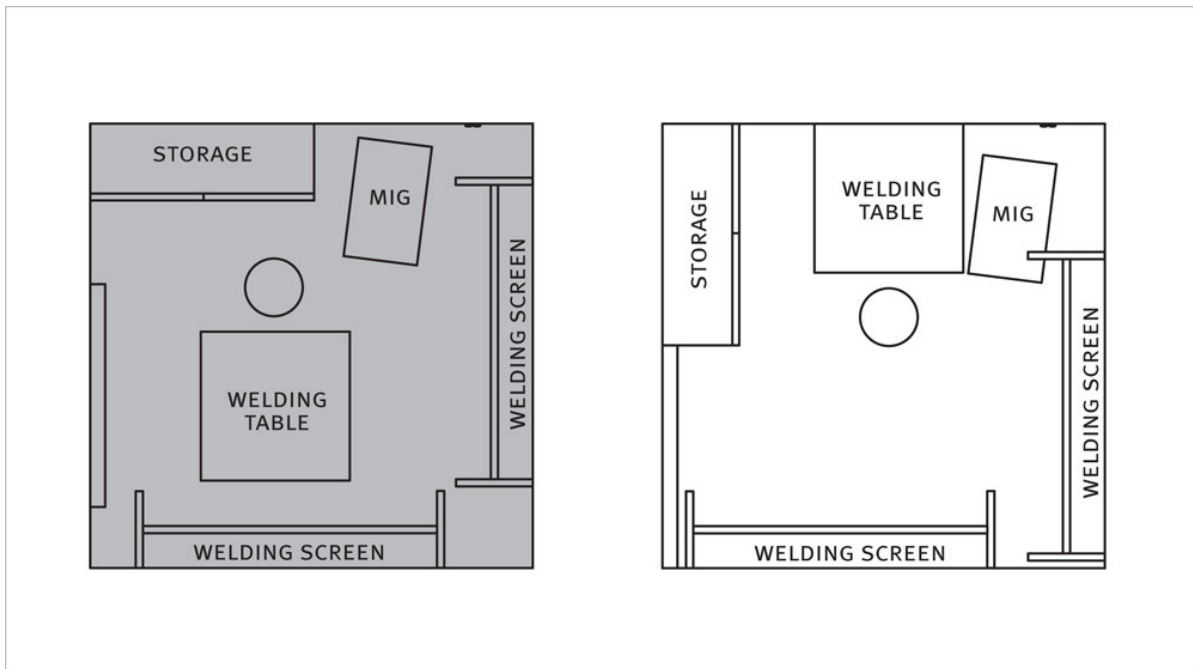
Ventilation and protection from fumes and vapor can be as easy as turning on an exhaust fan or opening a door—something that will allow fresh air to flow in and circulate the contaminated air out. This can also be



achieved by air purification or welding exhaust systems on the market. These have a tendency to be pretty pricey, so they probably aren't the route to go in right away if you have another option, but they're something to consider down the road. A centralized exhaust extraction system can also be made with corrugated hoses hooked up to an exhaust fan.

Another method of fume and vapor protection is using respirator masks. These masks come in all types of filtration from gases and fumes to light particulates. Some manufacturers have masks that can fit under welding helmets.

You will also want the welding area to be well lit. Chain-hung halogen or florescent lights directly above the welding area should be an abundant enough light source for welding. You will appreciate a well-lit welding area when setting up to begin welding and your lid goes down. The most common complaint I hear from my students is that they can't see anything. Good lighting is going to help you set up and get comfortable before starting a weld.



After safety, the most important considerations when setting up your work space are your comfort and access to your equipment. Here are a couple of potential layouts.

## Studio Layout

For a small welding area, the layout is pretty simple. Arrange everything in a way that it is easily accessed. Arms lengths are great for grabbing a grinder or a clamp while still seated at the welding table. A wall-mounted hand tool rack is a great way to organize, conserve space, and have everything close by.

I have old steel filing cabinets for my handheld power tools such as grinders. They are durable and can normally be found for relatively cheap. One four drawer file cabinet can hold everything you need from protective gear to grinding abrasives to extra extension cords.

The second project in this book is building a welding table. The table I designed for you has 1 inch (25 mm) square tube rails to store clamps. You will want easy access to clamps as you will need them a lot. Last but not least, get yourself a comfortable stool. The best tip any welder can give to a beginner is to be comfortable.

The amount of space will also be determined by what you plan on building after you learn to weld. The larger the project—furniture and motorcycle frames, for example—the larger the space you will need. But to get started, a small space will be fine.

After you learn to weld, your enthusiasm will grow and so will your workspace. You'll start to consider acquiring larger metal work machines, such as metal working lathes, benders, and drill presses. As you expand the work area, it is best to have more permanent areas for these machines due to their weight and size. These machines will also have accessories that will need to be stored. Finding or making new storage solutions will have to be determined while you decide to expand. You will find that this will happen over a slow period of time while you acquire more tools and interests.

I have moved my shop several times and worked in many different fabrication shops, and all of them are all a little different. It really all comes down to personal preference, needs, and your level of organization.



Be aware of all safety symbols provided by the manufacturer of the equipment used, such as these that represent welding helmet, safety goggles, ear protection, dust mask, and harmful vapor.



# Safety and Protective Gear

Welding involves high heat, lots of very hot airborne projectiles, and intense light with concentrated rays such as ultraviolet, which can be harmful to your skin and eyes. Just like a cook in a kitchen, sometimes you will burn yourself. The longer you do metal work, the higher your probability of getting burned.

The most common way to burn yourself is to grab a fresh weld, not realizing how long you've let it cool (or haven't). I've seen beginners do this many times. The best thing you can do to prevent burns is to be hyperaware of the temperature of the metal that you are welding. When in doubt, check the temperature before you touch it by holding your hand about 3 inches (7.6 cm) to 5 inches (12.7 cm) from the weld and slowly lowering it. If you think it's too hot, it probably is.

## First Aid

Keep a first aid kit in close proximity to the welding area. A standard first aid kit does not normally have burn treatment products. You should include some additional burn relief treatments such as burn gel, sterile bandages, and aloe. Or you can also purchase a burn kit to supplement the first aid kit. Minor burns can be treated by running room temperature or cool water over the affected area for several minutes. This will decrease the temperature of the skin and prevent further damage. Burn gel, triple action ointment, or aloe with a sterile bandage should be applied. Most importantly, if you have any doubt as to the extent of the burn, consult a physician.



Despite what you might see on TV, sunglasses are not a replacement for a welding helmet. Always wear proper safety protection for your hands, face, and body. It only takes a fraction of a second for something to go wrong and for you to get seriously hurt.

## Sparks Are Flying

Spatter can reach great distances. Sparks from grinders and chop saws have been known to fly up to 40 feet (12 m) and smolder for up to 30 minutes, causing fires. Make sure that there are no flammable materials such as wood, gasoline, paint thinner, etc., in the welding area. Keeping a few buckets of water near the welding area gives you a great method of extinguishing small blazes quickly. Buckets of water are also useful for quenching hot steel.

Fire extinguishers are ideal for grease fires and other chemical-related fires and should be strategically placed around the shop. One should be centrally located, mounted to a post or wall between 4 and 5 feet (1.2 and 1.5 m) from the ground. Another should be kept within 6 feet (1.8 m) of the welding area and should also be mounted to a vertical surface. If the

welding area is small, one extinguisher will do. Make sure the fire extinguishers are up to date and are checked annually.

Arc welding, which uses high amounts of electricity, can produce electric shocks, severe electrical-related injuries, or worse. In MIG welding, the wire is the electrode. Most MIG welding machines initiate all the elements of welding simultaneously when the trigger is pulled and cancel them when it's released. Following a few basic rules will prevent injuries while using a MIG welder:

- Never get between the ground and the electrode when the arc is engaged.
- Never be grounded and pull the trigger near any body part.
- When clipping the filler wire, step away from the grounded piece.
- Hold gun handle below the trigger to avoid pressing when cutting wire.
- Always be aware of the gun in relationship to yourself and the ground.
- Always wear proper welding protective gear.
- Insulate yourself from the ground.
- Don't weld wet, meaning you or the material.

If you don't think you can do it yourself, have any power source and plugs for the machine(s) installed and inspected by a professional electrician to prevent electrical hazards. I'm more of a hands-on kind of guy, but even I have my limits. If you don't know how to do something in the electrical arena, don't. You can only hurt yourself. Use wire and breakers that are rated for the output of the machine. Always read all instructions, labels, and installation manuals before installing, operating, or servicing any welding or electrical equipment to prevent injury.





Here's the safety gear you'll need to get started: A. Muffs (hearing protection); B. MIG welding gloves; C. Clear visor ; D. Steel toe boots; E. Welding helmet (lid or cover); F. Beanie (scalp protection); G. Work gloves; H. Safety glasses or goggles; I. Welding jacket

## Protective Gear

The arc light produces extensive amounts of harmful rays that can burn skin. Every 10 to 20 seconds in direct arc light is roughly the equivalent of a half hour of direct afternoon summer sun. Protect the skin with long sleeves, long pants, and MIG gloves to prevent UV burns.

MIG gloves can be bulky and cumbersome, but they provide protection from intense heat. The longer cuffs protect the forearm skin from arc rays that can burn the skin.

The welding helmet, hood, lid, or cover, no matter what you call it, should always be worn at all times during welding. The arc light is very intense and can blind you. The lid creates a shield for the entire head and neck to protect you from the arc light. It also protects the face and neck from UV burns and spatter.





When considering eye protection from arc light, one should be aware of the rating scale. The DIN is a shade rating of how dark the lens is or will become. Depending on the manufacturer or type of lid, the DIN can range from 0 to 13, sometimes higher depending on the application. Zero is the

equivalent of clear safety glasses or goggles, and 13 DIN is the darkest transparency to look through to prevent flashing the eyes with intense arc light.





This is a classic single shade (DIN) welding lid. The new auto-darkening helmets allow you to set up with the lid down; the lens darkens as soon as the arc light hits the photo cells.

When I started welding, there were only single shade welding helmets, which were normally 13 DIN. You would have to get set up before flipping the lid down and starting to weld. The single shade helmets are perfectly good helmets, just not as versatile. The auto-darkening helmets make setting up and staying on the weld zone before welding much easier.

Most welding helmets these days are auto-darkening and are equipped with photocells. The photo sensitive cells signal the shield to go from the inactive shade to the active shade that the helmet is set for. For example, if the inactive DIN number is 5 and the active is 12, then when the arc light is detected by the photo cell, it changes to a 12 DIN setting in a matter of fractions of a second.

Most autodarkening helmets have a range of 5–13 DIN and have solar panels that feed the power source. The lower DIN shades are used for different applications such as plasma cutting, oxy gas cutting, and grinding. When setting the helmet, make sure to use the recommended DIN set by the manufacture. I normally have my helmet set at 12 DIN unless the voltage or amperage is dramatically different, higher or lower. I don't recommend going lower than 12 when welding unless the manufacture of the helmet says differently for lighter duty applications.

I don't care how many times you have seen another welder on TV weld without full-face helmet, no gloves, and no skin coverage, this is wrong. Get a good lid. Always make sure to use the proper shade shield for the job and make sure it is not damaged, cracked, or missing parts that will affect the performance or the fit. This book is not going to get into overhead welding, but additional protection may be needed for different welding positions. So, if you are a car person who intends to weld under a project car, you may want to consider additional scalp protection.

Skull caps or beanies should be worn under the welding helmet to prevent your hair and scalp from burning. Most caps are made of flame resistant material that will deflect most sparks and spatter. No matter what, scalp protection should always be worn unless you enjoy your hair catching fire.

When considering the torso, leather is normally the way to go. A good welding jacket or apron will last a long time. Modern fiber technology for welding has come a long way. There are many new protective gear options on the market that are more breathable than leather and provide more

protection. Whatever you choose, make sure it is free of holes and protects the entire torso and arms. Welding is not a good way to work on your tan.

When welding, never wear nonorganic material unless it is specifically made for welding. Nonorganic materials such as nylon and polyester catch fire very quickly. They also melt into the skin and cause extensive damage. For example, most mechanics gloves do not make good metalworking gloves. Normally, the backs of these gloves are made of polyester and spandex that will melt and catch fire very rapidly if sparks or spatter hit them, just as with most tennis shoes.

I was working at a small foundry/fabrication company several years ago. One of my workers decided to wear tennis shoes to work one day against company policy. Right before lunch he was finishing up a fabrication job. As he started to walk away, he stepped in a coin-sized piece of spatter that was still molten. The spatter quickly burnt through the thin sole of his shoe. He was lucky and quickly removed his shoe before it could give him a more severe burn. You should always wear leather shoes with a good sole. Steel-toe boots are highly recommended, especially if you are going to be using heavier materials. There are a lot of work boots on the market that also come with metal strips in the soles to prevent burns and punctures to the bottom of the feet.

I shouldn't have to mention at this point that your legs should be covered as well, but I will. Jeans and work pants, such as heavy duck cloth, are the norm. Once in a while, normally on the hotter days in the summer, people like to wear shorts. UV and spatter doesn't care that you didn't cover your legs or how hot it is outside. Also, do not cuff your pants. If a larger piece of spatter happens to fall into the cuff, then it's a safe bet that your pants will catch on fire.

Never wear loose or baggy clothing when grinding. The material from loose clothing can catch on to a grinding wheel, binding into the arbor. This can be a quick way to get cut badly.

Metalwork such as welding, grinding, and cutting emits a good amount of harmful fumes and gases. Fumes are solid particles that originate from metal fabrication methods from the consumables, base metals, and any coatings present on the base metal such as zinc. Some of the airborne particulates can cause nausea, headaches, dizziness, and other health-related issues. If adequate ventilation cannot be maintained, a fume extraction





machine or respirator mask may be used to reduce these harmful fumes.



Always keep your cylinders chained to the welding cart or to a wall. You don't want a cruise missile going through your home.

Once when I was growing up, my dad took me down to the valley in Flint, Michigan, where he worked and where all the automobile manufacturing plants were. Earlier that morning there was a small industrial accident. He pointed at a large hole in a concrete wall of one of the factories and then at a hole that went through a conversion van and then a train car

about 50 feet away from the van. They happened to line up perfectly. “You know what did that, kid?” he asked. “A cylinder of compressed gas fell over and knocked off the valve.” He went on to explain how the cylinders become steel rockets if they still have pressure when a valve breaks off and they fall. The moral of this story: cylinders have so much pressure they will go through a concrete wall and only stop after they hit the other side of a train car. Or worse, they can explode.

When storing cylinders of any kind, flammable or nonflammable gas, make sure they are on level ground and secured with a chain or heavy strap to a wall, table, or cart. When not in use, always keep the cylinder caps screwed on tight. Unless you’re looking for a very interesting and dangerous way to add some ventilation, always make sure all cylinders are secured.





When a cylinder is not in use, the primary valve should be covered with its cap.

It is also a good practice to separate the flammable gases from the nonflammable gases. Chain them up in two different locations. This will prevent any confusion when changing out gases. The cylinder valve threadings are different for flammable and nonflammable gases, so you don't have to worry about using propane or acetylene as the gas for a MIG welder, but it is safer to err on the side of caution. It is also best to keep the flammable bottles further away from heat sources such as the welding area.

If you happen to have a larger shop space, welding carts are great for increased mobility. When using any welding cart, make sure that the cart

can accommodate the load and has a secure way of mounting the shield gas cylinder. If working in a smaller space where the welder is going to be stationary most of the time, make sure that the shield gas cylinder is secured to a wall or heavy table.



Keep flammable gas cylinders separate from nonflammable gas cylinders.

You should always read all instructions, labels, and installation manuals before installing, operating, or servicing welding or electrical equipment to prevent injury.

So, I have covered the basics. If you have more concerns in regards to welding safety, please feel free to reference the American Welding Societies web page at [www.aws.org](http://www.aws.org). They have an extensive free library of safety sheets that can come in handy when in doubt.



# Equipment and Tools

Basic welding and metalworking doesn't require going out and buying lots of different equipment and tools. Even though there are a wide variety of tools for metalworking, there are only three simple things that you will need to get started: a MIG welder; a 4 1/2-inch (11.4 cm) angle grinder; and a metal-cutting chop saw. That's it. Learn to use these three tools properly and you can build nearly anything. In time, as you grow your knowledge of metalworking, you can add to your arsenal of equipment as you explore different methods of building.

Fabrication always follows the same steps: Design–Measure–Cut–Prep–Tack–Weld–Finish. The design and measuring can be considered part of the cutting step. You never cut anything without knowing the length. Since the finish is subjective and is chosen by the fabricator, the mantra that will echo through this book will be “Cut–Prep–Tack–Weld.” Cutting will be done for the most part by a chop saw, Prep with a grinder, and Tacking and Welding with a MIG welding unit.



A chop saw is great for making straight or angled cuts. This will be the cutting tool we will be using for the projects in this book.



When setting up or changing the disk on a chop saw, follow the recommended safety steps from the manufacturer. Always remember to unplug the saw before changing the disk or clearing debris from the guards.

## The Chop Saw

Fabricating in metal is as simple a concept as cutting and pasting. It's just on a much heavier, more industrial level. For the cutting aspect of fabrication, we will be focusing on the chop saw. A metal-cutting chop saw is specifically designed for straight and angled cuts. Unlike the miter saw (its woodworking counterpart), the chop saw is limited in its ability. Miter saws have more options for cutting angles, but should never be used for metalworking.

There are many other methods for metal cutting, sanding, grinding, bending, and shaping—methods using tools such as band saws, plasma cutters, press breaks, and shears—all of which have their place. You can spend a lot of time and money developing a full-scale metal fabrication shop. If you already have some of this equipment, that's great, but I wouldn't start there.

Whatever machine you decide to use, make sure it is specifically designed for metal. Cutting and sanding metal produces high heat that can actually melt components in non-metalworking equipment. The speed of the blade, the power of the motor, and the components used to build a metalworking machine are designed for friction, high heat, and metal dust. Using wood-only machines on metal can cause damage to the device and cause serious injury to you.

For our purposes, a consumable blade chop saw will work just fine. A consumable blade chop saw is just that: the blade is made from a composite material, normally aluminum oxide reinforced with fiberglass, which consumes itself as it cuts. Metal-cutting chop saws can also come with metal blades that cut cleaner and with more accuracy. They also tend to be twice as expensive as their consumable blade counter parts. Even though these machines are very nice to have in a metal shop, this is not the place I would recommend starting.

When using a chop saw, understand that these saws will not cut as quickly as a standard miter saw cuts through wood. You will want to be aware of how much pressure to put on the metal as it cuts. Not enough pressure and it will produce more heat and take much longer to cut. Too much pressure and you can overwork the motor. This can lead to stoppage of the blade or damage to the motor. When in doubt, listen to the machine. If it sounds like it's whining and working too hard, you are probably putting too much pressure on it.

The chop saw is a great tool for cutting bars and tubes with straight or angled cuts. This is a good machine when fabricating furniture or anything that has to be framed out.

## **Setting up the Chop Saw**

Right out of the box, the chop saw is relatively simple to set up. Most of the time, you'll only need to assemble the fence and attach the blade. Always leave the saw unplugged before you install a blade. Pull back the lower guard and secure it in the up position with a pair of clamps. Using the provided arbor wrench, hold down the arbor lock and unscrew the arbor nut. Slip the blade under the upper plate guard in order to position the blade on the arbor. Make sure that all of the flanges and spacers are assembled properly.



## ➤ CHANGING THE CHOP SAW BLADE

After you've used a blade or two, there will be a lot of debris inside the upper plate guard. When you put a new blade in, stay at arm's length from the saw and let it run for a few seconds to knock out all of the metal and old blade remnants. You should be wearing eye protection and a mask or respirator.



It's easier to access the arbor nut when the front guard is clamped back.



2 Hold down the arbor lock (located on the opposite side of the nut) and unscrew the nut with the wrench provided by the manufacturer.



3

Remove any metal debris or buildup from the inside of the guard before you replace the disk.





4 Before you replace the arbor nut, make sure the collar and flange assembly are lined up correctly with the arbor.



5

When tightening the nut, make sure the disk is flush to the back flange. If it is off, the disk can wobble when in motion.





Grinders have a wide variety of disks and attachments for cutting, grinding, polishing, and finishing. Never place a grinder face down on a surface.

## The Angle Grinder

The angle grinder is one of the most common tools in metalworking and one of the most diverse. The angle grinder can be used not only for grinding, but also cutting, sanding, shaping, and polishing. These versatile little machines have a wide variety of different disks for all of these purposes. They also come in many different sizes. We are going to be using a 4 1/2-inch (11.4 cm) angle grinder for cleaning and preparing our metal before welding and also to grind down some of our welds.





Sparks will always fly in a clockwise direction 90 degrees from the point of contact in relation to the arbor (center of the grinder head).

An angle grinder got its name for two reasons. The first is that this machine allows you to hit multiple angles in three-dimensional space, which allows for any number of angles for chamfers or bevels on a piece of base metal or to get into hard-to-reach areas. The second reason is that it is actually necessary to hold the grinder at an angle to prevent grinding on the arbor. If you are not at the proper angle to clear the arbor, you are just grinding metal-to-metal and possibly damaging the machine.

The disk on a grinder is always moving in a clockwise direction, normally indicated by an arrow at the top of the head. This is good to keep in mind, considering the majority of the sparks will fly in a clockwise direction 90 degrees from the point of contact in relation to the arbor. So, if

you draw a line from the point of contact to the arbor and then draw a right angle to the right of the contact point, that will be where most of the sparks will go. A small amount of the sparks will follow the wheel. Knowing this will allow you to direct the sparks away from people or things that have the potential to catch fire.



Angle grinders got their name because their exposed wheel allows you to hit pretty much any angle. The grinder needs to be held at a minimum of 15 to 30 degrees to keep from grinding on the arbor or arbor nut.





Keep a firm grip on the handle and body of the grinder. Keep your angles consistent. And as with all power tools, never take your eyes off of what you are doing.



## Grinder Safety Tips



- On the top (or back) of the grinder there is a flat landing right where the head and block meet. When you are done grinding, *always* place the grinder upside down on this flat landing; this is what it is designed for.
- Never put a grinder face down on its belly. If you place it face down while the machine is still on, it can speed away and hurt someone or cause damage or speed towards you and hurt you. This can also happen if you accidentally turn the device back on while it is face down. Setting it down on its belly can also crack the disk. What happens when you turn it back on? The disk blows up, throwing shrapnel chunks of grinding disk everywhere, hurting you and anyone else in the room, and causing damage to the machine and anything else in the path of the debris.
- Always use the blade guards. Not using the guard is also more than likely against the safety guidelines in the manufacturer's owner manual. Without guards, angle grinders will spray more sparks in more directions, so you make up your own mind. You have been warned.
- While the grinder is not in use and properly at rest on its back, you can inspect the blade of a consumable disk for any damage or cracks that

may lead to the shrapnel scenario mentioned above. This device is very easy to use but if you don't respect it, it can do a lot of damage. Remember to wear all safety gear and follow all the guidelines set by the manufacturer.

- Wearing gloves with anti-vibration liners helps keep your hands from going numb after long periods of grinding.

It is never a good idea to point your fingers when using an angle grinder. I know that may sound obvious, but sometimes when people re-grip the grinder they aren't thinking of where the blade is in relation to their hands and off comes a finger. Another good practice for keeping your fingers intact is to never move your hand past the block. The block is the bulky part of the body near the head. This acts as a stopper to prevent you from putting your hand on the moving disk. If you accidentally jam a finger under this part of the grinder, it will quickly sand through your glove and burn you or remove your index finger.



Be aware of your hands and the position of the disk at all times. Keeping your fingers intact is a good thing.





Here are some of the commonly used attachments for an angle grinder: A. Synthetic rust and paint removal disk ; B. Braided cup brush; C. Flap-disk (available in a wide range of grits); D. Aluminum oxide cutting disc; E. Fine wire brush; F. Grinding or stone disk



Using a grinder with a cutting disk will allow for straighter cuts. Keep the disk straight into the cut or it could bind or kick.





Don't apply too much pressure; it's best to let the grinder do the work. Keep the cut point in the bottom front quarter of the disk.

## **Setting up the Grinder**

The setup process is very similar to the chop saw. It also has an arbor lock and wrench that you will use to release the arbor nut. Hold down the lock while using the flange wrench to remove the nut. Leaving the lower flange on the arbor, place the disk on the arbor with the correct side up. Replace and tighten down the nut.

There are many different types of disk that can be used. The three types that we will be using most throughout this book are the grinding disk, cut-



off wheel, and the flap disk. There are different types of disks for different metals. For carbon steel, an abrasive should be an aluminum oxide type disk. There is no need to break the bank on zirconia, zirconia alumina, or other composites if you'll just be grinding on mild steel.

Metal sanding and grinding grit is the exact same as the woodworking scale of abrasives: the lower the number, the larger the granules. For example, a grinding disk, or stone as it is sometimes referred to, is normally a very low number grit, around 18. This is a very large grain that will remove a greater amount of material very rapidly. The finish with lower grit abrasives will be coarse. A 120-grit flap disk will remove material more slowly but have a much smoother finish. The higher the number, the smoother and shinier the metal becomes. You can bring metals up to a mirror shine by increasing the grit number and method of grinding and polishing.

A good disk to use for metal prep is a 60- to 80-grit. This will clean off all the grease, rust, dust, dirt, oil, and mill scale from the steel to prepare it for welding.

For the projects that we are doing in this book, most of the cutting for the tubes and bars will be done with a chop saw. Sheet metal will be cut with a grinder using a cutting disk.

When cutting with a grinder, always securely clamp the material. During cutting, make sure the disk spins into the direction of the cut. Always use the bottom front quarter section of the disk; if the disk starts cutting more toward the top of the disk, it will want to kick. Let the blade do the work; it doesn't require a lot of pressure to cut.



Have everything you need out and ready to go.

## The Welder

Most MIG welders that a hobbyist or beginner welder would buy are all pretty much the same. The standard housing contains the drive motor for the wire feeder, the power source, and other components that help control the machine. The components that you will need the most understanding of are the day-to-day maintenance parts, such as the MIG gun, or weekly and monthly maintenance, such as how to load the wire spool.

The gun, or torch as it is called, is the handle piece of the equipment where all three components for welding exit to create a weld. I sometimes call it the stick. Normally, the assembly for the gun is pretty straightforward. The gun consists of the gun handle, weld trigger, contact tip, nozzle, and the shielding gas diffuser ports.





This is the contact tip and nozzle for the gun. These are consumable products and will need to be changed periodically.

All of the elements of welding initiate at the same time when the welding gun trigger is pressed and held down. The filler wire will feed through the tip, the arc will form at the tip of the filler wire (which is also the electrode), and the shielding gas will flow from the diffuser ports to create a pure environment for the arc to exist. The nozzle directs the shield gas over the tip and then over the arc.

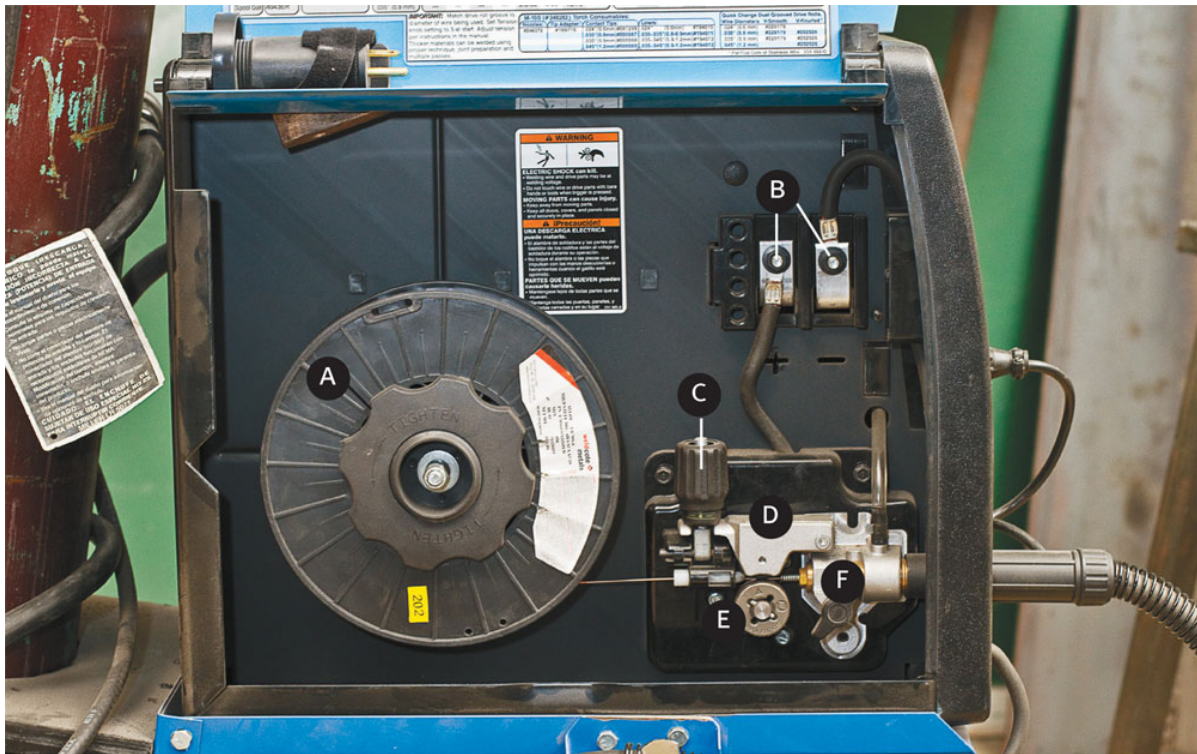




The distance the filler wire comes out from the contact tip is referred to as the "stick out." The stick out should always be  $\frac{3}{8}$  inch (9 mm) while welding.

Right out of the box this gun is simple to set up. Most guns will only have two pieces that you will need to attach, the tip and the nozzle. Screw the tip in to the threaded adapter opening at the face of the shielding gas ports. Make sure that the tip size is the same as the welding wire used. For example: if the wire is 0.030 inches (0.762 mm) in diameter, make sure that the tip is clearly marked with a 0.030 inch (0.762 mm) stamp. You will also have to make sure the threading of the tip matches the gun (this will vary depending on the manufacture). After the tip is secure, connect the nozzle

over the tip and onto the gun neck. Nozzles can be a screwed in or have a pressure fitting, also depending on the manufacturer. The tip should be even with the nozzle's face. As you develop a better understanding of the MIG process, you may prefer to have the contact tip sticking out of the nozzle face about 1/8 inch (3 mm) or so. This is fine, but don't go too much past that distance.



This is the inside of a fully assembled MIG welder. A. Spool of filler wire; B. Positive and negative terminals; C. Tension adjustment knob; D. Tension arm; E. Drive wheel; F. Opening to gun liner.

Now that the gun is assembled, it is time to connect the hose and ground. Connect the hose first by pushing the feed connector end of the hose into the receiving port on the housing. Make sure the fitting is all the way in. If the connector is not in the port securely, the machine will not have enough of a seal for the shield gas hose. After this has been secured, tighten the screw that fixes the connector into place.

The ground normally will come already connected to the machine. If it is not, feed the ground through the ground port receiver and secure the ground cable to the ground terminal. This is also a good time to make sure the machine is set to the correct current. Solid wire carbon steel welding requires a DC+ connection. This is an adjustment that would need to be

made to the positive (+) and negative (-) terminals, normally right above the wire feed drive assembly (unless the welder is a top feed machine in which case it would be below). Sometimes, if you purchase a used MIG welder, it may be set for flux-core welding (which is DC-). This can cause problems when welding with solid wire. Other steps may need to be taken to ensure the uses of the proper voltage such as switching the positive and negative terminals. Smaller machines will normally be single-phase 120 V or 230 V; check with the manufacturer to make sure the unit is connected properly.





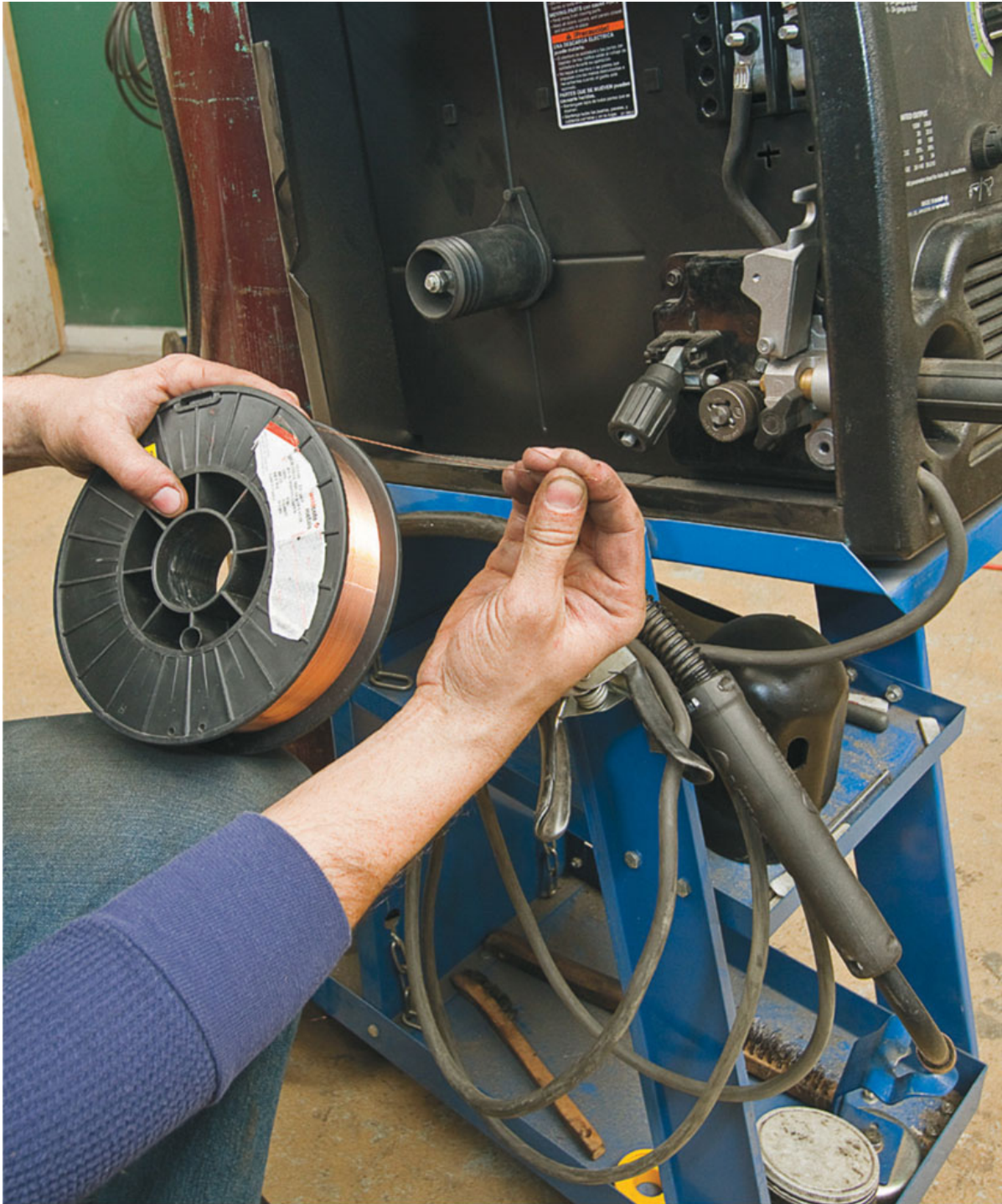
Before cutting the wire away from the spool, make sure to secure it with your finger and hold it down to prevent it from unraveling.

You're almost there! It's time to feed the wire through the wire feed assembly, gun liner, and gun. Before doing so, inspect the wire feed roller to make sure the groove is correct for the wire size. The feed roller can have

multiple grooves for different diameter wires. If the groove does not correspond to the wire, it can have the wrong effect; too big or too small and the roller will not have enough bite and will slip over the wire.

There are two types of wire that are commonly used for mild-steel welding. ER70S-3 is an all-purpose type of filler wire that is great for everyday use, and ER70S-6 wire is higher in deoxidizers for welding on rusty or dirty steel. Most of the wire sold in home improvement stores is ER70S-6.





It helps to straighten the wire before you feed it.

Release the tension knob and lift the tension arm up. Now listen, this is important. This is also something most handbooks don't tell you. The spool of mild steel filler wire is essentially a spring. As soon as you cut the wire away from the spool it's going to want to unravel. Before or after putting



the spool into place, make sure to hold down the wire and hold the spool in place with one hand. The wire needs to be secure at all times. If it is not, it will spring out quickly and unwind. If this does happen, you will spend a lot of time winding it back onto the spool or cutting a lot of wire away (which is wasteful).



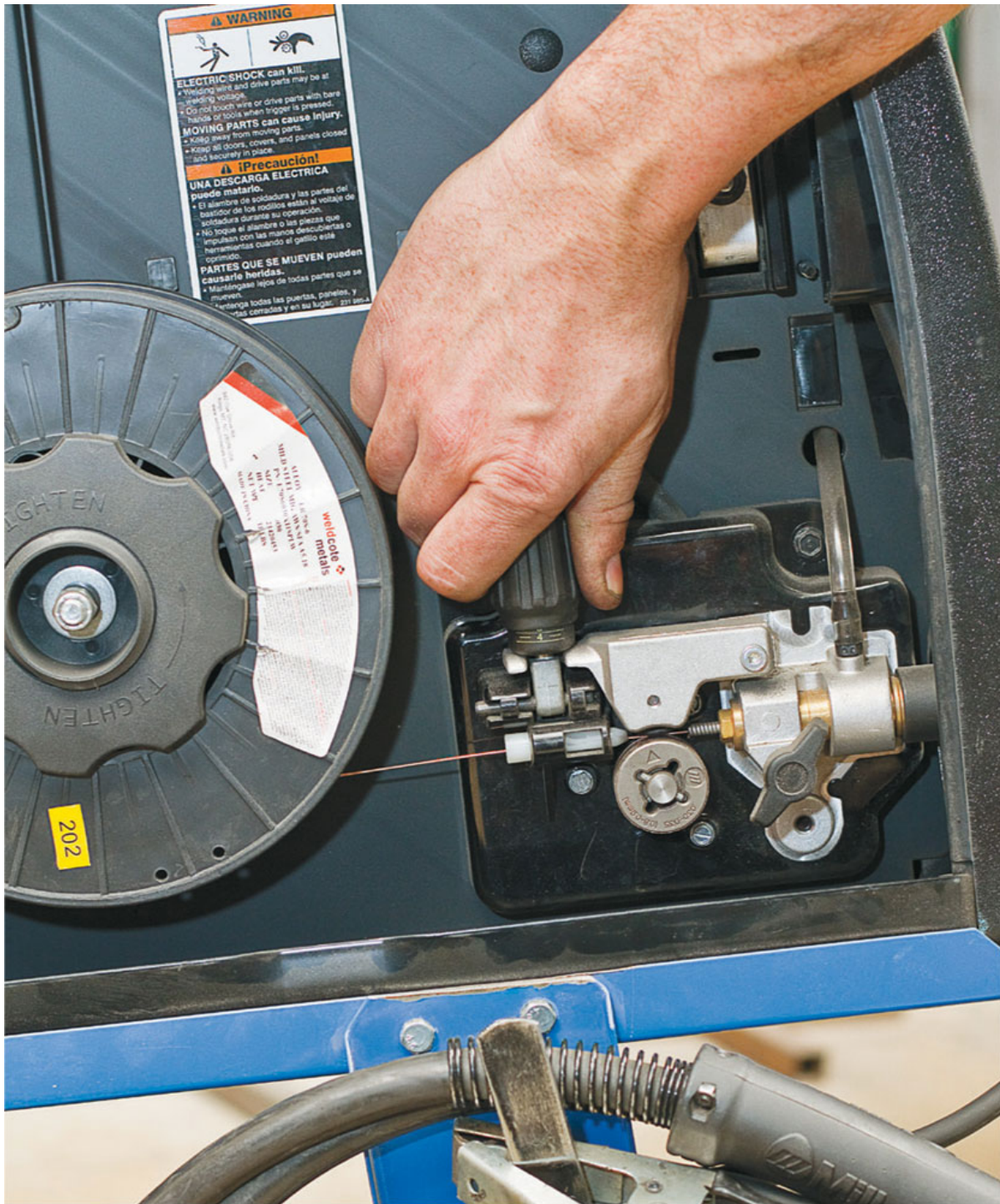
Feed the wire through the guide, over the drive wheel, and into the gun liner opening. Feed the wire a few inches into the gun liner.

Hand-cut the wire away from the spool with a pair of wire snips. Once you have cut the end away from the spool, grab the wire securely and feed

the wire through the wire feed drive assembly. You may need to straighten the wire before feeding.

Feed a few inches (5 to 8 cm) into the gun liner (hose) and lock down the tension arm; then turn on the machine. Set the wire feed to about 30 or 40 percent, which is normally about a number 4 to 7 setting on the wire feed dial. Pull the gun trigger to allow the filler wire to feed all the way through the hose. Keep the gas off and the voltage turned all the way down. Make sure the gun's contact tip is away from the ground to prevent unwanted arcing.





Lock down the tension arm with the tension adjustment knob. Make sure to hold down the wire at all times while putting the spool into place and tightening the screw.



To set the tension properly, put a 90 degree bend in the wire so it points outwards and mirrors the gun neck.

Once you see the wire come through the tip, release the trigger. You may need to make an adjustment to the tension using the tension knob. Too much tension will overwork the motor, causing it to feed improperly; not enough tension will cause the wire to slip or not allow the wire to feed at all.

It's possible that the contact tip could obstruct the wire from feeding all the way, and it may be necessary to remove the contact tip from the gun in order to feed the wire. After removing, press the trigger until the wire is



exposed; then feed the tip over the wire and secure the tip back into position. Turn the welder off while re-securing the contact tip.

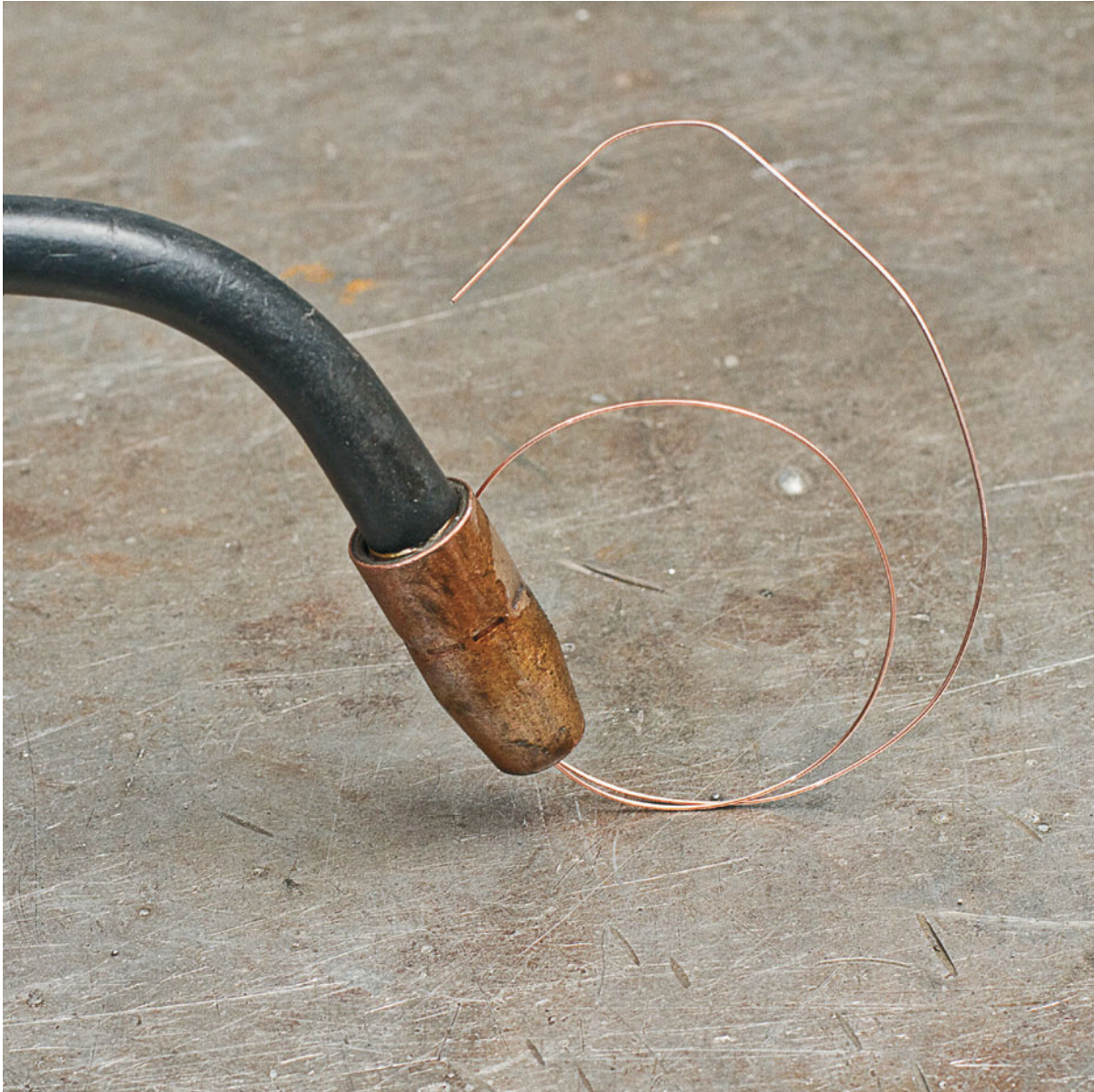


Hold the nozzle 1 inch (2.5 cm) from an ungrounded surface, with the bend in the wire touching the surface. Double check to make sure the ground clamp is not attached to your surface.

To set a good tension for the wire feeder, first set the tension knob to zero. Set the wire speed for half the capacity of the machine's wire speed output; for example, if the machine has a maximum 100-feet (30.5 m)-per-hour setting, set the wire speed for 50 feet (15.2 m) per hour. That should be a good average wire speed to properly set the welder. Feed 2 inches (5 cm)



of wire out of the gun. Using your finger, put a 90-degree upward bend in the wire. At this time you do not need the gas or the voltage on. Turn the gas valve off and the voltage all the way down.



Press and hold down the gun trigger. Adjust the tension until the wire can form a 3 inch (7.6 cm) loop with no problem.

Place the bend of the wire onto an ungrounded surface, holding the gun tip 1 inch (2.5 cm) from the surface at a 30-degree angle (or at an angle where the gun handle is parallel to the surface being used). Again make sure the ground clamp is away from the gun and not clamped to the surface

of the table or use a piece of wood for the surface test. We do not want an arc! Pull the trigger. If the wire does not feed, release the trigger and add tension with the tension knob. Repeat this process until the wire is feeding smoothly and not getting hung up. This may take a few times to get a good consistent tension. The wire should flow freely and also have the ability to create tight loops about 3 inches (7.6 cm) in diameter with the wire.



Pound-force per square inch ( $\text{Lbf}/\text{in}^2$ ) is also commonly referred to as pounds per square inch (psi) or kilogram-force per square centimeter ( $\text{kgf}/\text{cm}^2$ ) and is always the pressure of a compressed gas. Cubic feet per hour (CFH), or cubic meters per hour (CMH), is always the flow of the pressure going through the regulator.

Next is connecting the shield gas cylinder to the machine. Before screwing in the regulators, open the cylinder knob for a second to knock out any dust or debris that may have collected inside the fitting. Use Teflon tape on the regulator threads to seal the fitting before screwing it into place. Don't overtighten this fitting; you want a fit snug enough to create an effective seal while also allowing you to release the fitting when the tank is spent. Repeat this process for the fitting on the machine. It should be snug but not tightened down too much. Open the cylinder knob all the way and

then turn back one half to one full turn. This will ensure the shielding gas is flowing through the regulator smoothly. To check the seal, use a cup of soapy water and a small paintbrush or a spray bottle to coat over the connections. If tiny gas bubbles form in the soapy water on the connection, repeat the process until the fittings are completely sealed. I prefer to orient the regulator gauge faces at an upward angle so I have clear vision of my pressure gauges. After everything is set up, wipe off the soapy water. The machine is now ready for use.

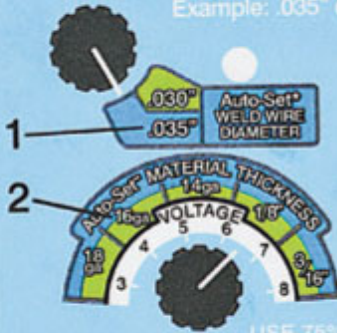




# Millermatic® 211 Auto-Set™

## Auto-Set™ - SIMPLE SETUP FOR WELDING MILD STEEL

Example: .035" diameter wire, welding 1/8" material.



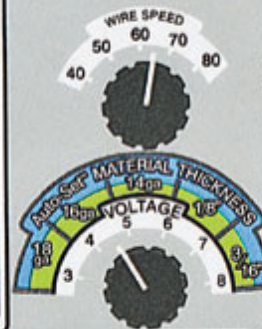
1. Activate Auto-Set™ by selecting the diameter of the welding wire with the WIRE SPEED knob. Auto-Set™ light comes on.

2. Select thickness of the mild steel being welded with the VOLTAGE knob. Setup complete.

USE 75% ARGON / 25% CO<sub>2</sub> SHIELDING GAS

## Manual Setup

Refer to chart below to select Voltage and Wire Speed based on thickness of metal.



1. Number of slash Speed I (Examp  
2. Number slash is Knob S (Examp

NOTE: approxi required recom

Material	Suggested Wire Types, Polarity	Suggested Shielding Gases (Flow Rate of 20-30 cfh)	Wire Sizes (Diameters)	120 Volt - 24 gauge to 3/16"									
				24 ga. (0.6mm)	22 ga. (0.8mm)	20 ga. (0.9mm)	18 ga. (1.2mm)	16 ga. (1.5mm)	14 ga. (1.9mm)	1/8" (3.2mm)	3/16" (4.8mm)		
Steel	Solid Wire ER70S-6 (DCEP)	C <sub>25</sub> Gas Mixture 75% Ar / 25% CO <sub>2</sub>	.024" (0.6 mm)	2/22	2.5/30	2.5/30	3/35	3.5/45	4.5/60	5.5/70	10/80	2/22	2.5/30
			.030" (0.8 mm)	2/20	2.5/25	2.5/25	3.5/30	4/40	4.5/50	6/60	10/60	2.7/20	3.5/30
			.035" (0.9 mm)	---	2.5/20	2.5/20	3.5/25	4.5/35	5/40	6.5/45	10/45	---	2.5/30
	Solid Wire ER70S-6 (DCEP)	100% CO <sub>2</sub>	.024" (0.6 mm)	---	3.5/30	3.5/30	4/35	4.5/45	5/50	7/60	---	---	3.5/30
			.030" (0.8 mm)	---	3.5/25	3.5/25	4/30	4.5/35	5/40	7/45	10/50	---	3.5/30
			.035" (0.9 mm)	---	3.5/20	3.5/20	4/20	4.5/25	5/30	7/35	10/40	---	3.5/30
	Flux Core E71T-11 (DCEN)	No Shielding Gas required. Good for windy or outdoor applications.	.030" (0.8 mm)	---	---	---	2.5/30	3/30	4/40	5/45	10/50	---	---
			.035" (0.9 mm)	---	---	---	2.5/20	3/20	4/30	5/35	10/40	---	---
			.045" (1.2 mm)	---	---	---	---	---	---	---	---	---	---
Stainless Steel	Stainless Steel (DCEP)	Tri-Mix 90% He / 7.5% Ar / 2.5% CO <sub>2</sub>	.024" (0.6 mm)	---	4/35	4/35	4/40	5.5/60	6.5/75	10/80	---	---	4.5/60
			.030" (0.8 mm)	---	4/25	4/25	4/30	5.5/40	6.5/50	10/55	---	---	3.5/30
			.035" (0.9 mm)	---	4/20	4/20	4/25	5.5/35	6.5/40	10/45	---	---	---

Selecting Wire, Gas and Control Settings for Aluminum. Use optional Spoolmate 100 series Spool Gun (Patent Pending)

Aluminum Spool Gun	Aluminum Wire	Shielding Gas	Wire Size (Diameter)	24 ga. (0.6mm)	22 ga. (0.8mm)	20 ga. (0.9mm)	18 ga. (1.2mm)	16 ga. (1.5mm)	14 ga. (1.9mm)	1/8" (3.2mm)	3/16" (4.8mm)
Aluminum Spool Gun	Aluminum 4043ER	100% Argon	.030" (0.8 mm)	---	---	---	2/65	2.5/70	6/85	10/90	---
			.035" (0.9 mm)	---	---	---	---	3.5/60	4/65	10/70	---

**IMPORTANT:** Match drive roll groove to diameter of wire being used. Set Tension knob setting to 3 at start. Adjust tension per instructions in the manual. Thicker materials can be welded using proper technique, joint preparation and multiple passes.

M-100 (#245282) Torch Consumables:		
Nozzles:	Tip Adapter:	Contact Tips:
#246372	#165715	.024" (0.6mm)#0007295
		.030" (0.8mm)#000067
		.035" (0.9mm)#000068
		.045" (1.2mm)#000069



Most MIG welders will come with a chart or have the dials with indicators to help you set the voltage and wire speed correctly.





Set the whole system to the thickness of the metal.





# Millermatic<sup>®</sup> 211 Auto-Set<sup>™</sup> with MVP

120/230V Wire Welder  
Welds 24 gauge to 3/8" Mild Steel  
120 Volt - 24 gauge to 3/16"  
230 Volt - 24 gauge to 3/8"



.030" Auto-Set<sup>™</sup>  
.035" WELD WIRE  
DIAMETER



### ⚡ RATED OUTPUT

	120V	230V
VOLTS	20	23.5
AMPS	90	150
DUTY CYCLE	20%	30%
MAX OCV	30	34
AMP RANGE	30-140	30-210

\* See weld parameter chart for Auto-Set<sup>™</sup> instructions.

MADE IN USA

MILLER ELECTRIC MFG. CO., APPLETON, WI

Set the wire speed and voltage dials to the proper position for the thickness of the metal you are going to weld.

For welding, the machine will always be set for the thickness of the metal to be welded. A MIG will have two knobs to set. One will need to be set for the voltage, which will determine the heat or intensity of the arc. The other is the rate at which the filler material will feed from the gun tip into the weld zone. Most machines will have a chart that you will need to follow to determine the proper voltage and wire feed settings for the specific thickness or gauge (ga) of metal.

Besides the thickness of the metal, there are a few other things that will determine the settings of the machine. These components are normally constant, and you probably took notice of them while setting up the welder. This includes what the machine is plugged into, whether it is 120 V or 230 V, and the size of the filler wire, most likely 0.030 inches (0.762 mm).

On your machine, you will find a chart that shows the proper wire speed and voltage combinations to use while welding. Most charts will have a line that will begin with the type of metal to be welded on and then the gas set up, wire size, and the proper combination below the gauge to be welded.

For example, to set the machine to weld 16 ga steel using 230 V, in this chart, it indicates steel, the gas mixture, and type of wire and size. You follow the chart over to the 16 ga for 230 V, and the setting is 3.5/45. The 3.5 is the voltage setting and 45 is the wire speed setting. Now set the knobs accordingly.





There are four items you should always have around your MIG: A. Spatter protection (tip dip); B. Stainless steel wire brush; C. MIG pliers; and D. Soapstone.

The shield gas pressure is very important. As you will notice, the regulator closest to the gas cylinder reads in pound-force per square inch ( $\text{lbf/in}^2$ ) or kilogram-force per square centimeter ( $\text{kgf/cm}^2$ ). This measurement is also commonly referred to as pounds per square inch (psi) and is the pressure of the cylinder indicating the amount of gas left. The outside regulator, normally the one to the left, indicates the output pressure that will go through the gun liner and out the nozzle. Just like the machine, this should be set in accordance to the material thickness, normally between 20 cubic feet per hour (CFH) (0.57 cubic meters per hour, or CMH) to 30 CFH (0.85 CMH). If you're welding on very thin gauge material, such as an auto body, you will want the pressure to be low, around 20 CFH (0.57 CMH). Car bodies are amazingly thin metal; if the output CFH (or CMH) is too high, you can still burn holes through the steel even if the machine is set properly. Inversely, if welding on thicker materials, more gas is required. The max thickness of a machine will normally require the flow to be 30 CFH (0.85 CMH). Even though the scale of the flow regulator reads high,



too much shield gas can also be problematic as it can push molten metal out of the weld zone.

To understand this concept better, think of it this way: the thinner the material, the less time and distance you can draw out a bead. For thinner material such as auto body, a bead cannot even be made. It is more of a series of tack welds in order to spread out the heat to prevent warpage and burn through in the material. The thicker the material becomes, the more time or length of the bead that can be created.



## Always Within Reach

Whenever you are operating a MIG welder, keep these items close by, as you will need them for every welding task.

**MIG PLIERS OR MIG SNIPS:** These can be used for a lot of different reasons, but the primary purpose for them is to cut the filler wire so that the electrode stick-out is at the ideal  $\frac{3}{8}$  inch (10 mm) length. MIG snips are normally  $\frac{3}{8}$  inch (10 mm) thick, so when the wire is cut, the stick-out is perfect.

**SPATTER PROTECTION:** What I like to call tip dip or nozzle dip, this is a petroleum gel that protects the contact tip and nozzle by preventing spatter from fusing to them. Too much spatter buildup on the inside of the nozzle and on the tip can create a conductive metal bridge that will allow the nozzle to double arc, which is when there are two arcs, one at the tip of the electrode and the other at the edge of the nozzle, normally fusing the nozzle to the base metal. It also obstructs the shield gas from flowing freely through the nozzle and then over the arc.

**STAINLESS STEEL WIRE BRUSH:** I can't stress the importance of always welding on raw, clean metal. In between a series of tacks or between welds, the burn off should always be removed with a stainless steel brush. This is proper maintenance for welding. Brushes should always be stainless steel. NEVER use one brush for all metals. Always have a separate stainless steel brush for each metal type. It is best to label them according to the metal they are used on such as carbon, stainless, and aluminum. Cross contamination from metal to metal can cause big problems when welding.

**SOAPSTONE:** This is great for marking the surface of steel because it is non-inclusionary, meaning it won't get into the weld and cause any problem to its integrity.

## **Other Cutting Tools**

There are all kinds of ways to cut metal. In this book, we are really only going cut with chop saws and angle grinders, but I thought I would let you know of a few other methods of cutting that I use in my shop.

For the most part, the average beginner or hobbyist isn't going to go out a buy a hydraulic sheer or industrial metal-cutting band saw. These kinds of metal-cutting machines are used when milling and fabricating on a much more industrial level such as manufacturing. Computer Controlled (or CnC) cutting machines—such as water jet, plasma, or laser—create beautiful cuts in all sorts of shapes and designs. Some CnC machines, such as CnC mills, allow the operator to create things in three dimensions. CnC mills have the ability to take a three-dimensional digital file and mill away the material, such as an aluminum billet, to create things like engines and custom parts for motorcycles, cars, and aircraft.

Machines of this size and expense really aren't available to the individual. So how would one go about getting a straight cut on a piece of sheet metal or cutting shapes?

### **Oxygen-Acetylene Torch**

This is a method that has been around since the beginning of the twentieth century and is still used today for cutting thicker materials. Oxy-acetylene torches use oxygen as a fuel to increase the heat created from the combustion of the compressed gas acetylene, creating a stream that exceeds 6000°F (3316°C).





When cutting with an oxyfuel torch, it is necessary to wear proper safety gear. Eye protection should have a 3 to 6 shade DIN.





Here is an oxy-acetylene torch setup chained to hand truck. All cylinders need to be chained to something for safety. If a hand truck is not available, chain the cylinders to the wall or stationary table.





Use a paintbrush and soapy water to coat around the connections. Open the main valve. If bubbles form you have leaks and will need to reseal the connections.

Having the ability to not only cut steel but to weld, heat, solder, and braze, makes the oxy-acetylene setup very versatile. Although it is limited in its ability for welding, it makes a great cutting tool. Oxygen can be combined with other gases such as propane and MAPP gas for the same purpose. The oxy-acetylene flame burns between 5600°F and 6300°F (3093°C to 3482°C), which is the highest temperature of any of the oxyfuels; this allows it to cut through most metals.

Since the oxyfuel torch doesn't require any electricity, it's great for onsite work. It has a high cutting capacity that makes it commonplace on



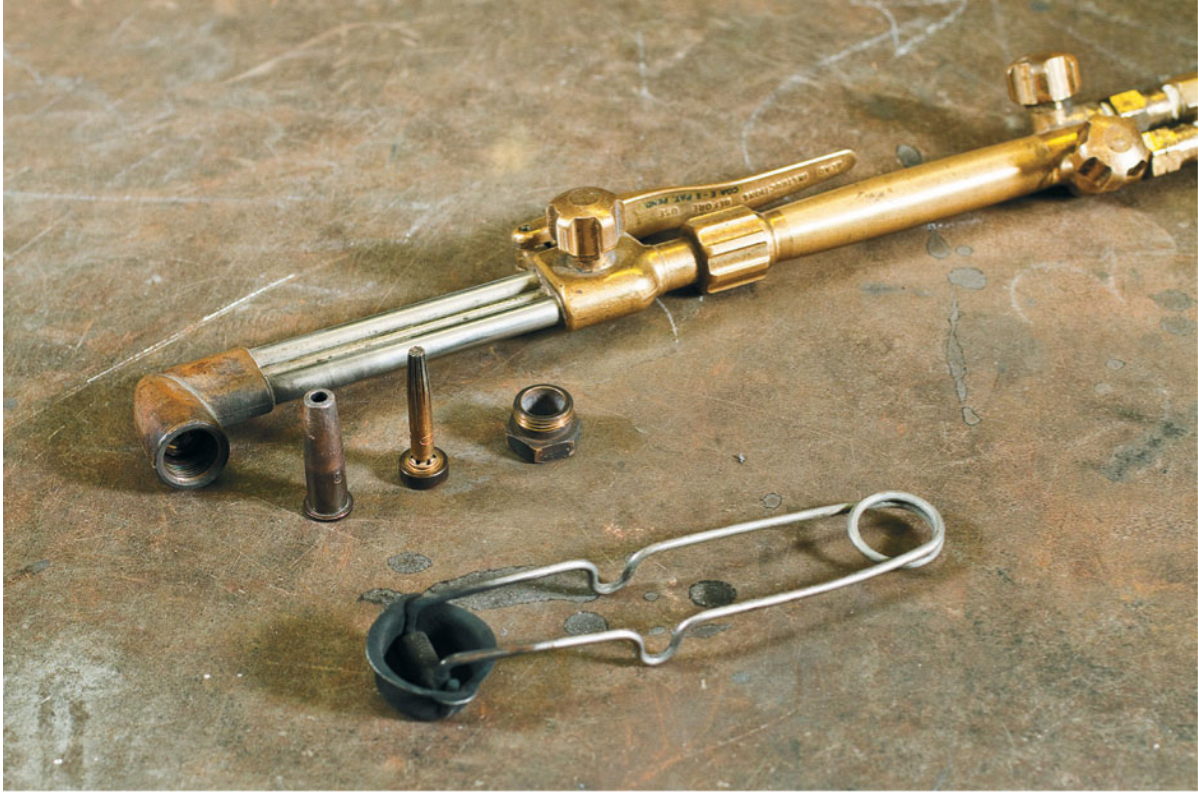
work sites such as bridge building.

The oxy-acetylene setup requires a cylinder of compressed oxygen and acetylene. Both tanks require regulators for a pressure reading in lbf/in<sup>2</sup>, or psi (pounds per square inch), or kgf/cm<sup>2</sup> (kilogram force per square centimeter) and a flow regulator. For safety purposes and to avoid confusion, the regulators for acetylene and oxygen have opposite threading for attachment. When you are attaching regulators to cylinders, never use oil, grease, or lubricant of any kind. The mixture of oil and oxygen only takes one spark to ignite a fire in the regulator, which can lead to an explosion. This can cause you to have a very bad day.

The oxygen tank is pretty straightforward and setting up the regulators is very similar to setting up the Argon-CO<sup>2</sup> tank on a MIG welder. Acetylene, however, is a little more complicated. Acetylene is the combustible gas that creates the flame. It is also a very unstable gas. Acetylene alone cannot be compressed above 15 lbf/in<sup>2</sup> (1.05 kgf/cm<sup>2</sup>). To have the ability for acetylene to be pressurized further, it has to be combined with a porous fiber and acetone. As it is pressurized in the tank, the fibers and acetone absorb the acetylene.

This is important safety information to know. Never use an oxy-acetylene torch when the acetylene tank is not upright. Lying on its side can cause the acetone to run through the regulators and into the hoses, thus causing damage. It can also lead to sudden combustion. You should also wait 25 minutes or more from the time the tank has been lying down to use an acetylene tank, allowing the acetone and other material to settle back to the bottom.

Never use an oxy-acetylene torch when the acetylene tank is not upright.



A standard torch cutting set up includes the cutting head and tip. The striker is used to ignite the acetylene gas.





Ignite the acetylene gas first by opening the valve a little and using the striker. Once ignited, slowly add oxygen until you have the proper flame for cutting.



The acetylene tank valve should never be open more than one rotation or less than a quarter. This will allow the valve to be shut quickly in case of an emergency while also permitting enough flow for the proper flame. Acetylene is extremely unstable under pressure and the regulator should never be set over 15 lbf/in<sup>2</sup> (1.05 kgf/cm<sup>2</sup>) to prevent explosions. The acetylene tanks should never be spent at more than a seventh of the bottle per day. This will prevent the acetone from leaching into the lines, which can cause damage to the hoses and even the torch.

The hoses that connect to the regulators are flexible and designed to withstand high pressures. The hoses carry the gases to the valves in the torch body. The green hose is for oxygen, and the red hose is for the acetylene. You can remember this as red for flammable.

In a cutting torch setup, the torch head will have three pipes: one pipe for the acetylene flow, one for the continual flow of oxygen, and one for the oxygen blast. The correct ratio of oxygen and acetylene creates the correct flame. The flame heats the metal until it begins to melt. The oxygen cut lever releases a higher flow of oxygen that fuels the heat further and blasts the molten metal through the cut.

The tip attaches to the torch head. The two gases stay separated until they reach the mixing chamber. The holes in the tip allow both of the gases to flow through to create the flame, allowing the metal to be preheated before the high-pressure oxygen. There are normally between 2 and 6 holes on the tip, depending on the duty it needs to perform. The tip is fitted with a center hole through which a jet of high-pressure oxygen passes. A striker is used to create a spark that ignites the gas.

The valves are used to fine-tune the amount of flow between the two gases and to generate the correct flame for cutting. The middle valve is the release and also the fine-tuning oxygen control. The spring valve connected to the lever release is the power switch for after the metal has become hot enough to cut, normally a cherry red color.

In a well-ventilated area, start the acetylene flame by cracking the valve at the base of the torch body indicated by the red hose. Hold the torch away from you and then light it by sparking the striker to ignite the acetylene. The acetylene has a very distinct odor and should never be inhaled directly. Slowly release the oxygen until the flame concentrates into a cone. Continue to add oxygen until smaller cones appear in front of the smaller preheat holes. This is the correct flame. The material and its thickness

should determine the intensity of the flame. The highest temperature an oxy-acetylene torch can go is roughly 6000°F (3316°C). For thicker materials this will be the heat to use and will take more time to heat up and cut. For thinner materials, you will want to dial the heat of the torch down to create a finer cut.

To cut with an oxy-acetylene torch, position the flame to begin heating the steel by holding the torch perpendicular to the surface and edge of the steel. Hold the inner cones of flame about 1/16 inch (2 mm) to 1/8 inch (3 mm) above the plate. The proper distance away from the plate will prevent metal from sticking to the tip. Once the metal is a cherry red color, it is hot enough to start cutting. Slowly depress the oxygen lever until it is fully open. Move the torch through the cut path, maintaining the same distance and angle. For thinner materials, it is necessary to angle into the cut roughly 75 degrees. For thicker materials, decreasing this angle and slowing the movement through the cut path will be necessary.



Wait for the steel to become a cherry color before starting the cut.



The side opposite from the cut side will normally have dross, or what is commonly referred to as slag. This is the molten metal that was blown through the cut and then fused and solidified underneath the material.



A basic plasma cutting system will include a power source, torch, and ground clamp. Most systems will require a separate air compressor. Wear proper eye protection with a shade between 3 to 6.



## The Plasma Cutter

The plasma cutter is a much more elegant machine than the oxy-acetylene torch. The concentration of the plasma arc delivers a finer cut with less dross than an oxyfuel cutting method. Like the MIG welder, the plasma-cutting machine is an arc process. Plasma is a state of matter created by the ionization of gas that produces an intensely hot airborne electrical current. One of the most common examples of plasma is lightning.



The plasma cutter has a lighter, more workable torch that allows for greater control, giving the operator a more fluid motion that allows for tighter curves and more intricate designs.

In the plasma-cutting machine, this arc is produced by compressed air passing through a chamber that houses an electrode. The gas in the chamber is constricted as it ionizes, building up pressure before blowing through the tip where it is met by the grounded piece of material to form an arc. This



arc is a concentrated plasma stream that can burn in excess of 40,000°F (22,204°C). The high temperature of the plasma makes it possible to cut any conductive metals, whereas oxy-fuel cutting systems are restricted to certain carbon metals such as mild steel.

The intensity of the heat and power of the arc gives the cutter many advantages, such as the ability to move much faster through the cut. The combination of a shorter cutting time and higher temperature cuts down on the probability of thermal distortion or warpage.

One of the drawbacks of the plasma is that the flow in which the arc cuts will create a curve on one side of the cut called a kerf. The kerf will become more prominent on thicker materials and metals such as aluminum. Knowing which side the kerf will be on will help you come up with a plan to produce a cleaner edge and minimize grinding time. Practicing the speed in which to cut with plasma will minimize the kerf by producing a cleaner cut with less dross.



Sparks will be flying when you use a plasma cutter, and you will need proper ventilation.

Unfortunately, plasma cutters are initially much more expensive than oxyfuel cutting systems. Most plasma cutting machines also require air compressors to produce the necessary air pressure to create the plasma arc. If you plan on doing most of your cutting in your shop, then it might be worth the investment.

When cutting with plasma, be sure to take the necessary safety precautions. Wear the required safety gear: number 3 shade eye protection or higher, leather gloves, long-sleeve shirt, leather shoes or boots, and jeans. Cutting with plasma is just like MIG welding, so follow all of the same safety rules and never wear synthetic fibers while welding or using a plasma cutter.



The torch of the plasma cutter is smaller and lightweight. The trigger is fitted with a safety switch to prevent accidental fire. Just like the oxyfuel torch, the plasma torch has similar consumable components. The tips and electrode will be the most frequently replaced components of the torch, but over time the other components will have to be replaced as well.





From left to right: retaining cap, deflector, drag shield, swirl ring, electrode, and tip. In this model, the drag shield and deflector are interchangeable. The drag shield encloses the tip, allowing contact to be made with the grounded base metal. When making free-hand cuts, it is changed out with the deflector, exposing the tip for added vision.

Cutting with a plasma cutter is very similar to welding with a MIG. The ground has to be clamped directly to the work piece or on a conductive metal surface that the piece is resting on. Set the machine to the proper output for the thickness of the material—most plasma-cutting machines will have a thickness scale surrounding the control knob that sets the machine. Check to make sure the air hose from the air compressor is attached correctly and that the proper amount of air pressure is set. Most machines will have a pressure gauge that will tell you what pressure to use, and some even allow you to make that adjustment on the machine. Newer machines will regulate and adjust the pressure going through the machine automatically as long as there is enough pressure coming from the line.

Once the machine and work piece are set up and secured into place, you are ready to cut. Just like when you're welding, you should be comfortable. Put your body in a position where you are not tense but relaxed. Brace and support your torch hand with your opposite hand.

When cutting, the tip should always be a consistent distance away from the work piece. The closer you are, the finer the cut will be. Aim for a 1/16-inch (2 mm) distance; more than that and the cut will become too wide. If you are using a drag shield (as seen in the image at the right), then the shield should make contact with the base metal.

Pull the trigger when the tip is just off the material to start the plasma arc. This will start the initial ungrounded plasma arc that will help you to engage the metal. Once the arc engages, draw the torch toward the metal. When the arc grounds as it hits the metal, it will intensify and cut into the material. You'll need to practice to develop the right pace for a smooth cut.

After cutting with a plasma cutter, the other side of the cut will have a small amount of dross fused to edge. Simply remove the dross with anything that has a solid edge to it, such as a tack hammer or a piece of scrap. Hit the dross in a sharp downward motion to knock it off.





Note how I am cutting with a guide for a straight cut and am using a drag shield (the detachable tip on the plasma gun) in order to make contact with the base metal and my guide.





Plasma cutting is an extremely accurate method of cutting metal and provides a very clean cut. Make sure the area around and below the cut is clear of anything that may be affected by high heat.





1

Start the arc off of the piece and move into the cut.





2 Keep the torch perpendicular to the cut.





3  
Movement through the cut will be determined by the thickness of the material. Find the speed that gives you the cleanest cut with the least amount of dross.





The torch will pick up on any jitters or minor movements in your hands. Just like when you're welding, brace and support the torch with both hands and be relaxed. It's not a good idea to have too much coffee before freehand cutting with a plasma torch.





5

When cutting without a drag shield, try to keep the tip  $\frac{1}{16}$  inch (2 mm) from the metal. Contact without a drag shield will cause double arcing.





When cutting straight edges with a guide, make sure to measure out from where the drag shield makes contact to the guide to the center of the torch tip for a more accurate cut.





7

Keeping the center seam of the torch in line with the guide line will help you keep a straighter cut.





8  
On long cuts, cut from both ends and meet in the middle to prevent the metal drop from bending. You can also clamp a support underneath the piece after starting the cut.





This is dross on the other side of a plasma cut. Use a piece of scrap or a chipping hammer to remove the dross.

## Selecting, Buying, and Prepping Your Metals

Mild steel is a good place to start when learning any welding process. Mild steel is one of the most common types of metals used in fabricating. It is used in everything from machine parts, automotives, bicycles, and motorcycles to file cabinets, mailboxes, furniture, and home decoration. Mild steel also falls in the category of carbon steel along with other metals such as stainless steel, tool steel, and forged steel. Known as “ferrous” metals, they all contain iron and/or a combination of carbon or other elements to give them their unique characteristics. In general, most carbon steels will be magnetic. In the case of stainless steel, chromium, and nickel, other alloys can be added to create different grades. The grade or combination of alloy elements used to create that specific grade determines the properties of that grade. Steel can be manipulated to create a wide range of alloys by adding different elements such as chromium and nickel.

Mild steel has a low carbon content, which makes it softer and easier to work with. In contrast, adding more carbon and heat-treating the material will make the metal harder, but at the same time more brittle. Steel with more carbon is subjected to a high-heat tempering process that decreases its ductility, depleting its ability to bend under stress. These high carbon metals are known as tool steel or hardened steel and are used for nuts and bolts or creating tools for cutting, drilling, and machine parts. Carbon steel can be hardened further by adding other elements (such as manganese) to create

gears, sprockets, and even stronger tools. These types of carbon steel are notorious for being difficult to weld and cut.



Plate metal refers to sheets that are  $\frac{3}{16}$  inch (5 mm) or thicker. Sheets that are  $\frac{3}{16}$  inch (5 mm) or thinner are called sheet metal.





# Hot Roll vs. Cold Roll

There are typically two different kinds of mild steel that people will refer to when speaking or ordering steel: hot roll and cold roll. When a mill forms mild steel from stock into any number of shapes such as sheet, bar, or tube, it is pressed through a set of rollers that forms it into its desired shape through a process called rolling. The classification of rolling comes from the temperature of the metal as it passes through the rollers.

When steel is heated to a certain temperature, it begins to crystallize. This temperature is called the recrystallization temperature. When metal is heated to this point to be formed, the process is referred to as hot rolling. When hot rolled metals are produced, this recrystallization forms a scale on the surface of the metal as it cools. This surface is a murky blue-gray colored flaky oxide that is called “mill scale.”

When metal is formed below the recrystallization temperature, the method is referred to as “cold rolling” and produces cold roll steel. This material will not have a mill scale as prominent as hot roll but rather a much more polished and shiny appearance. Cold roll steel will also have an increase of strength and hardness over its hot roll counterpart. It costs more to produce, so the price for cold roll is normally higher than hot roll.

Hot roll materials have softer and more ductile characteristics than cold roll steel, but have relatively the same characteristics when welding. These two types of steel can be welded together with a common MIG welding setup, and both should be prepped in the same way.





Here you see a piece of cold roll steel between two pieces of hot roll steel. Notice the difference in color. Hot roll has a murky blue/gray patina called "mill scale."





Engine parts, screws, and drill bits are all hardened steel.





Metal is made in all different shapes and sizes to suit almost any job you can think of. You can find it in plate, bar, angles, and tubes that come in square, round, or rectangle.

# Filler Material

Since welding is a process of liquefying the two pieces of base metal, the filler metal should have the same characteristics, such as the melting point. When welding mild steel, a mild steel welding wire or rod should be used. Dissimilar metals normally cannot be welded together. Nonferrous materials such as aluminum cannot be welded to a ferrous material like stainless steel. Aluminum and iron have different properties that will not allow them to be welded together, mostly due to their melting points. Steel has almost twice the melting point of aluminum. Some more advanced welding techniques require you to use different filler and base metals combinations, but for now, we'll stick with the basics and mild steel.



# Decorative Options

Metal comes in all different shapes and sizes, from bar to tube and round to rectangle. Bars, sheets, and tubes are most common for straight fabrication, but what if you are looking for something a little more decorative? Mills and foundries also create a wide variety of ornamental metals that can be used in projects. Cap rails are a good example of a decorative bar that is used for the tops of hand railings. Other decorative elements such as rosettes can be purchased to give a fence or piece of art a more attractive look.

Sheet metal also comes in a wide variety of styles and patterns. Diamond plate, expanded, and perforated sheet metal are popular for not only their decorative characteristics but their functionality as well. Diamond plate works as a tread for its strength and its durability. Expanded metal sheet and perforated sheet metal are great for threads, drainage, fencing, and industrial applications such as shelving and catwalks.



Diamond plate steel and expanded steel are just two examples of the many different styles of metals you can get. Diamond plate and perforated steel are great for steps. Expanded steel can be used for anything from steps to enclosures and decorations.

# Buying Metal

No matter what the project may be, it is normally easy to find what you are looking for if you know where to look. Typical home improvement or hardware stores are not the best places to go to purchase metal. They tend to have very small selections, which they sell at a high markup. The best thing to do is to go online and search for metal distributors in your area. Be aware that the majority of them are going to be large mills or metal distribution companies that only deal in large quantities and sell to businesses such as construction. A small privately owned metal distributor that deals with local business or small manufacturers is what you are looking for. This size distributor will normally sell single pieces such as a 4 x 8 foot (1.2 x 2.4 m) full sheet, 14 ga hot roll steel, or a 24-foot (7.3 m)-long stick of 2-inch (5 cm)-square tube with a 0.065-inch (1.7 mm)-thick wall. Don't worry, I will explain.

When buying metal, it is best to research several places to find the best price. I know this sounds elementary, but pricing differences can actually be much more drastic than you think, so shopping around could save you a lot of cash. Metal is mostly sold by the weight. The more you get, the less expensive it is. Some places may sell you an 8-foot (2.4 m) drop (a piece that is cut away from the measured purchased material) for a certain price where another place will sell you the whole stick (a complete length of milled metal) for less than the price of the other guy's drop.

When I first moved to Chicago, I found one place with good prices and service. I have yet to find another distributor that will beat them. But it is always a good idea to find two or three places just so you know you are getting the best price. Normally, once you establish a good rapport with a distributor, they will give you a better deal.

<b>Metal Thicknesses</b>		
<b>Gauge (ga)</b>	<b>Steel Thickness in Inches</b>	<b>Steel Thickness in Millimeters</b>
3	0.2391	6.073
4	0.2242	5.694
5	0.2092	5.314
6	0.1943	4.935
7	0.1793	4.554
8	0.1644	4.176
9	0.1495	3.797
10	0.1345	3.416
11	0.1196	3.038
12	0.1046	2.657
13	0.0897	2.278
14	0.0747	1.897
15	0.0673	1.709
16	0.0598	1.519
17	0.0538	1.367
18	0.0478	1.214
19	0.0418	1.062
20	0.0359	0.912
21	0.0329	0.836
22	0.0299	0.759
23	0.0269	0.683
24	0.0239	0.607

## **How to Order**

In welding, the thickness of the metal is very important. It's what you use to determine the settings for your welding machine. Metal thicknesses are typically measured in gauges (abbreviated as ga). For most materials, as the gauge number increases, the material thickness decreases.



The gauge of the material corresponds to the thickness of the material in inches or centimeters. The measurement of the thickness in gauges will vary depending on the material. In this chart, you will see that a 16 ga piece of mild steel is 0.0538 inches (1.4 mm) thick, but a piece of 16 ga aluminum could range from 0.070 inches (1.8 mm) to 0.0508 inches (1.4 mm) thick, depending on the manufacturer. These numbers also can vary depending on what form of the material you order, such as sheet as opposed to tube.

The gauge is a general measuring tool that has a fairly loose range. The decimal equivalents of the gauge of the metal you are purchasing are more exact. Since the gauge for measurement can vary so much, when you're working on something with a tight tolerance, I recommend you order by decimal, not gauge.

Unlike the filler metal, the welding wire for the MIG welding machine will always be measured in decimals for accuracy, as will the corresponding gun tips and drive wheel.

So what do you need to get started? There are a few projects in this book that will have a list of materials that you will need to get in order to complete those pieces. But for now, I want to teach you how to weld. After all, that's what this book is all about.

Most local metal dealers will allow you to go onto the warehouse floor and take a look at what they have. Even better are the guys that will let you look through their racks of drops. These are pieces that are cut from stock material and left behind by other companies doing larger jobs. If it's a large enough distributor, they will have a huge rack of drops with all sorts of cuts to choose from; this is what you will want for practicing. Find a sheet of 1/8-inch (3 mm)-thick steel, cold or hot roll, 10-inch (25.4 cm)-square or larger. This piece of steel is what you will need for the first exercise. Next, you will need to get three or more feet of cold or hot roll 1/2-inch (13 mm)-square steel bar.

If you are having trouble finding a metal distributor, try a junk or scrap steel yard. Right now we are just looking for small pieces of mild steel to get you started. Don't break the bank for his material. A good chunk of an old car chassis will work fine for the first exercise.



It may be necessary to use a grinder to even out some cuts that may be a little off before you can prep the steel for welding.

# Preparing Your Metal

The preparation of the metal is crucial to the welding process. When welding on any metal, it must be raw and free of any grease, oil, dirt, rust, paint, oxides, and other inclusionary elements that can contaminate the weld. Surfaces that are not cleaned properly can affect the weld quality. A clean weld will last much longer and will be free of included elements that may cause porosity and create a poor weld.

All of these contaminants can include themselves in the puddle and create all kinds of problems. Some particles heat to the point of off-gassing to create bubbles in the metal as it solidifies. This type of porosity is sometimes called “moon craters”. Other causes of porosity will be addressed in the next chapter.

It is common for dealers to coat carbon steel in oil to protect it from rusting in the warehouse. This oil attracts dust and dirt and over time becomes extremely grimy. It is not necessary to remove all of this grime at first; removing it from just the areas to be welded is fine. After completing the fabricated piece, you will want to remove the rest of the dirty oil with denatured alcohol or acetone. This will allow a clean and prepped surface for painting or whatever else you may decide. A wire wheel or brush can also be used for further cleaning. Wire brushes come in a wide range of bristles. Just like the grit of sandpaper or flap disk, some will add a texture to the metal’s finish. If the metal surface already has the look or texture you want, make sure to use a softer stainless steel brush.





Prepping multiple pieces at once will save you time.

Most of the cleaning and metal preparation for the weld zone is normally done with a small angle grinder. There are all kinds of grinding disks that can be used to prep the metal depending on the desired task. For some joints, it is necessary to remove a considerable amount of metal from the edges. This will require a grinding disk with a low grit such as a stone, whereas a 60-grit flap disk will work fine for cleaning the surface of cold roll steel. The amount of what needs to be removed or how dirty the metal is will normally dictate what will be used to prep that particular surface.





Failure to remove inclusions from the weld zone will cause poor weld quality. Dust particles can off-gas at high temperatures, creating gas pockets that lead to fracturing and poor welds. The effects of inclusions will appear as pores, pitting, and voids on the weld surface known as porosity.



Here is a crosscut of a weld that has deep porosity. This weld is not structurally sound.





You always want to weld on clean raw steel. Prep the weld zone with a flap disk and chamfer if necessary.

There are other methods of cleaning and preparing metal for welding. Media blasting is a great way to remove debris from larger surfaces. Media blasting cabinets can be costly, so it's not the best place to start. A simple 4 1/2-inch (11.4 cm) angle grinder will work for what we will be covering in this book. But if you plan on stripping a motorcycle frame or removing a lot of paint and rust from something that size, a media blaster is the way to go.



Manufacturers and large fabrication companies will also use a wide variety of chemicals to remove mill scale and other inclusions from large surfaces. Chemical removal cleansing methods are extremely corrosive and can be dangerous. They are not recommended for the home hobbyist. If you do plan on using muriatic acid to remove the mill scale from hot roll steel, make sure to take the necessary safety precautions and have a lot of baking soda accessible to neutralize the acid if something does go wrong.



When grinders are not in use, always put them down on the back. Never place a grinder on its front.





A bench grinder with a wire wheel is a nice tool for prepping small metal pieces. It allows you to hold the piece by hand, as in the photo, or with a set of clamps in order to do proper metal preparation.

## **Let's Prep**

When prepping the metal with a grinder, secure the piece into place with a clamp or in a vice with the area to be prepped accessible. At a proper angle with the grinder and using medium pressure, move in a back-and-forth or up-and-down pattern until the entire area that is to be welded is clean and has a raw-metal appearance.





Start a chamfer by setting up the angles and pull 3 or 4 times towards you. This will create a flat surface with the grooves going in the same direction as the disk. Pushing too hard right away will cut into the piece and make a divot.





The correct angles for chamfering are  $15^\circ$  to clear the arbor and  $45^\circ$  or greater for the chamfer.

When creating a butt joint for thicker materials, it is necessary to create a chamfer. A chamfer is a bevel ground away from both pieces of base metals at a 45-degree angle to create a channel when the two pieces are put together. This does three very important things: it creates depth for penetration; it creates more surface area for the puddle to liquefy; and it forms a reservoir to receive the filler metal. The most common way to prep the metal with a chamfer is with a stone grinding disk. The stone has a low



grit, meaning it will take off a lot of material very quickly as opposed to higher grits that will take material off more slowly but have a nicer finish.



Notice how the bottom piece has been chamfered and prepped.

Just like when cleaning the material, make sure the piece is secured with a vice or clamp. To start a chamfer with a stone in an angle grinder, it is a good idea to make the first few motions a motion toward you with medium pressure. This will put a flat surface on the edge of the metal with the grain going in the direction of the spinning disk, which will make it easier to go back and forth without getting hung up. Grinding too hard right away can cause a cutting action, which will make a divot that you will then have to grind out.

When grinding, remember to be at an appropriate angle to clear the arbor and at the same time be at a 45-degree grinding angle for the chamfers. It is not necessary to grind all the way down to a razor edge, and it is recommended to leave a flat surface for the butting joint. The flat-butted portion of the material will be determined by the thickness of the material. For example, if the material is  $\frac{1}{4}$  inch (6 mm) thick, I will chamfer and leave  $\frac{1}{32}$  inch (0.7 mm) on the vertical face. Knowing what you plan to use the joint for will help you determine how the material is to be prepped. In addition to chamfering, leaving a small gap between the base metal is another good method that provides even deeper penetration.



## ➤ CHANGING THE GRINDER DISK



Using the arbor wrench, loosen and remove the arbor nut. Notice the grinder is unplugged.



Switch out the disk, replace the arbor nut, and tighten by holding down the arbor lock and using the arbor wrench.

When replacing disks, it's always a good practice to unplug the grinder first. Hold down the lock located on the top of the grinder (opposite side from the disk on the grinder head). Using the arbor wrench, loosen the arbor nut and remove. Switch out the disk, replace the arbor nut, and tighten by holding down the arbor lock and using the arbor wrench.

On thinner metal, it is not required to chamfer the base metals. In fact, the thinner the material, the less chamfer or gap it needs. If the metal is extremely thin, such as 22 ga or lower, the MIG should penetrate into the metal enough to create the necessary weld if set properly. You will find that these thin gauges are the most difficult to weld. Most of the time, you will not even be creating a bead, such as in auto body repair, more of a series of

stitch welds or tacks. The thinner the material, the less of a gap you need and the less heat the metal can take without warping or creating holes.

When working with a MIG welder, keep a stainless steel wire hand brush around to clean off the materials between a series of tacks or if going back to a bead that you have already created. A carbon-burn byproduct will usually be around a weld or tack that has just been created. Remove the byproduct with the brush to avoid reintroducing this material back into the puddle and weld zone.



## How It Works

There are a lot of aspects of welding that I love. From the basics of joining two pieces of materials together to create one, working with intense heat, or simply just playing with fire, the truth is I love welding and metalworking because it gives me the ability to manipulate this seemingly unyielding material. Even deeper still is the idea that I have the ability to control the elements that are only formed in the final moments of a dying star to create anything in my imagination. It's also pretty handy when it comes to fixing things such as cars, motorcycles, or furniture.

# Technique

From the very first moment I welded, I had this overwhelming feeling of having the power of the sun in my hand. I had never before felt this sort of power of creation in any other medium that I had felt with metal work: the immense heat, the liquefaction of the steel, the solidification of the bead on the surface, to this day it all still fascinates me. It is a truly amazing process.

I hope you feel the same way. I'm excited to be the one to share this with you. Now let's get started.





# The Puddle

Most people aren't aware of this, but the primary job of a welder is to control fluid. It happens to be a 3000°F (1649°C) or more fluid, but a fluid nonetheless. When the arc liquefies the base metals it creates a molten pool of liquid metal called the puddle. No matter what technique is used or motion created with the gun, the puddle is the primary focus of controlling how a bead is created.

As a beginning welder progresses, they will find that there are a lot of different techniques to control the puddle to create different effects in the surface of a bead. For the most part, a welder's responsibility is to make sure the weld penetrates into the metal enough to create a proper weld. Before this can happen, a beginner needs to build a feel for movements that make even and steady motions that will produce a proper bead.

## Push or Pull

There are two methods to the madness in welding when it comes to controlling the puddle: pushing and pulling. These terms are decided by the direction of movement in which the weld is created. The "push" method is the movement of traveling into the weld zone so that the weld is created behind the gun nozzle. The "pulling" method (or what I like to call the "draw") is a dragging movement through the weld zone so that the weld is being created in front of the gun nozzle and contact tip.

Both of these methods have their good points and both should be learned as there are always going to be situations in which one will be better suited than the other. But as a beginner, the best one to start with is the pull method as it will penetrate slightly deeper into the steel than the push method and will also create a narrower bead.

Straight pull welds originated from welding butt joints. Pulling a surface weld helps beginners to practice butt joints and is also the best place to start building a speed of motion to produce a weld. What this does is help you get a better understanding of your hands' movement in relation to the material's thickness and the settings of the machine. It also makes you more aware of what you are trying to accomplish after completing a bead.

Developing a good pace or rhythm of the hand movements for the pull will translate to many other techniques that will help you develop as a MIG welder. As you develop your welding skills, you'll find that there are a lot

of variations in technique—the way you hold the gun, or the way you position your body in relation to the weld or angle of view—that affect the way you create a weld. For now, focus on the basics and you will discover these things and acclimate to your own style.





## **Stance and Comfort**

Seventy-five percent of welding is being comfortable, or as comfortable as you possibly can be in any given situation. Whether it's a welder on an oil rig, someone building a sky scraper, or a hobbyist just fixing a small part of a car, that person will always try to orient him or herself in the most comfortable position possible.

For example, a buddy of mine likes to sit low with his armpits at table level while he TIG welds on racecar parts. I, on the other hand, like to weld sitting on my favorite shop stool. I built my table to the perfect height for me and I'm nice and relaxed—to each their own.

Being comfortable is a critical part of welding. The position of the body, bracing your gun hand, and avoiding hovering with the gun are all crucial points to prevent tension and decrease fatigue. It will also allow your hands to be steadier when welding.

## ➤ COMFORT TIPS

If you have to stand at the welding table, pay attention to your stance while welding. A good stance for our first exercise is to take a step back with the dominant foot roughly shoulder width. To stay balanced and relaxed, bend with your knees and waist so that your chest is lined up with the ball of the front foot.



With your dominant foot, take a step back a little more than shoulder width. (If you are right handed, step back with your right foot.)



Brace and support the gun at the proper angles.

## Vision

The number one complaint from all of my student or beginner welders that I hear all the time is “I can’t see anything.” I’m going to tell you right now that it will be hard at first. First of all, as a beginner you don’t know what you are looking for. Secondly, you haven’t trained your mind to really focus on what you need. Additionally, your vision has not become acclimated to adjust to what you need to see right away—yet.

But the more you weld, the more you will know what you are looking for and your mind and eyes will adjust to it faster. You need to see all of the elements that create the weld: the arc, puddle, and the weld zone (or line) to follow. All of these components are key in creating a good weld.

Every welder I have ever met has his or her own methods of seeing. Some even say they go entirely off of feel. Personally, I get real close and look way over my nozzle so I can see everything. To help me see my weld zone (my line), I move my head just a little to the side. Be careful not to go too far to the side. The natural mistake while drawing out the bead if your vision is too far off to the side is to go off the weld zone diagonally to the opposite side.

When you catch yourself leaving the weld zone, stop welding immediately. When you weld outside of the weld zone, all you’re doing is



creating more work for yourself because you're going to have to grind off that extra metal later if you want to make it look pretty. Stopping and starting is not that big of a deal. Just clean off the weld and start from where you left off.



## Keep Your Helmet Clean

Make sure your welding helmet is clean. When my outer clear shield gets fogged or scratched up, I use a scratch remover/polish that is formulated to work on plastic. Keep the shields clean both inside and out. And if you normally wear reading glasses, wear them under the lid. When welding on thin materials, the puddle and arc are much smaller, and the lack of arc light will make it harder to see the weld in progress.

## Hand Position

The way that the gun is held and supported will become personalized over time to you and the style that you develop, and it's one of the more important things to keep relaxed and steady. Never hold the gun with one hand or hover with both hands while welding, as the tension you'll create in your hands translates into shaky welding. Instead, always support the trigger hand with the opposite hand for stability when welding.

The dominant hand will normally be the trigger hand. The opposite hand is going to be the brace and support hand. It will also be the hand that will drag, so it plays a lot of important rolls when drawing out a bead. Don't support the weight of your body on your hands; just rest them on the table so that they can slide easily. You'll be making a motion similar to wiping sand off the table.



For best results, grab the gun handle with the dominant hand so that the index finger can depress the trigger. With the opposite hand, grab the neck of the gun in front of the gun body, leaving the hand open and only gripping the neck with the thumb.





When you get into position, place the heel (or edge) of your hand on the table to support the gun. Do not lean on your hands.

## **Angle of the Gun**

When lining up the gun, the nozzle should be straight on to the weld zone and perpendicular. This means that the nozzle of the gun should be pointing in the same direction as the weld zone with an even 90 degrees on both sides.

These two angles are very important for the proper distribution of the shield gas. If the gun is not straight and perpendicular to the weld, several things will go wrong: the shield gas will not protect the puddle properly; and the flow of the gas over the puddle and weld will create opportunities for inclusions, uneven heat, and poor control. This becomes more of an issue when welding on thicker materials.



Being perpendicular with your drag angle pointing straight into the weld will allow the shield gas to hit the puddle evenly on both sides. Note: To avoid putting too much heat into the table you are welding on, it's a good idea to put risers under the sheet metal, such as two small pieces of square bar. (This is not shown in the image above.)

The third angle to pay close attention to is the travel or drag angle. When first starting out, this angle is a little bit looser, and you can play with it a little. The manufacturers of most MIG machines have put a bend in the gun neck with a decent travel angle (normally  $45^\circ$ ), as long as the top of the gun handle is parallel with the surface that is to be welded. You will find that increasing the drag angle to 75 or even 80 degrees will give you better penetration for certain applications. But for now, let's use the neck angle for our drag angle in order to develop vision and control.





The back of the gun handle should be parallel to produce the correct drag angle. Do not drop the gun hand below the parallel point. This would direct the shield gas to push the bulk of the puddle up on to the back of the bead that was just created, instead of down and assisting with penetration.

A lot of people first starting out will set up and support themselves with their elbow. Now, I don't have a problem with this at first, but don't get used to doing this. It sets you up to be a short distance welder because you can only weld so far before you have to set up again and move your elbow. I would recommend getting used to dragging the heel of the support hand on the surface of the piece or table. This will help to avoid unnecessary stopping and starting.



## Heat vs. Thickness

One of the jobs of a welder is to know how to control the amount of heat going into the material in relation to the material's thickness. This is done in several ways. The machine voltage and wire speed combination is normally set to the thickness of the metal. Additionally, the speed of the puddle moving through the weld zone, the technique used, the length of time in a given area, and shield gas settings are all components of control to help monitor the puddle and the heat moving through the weld.



When metal is heated, it wants to expand away from the heat. As it cools, it wants to come back. Depending on where you are in the weld and how much heat is put into one given area can cause variation of heat that produces warpage, as seen in the 14 ga steel above.

The area that is heated is known as the heat-affected zone (or HAZ). There is actually a mathematical formula that involves the factors of welding such as voltage, current, heat intensity, etc., but it's not mandatory to welding that you know this formula. What you do need to know is that metal moves when it is heated. Most of the time it will begin by moving away from the heat; then as it cools it wants to come back. The amount of heat going into the steel, and the time it takes to cool, will normally

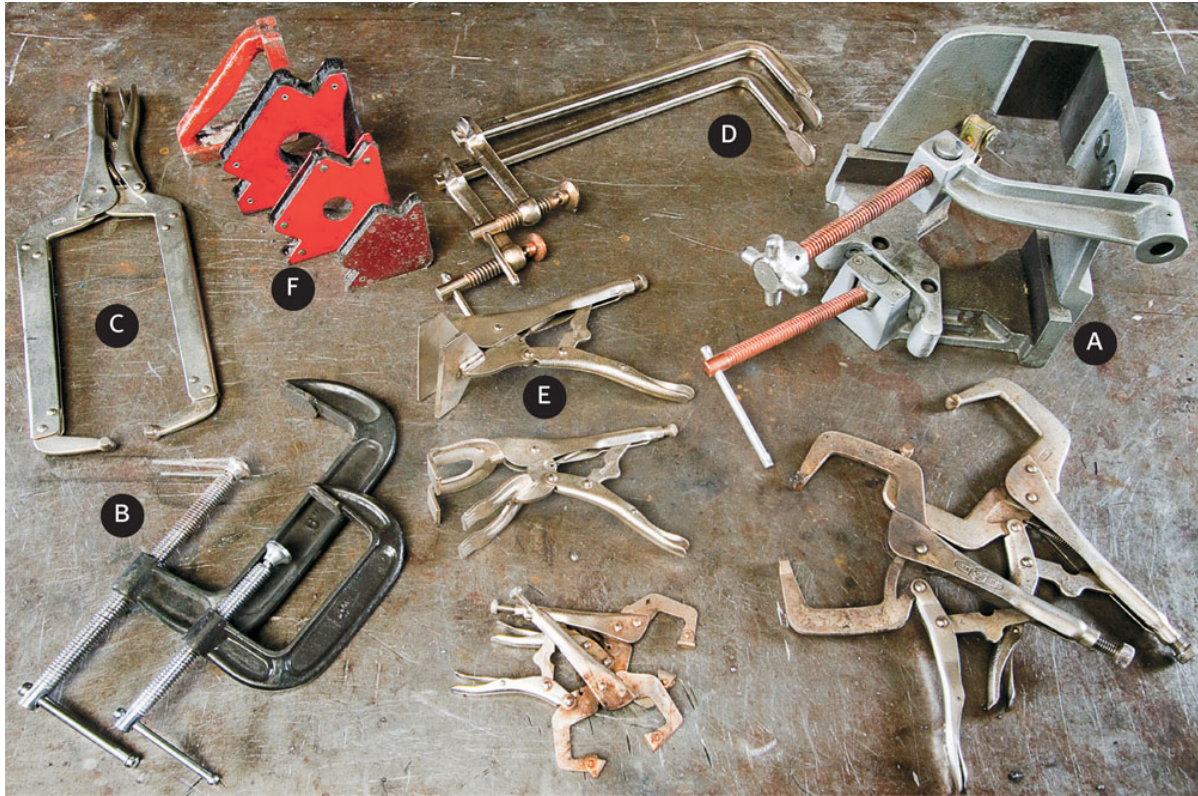
determine the plus and minus of the metal's movement or what is referred to as warpage.

Steel normally starts off cold. As you begin to weld, the heat radiates through the material from the point where the weld began. As the heat moves through the weld zone it creates variation in heat. The starting point is also now starting to cool, causing another variation of temperature. The longer the weld, the more heat is produced, and the more variation in the metal, the more potential for warping.

As you can see, the sheet of 14 ga steel on page 93 is completely warped from the massive amount of heat that went into the material. This once flat piece of sheet metal has been completely deformed by random amounts of heat going into the surface in various places.

The thinner the material, the less mass it has; this decreases the material's ability to carry the heat away from the HAZ, and it becomes more susceptible to warpage. Thinner materials will warp much faster than thicker materials. The thinner you go, the more likely the heat will burn through as well. This is a particular concern in auto body repair, as these thin-gauge sheet metals can really only be tacked together.

In contrast, thicker materials have much more mass to help spread the heat out to decrease the HAZ. This means a longer bead can be maintained. Look at it this way: you don't want to weld much more than a 2-inch (5 cm)-long bead on sheet steel 14 ga or the danger of warping and drop through increases. As the material gets thinner, the length in which a bead can be created decreases as well. Inversely, as the material becomes thicker, the longer the length of a bead and the more heat the material can maintain.



There are a wide variety of clamps, magnets, and vices that help to prevent movement during tacking and welding. 3-axis clamps (A) are great for making tables. C-clamps (B), vise grips (C), F-clamps (D), and locking sheet metal clamps (E) are great for creating jigs or securing the piece to a table. Square magnets (F) are great for keeping the angle in quick tacking situations.



# Clamps and Tacking

To prevent warpage while fabricating a piece, a good welder will have a lot of different clamps handy. Clamping a metal work piece down is one of the most common methods to help prevent movement while welding the piece together. Clamps also create stability for the welder if they accidentally bump it out of placement.

There are many styles of clamps, and they all have their purpose. C-clamps, vise grips, adjustable clamps, and even magnets can help you hold the pieces in place while you tack them together. The more you can minimize movement the better.

After the pieces are clamped together, it's never a good idea to just start welding straight away. Even when the metal is clamped, it will still move whether you like it or not. To prevent movement even further, the next step is to tack the pieces of base metal together.

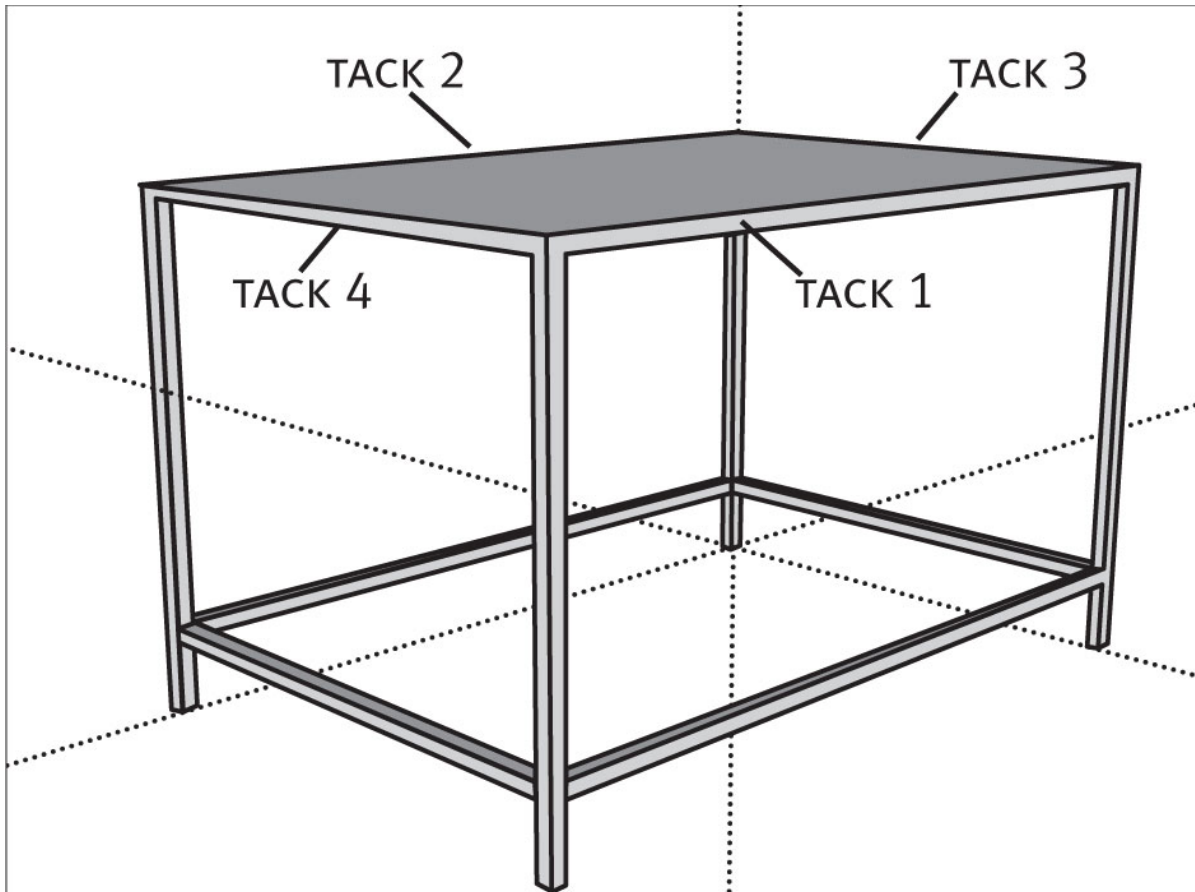


If you want to completely weld the surface of a table all the way around, you must first tack the surface down. For example, a sheet of 14 ga material can only be welded for a couple of inches before it starts to warp. To prevent this, spread out the heat. Start by tacking in the middles first, and then the corners, then splitting the distance in half until the tacks are a couple of inches apart. Then weld tack to tack to spread out the heat as you go. You have a lot to weld, so don't keep too much heat in the same area.

Tacking is a series of short welds that will help hold the individual components in place while you weld the piece. Tacking allows you to put the entire piece, or portion of the piece, together, and it acts as a clamping tool. This provides the opportunity to remeasure before welding the piece together permanently. Tacking also serves as a buffer for any mistakes you may have made in measurement. If you see after doing a few tacks that you are off by an unacceptable amount, it's not a problem to chop through a few tacks with a grinder. But if you had a full weld on there, not only would you have the warping to deal with, but the measurement would be off as well, and you would have to cut through an entire weld and start over.

The most common way to prevent warpage, besides knowing the limitations of the steel, is to spread out the heat. This means welding in multiple areas for shorter periods of time. For example, let's say I wanted to seal up this 14 ga sheet metal to the top of this welding table.

You wouldn't just pick a corner and start welding. First you would clamp and tack the sheet metal down to the frame. The first series of tacks would go in a cross pattern to balance any movement from the heat. Start in the middle of a side, then straight across to the middle of the other side. Then repeat the same steps for the adjacent sides.

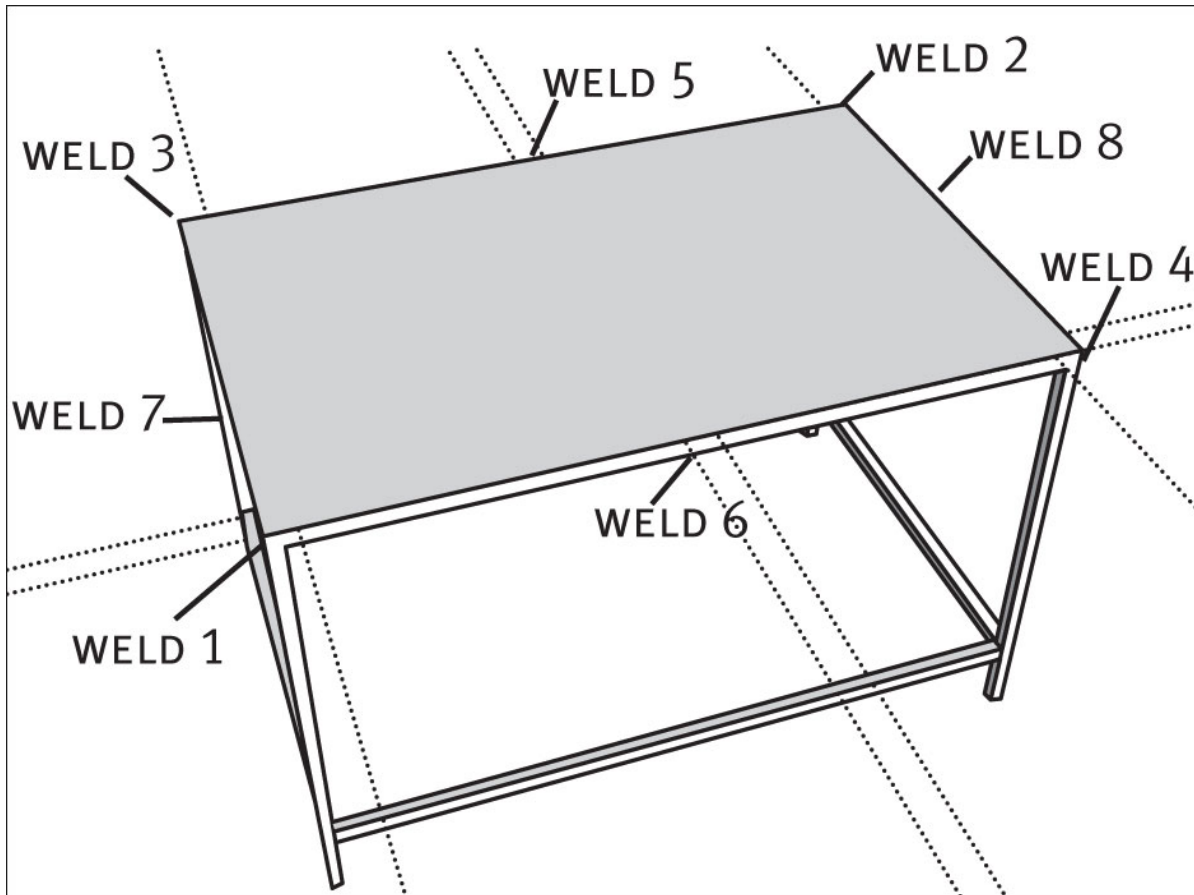


This is good tack pattern for this 14 ga top. Tack the first four corners and then check your measurements again.

After making sure the sheet metal is in the correct position, tack the corners; then continue a series of tacks by splitting the difference of the distance between the tacks by half repeatedly until the tacks all the way around the table are roughly 2 inches (5 cm) apart.

Weld the sheet metal to the frame by welding from tack to tack, spreading out the welds to prevent warping. Shown in the diagram above is a cross pattern from corner to corner and then side to side. The next welds would be in between the first series of welds in a similar pattern.





Now weld tack to tack. After welding 2 inches (5 cm), move a minimum of 8 inches (20 cm) away before you start your next weld. You have a lot of area, so the more you can spread out your welds, the less likely it is the material will warp.

Welding is just like changing the tire on a car: you never tighten the lugs by going in a circle but by going in a cross or star pattern to spread the compression out evenly. The same concept applies to welding. Start welding tack to tack at one corner and then go to the opposite corner, then the middle, spreading out the heat.

There are a lot of schools of thought when it comes to spreading the heat. Another method of spreading out heat, for example, on a sheet of 14 ga steel is to weld for 2 inches (5 cm) from tack to tack and then move 4 to 7 inches (10.2 to 17.8 cm) down the same edge and make another 2 inch (5 cm) weld. Seven to eight inches (17.8 to 20.3 cm) should provide enough distance to move past the HAZ.

The way I look at it, if you're welding on a big enough piece, then why not move further away. I like to err on the side of caution and do a star pattern to really spread out the heat. That way, by the time I get back to the

original weld, it has cooled enough to continue the weld. This may be overkill, but like I said, I err on the side of caution, especially when making a table.

Tacking is one of the most important steps in fabrication. Always tack a structure or piece together before welding any part. This will ensure the piece stays as true as possible.



## Basic Rules and Principles for Tacking and Welding

### TACKING

- Always tack the piece together first before welding, as tacking acts as a clamping mechanism and secures the metal in place, preventing it from moving while you weld.
- Always secure the pieces to be connected in place with clamps.
- Tacking does not require arc movement, so an increased angle will help penetration.

### WELDING

- The angle of the nozzle must be straight on and perpendicular to allow the shield gas to hit both sides of the puddle evenly.
- The drag angle should never be less than a 45-degree angle.
- Brace and support the gun hand with the opposite hand.
- Always be as comfortable as possible.

### MATERIAL

- Steel only has limited ability to radiate the heat away from the puddle before it becomes too great and "burns through."
- The thicker the material, the further the distance a bead can be created. The thinner the material, the shorter the distance.
- For very thin metal such as sheet metal for auto body, you can't draw a bead—just use short tacks.
- Control the amount of heat you are putting into the steel by limiting the distance of your bead; then move away from that point of heat when tacking or welding.



# Exercise 1: The Draw



**DIFFICULTY:** BEGINNER

**MATERIALS AND EQUIPMENT:**

- MIG welder
- 5" x 10" (12.7 x 25.4 cm) piece of 16 ga (minimum) sheet metal
- Welding Helmet
- Welding gloves
- Long-sleeve shirt
- Leather welding jacket or apron
- MIG pliers
- Stainless steel wire brush
- Soapstone

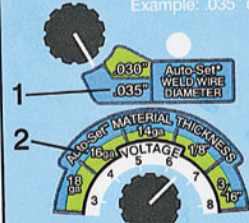


# Millermatic® 211 Auto-Set™

1-800-4-A-Miller  
MillerWelds.com

## Auto-Set™ - SIMPLE SETUP FOR WELDING MILD STEEL

Example: .035" diameter wire, welding 1/8" material.

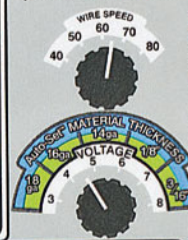


1. Activate Auto-Set™ by selecting the diameter of the welding wire with the WIRE SPEED knob. Auto-Set™ light comes on.
2. Select thickness of the mild steel being welded with the VOLTAGE knob. Setup complete.

USE 75% ARGON / 25% CO<sub>2</sub> SHIELDING GAS

## Manual Setup

Refer to chart below to select Voltage and Wire Speed based on thickness of metal being welded.

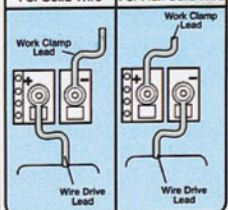


1. Number on right of slash is Wire Speed Knob Setting. (Example: 4.5 / 65)
2. Number on left of slash is Voltage Knob Setting. (Example: 4.5 / 65)

NOTE: Settings are approximate. Adjust as required. "-" Means not recommended.

## CHANGING POLARITY

DCEP Electrode Positive For Solid Wire	DCEN Electrode Negative For Flux Core Wire
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Material	Suggested Wire Types, Polarity	Suggested Shielding Gases (Flow Rate of 20-30 cfh)	Wire Sizes (Diameters)	120 Volt - 24 gauge to 3/16"							230 Volt - 24 gauge to 3/8"											
				24 ga. (0.6mm)	22 ga. (0.8mm)	20 ga. (0.9mm)	18 ga. (1.2mm)	16 ga. (1.5mm)	14 ga. (1.9mm)	1/8" (3.2mm)	3/16" (4.8mm)	24 ga. (0.6mm)	22/20 (0.8/0.9)	18 ga. (1.2mm)	16 ga. (1.5mm)	14 ga. (1.9mm)	1/8" (3.2mm)	3/16" (4.8mm)	1/4" (6.4mm)	3/8" (9.5mm)		
Steel	Solid Wire ER70S-6 (DCEP)	C <sub>2</sub> Gas Mixture 75% Ar / 25% CO <sub>2</sub>	.024" (0.6 mm)	2/22	2.5/30	2.5/30	3/35	3.5/45	4.5/60	5.5/70	10/80	2/22	2.5/30	3/45	3.5/50	4/65	4.5/80	4.5/100	---	---		
			.030" (0.8 mm)	2/20	2.5/25	2.5/25	3.5/30	4/40	4.5/50	6/60	10/60	2/20	2.5/30	3/45	3.5/50	4/65	4.5/80	5/75	6/90	10/100	---	---
			.035" (0.9 mm)	---	2.5/20	2.5/20	3.5/25	4.5/35	5/40	6.5/45	10/45	---	2.5/20	3.5/30	4/35	4/40	5/55	5.5/60	6/65	10/75	---	---
	Solid Wire ER70S-6 (DCEP)	100% CO <sub>2</sub>	.024" (0.6 mm)	---	3.5/30	3.5/30	4/35	4.5/45	5/50	7/60	---	---	3/30	3.5/35	4/45	4.5/55	5.5/65	6.5/85	---	---		
			.030" (0.8 mm)	---	3.5/25	3.5/25	4/30	4.5/35	5/40	7/45	10/50	---	3/25	4/30	4.5/35	5/45	5.5/55	6/60	7/75	---	---	
			.035" (0.9 mm)	---	3.5/20	3.5/20	4/20	4.5/25	5/30	7/35	10/40	---	3.5/20	4/25	4/30	5/35	5.5/40	6/50	7/55	---	---	
Flux Core E71T-11 (DCEN)	No Shielding Gas required. Good for windy or outdoor applications.	.030" (0.8 mm)	---	---	---	2.5/30	3/30	4/40	5/45	10/50	---	---	1/20	2.5/25	3/35	4/50	5.5/70	7/90	---	---		
		.035" (0.9 mm)	---	---	---	2.5/20	3/20	4/30	5/35	10/40	---	---	1/18	2.5/20	3/30	4/40	5.5/60	7/80	10/85	---	---	
		.045" (1.2 mm)	---	---	---	---	---	---	---	---	---	---	---	3/10	3.5/20	4/25	5.5/35	6.5/40	10/50	---	---	
Stainless Steel	Stainless Steel (DCEP)	Tri-Mix 90% He / 7.5% Ar / 2.5% CO <sub>2</sub>	.024" (0.6 mm)	---	4/35	4/35	4/40	5.5/60	6.5/75	10/80	---	---	4/40	4/45	5/55	5.5/80	6/90	---	---			
			.030" (0.8 mm)	---	4/25	4/25	4/30	5.5/40	6.5/50	10/55	---	---	3.5/30	4/35	4/40	4.5/50	5/60	6/75	6.5/85	7.5/100	---	---
			.035" (0.9 mm)	---	4/20	4/20	4/25	5.5/35	6.5/40	10/45	---	---	4/25	4.5/35	4.5/40	5/50	6/60	6.5/70	10/85	---	---	

Selecting Wire, Gas and Control Settings for Aluminum. Use optional Spoolmate 100 series Spool Gun (Part no. 300371)

Aluminum Spool Gun	Aluminum 4043ER	100% Argon	.030" (0.8 mm)	---	---	2/65	2.5/70	6/85	10/90	---	---	2/60	2.5/65	3/70	5/70	6/75	10/90	---	
			.035" (0.9 mm)	---	---	---	3.5/60	4/65	10/70	---	---	---	3.5/60	4/65	4/65	5.5/65	6/65	7/75	10/85

IMPORTANT: Match drive roll groove to diameter of wire being used. Set Tension knob setting to 3 at start. Adjust tension per instructions in the manual. Thicker materials can be welded using proper technique, joint preparation and multiple passes.

M-100 (#246282) Torch Consumables:	Nozzles	Tip Adapters	Contact Tips	Lehrs
#246372	#160716	.024" (0.6mm) #081799	.024" (0.6mm) #194010	
		.030" (0.8mm) #080067	.030-.035" (0.8-0.9mm) #194011	
		.035" (0.9mm) #080068	.035-.045" (0.9-1.2mm) #194012	
		.045" (1.2mm) #080069	.035-.045" (0.9-1.2mm) #194012	

Quick Change Dual Grooved Drive Rolls, Wire Diameters V-Smooth V-Knurled

.024" (0.6 mm)	#220179	#202926
.030" (0.8 mm)	#220179	#202926
.035" (0.9 mm)	#220179	#202926
.045" (1.2 mm)	#202926	#202926

\* For Flux Core or Stainless Wire 239 992-C

Refer to the reference chart on your welder and set the unit for 18 ga.

For the first exercise, we will be creating a series of 2 inch (5 cm) straight draws called pull welds. These will be surface welds, meaning we are not going to be actually welding anything together right now. This exercise is designed to develop hand motion, vision of the weld zone, and understanding of how to pull weld. This will help to build the feel of the speed needed to move through the weld zone to create a proper weld without melting through the steel, a problem known as "burn through."

Find a piece of scrap sheet steel about 5 x10 inches (12.7 x 25.4 cm) hot or cold roll. The surface dimension doesn't matter too much as long as there is enough room to practice. The thickness of the piece should be at minimum 16 ga. This is a good thickness for this exercise to show and help give a better understanding of penetration.

Locate and set the voltage and wire speed combination for 18 ga based on the reference chart that's normally found on the door of your MIG unit.



Set the machine for a lower voltage and wire speed than the metal for these welds to allow practicing without blowing holes in the material.



Tack at the top of the line and then the bottom. For this exercise, the tack will be a two count.

Because this is practice, it is not completely necessary to remove mill scale from the surface of the steel. Cleaning the metal with a stainless steel brush should provide enough removal of surface debris. If the piece has paint, rust, or excessive amounts of grime, then it should be prepped with



some type of disk such as a 60-grit flap disk on 4 1/2-inch (11.4 cm) angle grinder. (In the future, prep all welds with a grinder.)

With the soapstone, mark six to ten 2 inch (5 cm) straight lines next to each other about 1 inch apart; these lines will represent the weld zone that the bead will be created on. Use some scrap steel bar to elevate the piece of sheet metal to protect the table surface. Make sure that the ground is clamped to the table or directly to the work piece.



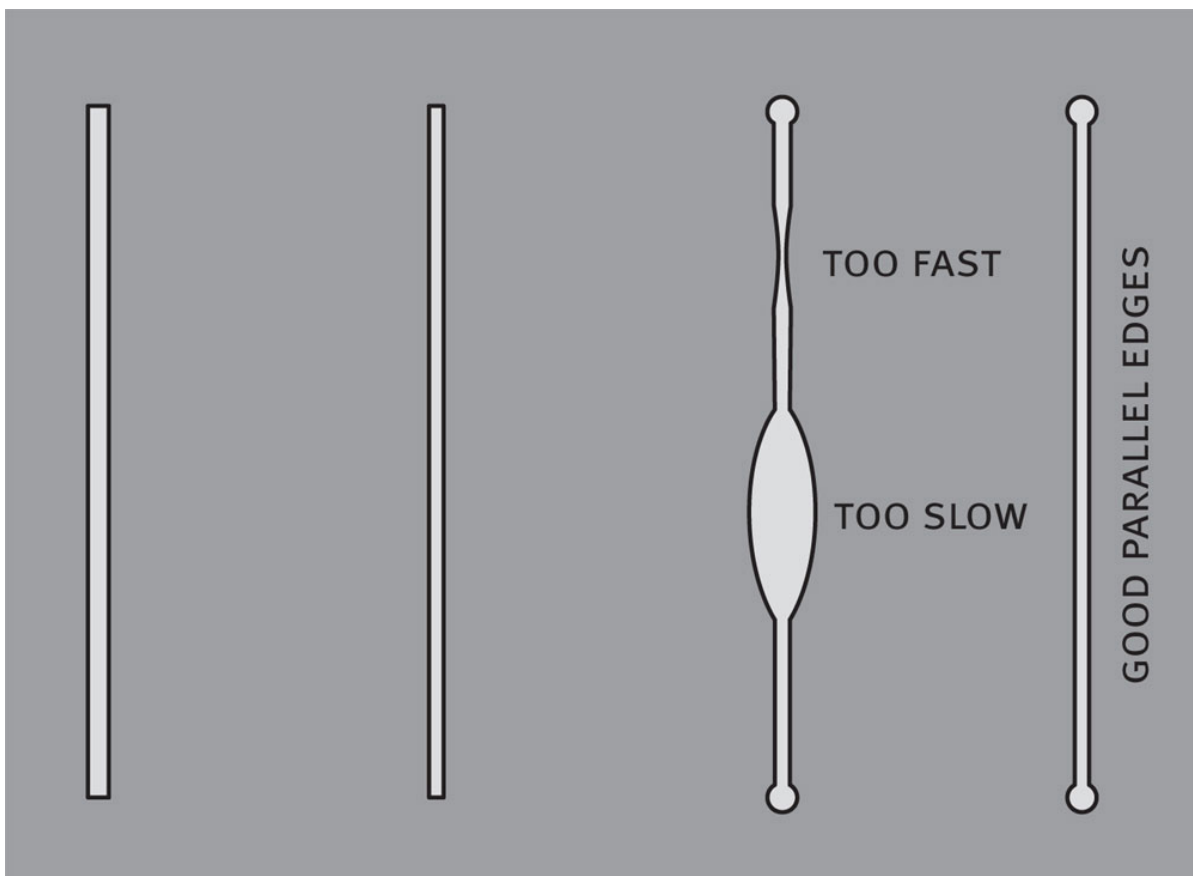
Concentrate on maintaining a 3/8-inch (10 mm) wire length (called the stick out) during tacking and welding.

If you are right handed, start with the far right line and move left. If left handed, start at the far left line and move right. This will allow you to move away from the heat as you practice.

What we are going to do is tack at the top of the line and then at the bottom. For this exercise, a tack is going to be about a two count. Not seconds, just say “one, two” in your head. This should give us a tack that is proportional to the thickness of the material and the size bead that we want to create. Then we are going to connect the two tacks with a bead.

## The Unbreakable Rules

- Keep the drag angle pointing into the weld zone.
- Keep the gun perpendicular so the shield gas hits the puddle evenly.
- Brace and support the gun.



Try to be as even and consistent as possible when moving through the weld. The purpose of this exercise is to learn the correct speed of the draw through the weld zone in order to produce the correct bead. Move too fast and the edges pull in, producing smaller walls. Too slow and the heat radiates and will end up burning through.

Before tacking or welding, make sure that the stick out is at its proper 3/8-inch (10 mm) length. If it is too long, snip it with the MIG pliers; if it is too short, let some line out with the trigger (away from the ground). While



conducting the draw, if you start to pull away and the stick out becomes longer than 1/2 inch (13 mm), the arc will not reach its proper heat. The shield gas also can no longer create the proper environment for the arc and keep out inclusions or oxygen, resulting in a poor weld. This is what I like to refer to as going fishing, and it will result in popping, crackling, and skipping sounds. The sound of the arc should be a consistent buzz like bacon frying.

When positioning the gun into place, touch the wire down to the metal before pulling the trigger, but do not keep pressure on the wire. The wire is the electrode and the filler material that feeds into the weld, so if pressure remains on the wire as soon as the trigger is pressed, the contact tip will plunge into the arc and burn back the wire. At higher voltages, this will sometimes cause the wire to weld to the inside of the contact tip. If this happens, you will need to unscrew and cut away the contact tip with your MIG pliers so that a new contact tip can be used. You will not feel the wire feeding into the puddle. You'll need to learn to maintain that 3/8-inch (10 mm) distance by sight and feel.

When tacking or welding, squeeze and hold the trigger. When finished, release the trigger before pulling away. This will prevent additional wire from being fed.

Once you have the two tacks down, move to pulling a weld. Put the wire on the top tack between the top and the base of the tack right above the line. We are now going to do a pull weld.

What we want to accomplish here is a nice even and straight bead with parallel edges. Go too fast and the edges of the bead will suck in and not provide the necessary heat and filler metal to complete a good weld. Too slow and the heat will spread to the point where the base metal cannot support the heat and filler metal. If you move too slowly for too long, the metal will eventually end up dropping through and create a hole in the metal, what is referred to as burn through.

If you flip the piece over and look on the other side of the weld, you should be able to see where the weld has penetrated. If it looks as though you have welded it from this side, that means you were going too slow and the bead burned though too much. For this exercise, you should only see heat discoloration with an innermost line that mirrors the weld you just created.



You want to end up with a bead with parallel edges. If you look at the other side, you can see if you have burned though too much. This will be an indicator that you will need to speed up your pace.

Repeating this exercise several times will help develop a consistent straight draw. You should stop and critique the welds after each draw. Focus on the rules and principles each time while tacking and welding. When you create a few straight and even beads with parallel edges with little to no burn though, you have learned the straight pull weld. By practicing this on different thicknesses of steel for different sized beads, you will find that the speed of the movement will have to be adjusted slightly.

Welding traditionally involves setting the machine to the proper combination of wire speed and voltage, as well as drawing through the weld zone to create a bead. This method can be used on thick or thin metals. As you develop your skills as a welder, you'll begin to understand when and how to adjust the settings in accordance with your technique.



## **Listen to the Weld**

Vision is not the only sense used when welding. Remember to listen to the arc during the weld. When you weld, you want to hear a constant and steady buzzing that sounds like frying bacon. If you hear a lot of popping, cracking, and skips, chances are you are pulling too far away from the work piece.



## II Using Your MIG



## The Basics

Whether you're welding a lamp, a car, or a skyscraper, all projects require you know some basic joints and techniques. The more advanced the project, the more advanced the techniques you'll use, but we'll stick with the basics for now.

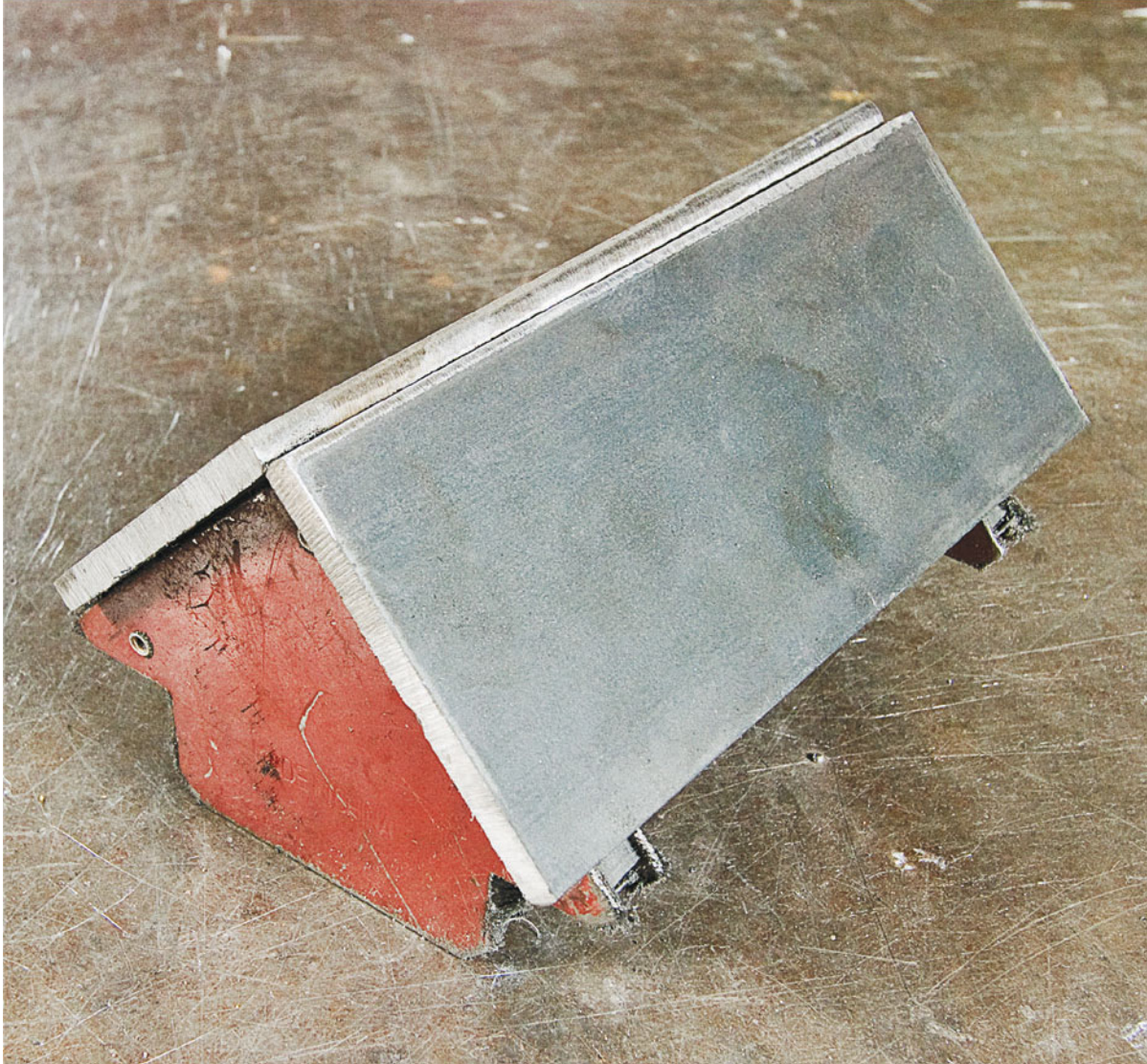
# Basic Joints

Depending on who you talk to, what textbook you read or website you visit, there can be any number of different joints, from one to over four dozen. In one of the fabrication shops I worked, there was a chart of 48 different weld joints with all sorts of names. These all have their purpose for very specific tasks. Don't feel as though you have to go out and memorize all the names for all these welding joints though. Most of these joints refer to how the weld is chamfered and prepped.

There are really only five basic welding joints that you should concentrate on right now: the butt joint; the corner (or fillet) joint; the tee joint; the lap joint; and the edge joint. These five joints are actually derived from only two joints when it comes down to how they are welded together: the corner (or fillet) joint and the butt joint.

The corner joint, the tee joint, and the lap joint are all welded with relatively the same technique and are all examples of the fillet weld. They are made by going into a corner at roughly a 45-degree angle to create the weld in a 90-degree corner.





Corner Joint

The corner joint is used in many different applications. It's the most common joint used when making furniture, working on a car, or building a flight of stairs. There are several schools of thought when it comes to corner joints and its variations. A corner joint is defined as two pieces of material that are welded to create a corner. Outer, inner, closed, and open are all examples of different names of corner joints.





The only joint that is different from these three is the butt joint. The butt joint is just that: two pieces of base metal butting up to one another to create



an even surface. Practicing the method of how to weld a butt joint is the best place to start learning how to weld.



Tee Joint





Lap Joint





Butt Joint





Edge Joint

As we move through the book, we will learn more about these joints and the proper way to execute a weld for each of them. For now, the focus will be on butt joints and developing the movement through a weld.



# Technique

MIG welding was developed in the 1940's as an alternative process for welding aluminum. It was quickly adapted to the steel industry and is now the most widely used electrode arc process today.

In the early years of arc welding, the traditional way to conduct a weld was a straight pull or push method of controlling a weld in progress. The machine's voltage and wire speed combination in relation to the speed of the arc moving through the weld zone were the only controls for penetration and performing a weld.

Now that you have a straight pull weld down, it is time to teach you the next level of control. Remember what I said: "The number one job as a welder is to control fluid."

Gas welding—such as oxy-fuel and gas tungsten arc welding (or TIG)—are manually fed electrode arc processes where the operator has to heat the base metal with a torch in one hand and with the opposite hand has to feed the filler metal into the puddle. This style of welding allows for more control but limits the speed in which a weld can be created. Traditionally, having more control over the puddle meant having more control over the outcome and look of the weld after it was completed.

In modern welding, terms such as "dimes on the side" or "stacking nickels" have become synonymous with TIG welding. These terms refer to the welder's ability to control the outcome of a weld to make it look like a row of coins lying on their sides. This became the signature of a welder who has honed their craft. This style has become the look for welds on everything from bicycles to custom car frames to furniture. It is now the benchmark for recognizing a quality weld and welder.

The looks of these welds have become so popular that robot welders have been programmed to duplicate the weld to produce the same outcome. Even though at the atomic level the weld may not be any better of a weld than a straight weld, it is more difficult to execute. Some techniques of welding do increase penetration, but these techniques are not something that a beginner welder needs to worry about.

This outcome for a TIG weld can be mimicked with MIG. The term "MIG like TIG" was developed when MIG welders began to experiment with the control of the puddle. This control not only produced the TIG

effect in the final weld, but also allowed more options for conducting welds in progress. This sparked new styles and techniques and improved methods for many aspects of welding, such as a greater ability to control the heat going into the base material.

There are several of these techniques that will produce a wide range of patterns in a weld. The one that you are about to learn is a basic hand (or I should say arc) motion technique that offers the next level of controlling a weld. This is not the technique that will produce the MIG like TIG effect, but it will give you a better understanding of how to control the puddle and work your way up to that effect. This technique is the root of most other techniques.

# Exercise 1: Butt Joints



**DIFFICULTY:** BEGINNER

**MATERIALS AND EQUIPMENT:**

- MIG welder
- Two 6 to 10" (15.2 x 25.4 cm)-long sections of 1/4" (6 mm)-thick plate
- Welding Helmet
- Welding gloves
- Long-sleeve shirt
- Leather welding jacket or apron
- MIG pliers
- Stainless steel wire brush
- Soapstone
- 4 1/2" (11.4 cm) angle grinder outfitted with an aluminum oxide grinding disk (stone)

The technique that we will start with is a pattern that moves the arc back and forth between the edges of a “V” chamfered butt joint. This will be the first exercise where you’ll actually be welding two pieces of steel together. Since techniques like this keep the heat in one place longer, they will normally only apply to thicker materials.

For this exercise, you will need to grind a 45-degree chamfer in two 6- to 7-inch (15.2 to 17.8 cm)-long pieces of 1/4-inch (6 mm)-thick plate steel. Remember the order of every project in metal fabrication: cut-prep-tack-weld.

Remove the mill scale away from the weld zone after chamfering the edges. This will ensure that if the weld rolls over the chamfered edge, it will not pull any inclusions back into the weld that may cause porosity.



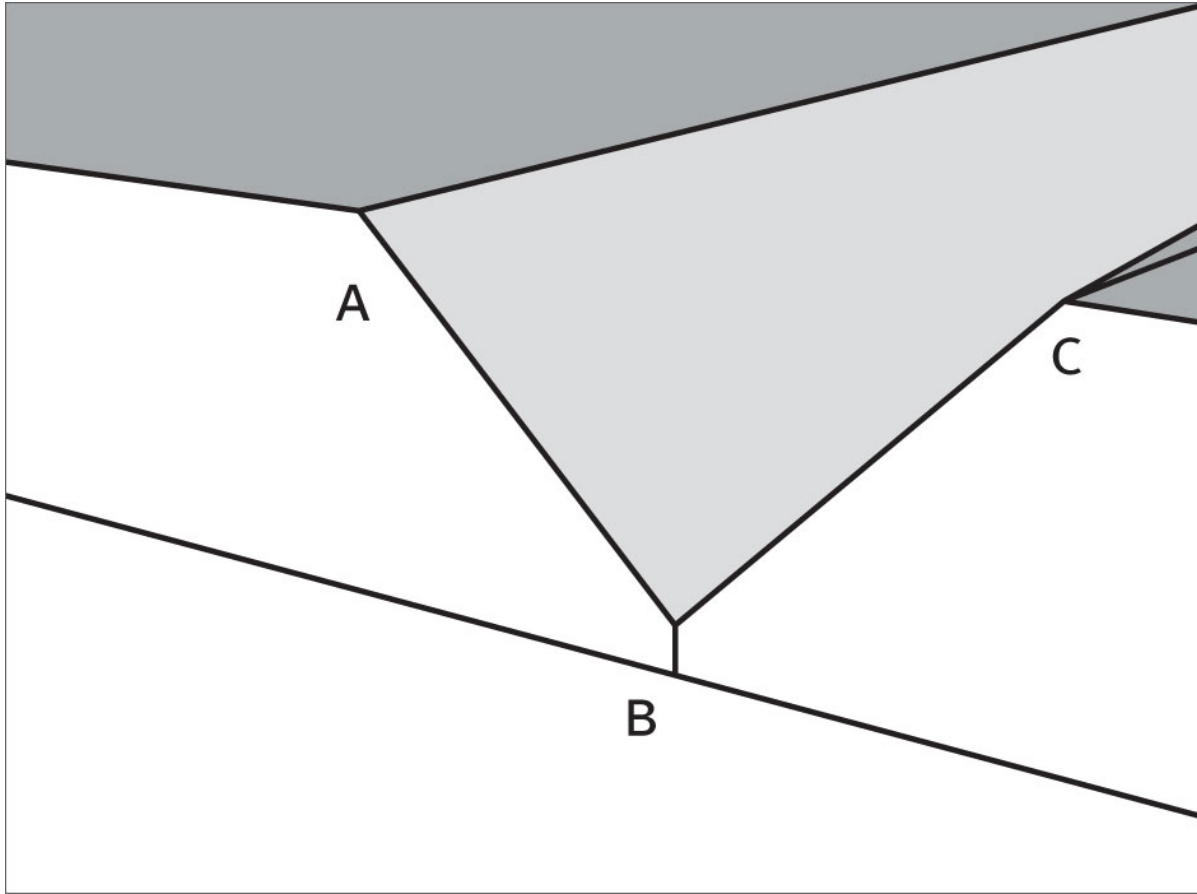


When chamfering, lock in the angles to get a nice flat surface.





When you are done chamfering, prep the weld zone by grinding and cleaning the steel close to the weld.



A and C are the outer lines that will complete the plain. The middle line, B, is where the metal butts together.

One of the advantages of learning a technique on v-chamfered butt joints on material this thick is that there are three distinct lines that define the weld zone: the two edges of the reservoir, “A-edge” and “C-edge,” but also the actual line of the butt joint, “B.” These lines will help in the same way three-lined paper helped people to learn cursive writing. In essence, this is the same thing, only writing with the molten puddle of steel.





Tack at the top first, then the bottom, and finally the middle.





Don't worry about a two count when you're tacking this time; instead, just worry about filling the chamfer up to the A and C edges. You may need to clamp down on the piece to prevent movement (not shown).



Tack the pieces together with three tacks—one at the top, one at the bottom, and one in the middle—to create two weld zones. Tacking for this exercise is not going to be a two count; instead, watch the puddle fill the reservoir to its edges (A and C) and then stop. For tacking, always set the machine for the thickness of the material being tacked, in this case 1/4 inch (6 mm). For this exercise, it will be necessary to increase the CFH (CMH) for the shield gas. The last exercise was a thinner piece of metal that required less shield gas. Now that it's a 1/4-inch (6 mm)-long weld, it should be set higher; 30 CFH (0.85 CMH) or the recommended flow from the machine's manufacturer should do the job.



Clean the metal after each weld and series of tacks.



This is a practice piece so it's not necessary to clamp these down to prevent the steel from moving when heated. It is a good idea to elevate the base metals with two pieces of the same size bar to avoid putting heat into the table surface.



## Welding Checklist

Before you do any welding, you should always go through a checklist. Start from the back of the tank and work your way to the table checking everything.

- Is the shielding gas tank on and set to the correct CFH (CMH) for the gauge metal?
- Are the machine's voltage and wire speed set properly?
- Is the piece grounded?

From now on, after completing a series of tacks and before each weld, clean the weld zone with a stainless steel wire brush. Notice the carbon burn around the tacks that were created? This is all of the ambient particles and debris floating around in the air that the shield gas pushed out of the weld zone but stayed close enough to the puddle to burn. Welding over this would reintroduce these potential inclusions back into the weld zone and create a poor weld. Get into the habit of scrubbing your metal now.

Now that we have everything tacked together, the next step is to weld. For these welds, we will be introducing our motion technique. When setting up for this weld, it will be necessary to turn down the voltage and wire speed on the MIG. The adjustments for the wire speed and voltage are going to be determined by the technique used and the machine.

The shield gas output should be set for the thickness of the material just like the rest of the machine. For 14 ga and thicker, the flow should be 30 CFH (0.85 CMH). This will provide a large enough environment for the larger puddle to be protected from oxygen inclusions.

The back and forth motion you'll be using will allow the heat to stay in an area for a longer period of time so less heat and filler from the machine are needed. As you develop as a welder, you will find that you can adjust the machine for a number of different approaches. If you find that you like to move a little faster with motion and travel, more heat and filler will be

required. Slower movements will require less. Understand that there is a range: turning down the machine too far would result in a small puddle, less penetration, and a poor weld. Setting the machine too high will require a faster motion and more heat. Finding the appropriate balance of heat and filler for the technique used may take some time and practice.

Another aspect of heat to consider is how hot the material becomes as you weld. When welding on plate metal, you have the ability to go greater distances but the heat is also radiating through the metal. The weld zone that is now to be welded is at a greater temperature, which makes the metal liquefy faster and causes the weld to become too hot. In this case, you would need to decrease the heat. This is getting a little ahead of the game though; for right now, it's best just to understand that you can make adjustments to the heat and flow of the material depending on the technique you use.

For this exercise, set the MIG for 1/8-inch (3 mm)-thick steel. This will provide enough heat and filler metal to move slowly through the weld zone as we execute our technique. This will also depend on the machine itself; some machines have a tendency to run a little hot and some a little cold. Remember the sizzling bacon sound.

When setting up for this, put the wire on the "B" line at the very bottom of the top tack. All three metal pieces, the two pieces of base metal and the tack, should be used to develop the puddle to begin the weld. This may take a second; build the puddle until it reaches the A and C edge.

Once the puddle has reached the edges (A and C), start to move the arc to edge C, then back to edge A, in quarter circle motions while drawing the puddle back. Basically, you're lining the bottom quarter of the puddle, back and forth, while pulling the puddle with you. Each time, you bring the arc to just break the A and C edges with the puddle before going the other direction.

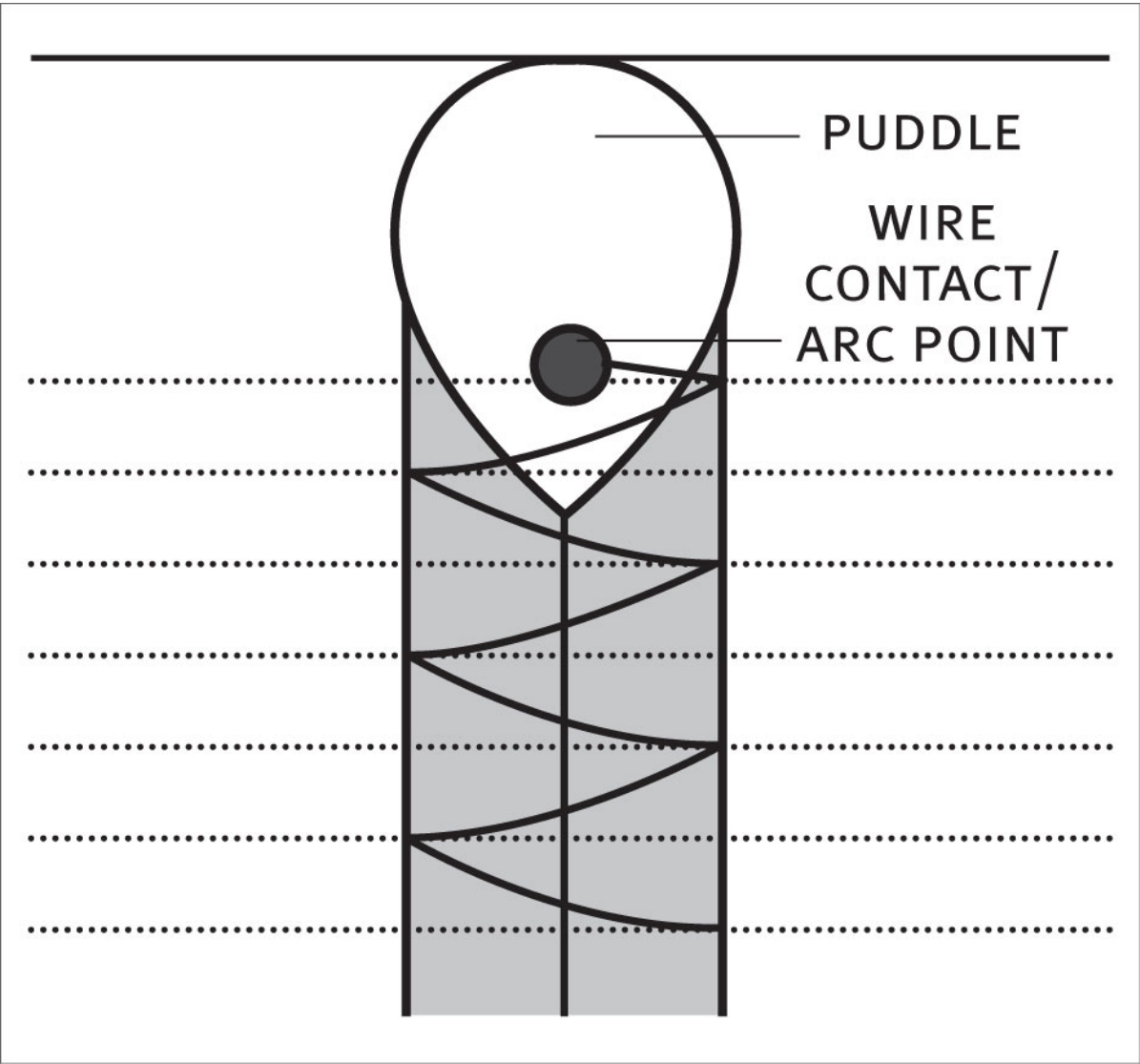
This motion is not that drastic; it is actually a small motion that only requires the movement of the fingers or a small movement of the wrists. It helps to get into a rhythm executing this "shark tooth" technique. For every movement to one side, the draw is 1/16 to 1/8 inch (2 to 3 mm). The manner in which the weld is conducted will determine the speed of the draw and the movement. Speed and movement will always be in relation to one another. Increasing the speed of the draw will require increasing the speed of the arc movement.



All of the settings and motions will be determined by the size of the puddle. The puddle should remain the same size through the entire weld, just breaking the edge as you execute the technique.

When the first weld zone is completed, take a look and evaluate the weld. Did you break the edges? Are you favoring one side? Were you too fast or too slow? The end result should be a weld with even edges and an even crown.

Practice this technique until the bead is consistent, even, the edges are parallel, and the pattern of the bead is uniform. Welding is just like learning a musical instrument: practice makes perfect.

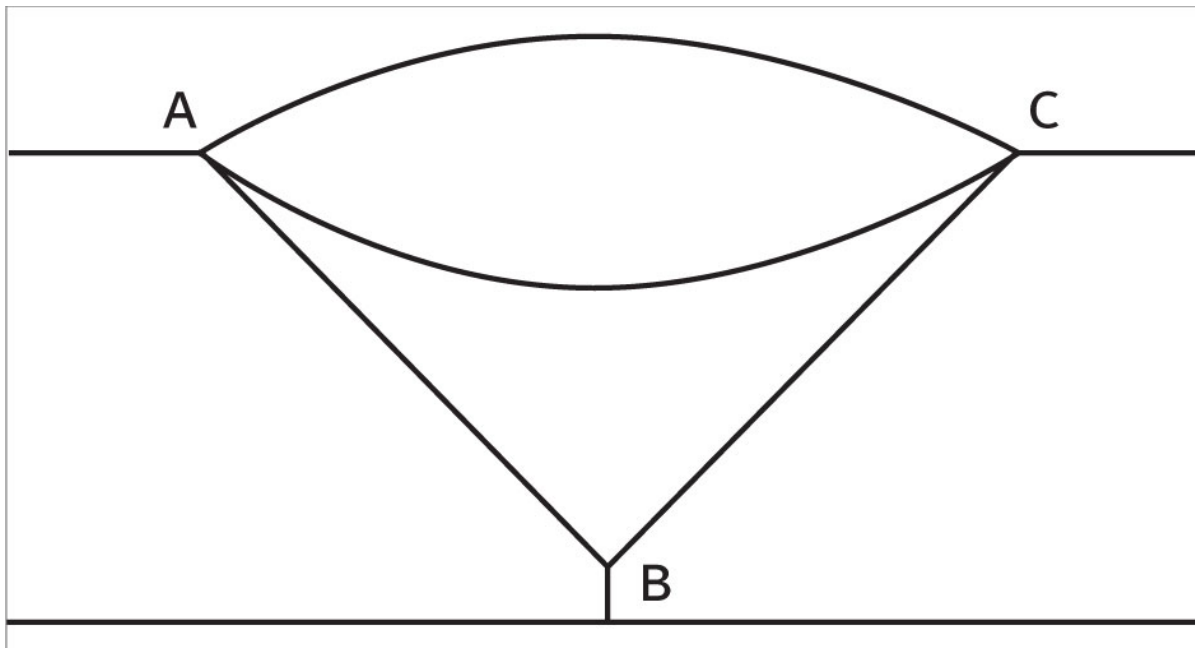


Just break the edge to complete a motion and then go the other way.



## Don't Leave the Puddle Behind

Just remember the most important thing: don't leave the puddle behind. The movement of the puddle is what creates the bead, building it with the motions of the arc. On thicker metal, the puddle does 75 percent of the melting of the base material. The arc's primary job at that point is to keep the puddle fluid. If the correct size of the puddle is not maintained, the heat and penetration are less and the bead will decrease in size, temperature, and its effectiveness to create the correct weld.



From this split view of the weld in progress, you can see there is a third dimension of movement: a slight half dip into the reservoir. Dipping too far can shorten the stick out and cause burn back.



Lining the bottom section of the puddle does not allow the arc to go all the way down to the bottom of the reservoir. Adding in a little dip into the lower section of the puddle helps to maintain heat and penetration.



## ➤ Remembering the Tip Dip



If the contact tip and nozzle look dry or powdery, it may be time to dip it in the spatter protection while the nozzle is warm. Don't dip the nozzle when it is cold; it could clog the nozzle and block the shielding gas.

# Exercise 2: Corner (or Fillet) Welds



**DIFFICULTY:** BEGINNER

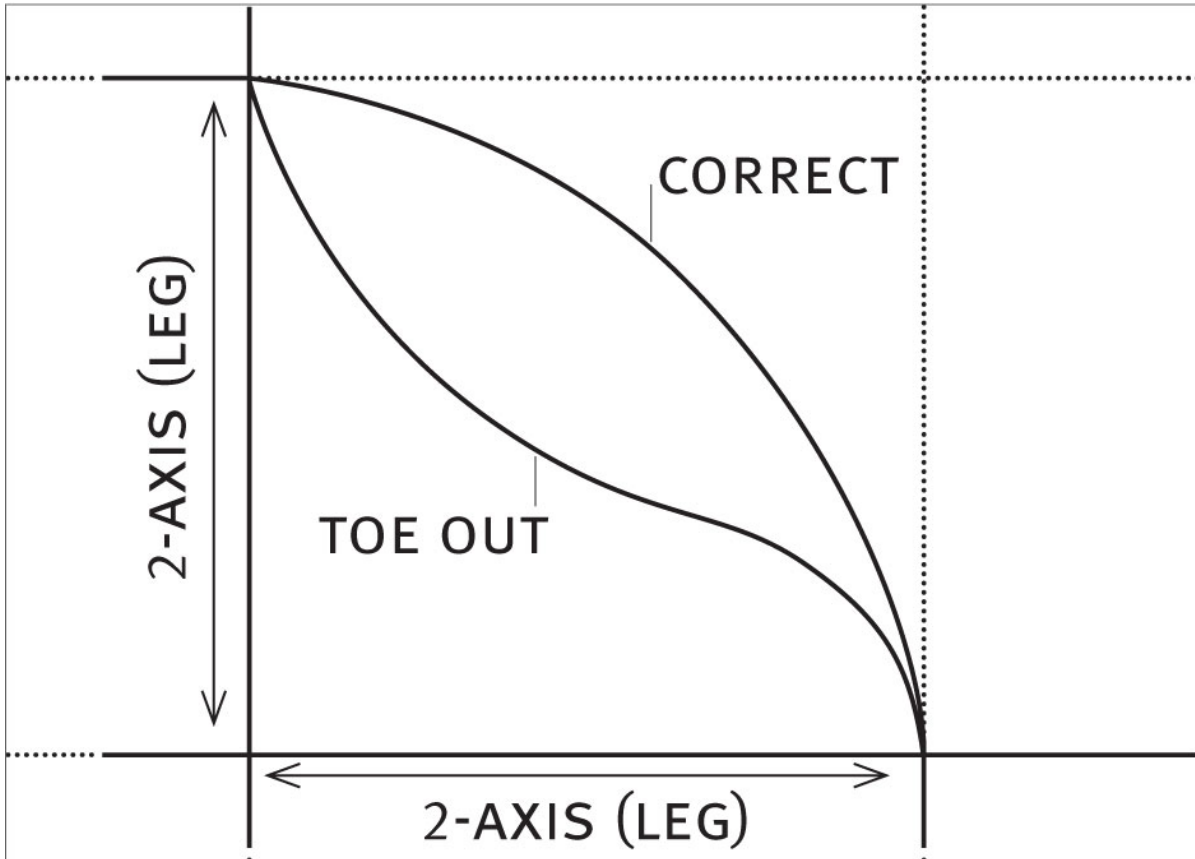
**MATERIALS AND EQUIPMENT:**

- MIG welder
- Two 6 to 10" (15.2–25.4 cm)-long sections of 1/4" (6 mm)-thick plate
- Welding Helmet
- Welding gloves
- Long-sleeve shirt
- Leather welding jacket or apron
- MIG pliers
- Stainless steel wire brush
- Soapstone
- 4 1/2" (11.4 cm) angle grinder outfitted with an aluminum oxide grinding disk or a 60- to 80-grit flap disk
- 2 right angle magnets

By now you should have a pretty good understanding of what makes a good weld. There are other factors that make a good weld but for now our focus is create them. The butt joint motion technique offers a level of control that puts the welder in a better position to create a weld and not have to rely so much on the machine. It forces the welder to concentrate on the elements creating the bead. The outcome is a cleaner and more aesthetically pleasing butt joint.

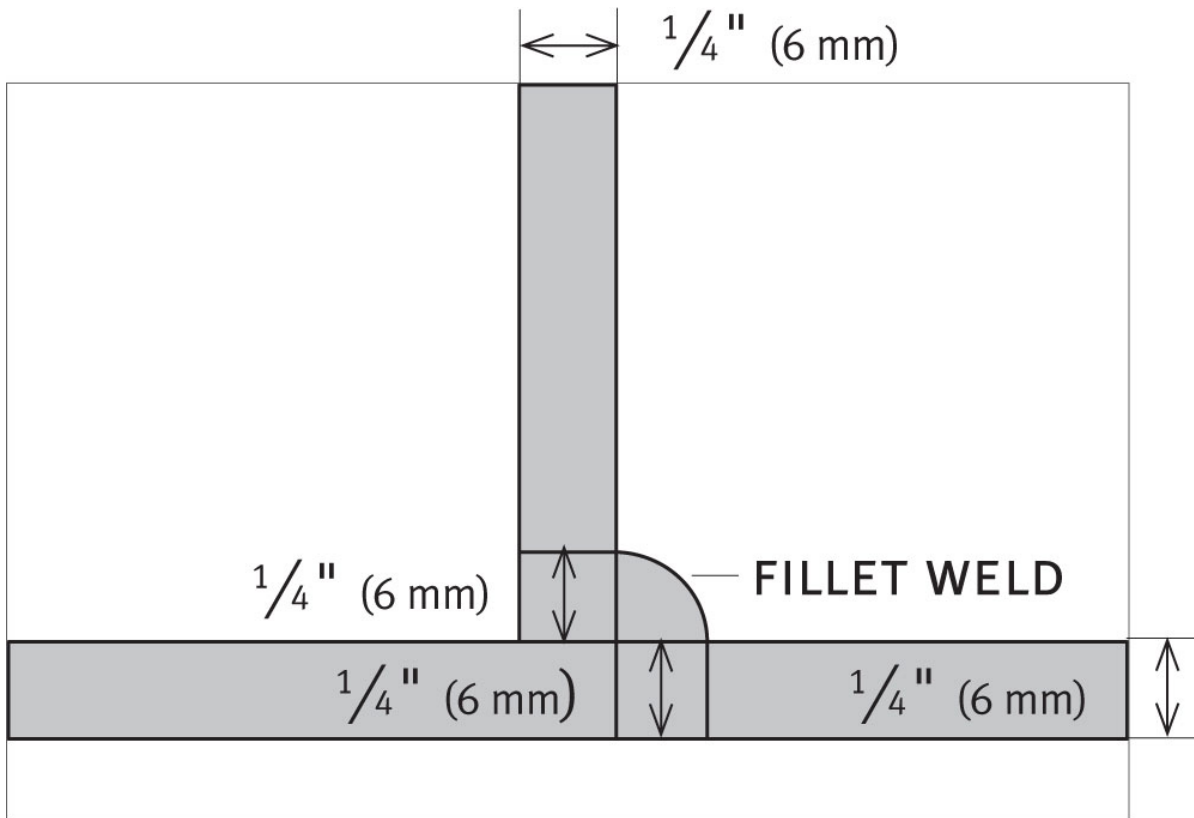
That was only one of the five basic joints. Like I said in the beginning of this chapter, there are only two joint techniques to start with that comprise the rest of the joints and will point you in a direction to other techniques and beads.

The advantages of learning the butt joint first are getting the timing and pace down, then developing a rhythm and pace for the techniques to create a bead. The next step is learning how to fight gravity. Yes, gravity.



This is the shape of crown for a fillet weld. The "A" and "C" edges of a butt joint are very useful in assisting with vision as the weld is created. When you produce a fillet weld in a corner, there are no lines to follow except for the very corner where the two base metals meet.





This is a cross section of a corner fillet weld.

Unlike the butt joint, there are two distinct issues that make the fillet weld harder than the butt joint. One is gravity. You now have a vertical axis to contend with. Fluid wants to naturally flow with gravity, so if the proper speed and angle of the pull weld through the weld zone is off, the puddle will want to sag and toe out. When a puddle toes out, the fluid metal flows with gravity and sags, creating a toe-like shape on the base metal.



Use a grinder with a flap disk to prep the tee joint weld zone.

Executing a traditional pull weld into a corner creates a few challenges. For the correct size weld, the bead “legs” should be as long as the material is thick; if the material in this diagram is  $\frac{1}{4}$ -inch (6 mm) thick, then each of the legs on the Y and Z axes should be  $\frac{1}{4}$  inch (6 mm). To avoid the puddle from toeing out, the speed of the weld needs to increase.

If the speed is increased, then the bead gets smaller. A smaller puddle means less penetration. To counter this, the wire speed and voltage combination have to be adjusted. This will increase the heat and filler metal for better penetration and allow for the puddle to move through the weld zone faster and produce the necessary weld.





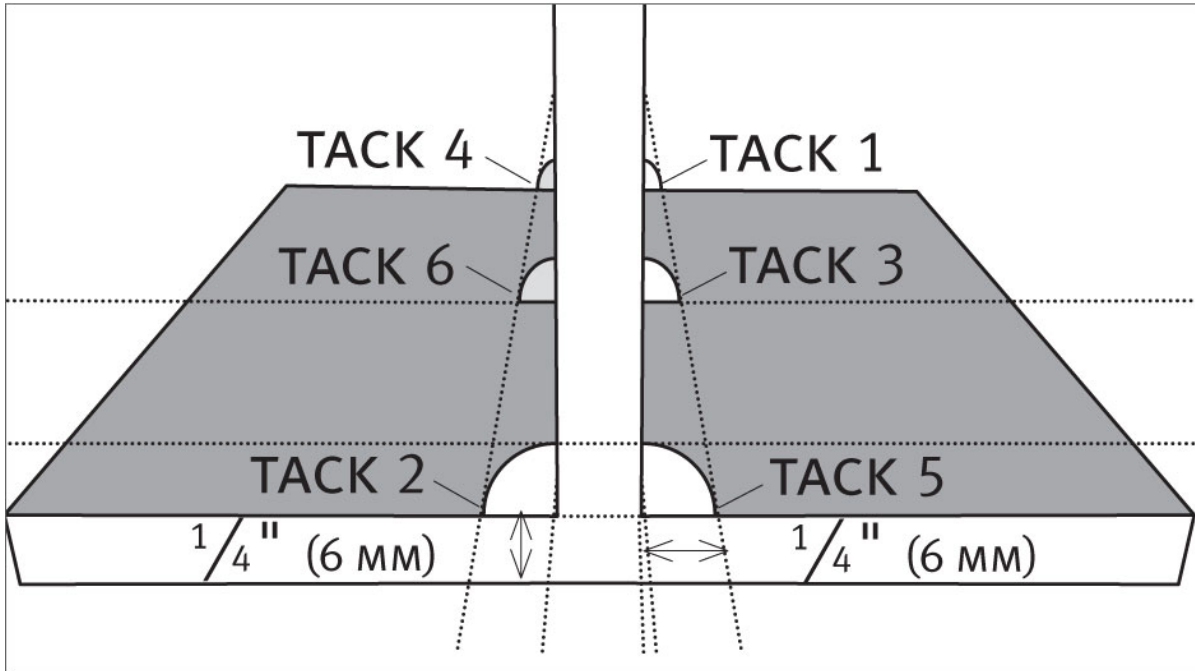
When tacking and welding, you always want to hit the puddle evenly. That means going into a 90 degree corner with the nozzle at a 45 degree angle.

The other way to produce a proper fillet weld is another motion technique that will allow for better control of the puddle. Just like the butt joint motion technique, the fillet has its own patterns and outcomes. Also just like the butt joint, the primary rolls don't change. Be comfortable, brace the gun neck with your opposite hand, point the nozzle straight into the weld zone, and have an even angle on both sides of the stick—in this case a 45-degree angle. The stance, posture, and support should all transfer to the set up and execution of a fillet weld.

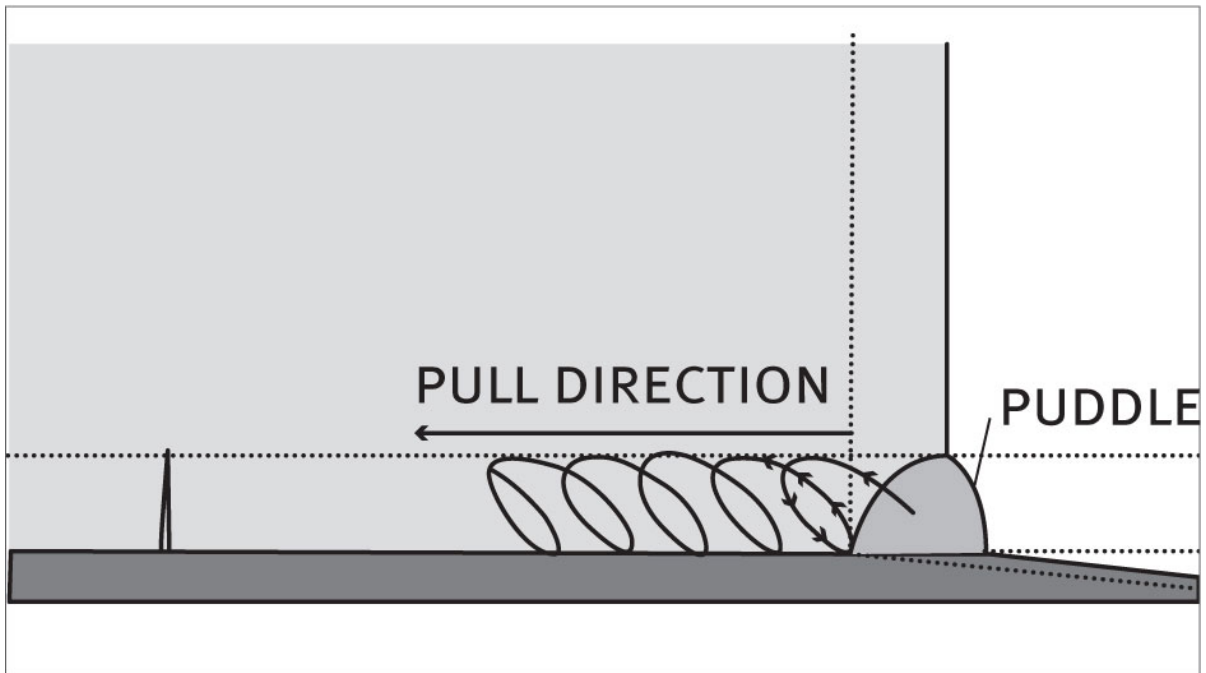




Set up first and get comfortable with the angle you will be welding at.



For tee joints, move from one corner to the next cross/opposite corner, as shown in this diagram.



With this looping technique, always move in an up and over direction. Think of a wheel rolling.





When tacking tee joints, it's a good idea to go from one side to the other in order to counter the movement from the heat going into the steel.

After the pieces have been prepped and secured in place, tack them together in a way that moves furthest away for the last tack. Set the MIG for 1/4-inch (6 mm)-thick material. Hold the gun at a 45-degree angle, go into the corner, and touch the wire down to tack the pieces together.

Now that the piece is tacked together, clean the tacks with the stainless steel wire brush in order to prep for welding. To assist in fighting gravity, the movement of the technique, or shape, is an inverted cursive lower case "L" or "E" pattern, as shown in the diagram on the left. Leave the machine set for 1/4-inch (6 mm)-thick stock. Set up with the gun at a 45-degree



angle. This movement will begin by starting the puddle at the base of the forward tack. As the puddle develops to the correct size, move the arc up and down in this pattern while pulling through the weld zone.

These elongated circular movements will create a sort of vortex or cyclonic action that will help push the puddle back up onto the vertical piece of material, not allowing the puddle time to toe out. The speed and length of this technique will be determined by the material thickness.

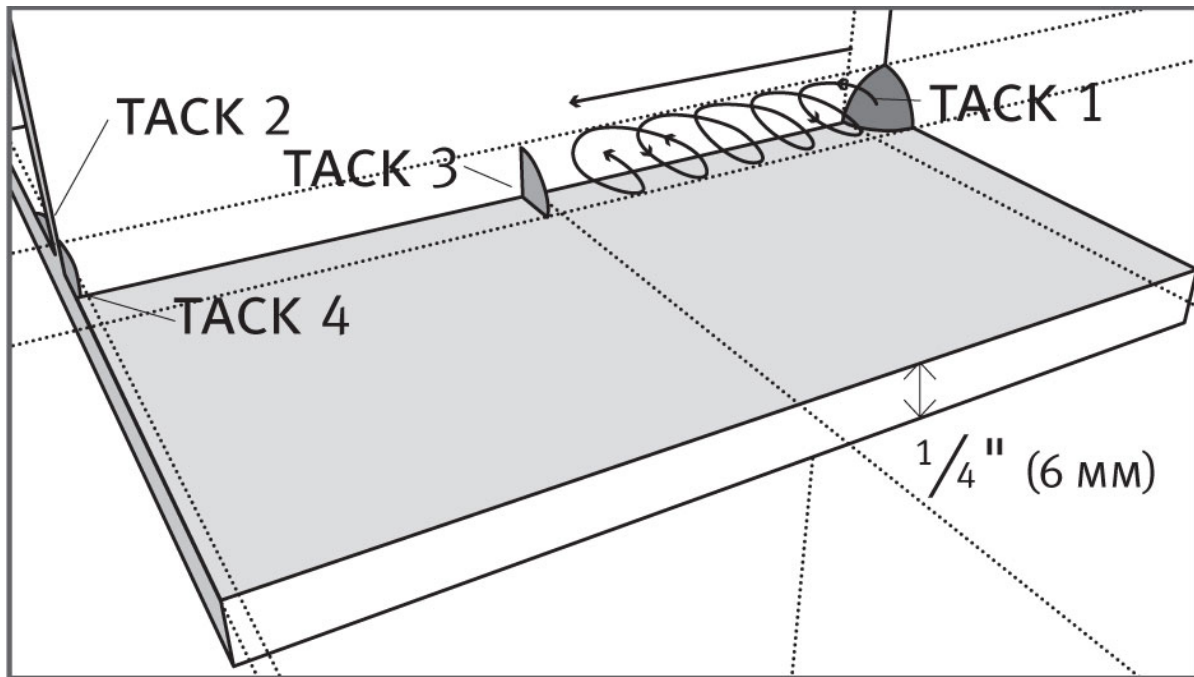


Split the angle of the corner in half so that the nozzle is 45° on both sides. Make sure the shield gas is hitting the puddle evenly.

As the material becomes thinner, the shape of the pattern shortens and becomes more of an inverted cursive lowercase “L.” As the metal increases in thickness, the more the shape elongates and becomes more of a cursive lower case “E.” This pattern can also be inverted for different effects on the surface of the puddle.

When going in to a corner from the right, I recommend using a counterclockwise motion as shown in the diagram on the right. This way, the movement of the arc is on the downward direction, then up again to pick up its own tail. Going in from the left would be opposite direction, clockwise. This means that on either side the motion is always up and over towards the direction of the weld.

Just like any other technique, this will only apply to thicker materials. The thinner the material becomes, the smaller the puddle and the better chance of burn through. Practice this technique until the edges are consistent, even, and the legs are equal to the thickness of the material.



The arc motions rolls like a wheel, up and over.





Clean the weld zone with the stainless steel wire brush and then continue the weld.





Here all the basic joints are tacked together, prepped, and ready to weld.

# The Rest of the Joints

After practicing the techniques for butt joints and tee joints, the rest start to fall into place with relatively few problems. The hard part is out of the way. Let's touch base on how the rest of the five basic joints weld together.

## Corner Joints

Corner joints can use the same technique that is used for butt joints. The technique used is determined by the way the corner joint is positioned. If it's an open outer corner joint with each leg 45 degrees from the floor, then it is better to use more of the back-and-forth shark tooth pattern, like a butt joint.

As with butt joints, the movement of the draw will always be in relation to the motion back and forth, dipping just under the A and C edges a little as you go. Because of the way the heat is distributed in a corner joint, the edges will break sooner than a butt joint. Remember that full voltage and wire speed combination may not be needed when doing a technique for this style of a corner joint.





Corner joints like this will use the same shark tooth technique as a butt joint.





Start tacking by putting the wire down at the bottom of the joint.





The same rules apply to all of these techniques—straight on and perpendicular so the shield gas hits the puddle evenly.



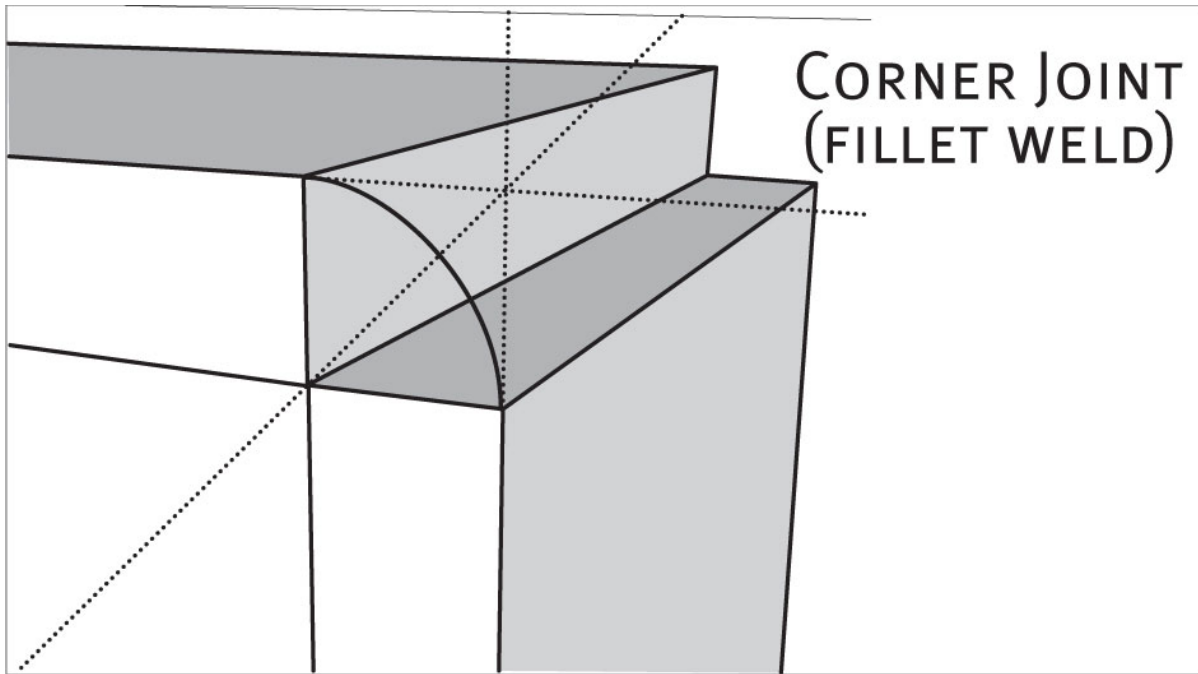


Try to remain braced and supported. If the weld is higher up, find something that height to rest your support hand on that will slide on the table.





You should have a drag angle of no less than 45 degrees.



For outer corner joints, it is only necessary to break the edges. This will happen faster than butt joints.





This is a great general purpose technique that can be used on all sorts of projects. The more you practice, the better you'll get.

## Lap Joints

You can now begin to see where I'm coming from in regards to the welding techniques for the basic five joints. They're all similar in the way they are set up and executed, with very subtle differences in the way they are welded. Gravity, the HAZ, and the angle are all factors that determine the way in which to conduct a weld.

The lap joint, for example, is essentially a tee or corner joint. The most noticeable difference is that one of the surfaces will spread the heat out



through the rest of the material, where the other surface has an edge to break.

The technique is the same as the fillet weld on page 116. Go into the corner at a 45-degree angle, create a puddle, and then draw back with the same pattern, breaking the top edge of the piece.



Edge joints radiate the heat straight down. You may not need to use a puddle control technique on them. In some cases, it is even necessary to dial down the voltage and wire speed.

## **The Edge Joint**

Most of the time an edge joint will be made with a straight draw. The way the two pieces are put together doesn't allow for the heat to be spread out the way it would for a butt joint or a tee joint. For an edge joint, the heat is more immediate. Since the heat is concentrated directly down, the puddle is essentially following the heat, which makes it more intense. The amount of time for the puddle to develop and to create a bead is almost split in half. On thinner metal, dialing down the machine setting is always helpful to create a bead on an edge joint.

I have to say that the edge joint is my least-used joint. I've only needed it a few times for fabrication projects that usually have something to do with angle iron and building steel staircases.





Here are all the basic weld joints. Practice arc movement and puddle control on thicker material. On thin metal, a more traditional straight draw will work best.

So there it is. All the basic weld joints welded together. Practice all of these techniques. Understand that the thinner the material gets, the less distance you can travel with the puddle and the less technique you can use. Techniques, such as the ones taught in this book, will only apply to thicker materials. I will use a similar technique down to about 14 ga; when the metal gets thinner than that it's time to start doing a straight draw. Once you are comfortable and feel that you are laying down consistent beads on both thick and thin metals, it's almost time to start making things.



## Exercise 3: Jigs



**DIFFICULTY:** BEGINNER

**MATERIALS AND EQUIPMENT:**

- MIG welder
- Two 2 to 3" (5–7.6 cm)-long pieces of scrap 1 1/2"(3.8 cm)-square tube
- 10" (25.4 cm)-square section of 14 ga (or thicker) sheet metal
- Welding helmet
- Welding gloves
- Long-sleeve shirt
- Leather welding jacket or apron
- MIG pliers
- Stainless steel wire brush
- Soapstone
- Carpenter or framing square
- 4 1/2" (11.4 cm) angle grinder outfitted with an aluminum oxide grinding disk or a 60- to 80-grit flap disk

In addition to knowing basic welding techniques and joints, it's also useful to know how to make a jig. A jig is a custom-made tool that is used to limit the motion of another tool or the motion of the piece clamped to it. This allows the project to be worked on with more accuracy.

For this jig, you'll need a few pieces of square tube. These can be drops you have lying around or ones you cut. These should be about 2 to 3 inches (5 to 7.6 cm) in length; they need to be long enough so that a locking C-clamp can clear one of the sides to be secured. You will also need a piece of sheet metal to weld the two pieces of square tube on. The best thing about this jig is that it will line up not only one edge but up to three axes for projects like The Cube in the next chapter.



You can use almost any scrap laying around the shop to make a jig.



To make a right angle jig, use two pieces of square tube and a carpenter square.





When the pieces are perfectly square, tack them into place. Avoid tacking on the side the material will be clamped to.

Cut two lengths of square tube to 2 or 3 inches (5 to 7.6 cm) in length. Line up the pieces of square tube so that the corners face each other. Using a square, line up the two outermost sides of the two pieces of tube.

Tack the tubes to the sheet metal with a fillet tack (see page 116). Make sure not to tack on the outermost edge, as this will be the edge that you'll clamp the sides of your work pieces when you use the jig. Tack the first tube into place and then check that the second tube is still square with the other. After both pieces are tacked into place, check again for square. If

they are not square, cut the tacks off of one piece and re-tack until they are square. With the jig squared and tacked in place, it is ready for use.

## Other Welding Situations and Positions

Before we get to building things, I want to show you a few variations of how to conduct a weld. Sooner or later there will be a situation where you don't have the luxury of welding on a flat surface. There will always be a need to be able to weld from different angles and directions.

It's great to work on a small piece on a nice flat work surface. Small pieces allow more freedom of movement. If you're not comfortable welding in a certain direction, or the piece is too far away, or if the piece needs to be welded in a different location, simply pick up the piece and situate it in a way that allows you to be comfortable and have the best angle.

But what happens when you're working on something larger than the table, like another table or maybe a vehicle? When the piece becomes too heavy or too large to make adjustments, you have to be the one to adjust. Putting yourself into situations where you have to do vertical welding or adjust the position you normally weld from will help you develop your skills as a welder.

### Vertical Welding

There are two methods of vertical welding, uphill and downhill. It is much more difficult to execute an uphill bead than a downhill bead: either you have gravity with you or against you. However, despite being harder to execute, uphill welds are stronger because they give you deeper penetration.

An uphill weld is the movement of the puddle up a weld zone with a push motion. The advantage to uphill welding is that the puddle penetrates deeper into the metal from the force of gravity pushing down on it. Since gravity is against the puddle, it wants to eject itself from the weld in progress, meaning the fluid that makes up the puddle wants to fall out of the weld. This makes it very difficult to control. This style of welding is normally used in industrial situations such as building ships, bridges, and other structures that require additional penetration.

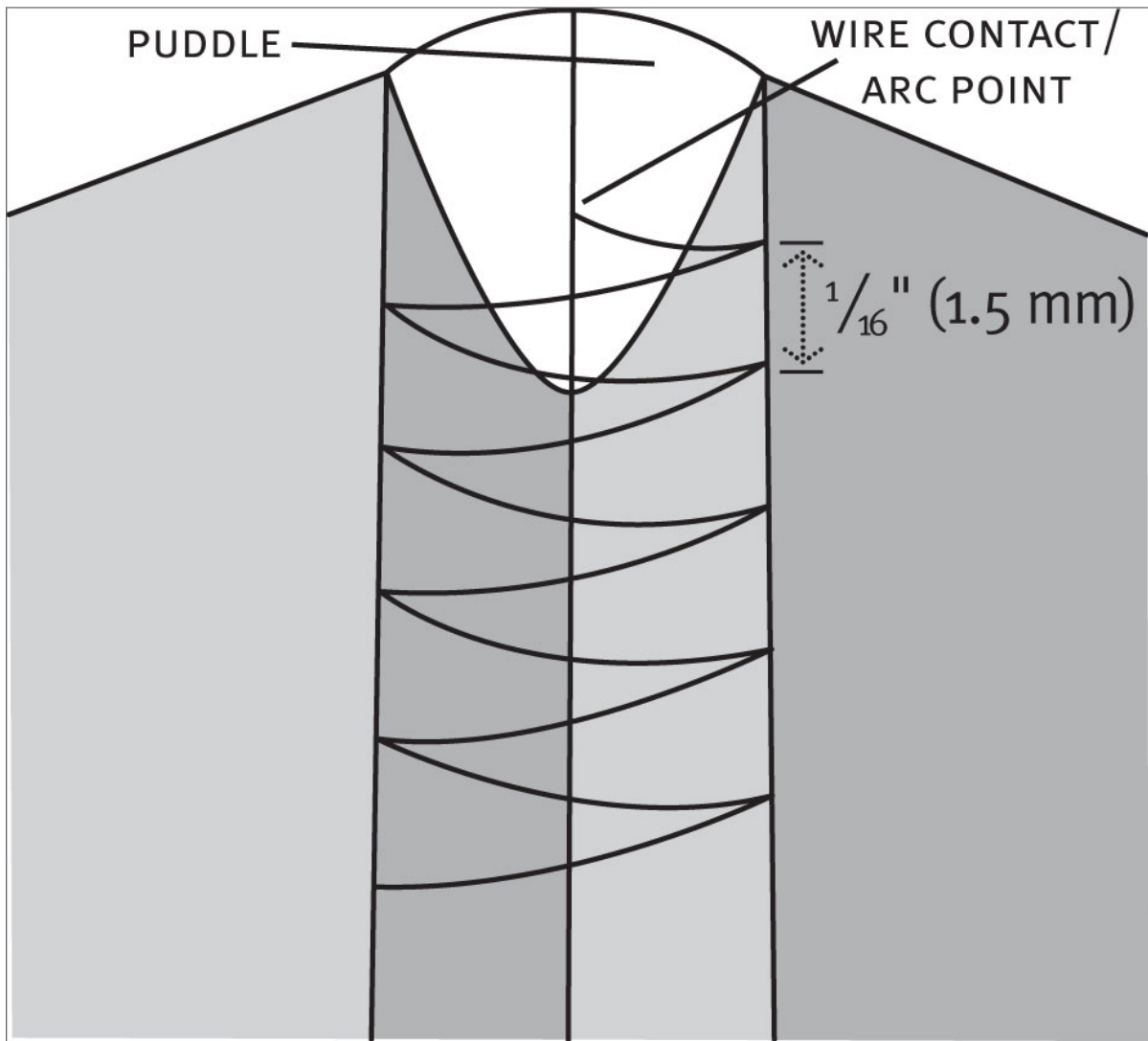
I'll confess I don't do much uphill welding because most of what I do does not require an uphill weld, nor do I work with material thicknesses that would require more penetration. There are also a few tricks that I have learned over the years to give me better penetration using a downhill weld.



Setting up for a vertical downhill weld is basically the same as you would for any weld: the nozzle still has to be straight on and perpendicular, you should still be as comfortable as possible, and you should still support and brace the gun with your opposite hand. What does change is the drag angle. I exaggerate the angle by positioning it under the puddle so that the shield gas actually helps decrease the speed of the fall. Then, with a back and forth motion technique, I slowly draw the bead out. I call this pattern the falling leaf. This pattern helps you control the puddle's fall and keep it in place longer.



When vertical welding, always try to find a way to support your hands; if you only have the ability to use your pinky, use your pinky. Magnets come in handy as supports when vertical welding.



Like the shark tooth motion for a butt joint, build the puddle and move the arc in a falling leaf pattern. For every motion in one direction, let the puddle drop  $\frac{1}{16}$  to  $\frac{1}{8}$  inch (2 to 3 mm).





As you can see in this cross body weld, the direction of the nozzle is still straight into the weld and I am perpendicular on both sides. In order to do a cross body weld, I don't break the rules, but I do have to position my trigger hand towards me a little in order to keep those angles and adjust my drag angle.





As shown in this image of welding a corner joint cross body, the nozzle is still straight on with an even angle on both sides. Again, weld straight on and perpendicular with a good drag angle.

## **Cross Body Welding**

Another great method of welding that helps a lot is cross body welding. You will see a lot of cross body welds in production welding. Set up so that the line of the shoulders is parallel with the line to be welded. A lot of welders prefer this method because it allows for better vision of the weld in progress. Instead of pulling toward the body, this is a movement across the front of the body.

The unbreakable rules do not change. The drag angle of the nozzle still has to point into the weld, you still need even angles on both sides of the puddle, and you still need a consistent  $\frac{3}{8}$  inch (9 mm) stick out.

Now that you know a few variations of welding positions and styles, you can develop your own way you would like to set up and weld. As long as you don't break the basic rules, with a little practice you should be able to execute a consistent bead every time.

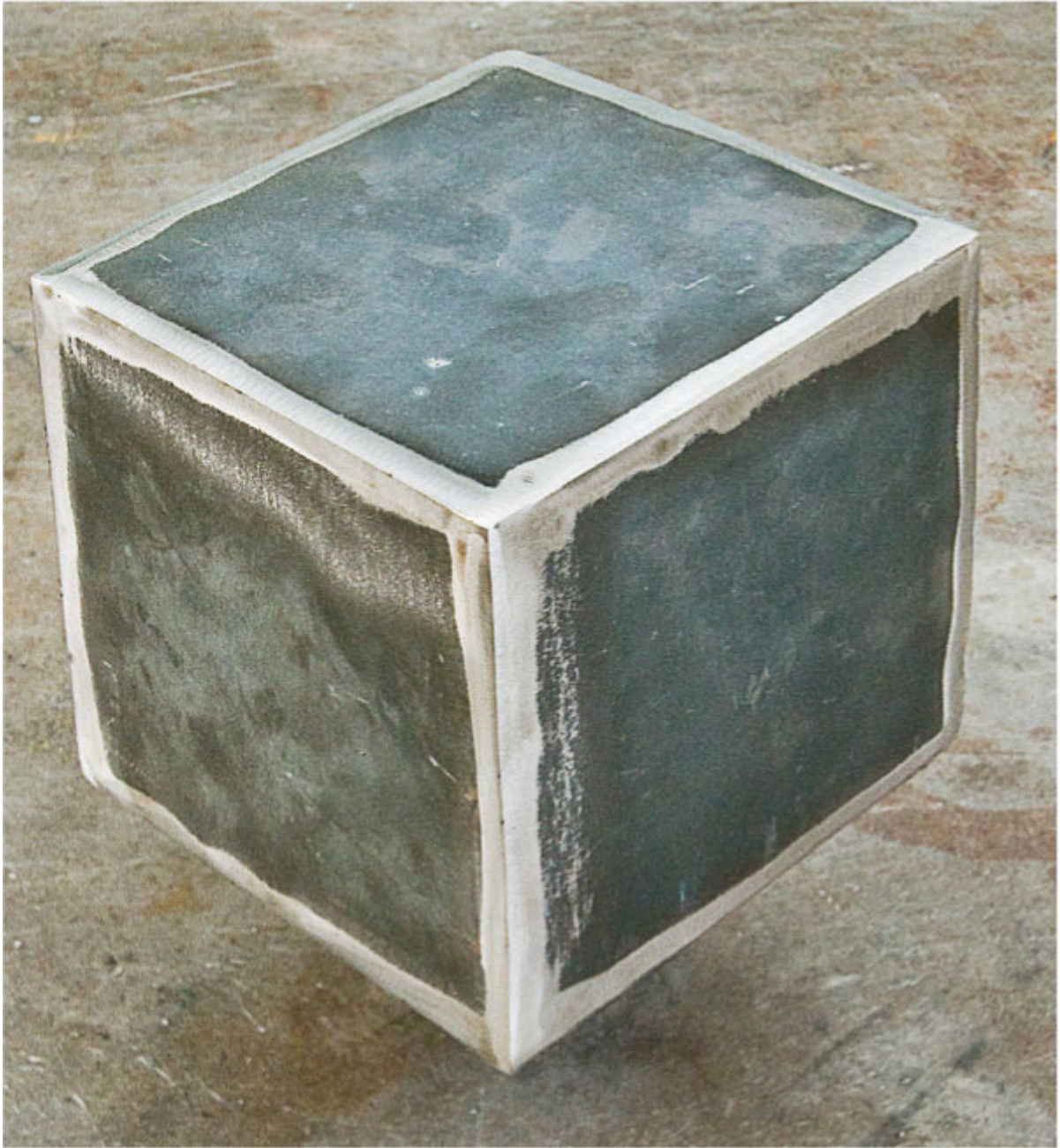
# 6

## Projects

By now you've mastered the basics and can draw a bead, tack, and weld a variety of joints and even a jig. Now we're going to put everything together with a couple of projects that will hone your skills even more.

Don't forget to follow the safety procedures we discussed in Chapter 2. Welding is only fun if it doesn't include a trip to the emergency room.















# Project 1: The Cube



**SKILL LEVEL:** BEGINNER

**MATERIALS AND EQUIPMENT:**

- MIG welder
- Two 2 to 3" (5–7.6 cm)-long pieces of scrap 1 1/2" (3.8 cm)-square tube
- 10" (25.4 cm)-square piece of 14 ga sheet metal
- Welding helmet
- Welding gloves
- Long-sleeve shirt
- Leather welding jacket or apron
- MIG pliers
- Stainless steel wire brush
- Soapstone
- 4 1/2" (11.4 cm) angle grinder outfitted with an aluminum oxide grinding disk or a 60- to 80- grit flap disk
- Cutting disks
- Corner jig
- 2 locking C-clamps

Creating a cube has a very important place in my life. It was the very first project that my professor assigned to me as a new metal arts student. I could only use a grinder, an oxy-gas torch, and of course a MIG. When finished, it had to be a perfect 6-inch (15.2 cm) cube. It taught me time, patience, and the importance of accurate measuring. Even more importantly, it taught me the reason why tacking a piece together first before welding is so crucial. That cube taught me so much that I incorporated that same assignment into what I teach today to my new welding students. That is why it will now be your first project.





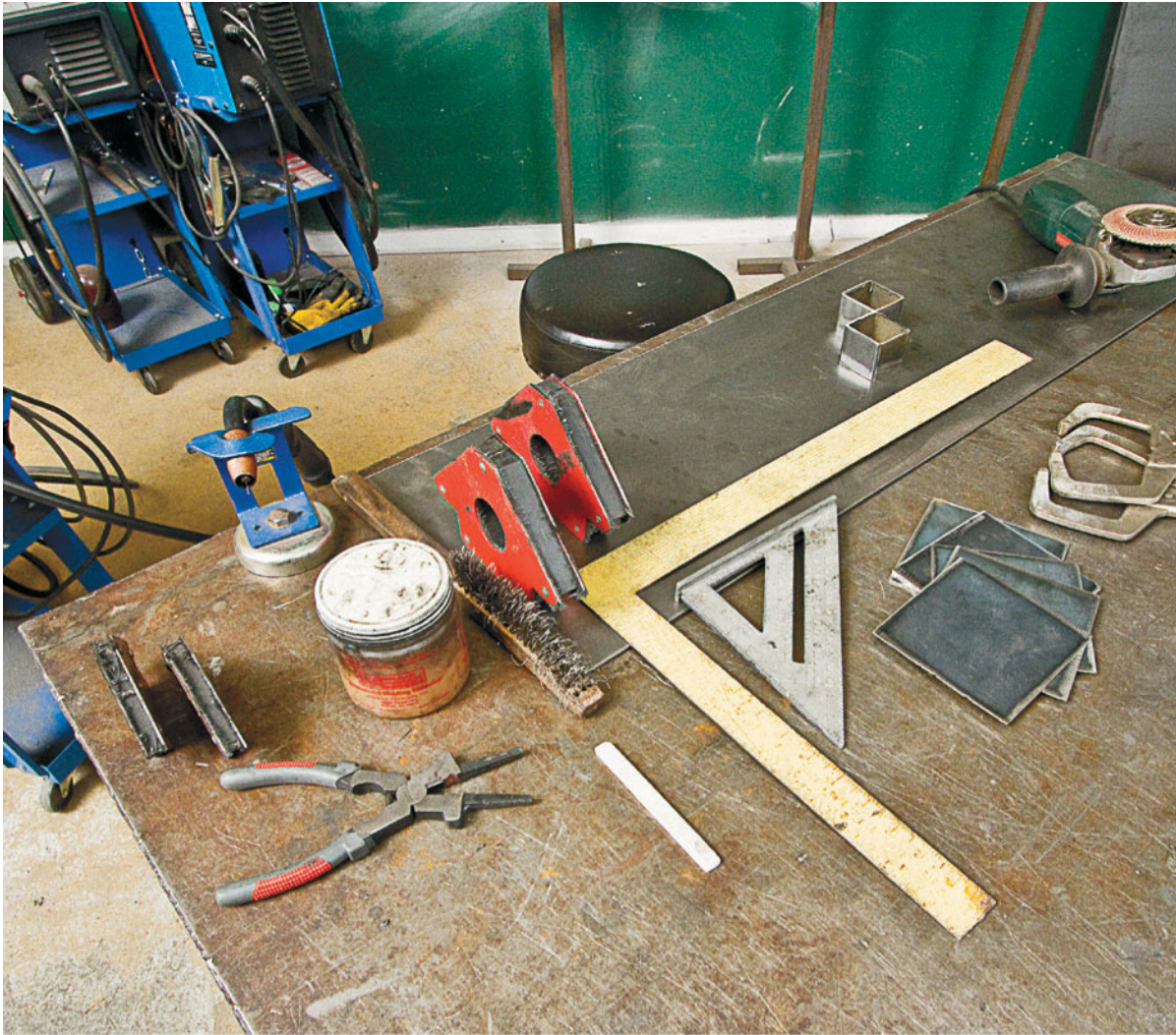
The cube that you will be fabricating will be made of 20 ga mild steel. Every weld on this cube will be outer open corner joint. How you weld them is up to you. The project will be an exercise in welding thin metal, spreading out the heat, and precision. It seems simple enough, right? By following the process of Cut-Prep-Tack-Weld, it will be.



## Cut

Start where all projects start in fabrication, by coming up with a list of the parts that you need to make the piece to be fabricated, in this case a 6-inch (15.2 cm)-square cube. You will need to measure and cut six 6-inch (15.2 cm)-square sections from a sheet of 20 ga mild steel (hot or cold roll). If you overlook anything, it will probably be the importance of size and shape of each side. Having squares that are exactly the same size will help you avoid a world of trouble.

After cutting out the squares, even them up by clamping them together so that two of the squared edges are flush.



For any project, make sure everything you need is ready to go and close by.



1  
Your squares will not make a good cube if they are not all the same size, even, and square. Clamp them together so they are even on two edges.





2

Grind down the two uneven sides until they are even.

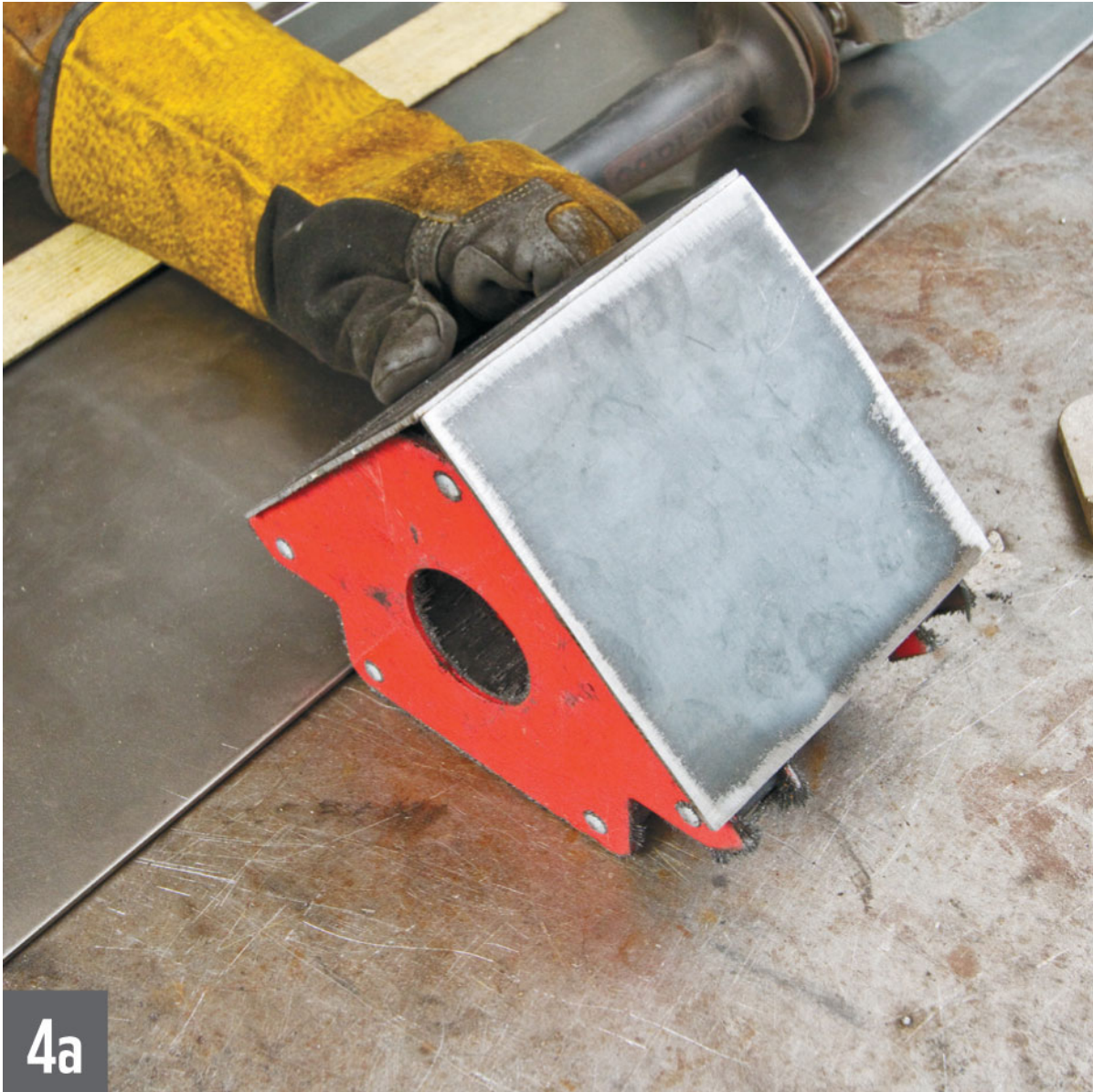




Check the length of the sides as you go to make sure they stay square.

Use a grinding stone on an angle grinder to even out the other two edges. You can also use a bench grinder, just be careful not to round off the edges and leave some edges shorter than the others.

After grinding each of the two sides, make sure the pieces are still the correct length and are still square.



After you have cut and prepped the squares so they're even, it's time to tack. Square magnets can be used to hold the sides in place.

## Prep

Now that all six sides are perfect 6-inch (15.2 cm) squares, the next step is to clean and prep the metal. With an angle grinder and flap disk, make sure that all the surfaces around the weld zone are raw steel.





Alternatively, a jig can be used to clamp each side in place while you tack.

## Tack

It's time to tack our pieces together. For this we will need to clamp our pieces together at a perfect 90-degree angle. We could use magnets similar to the method used in Chapter 5 for a corner joint. Instead, use the jig you constructed in Chapter 5. The jig will line up not only one edge, but three of the axes needed to make the cube.

Use two locking C-clamps to secure two sides of the cube onto the jig, one on each side.





Put one tack in the middle of the two squares.



Once one edge is completed, add another side the same way. Clamp and tack in place.





Once the cube is tacked, check to be sure everything is square. Small errors can be fixed with a hammer, but if it's off by a large margin you'll need to cut the tacks and start over.

After the edges of the two sides are lined up and everything is square, tack the two sides together with one tack right in the center.

Repeat the same steps as you rotate the box and add the rest of the sides.

If all has gone well, you should be able to fit the last two sides on the top and bottom. Tack each of them into place with four tacks, one for each edge right in the center. Once you have one tack in the middle of each edge of the cube, square it up.





Once the cube is tacked together, make adjustments as needed using a mallet. When it is completely square and in the correct alignment, tack the corners.

If the cube is not square, it may not be necessary to cut the tacks and redo the entire piece. If it appears to be out of alignment, use a hammer to tap it back into square. This method of tacking will still allow for a little movement; the tacks will bend enough for it to be realigned with a hammer. When the cube is aligned properly, secure it for welding with more tacks at all of the corners.





The cube should look like this when it is tacked together.

## **Weld**

We have cut, prepped, and tacked, and now it's time to weld. While you don't necessarily have to use a specific technique when welding on steel this thin, on thinner materials it is best to do a push weld with an increased travel angle (drag angle but pushing), about 10 to 15 degrees with the nozzle. All of the other rules are the same. The nozzle will still need to be straight on and perpendicular, and you always want to maintain even angles on both sides of the nozzle.





You will only be able to weld about a  $\frac{1}{2}$ - to  $\frac{3}{4}$ -inch (13 to 19 mm) at a time with a straight pull or push on steel this thin.





11

Mark sections on the cube in soapstone to plan your welds.

Because the metal is so thin, it will burn though and warp much faster than you may expect. You may have to adjust the setting on the MIG for a little less heat and filler. This means that while you're welding, you will need to do short welds in less time to really spread out the heat.

Use a soapstone to mark  $\frac{1}{2}$ - to  $\frac{3}{4}$ -inch (13 to 19 mm) sections. These marks represent the length of each of your weld zones. Start with one corner section and weld a  $\frac{1}{2}$ -inch (13 mm) length; then move diagonally across to the opposite side for the next weld. Repeat this so that the heat is



spread through the entire piece. After one series of welds, it may be necessary to let the cube sit for a minute to cool down and prevent warping.



This is an example of key holing.

While welding the cube together, you may notice a slight burn-through start to form ahead of the weld. This is referred to as “key holing” and is a good indication that you should stop welding. This overheating can also lead to the piece warping or further burnthrough. If it happens, quickly speed up the motion or dial down the heat and filler. It is perfectly fine if it happens right at the end of a section.

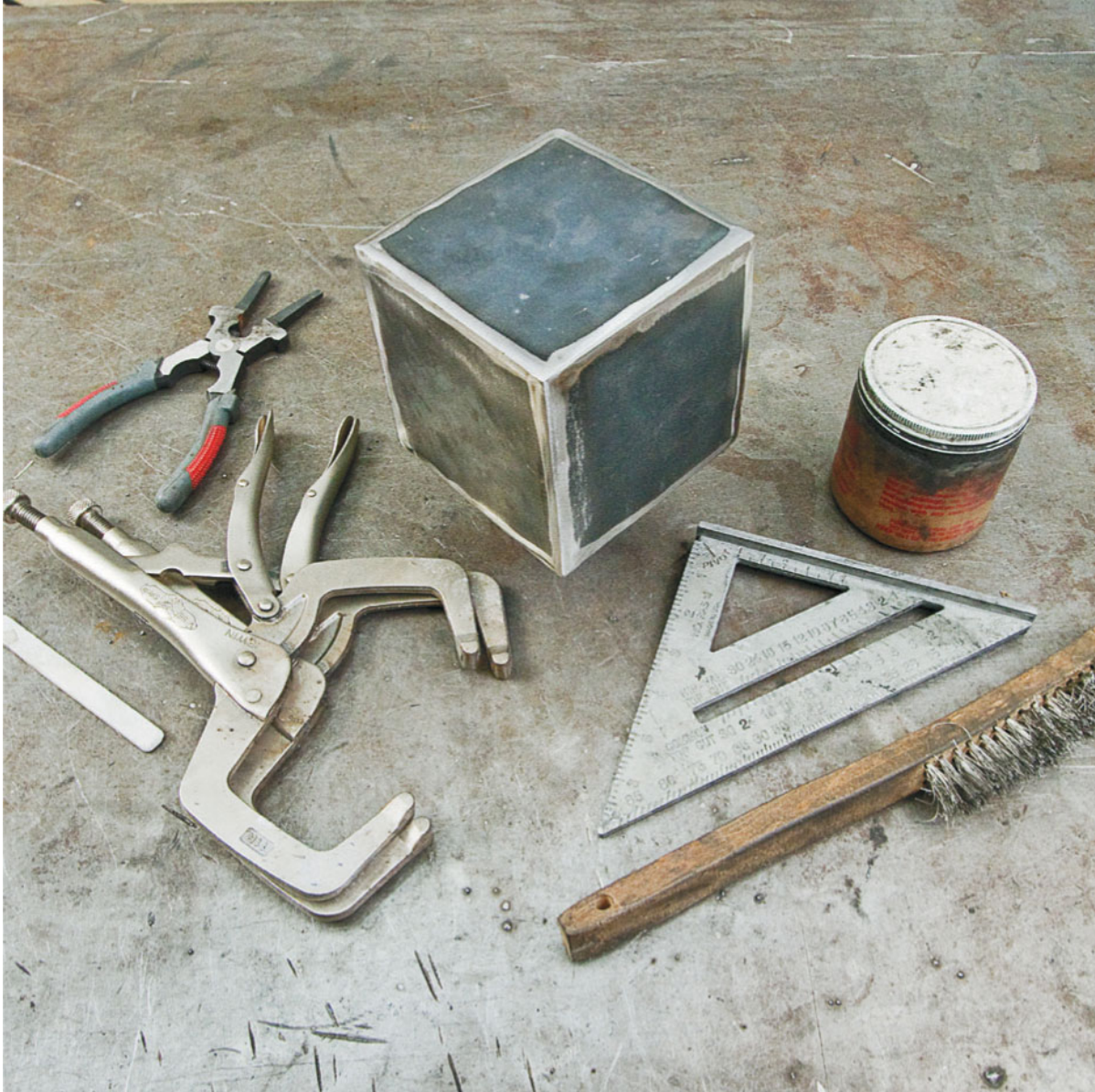


When the entire cube has been completely welded up, you're done. The only thing left to do is a little stress test. Find an area of concrete pavement like a sidewalk or schoolyard away from people or anything breakable. Throw the cube 10 feet (3 meters) in the air, stand back, and let it come down on the pavement. Pick it up and inspect the welds. If you don't see any cracks or fractures, good job! You have successfully fabricated a cube. If there are cracks, then do it again; at least it will be fun.



When fabricating the cube, remember to support your gun hand with your opposite hand. As you can see from this image, I'm using my jar of spatter dip to perch my hands on during welding.





There you have it—a perfect cube. Now cut it up and make something out of it.

# Project 2: The Welding Table



**SKILL LEVEL:** Intermediate

## **MATERIALS AND EQUIPMENT:**

- MIG Welder
- Two 24' (7.3 m)-long sticks of 1/8" (3 mm)-thick wall, hot roll 2" (5 cm)-square tube
- 24' (7.3 m)-long stick of 14 ga, hot roll 1" (2.5 cm)-square tube
- 4' (1.2 m)-square, 1/4" (6 mm)-thick cold or hot roll plate. (Note: This is for a very large welding table. Make adjustments to the measurements as needed to fit your space.)
- Welding helmet
- Welding gloves
- Long-sleeve shirt
- Leather welding jacket or apron
- MIG pliers
- Stainless steel wire brush
- Soapstone
- 4 1/2" (11.4 cm) angle grinder outfitted with an aluminum oxide grinding disk or a 60- to 80-grit flap disk
- Chop saw
- 3-Axis clamp, right-angle magnets, or jig
- Saw horses

As a welder, you will do a lot of projects, small and large, that require having a good welding surface. Aside from the welding machine itself, you will find that the welding table is one of the most important pieces of equipment in the shop. There are many different manufactures of welding tables that provide a wide variety of different options for accessories, sizes, and clamping systems. But starting off in welding by fabricating your own welding table is a great project. Creating a table that is true, square, level, and plum will give you a greater understanding of what to expect when



building future projects such as furniture. It will also provide you with a great new tool to help build those future projects.



There are a lot of factors to consider when creating a good welding table. In the future as your abilities and needs grow, you will discover other things



that you may want to incorporate into building the next welding table. For now, we are going to be focusing on something practical and simple.

# Considerations When Making a Good Welding Table

First and foremost is conductivity. The table has to be made of a material that allows the current to flow through the entire table. If working on something small, such as a jewelry box, you can't necessarily clamp the ground directly to the piece without it becoming awkward. You can, however, clamp the ground to a metal table that will allow the current to flow through the table and then through the work piece as you weld.

Normally, you want to make your welding table out of the same material you plan to do the most welding with. When welding high volumes of stainless steel or aluminum, it is good to have a stainless steel table to prevent contaminating the weld zone. Both of these materials are much more expensive and harder to work with, and you're not there yet. Most common welding tables are made from hot or cold roll carbon steel. A mild steel welding table will last a long time and provide a multitude of functions.

Second is size. This will depend on the amount of space you have to work with. If working in a small garage, you obviously don't want to build a table out of a full 4 x 8 foot (1.2 x 2.4 m) sheet of steel. Choose a size that will be enough to work on and at the same time not overpower the workspace.

This is also a great opportunity to customize the table for your needs and comfort. If you are six and a half feet (2 m) tall, consider making the legs higher so you are comfortable standing and sitting at the table. Predetermine your own height dimension by picking out a stool that is comfortable. Remember rule number one: be comfortable when you are welding. Pick a table height that will allow you to be comfortable both when you're sitting on your stool and when you're standing. Measure the height to your preference when you are seated and then find a surface that same height to see if you will also be comfortable standing.

The third thing to consider is mobility. Metalworking is a heavy lifting hobby. You are going to do enough of it without having to move a 300 pound (136 kg) steel table around. Heavy-duty locking swivel casters are great not only for the mobility of your table, but they also turn the table into

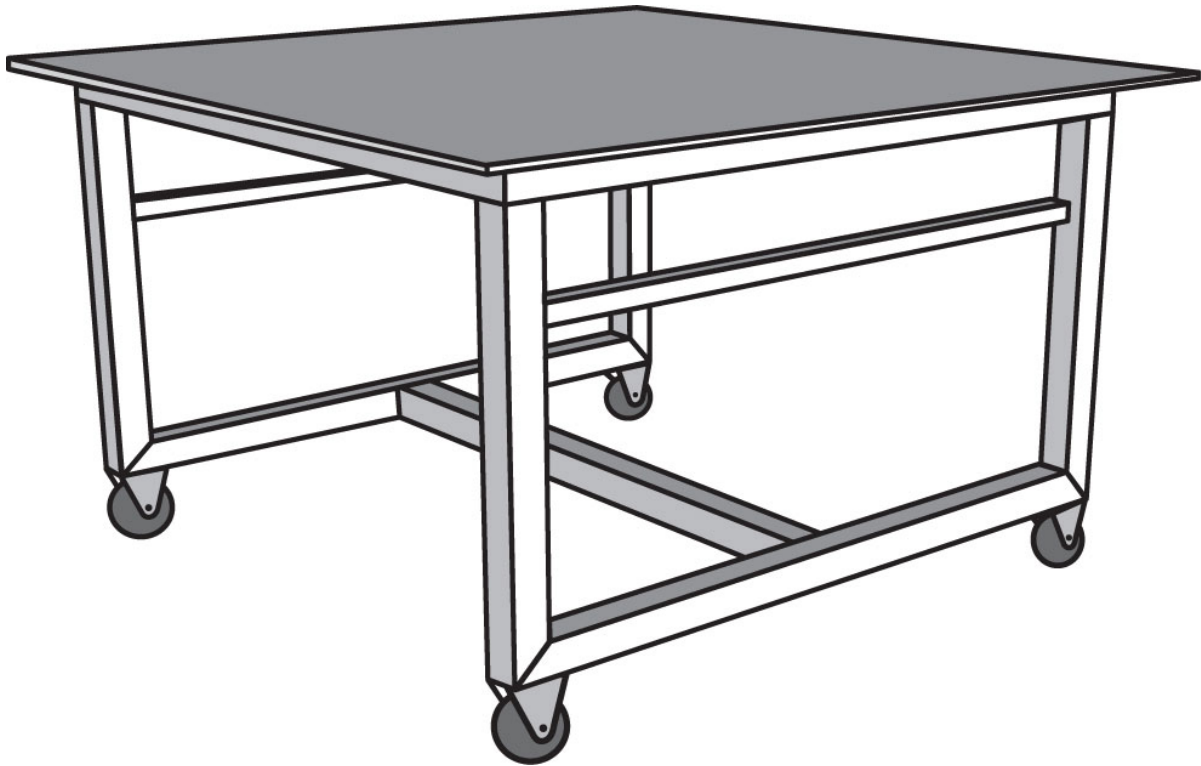
a cart. This means that as a work piece grows heavier as you work on it, you won't have to carry it around the shop to access other equipment.

The locking casters work great when you have to lean on the table to get more leverage. You don't want it rolling away from you mid-weld. When you are done for the day and want to save space for the car or motorcycle, simply roll the table to the side and out of the way. Casters are also something that needs to be considered when determining the height of the legs. Most casters that I use are roughly 4 inches (10.2 cm) tall, so remember that when designing your welding table.

Next is functionality. It is always good to be able to clamp your materials down to keep them still while you weld. Having clamps accessible and close by is always a good thing. Rails made of 1-inch (2.5 cm)-square tube on the side of the table will be useful for hanging and storing clamps. This will make the work go more smoothly as you won't have to search the work area for clamps. This will also make a great location for your ground to be clamped; some ground clamps don't open a full 2 inches (5 cm), so having a smaller, out-of-the-way piece of steel to clamp the ground to is preferred.

Another thing to consider when determining size and clamping is the sheet of steel that will make the top of the table. Having a good 2- to 4-inch (5 to 10.2 cm) lip from the outer edge to the table's top frame will help you clamp future projects in place. As you can imagine, this will greatly affect the size of the frame and the top surface.





One of the most important pieces of equipment in a shop is the welding table.

Functionality is also important when making decisions on the construction. Do you want the table to have a cutting surface? Do you need cutouts on the surface to give you more clamping area? If you want your table to double as a cutting surface, you will want to construct a portion of the top with a mesh or vertical bar stock to one side of the table so the spatter can fall through (see Tools and Equipment in Chapter 2 for methods on cutting metal). If you want more clamping area, you should have slats cut into the surface plate before welding it on. These are all things that you can consider. For now, we will have a 4-inch (10.2 cm) lip to help with clamping.

Even though I provide dimensions for this project, you should concentrate on the construction and welding. Adjust the measurements to the dimensions that fit the needs of you and your workspace. Right away you are going to notice the surface area and height are a lot more than what you might need, so make any adjustments you need. For example, instead of a 4-foot (1.2 m)-square, 1/4-inch (6 mm)-thick plate, try cutting something in between 2 or 3 feet (0.6 or 0.9 m); this may be plenty of surface area for your workspace and the projects you will be working on.

For this project, you need a nice beefy 2-inch (5 cm) square tube with an 11 ga wall. This will ensure that the structure is stable for a wide variety of projects and will be able to support their weight. This table is not going to be painted or a work of art, so to save money we are going to make the entire base from hot roll steel.

The top should be made of a piece of steel that is flat and true and will remain that way for the life of the table; the thicker it is, the better it will hold up against heat and warping. Don't go overboard though; you don't need a 2-inch (5 cm)-thick piece of cold roll. The top will be made from a 1/4-inch (6 mm)-thick sheet of 4-foot (1.2 m)-square cold or hot roll steel; this is half the size of a full sheet. If you are making a smaller 2-foot (0.6 m)-square table, you can use a thinner sheet of steel; I wouldn't recommend going under 14 ga. If you do use a thinner sheet, you will want to reinforce the frame underneath the sheet with some additional square tubes or angle steel.

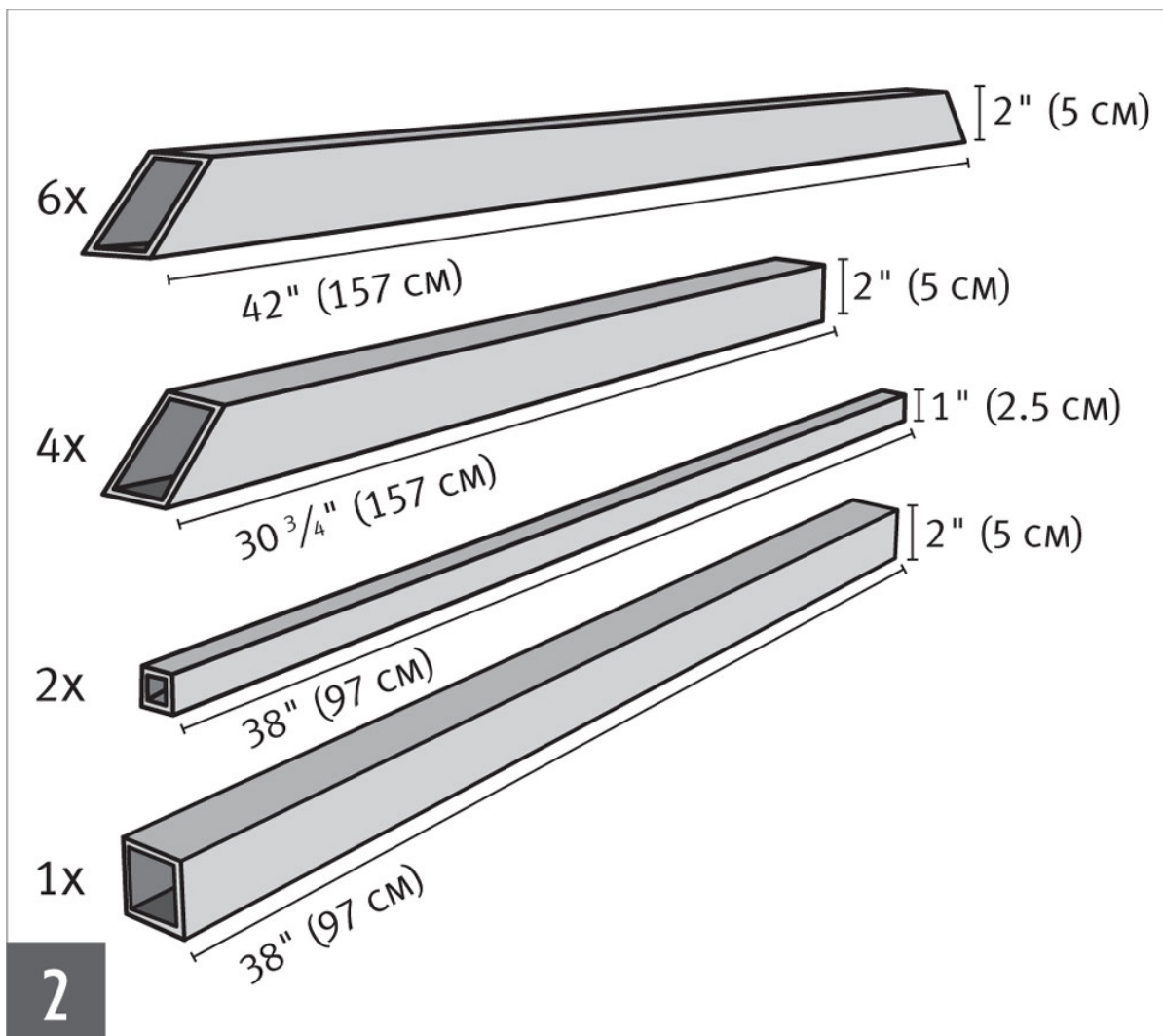


The mantra of any good craftsman is "measure twice, cut once." I normally throw one more in for good measure. (Pun intended.)



## Cut

At this point, you should have all of the materials and dimensions you need to fabricate the table. Count out all the pieces based on how many you need for each dimension and how they are supposed to be cut. “Measure twice, cut once” is pretty much the mantra for everyone in the construction or fabrication industry, welding included. We are going to be making miters for the top frame, legs, and base. This will require six identical-length cuts for the top frame and base rails that will all be mitered inward on each end. The legs will only be mitered on one end to fit to the bottom rails.



Follow your cut list to make sure you have all the right pieces in the right amounts at the right lengths.

The design and the cuts of the legs and base rails should also be determined by the casters you use. If you are going to be using a threaded stem caster, you will not need to miter the bottoms of the 2-inch (5 cm)-square legs or the tube that connects the legs. Leaving the bottom of the legs open will allow plates that you have drilled and tapped to be welded into place. I will explain that process later in this chapter.

The design I will be fabricating will use four-holed plate casters; this involves removing the coating and welding them on to the bottom of the table. In this case, I will be cutting and connecting the legs with a mitered support rail. What type of caster to use is up to you.



When cutting miters in steel, it's always a good practice to put the entire cut line on the metal before cutting.

Start by cutting all the longest parts that have the same measurements and angles; for example, the top frame and the two runner base pieces are all the same and they are the longest. These pieces need to be identical. There will be six total, all mitered on each end, and all outer dimensions will be 42 inches ([106.7 cm] or the measurement that you have determined).

Using a combination or framing square, mark the miter cuts needed on each end of all six pieces. Adjust the chop saw guide for a 45-degree cut.



Cut all miters inward. Remember that the lower frame does not need miters if you will be using stem casters, so adjust the measurements accordingly.



Try to be as accurate as possible. Cut the first one and make sure it's the correct length and angle. Then match the rest of them to it to make sure they are all the same.

Try to be as accurate as possible when making these cuts. It is best to be a little on the long side and make a rough cut. Just like any cutting method, the thickness of the blade is a factor. Make sure the blade is on the correct side of the cut line. Go slow and take your time. Put enough pressure on the saw so that it is cutting, but don't try to bang through it. It is normal to have



to even the material out to get each piece the proper measurement. Using an angle grinder with a stone grinding disk is sometimes necessary to get all the lengths and angles to match.



Lay out all the pieces and take inventory. If you have all the parts you need, it's time to true them up and prep.

To help mark and keep consistent outer lengths, line up all of the material side by side and then measure the length you need. Use a carpenter square to mark a line on all of the pieces that are going to be cut the same; this line will be where you mark off your 45-degree cuts.



After all of the cuts have been made, check them for accuracy. If some are a little long or have some burs, grind them to match.



Using the most accurate piece of each series, true up the rest to match that piece.





## Using Consumable Blade Chop Saws

When using a metal-cutting chop saw outfitted with a consumable blade, bear in mind that the blades are much more flexible than a wood-cutting blade. When cutting angles, be careful of how much pressure you're exerting when you push down. Too much pressure and the blade is going to want to deflect, causing a curved cut, which results in miters that are difficult to work with.



After everything is the same length, use a flap disk to prep all the pieces where they are to be welded. Chamfer the miters on the butt joints.

## Prep

Prepare all of the surfaces for welding by cleaning them with denatured alcohol or acetone. With a 60-grit flap disk, remove all mill scale from the weld zones and chamfer the edges if needed.

On material this thin, I only chamfer butt joints slightly—45 degrees—for half the thickness. Then I will clean the weld zone a minimum of 1/4 inch (6 mm) from the chamfered edge. It's not necessary to chamfer the



legs that connect with the top frame. The interior welds for the legs will be fillet welds. The rounded edges of the square tubes will provide a sufficient chamfer for the exterior welds.



Get your casters ready. Here are a single-screw stem caster and a four-hole plate caster.



## Mobility

The specific casters you have selected will determine the way they'll be attached to the table. A four-hole plate caster can be welded directly to a plate that is welded to the bottom of the legs or directly to the frame of the table if the frame is wide enough. There are also single screw stem casters that will require a hole to be drilled into a piece of plate metal to be welded to the bottom of the legs.

The point where the casters meet the legs will take a lot of abuse and a lot of torque. You don't want to weld a caster to thinner gauge metal, as the metal can buckle under the stress of pushing the table around with something heavy on it. If the materials the table is made from are not thick enough to handle the abuse, weld plates on the bottom first. The thicker metal for the bottom will reinforce the casters. For this project, we should be using 14 ga wall or thicker so we should be okay.

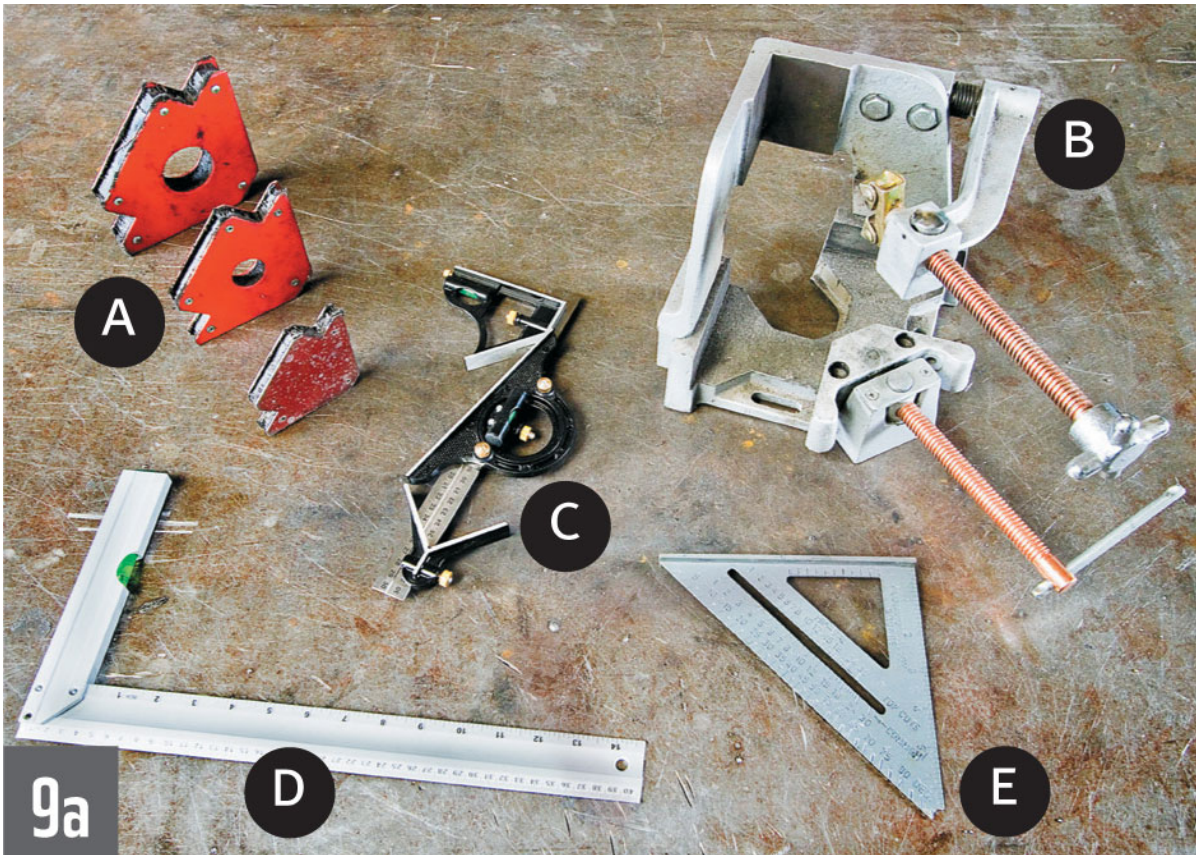
It is common for most casters to be covered in some kind of plating such as zinc. When welding casters to the bottom of the table or to a plate, make sure to prep the plate on the caster thoroughly with a grinder. When grinding and welding these types of plate, always wear a respirator to prevent breathing harmful chemical fumes.

A lot of things can happen to casters. They can lose their ball bearings, bend, or the lever locks can fail. If you have a drill press, you can also consider the single screw stem casters. You can create threaded holes on the bottoms of the legs to screw in this style of caster. It makes it much easier to replace the caster if it breaks or fails.

Drilling and tapping is the method used to create a threaded hole in a plate of steel to receive a threaded screw, or in this case a stem caster. Another method is drilling an oversized hole and welding nuts on the inside of the plate before you weld the plates to the bottom of the legs. This will allow for the caster to be replaced faster when necessary.

 **WARNING**

Most casters have zinc plating that must be removed to expose the raw steel beneath. Wear a respirator when grinding and welding on anything zinc plated.

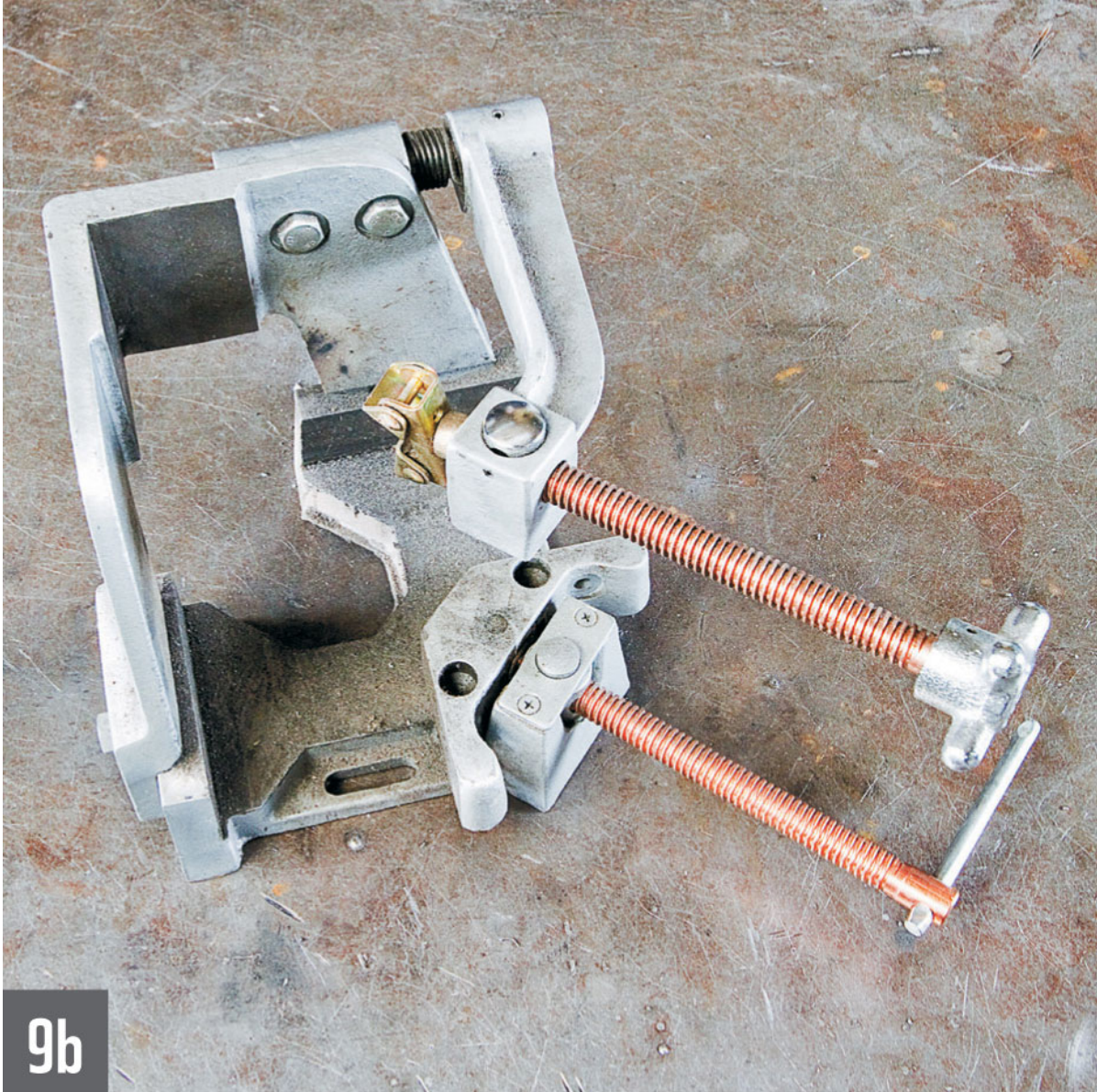


All of these tools have perfect 90 degree angles and help you make great corners. A. Magnetic squares; B. 3-axis corner clamp; C. Precision square; D. Multi-purpose precision square; and E. Rafter square

## **Four Ways to Create Good Corners**

There are several ways to get true 90-degree corners. The first method is a corner clamp. For the most accurate corners, a three-axis corner clamp is the best. These can be expensive, so most hobbyists won't invest in this piece of equipment. However, if you plan on becoming a furniture maker or doing a lot of framing projects, this clamp is well worth the price. The three-axis corner clamp allows you to tack and weld two pieces of the frame and a leg together all at once, which saves a lot of setup time. These clamps are known for their accuracy, so you will also know that your corners are square. It's not a bad idea to check its accuracy with another square once in a while, however, to make sure it doesn't need to be tuned.





This is a three-axis corner clamp.

A single corner clamp is just like the three axis corner clamp, just without the third axis. It only allows for two pieces to be tacked at a time to create a corner. These are great for creating frames. After a frame is completed, use them to corner the legs. When using this method, it is always good to have a square handy to check the third angle since the clamp is only able to secure the two axes.





Magnets are also really handy as a good hand support when doing vertical welds.

The second way to create corners is with magnetic squares. Magnets are a great and inexpensive ways to help keep angles of all degree corners as the pieces are being tacked together. They come in a wide variety angles, sizes, shapes, and power. Use four of the square magnets to frame out the entire frame or just one or two corners at a time.

Magnets by themselves will not be able to prevent movement from the heat-affected zone. Use the magnets to square up the piece, but clamp it down when tacking and welding.





Squares of all kinds can help you make a jig.

The third method is the same method we used to make our cube. Make a corner jig out of scrap wood or metal lying around the shop. Cut a few pieces of scrap that can be screwed or welded onto a flat surface. Using a square, line up the angle and clamp the pieces down and secure them in place. This will allow you to clamp the steel down at a 90-degree angle. Leave the corner open as an access point for tacking.

I recommend using steel if you have it available. It's much more ridged than a wood jig and obviously won't catch fire, but in a pinch wood can



work. The same technique can be achieved by just tacking some stock steel to a piece of flat heavy gauge steel.



It's a good idea to have more than one type of square available when you're working on a project.

The fourth and least expensive method of creating a corner is using the flattest spot on the floor and a square. This will require tacking quickly and being as careful as possible. This is not the most accurate way of creating a square corner, but in a pinch and if the tolerances for the project are pretty loose, it comes in handy. If you don't have a flat spot on the floor, the nice



piece of flat sheet metal for the top of your table can be put on sawhorses. This will provide a temporary table on which to make the table's frame.



Once everything is cut and prepped, it's time to tack it all together. Lay your materials and equipment out and make sure you have everything you need close by.

# Tack

Now that you have chosen the method of creating a corner, let's get to tacking the table together. One of the easiest ways to make any normal table is to start with the top and work down, working with the table inverted. We'll start by creating the frame for our top.

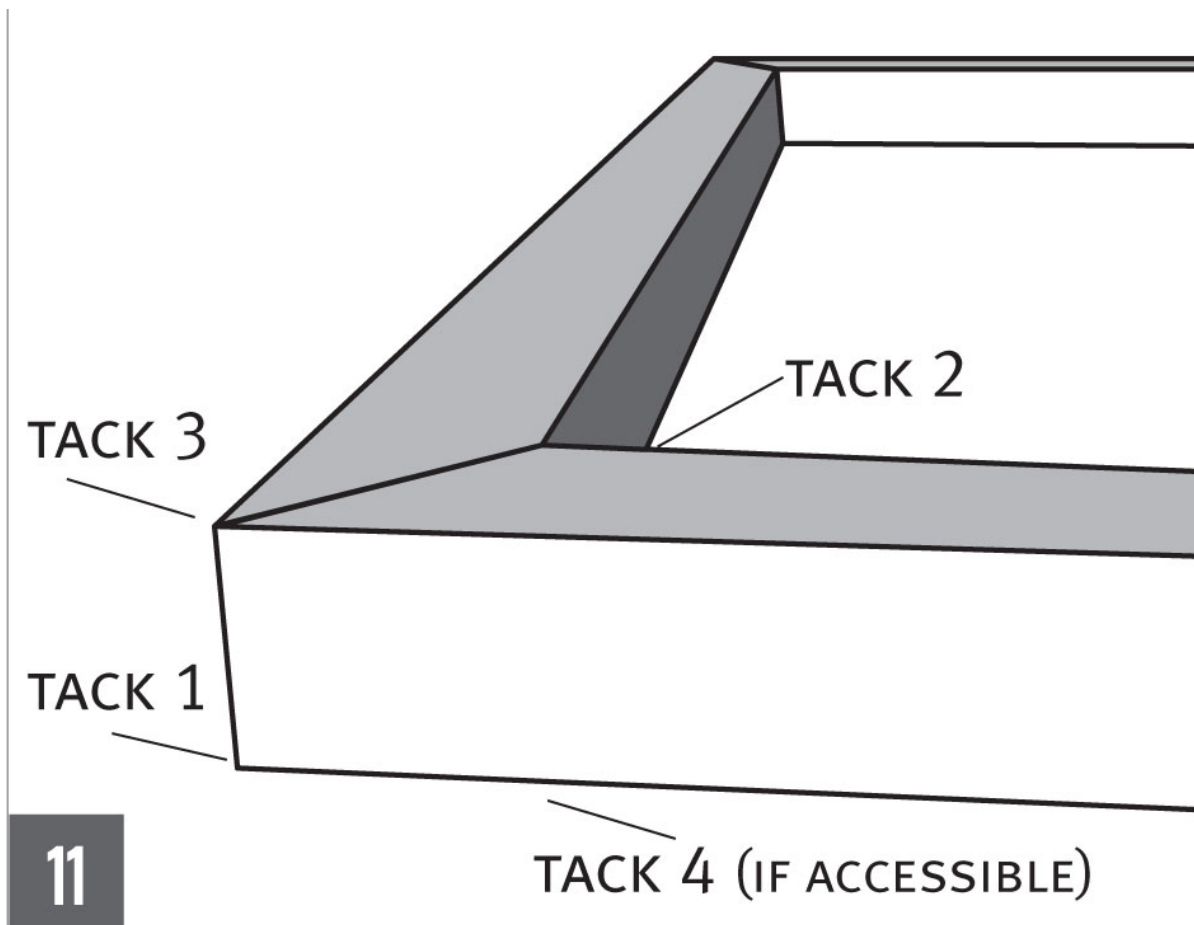
Run through the checklist of things that needs to be done. I will be using a 3-axis clamp for the demo.

Tack the top part of the frame together one corner at a time to make a square frame. For each joint, use four tacks, two on the outer corner of the joint and two for the inner. Always try to go to the opposite side from the last tack, spreading out the heat to reduce movement; the tack should have good penetration, enough to hold the structure together if it is moved.



## ➤ Welder Checklist

- Is the shield gas on and at the right CFH for the job?
- Is the voltage and wire speed combination correct for the thickness of the material?
- Is the ground clamp on the piece or on the table the piece is on?



Start by tacking one corner and then move to the corner diagonally across from the one you just did. For example: Start with the outer top tack and then move to the inner lower corner tack.



Tack the top frame together first and then add the legs to the frame.

Repeat this process with all the corners. Tack the entire frame together.

Repeat these same steps to create the two legs and a base rail, matching up the miters to create the corners. This will make up the two “U” shaped legs.

Using one of the corner methods described earlier (page 145 or 146), secure one of the U-legs into place. Square up the leg and tack it into place with four tacks, one at each corner, using a cross pattern. When finished with the first U-leg, tack on the second. **DO NOT** weld any parts completely together at this time. These U-legs should mirror each other.





13

Next, add the leg cross supports and center joining support.

After all the legs are tacked into place, tack in the lower support cross braces, again using the same cross-pattern corner-tacking method. Use magnets or clamps to hold it into place as you tack.

Tack in the 1-inch (2.5 cm)-square rails that will be the clamp holders. Here's a little quick trick: If you don't have magnets, use two pieces of 2x4 lumber or a drop from the 2-inch (5 cm)-square tube to evenly space out the supports by cutting two even lengths to prop the tube up. Tack them into place. Use the same corner-to-corner tacking technique as you used on the legs.





After it is all tacked together, the next step is to weld. Use a stainless steel wire brush to remove the burn from the weld zone left over from tacking.

## **Weld the Frame**

Now that the structure is all tacked into place, this is a good time to make sure all the measurements are accurate and the corners are square. If every thing meets up with your tolerances, it's time to weld.

Weld all the joints on the table so that the heat is spread evenly throughout the piece. A good pattern is to weld each joint and the opposite side, then move to another connection. For example: Start at one leg, weld

the two joints facing each other, and then do the same to the leg diagonal from that leg and repeat. If the tacks were done correctly, they should have enough strength to maintain the position they are in without breaking.

Repeat this process with the supports and cross beam. Remember to spread the heat out and minimize the HAZ of each area.



This table is going to be bigger than anything you have worked on so far. This means different positions. Just remember to be comfortable. Brace and support the gun the best you can.

Now that the frame of the table is complete, it is time to prep and weld in the casters. The method you use will depend on the type of caster you

chose. I prefer stem casters; if the table is going to be stationary for a long period of time, the casters can act as leveler feet. They can also be replaced much more easily in case one fails. Four-hole plate casters can be welded into place, which is a plus, and should be used if you do not have a drill press (which is required for stem casters), but they are harder to replace than the stem style. Regardless of the style chosen, all the casters should swivel and have a lock.

If you're using swivel casters, you will need to make the footers that will seal the legs. Using the piece of 2- x 24-inch (5 x 61 cm),  $\frac{3}{16}$ - or  $\frac{1}{4}$ -inch (5 or 6 mm)-thick stock (length doesn't matter; this will be chopped into 2-inch [5 cm]-square pieces after the holes are drilled), mark off 2 inch (5 cm) sections, leaving a  $\frac{1}{8}$ -inch (3 mm) gap between each of the 2-inch (5 cm) sections (or whatever thickness is appropriate for the cutting method used to allow for the kerf of the blade). For example,  $\frac{1}{8}$  inch (3 mm) is the width of a chop saw blade, while the width of a band saw blade is closer to a  $\frac{1}{16}$  inch (2 mm).





## WARNING

Never drill into metal without using drilling and tapping fluid.

Using a center punch, mark the centers of each of the 2-inch (5 cm)-square pieces for drilling. Choose a drill bit according to how the caster will be mounted. If the hole is to be drilled and tapped, a smaller bit will need to be used to allow for threading. If a nut is to be welded to the inside surface, a larger bit will be needed to clear the stem's threading.

Set up the drill press using the appropriate size drill bit for the stems of the casters. Align and clamp the fence 1 inch (2.5 cm) from the point of the drill bit (the distance to the center). Drill all four holes using drilling and tapping fluid to reduce heat from friction; then cut each of the 2-inch (5 cm)-square sections away using the lines that you measured.

Unless you're using the tapping method (in which case you can skip this step), it is time to weld on the nuts after all the holes have been drilled and caps have been cut. If the nuts are zinc coated, remove this coating with a flap disk on a grinder. Remember to always wear a respirator when welding anything with a zinc coating. Using spatter protection, spray, or motor oil, lubricate the stem and mount the caster in the hole, securing it into place with the nut. Weld the nuts into place using three heavy tacks; this is all that will be needed to secure them into place.

Unscrew the casters. Prep all of the surfaces by removing all mill scale from the weld zones and chamfering the end caps. These are now ready to be welded on.

During the fabrication of this piece so far, there may have been a small amount of movement that made the legs uneven. Here's a little trick to fix that. More than likely the most flat and true surface in the shop is the piece of steel that you purchased for the top. Make sure all of the surfaces have been leveled. Flip over the frame of the table so it is upright and standing on that sheet of steel; then put a cap under each leg. If there is any gap, it can be eliminated by welding over it to fill it in. Check the level of the top frame. Tack the caps onto the legs by two corners across from each other on each leg. Go back and tack the rest of the corners.

Weld the caps into place. Start with the two opposite side joints on one leg and move to the next. Then go back to the first leg and weld the other two joints to completely weld the caps into place.

If you are using the tapping technique to mount stem casters, flip over the frame. Using your feet to secure the table, begin tapping the hole using plenty of drilling and tapping fluid. Start slowly; once the threads start to form, it will catch. Make sure you stay level and upright. Screw the tap all the way down and then back it out smoothly. It's a good idea to put the tap back through the freshly made threads to remove any steel burrs or debris.

If using the four-hole plate casters, make sure to prep the plates to be welded by removing the zinc coating with a grinder and a 60- to 80-grit flap disk; then cut out four steel plates the same size as the plates mounted to the casters. Flip over the frame of the table so it is upright and standing on the sheet of steel and center the plate caps under each leg.

If there are any gaps, they can now be eliminated by welding over them. Check the level of the top frame. Tack weld the caps onto the legs by two corners across from each other on each leg; then tack the rest of the corners.

When you've completed the tacks, weld the plates into place. Start with the two opposite side joints on one leg and move to the next; then go back to the first leg and weld the other two joints to completely weld the plates into place.

## **Weld the Top**

Now we move on to the top of the table. Over a long period of time the plate of steel that is used for the top may become warped and distorted. When going to weld the top onto the frame it is not necessary to weld the top on completely in the square. A few 3-inch (7.6 cm)-long stitch welds will be fine to secure it into place and allow you to replace it later on if needed.

Begin by prepping all of the surfaces that are to be welded with a flap disk on a grinder.

Mark all the sides on the plate to center the frame. For example, if you decided to have a 3-inch (7.6 cm) lip, mark off the distance from the edge of the frame to the edge of the plate.

Secure the frame with clamps and tack into place. Before welding, remeasure for accuracy. Weld two 3-inch (7.6 cm)-long welds on the inside

a few inches (5 to 8 cm) from the corner joints connecting the frame to the plate. Warpage won't be as much of a factor for these welds, but it is always good practice to spread out the heat as much as possible. Start one weld and move straight across to the opposite side. Repeat until all six 3-inch (7.6 cm)-long welds are complete.

Congratulations! You have completed your welding table project, your first functional project as a welder. All that is left to do is screw in the casters (if you used that method), flip it over, and be done (unless you want to grind down the visible welds to make it look more appealing). Now you can be more comfortable when welding while saving space and time.





It is not necessary to weld all the way around the top of the frame you just made. Four to six 2" to 3" (5 to 7.6 cm) fillet welds will work fine.



## Protecting Your Table

It's not necessary to paint your welding table, and in fact, it may even be a bad idea. Most paints used on metal create a layer of insulation that acts as a barrier that will not allow the current from the ground to circulate through. You want to be able to clamp the ground in multiple places on the table, so I do not recommend painting. If you would like to protect it from rust, use a rag to wipe on some oil or rust inhibitor or spray it with spatter protection spray. Over time, a lot of metal dust and particles can take a toll on the casters, so keep the bearings well-lubricated. Axle grease makes a great barrier for protecting bearings.

# Project 3: The Runner



**SKILL LEVEL:** Intermediate

## **MATERIALS AND EQUIPMENT:**

- MIG Welder
- 24' (7.3 m) of 11 to 16 ga cold roll 1" (2.5 cm)-square tube
- Welding helmet
- Welding gloves
- Long-sleeve shirt
- Leather welding jacket or apron
- MIG pliers
- Stainless steel wire brush
- Soapstone
- 4 1/2" (11.4 cm) angle grinder outfitted with an aluminum oxide grinding disk or a 60- to 80-grit flap disk
- Clamps
- Chop saw
- 3-Axis clamp or right-angle magnets or jig
- 3/8 x 10 x 58" (1 x 25 x 147 cm) piece of oak, or other wood of your choice

## **Cut, Prep, Tack, Weld**

Sofa table, couch table, long table, or runner; no matter what you call it, this is a great table to fabricate. It's a stand-alone table that doesn't require a matching counterpart. It also doesn't have a set purpose like a coffee table or end tables. A runner can go anywhere in the house, from the back of the couch to the hallway to the kitchen. It's a nice and versatile table to have, plus it's fun to fabricate.





This is a runner table.

After making your own welding table, this should be a piece of cake, right? Well, I'm going to throw in a new little twist that is going to take a little more concentration when cutting and measuring. All the principles of what you have learned so far will apply to this table. At this point, I should not have to tell you to cut-prep-tack-weld, but I'm going to.

This table is something that is going to be admired for its appearance so we are going to do a few things to make sure the corners, edges, and lines remain clean. This will be a practice in patience and accuracy to make the final piece have a nice overall look.

For this project, we will be using cold roll 1-inch (2.5 cm)-square tube with a 1/8-inch (3 mm)-thick wall. The top four corners of the frame will be welded to the legs with a double miter, unlike the welding table where the four corners of the top frame were single miter with the legs welded on flush.

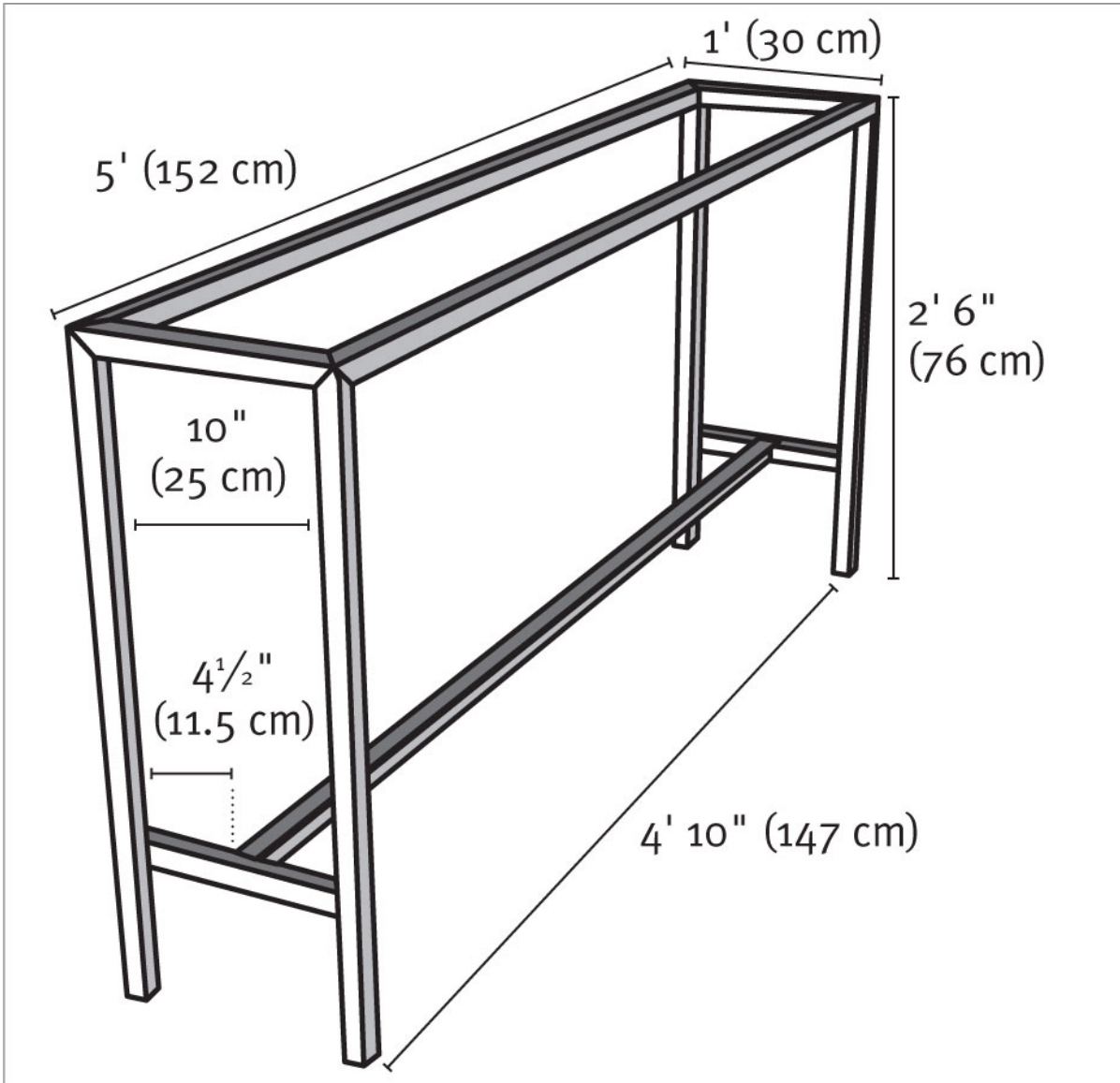
I prefer the double miter method when making furniture. It gives the piece a cleaner and more aesthetically pleasing look with all visible corner welds ending at the same point. And after the welds are ground down, it also looks as though the framework was made from one piece of metal, as the seams are not as obvious.

Since this project will require more accuracy, I recommend something a little sharper to mark with. Silver or black oil pencils, fine point markers, or to be extra accurate, a good scribe is the best. A scribe is a hard metal point used to scratch measurements in the surface of other metals, normally made of hardened tool steel, titanium, or other metal.

## **Cut**

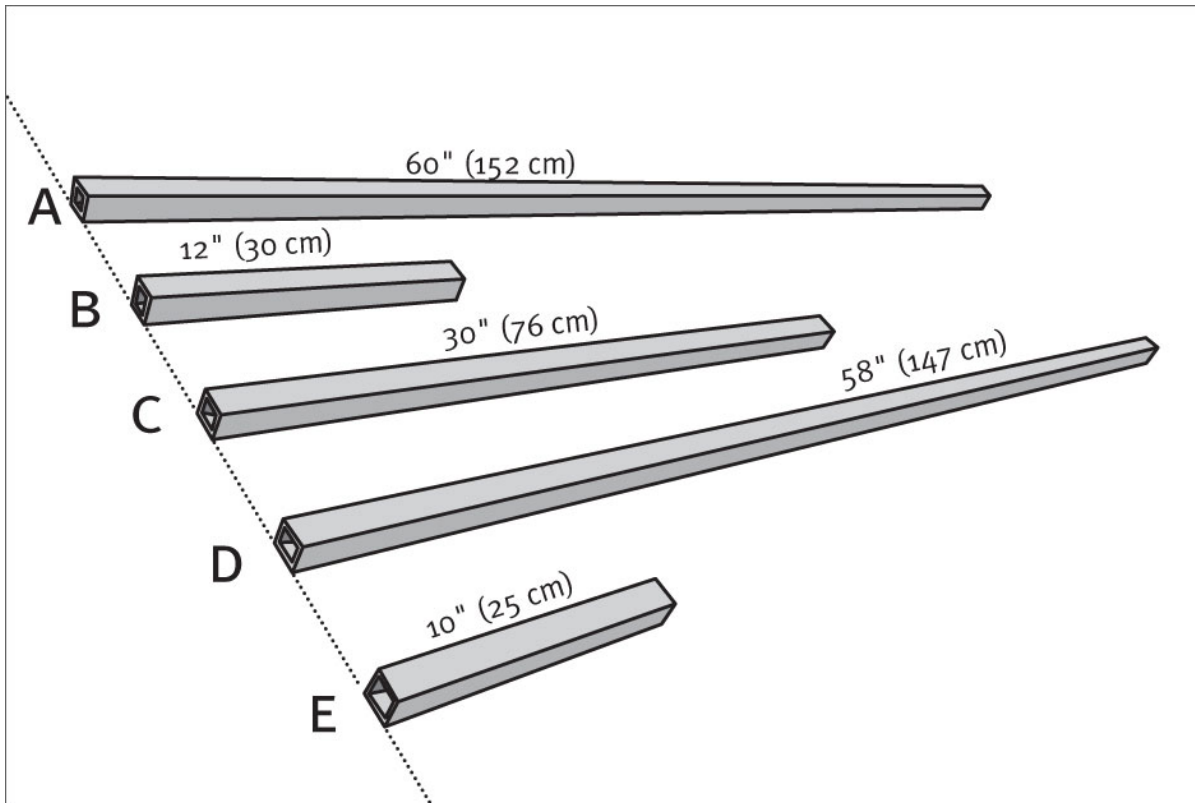
As you can see from the measured drawing, cutting for this project is going to be a challenge. Each length of the top frame of the table is going to be double inward-miter cut at both ends. All of the legs of the table will have a double miter at just one end.

This means that for the top frame, the longest part is going to be the edge that holds the miter cut. Cut the lengths of all the pieces to the full size with no miter first.

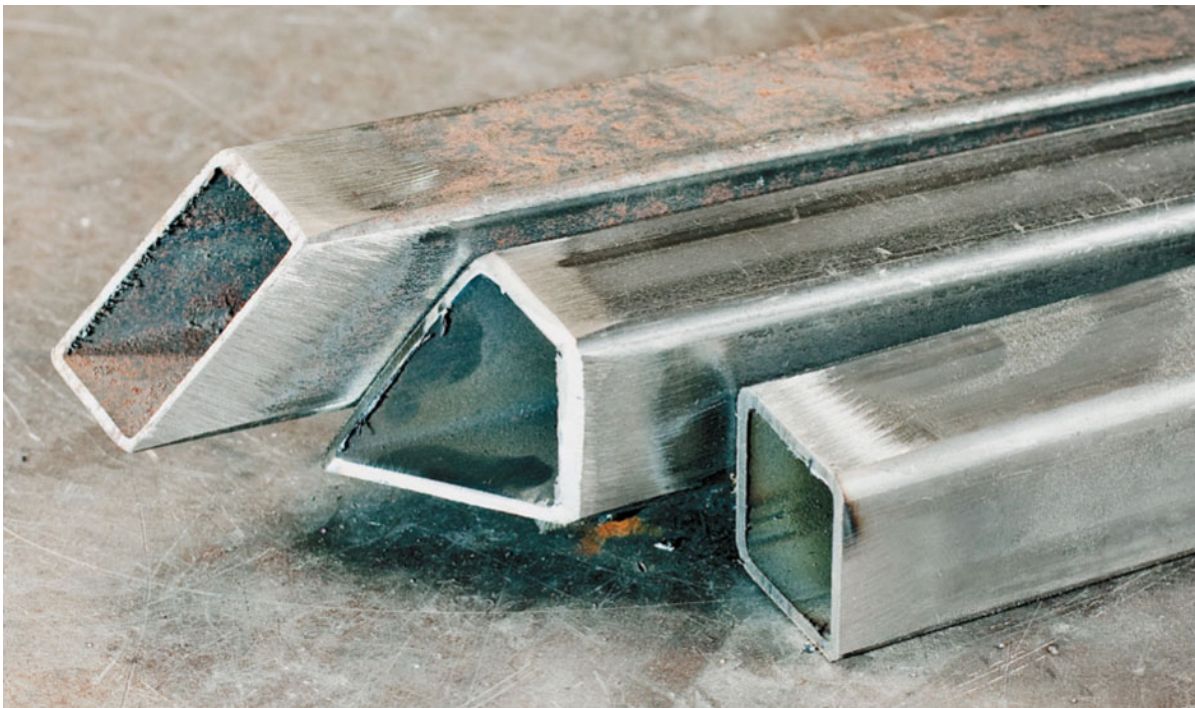


This is the measured drawing.





The cut list: A. Two top frame sides; B. Two top frame ends; C. Four legs; D. One low cross support; E. Two lower end cross bars



This shows a single miter, double miter, and straight cut.



1a

Always mark a double miter first.





1b

Mark the next cut for the second miter to the outer most edge of the first miter.

It's always a good idea to give yourself a little extra room (such as an extra  $\frac{1}{16}$  inch [1.5 mm]) when cutting. This way, if you need to correct the length, you can grind it down.

Cut the single miters first, clearly marking all the cuts. This way you don't accidentally cut the wrong edge.





1c





The very points of the final cuts of the double miters should be on the same edge.

Since the chop saw only cuts 45 degrees in one direction, you will need to pay close attention to which way you turn or flip the material to be cut. This is why it's also good to mark everything clearly before you cut.

Now that you have the first miter cut in all of the pieces, it's on to the second miter. In order to give yourself a better guide, mark a cut line. Use a square to draw a line down the side of the first miter using the outermost edge of the material wall as a guide.



2

Lay out the cut and prepped pieces to be tacked.





A 3-axis clamp is very useful when using a double miter.

## Prep

Once you've finished all the cuts and checked that the lengths and angles are correct, it's time to prep. Prep all of the weld zones with a 60- to 80-grit flap disk. The wall of the tube is  $\frac{1}{8}$ -inch (3 mm) thick, so a  $\frac{3}{32}$ -inch (2 mm) chamfer for our butt joints should be perfect.



## Tack

Once you're prepped and ready to tack, you should set up the MIG for 1/8-inch (3 mm) thick material. By now, you should have also selected your preferred method of joining corners (see Chapter 5).



4

Mark where the cross supports will be tacked into place.

You'll need to tack all three pieces together: two lengths of the top frame and one leg. I will be using my trusty 3-axis clamp once again; this allows the three pieces to fit together snug like a puzzle and makes it easier to



work on them. If you don't have a 3-axis clamp, make a jig instead as shown in Chapter 5.

Once you have secured the three parts, the tack pattern for this setup will be the outermost corner first, then the innermost corner directly opposite; essentially it is the two points where all three pieces meet. Finally, tack the three points where only two pieces intersect.



5

Use magnets or clamps to hold the cross supports in place while you tack them.

Tack the frame and legs together and then measure out the height of the two cross supports and mark where your welds will go.



Clamp or secure the cross supports in place with magnets, corner clamps, or cut lengths of scrap. Do not tack the cross supports in place with four tacks. This is the part where we become more meticulous about where we are going to weld and how it's going to look. We are only going to use two tacks to secure this into place: one tack per vertical butt joint right in the middle.



Mark and tack the center support to the leg supports.

Measure and tack the middle support piece in the center between the two cross supports. This will also only use four tacks. The four vertical inner

corner joints will not be welded, so do not tack on the inside.

By only welding the vertical butt joints and not the corner fillet welds, you'll achieve a cleaner look. The reason to only use two tacks for the supports pieces is to leave you the ability to weld over them. Leaving the corners alone will leave a perfect 90-degree corner. After grinding down the welds on the butted joints, it will have a cleaner look.



Tack the entire piece together before welding.





Weld the piece together, spreading out the heat as you go.

## Weld

Now that it's all tacked together, give your project a once-over. Check all of the measurements to make sure everything falls into the guidelines of your personal tolerances. If everything looks good to you, start to weld it up, making sure to go in a pattern that spreads out the heat throughout the piece. Start with the vertical butt joints. No, you don't have to do a vertical weld if you don't want to, just lay the frame down so the weld is horizontal. Then move on to the corner or fillet welds.





8b

With your system set for the thickness of the steel, maintain proper distance and angles while you weld.





Put yourself in the most comfortable position you can while welding large pieces.



9a





9b

Keep spreading out the welds as you go to keep the square tube from warping out of square.



10

This is the last weld on the frame.







Tack and weld in the mounting brackets that will receive the wood top.

Now that it's all welded up, it's time to fit the top. You have a lot of options for the top as anything from glass to butcher block to any of a wide variety of woods will look great. What I have chosen this time around is a nice piece of birch that I will dry-fit before sanding, prepping, staining, and then clear-coating.

There are a lot of ways to mount wood in or on a table frame. The system I'm going to use for this table is six  $\frac{3}{8}$ -inch (10 mm)-long wood screws driven through six tabs made from 18 ga steel welded to the inside of the frame.

Make spacers the same thickness as the material for the top that you have chosen. Pre-drill and then cut six 2-inch (5 cm)-square pieces of 18 ga for the tabs. Grind down the welds on the top of the table so they are flush to the tube, creating a flat surface. Now flip the table over onto your welding table. Using your spacer, weld four of the tabs into the corners and two into the center using fillet welds.

Now that the tabs are in place, fit the wood top in the frame to see if adjustments need to be made; then stain or finish it the way you would like. I'm going to grind down the rest of the welds and clear-coat the frame with a clear metal paint such as Rust-Oleum or Krylon. Then I'll give the birch a single coat of cherry stain and finish off with two or three coats of polyurethane.

Whatever you choose to finish with, I hope you learned a lot from this project. But most of all, I hope you have enjoyed making it.



After the brackets are welded in place, you can fit in your wood top. A few coats of clear on the frame and a few coats of stain on the wood and this table is done.

# Gallery

## Sculpture

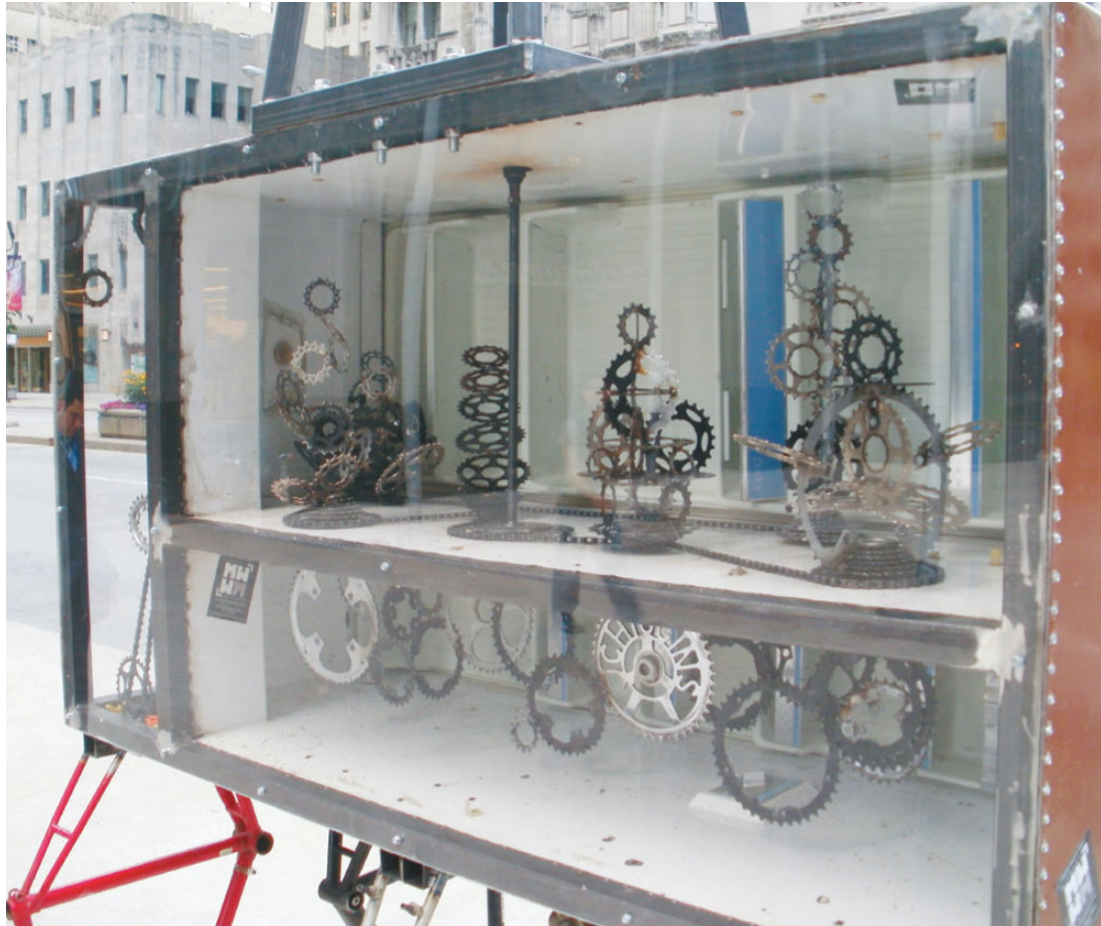


Photo by Stephen Blake Christena





Photo by Brad Cowan



Photo by Stephen Blake Christena



# Furniture



Photo by Casey Y. Spring





Photo by Casey Y. Spring



Photo by Casey Y. Spring



Photo by Casey Y. Spring





Photo by Casey Y. Spring



Photo by Stephen Blake Christena

# Architectural Elements



Photo by Stephen Blake Christena







Photo by Stephen Blake Christena



Photo by Stephen Blake Christena



Photo by Stephen Blake Christena

# Glossary

**Alloy**—This is a substance composed of two or more metals or a metal and other nonmetal material.

**Arbor**—This is the threaded shaft of a grinder or axis that holds, turns, or supports a rotating cutting or grinding wheel.

**Arbor Nut**— This is the threaded top piece that screws onto the arbor in order to secure a disk to the arbor. (Also see *flange*).

**Arc Welding**—These are the welding processes that use an electric arc to produce heat and melt and fuse the base metals. This term is often used to refer specifically to shielded metal arc welding.

**Backfire and Flashback**—This is the combustion taking place inside the oxyacetylene torch that creates a loud pop or explosion.

**Base Metal**—This is the work piece metal that is to be joined or cut.

**Bead**—This is the welded seam created by the puddle between work pieces that have been joined with welding.

**Bevel**—This means to remove edge materials so that the adjacent surfaces no longer form a right angle.

**Burn Back**—This is when the wire electrode filler metal becomes too short and/or overcharged and melts the wire into the contact tip of a GMAW or MIG welding gun.

**Burn Through**—This can happen during a weld; overheating metal to a critical point causes the material to no longer hold be able to its own weight, causing holes or an excess of material on the opposite side.

**Butt Joint**—This is a joint between two work pieces in the same plane.



**Chamfer**—This is the removal of a material's edge, usually at a 45° angle, to the adjacent principal faces.

**Consumable Electrode**—This is an electrode that also serves as the filler material.

**Corner Joint**—This is a joint between work pieces that meet at a right angle.

**Cutting Tip**—This converts an oxyfuel welding torch into an oxyfuel cutting torch.

**Dimes on the Side**—This refers to the formation of a pattern in the bead to give the appearance of a stack of coins that has fallen onto its side. It is most commonly associated with TIG welding. It is an indication of the control of a molten metal puddle to create ripples that gives the appearance of a stack of dimes, a stack of nickels, or row of coins.

**Direct Current, Electrode Negative (DC+)**—This refers to direct current welding where the electrode is negative and the work piece is positive.

**Direct Current, Electrode Positive (DC-)**—This refers to direct current welding where the electrode is positive and the work piece is negative.

**Double Arcing**—This is an unintentional secondary arc separate from the main electrode arc.

**Draw**—This is the pace of the arc moving through the weld zone.

**Drop**—This is a piece of material cut away from a whole, leftover metal, scrap.

**Dross**—This is solidified metal byproduct that was once molten material forced through the kerf and then fused to the back edge by an oxyfuel or plasma cutting system.

**Duty Cycle**—This is the amount of continuous time in a 10-minute period that an arc welder can run before it needs to cool down. It is expressed as a percentage at given amperage output.

**Edge Joint**—This is a joint between parallel work pieces.

**Electrode**—This is the conductive element that makes the connection with the work piece to create an electrical arc.

**Filler, Filler Metal or Fillet**—This is supplied metal supplied in the form of a welding rod, sometimes flux coated, melted by an arc or flame into a joint between components to be joined.

**Flange**—This is a base piece fitted over the arbor for securing disk to the arbor. It is normally unthreaded.

**Flashing**—This is a short duration of time in which the eyes are exposed to the arc light.

**Flux**—This is a chemical compound that produces cleaning action and reduces the formation of oxides when heated.

**Flux Core, Flux Core Wire**—This is a consumable electrode wire that contains a chemical compound that produces a cleansing ionizing environment for an electrical arc to exist to reduce oxides.

**Gas Metal Arc Welding (GMAW) a.k.a. Metal Inert Gas Welding (MIG)**—This is a semiautomatic arc welding process using a wire electrode, which also is the filler material. An inert gas flows over the weld area to shield the molten metal from oxygen.

**Gas Tungsten Arc Welding (GTAW) a.k.a. Tungsten Inert Gas Welding (TIG)**—This is an arc welding process using a tungsten electrode, hand-held filler material, and an inert shielding gas.

**Going Fishing**—This is the natural tendency for a beginner welder to pull away from the weld during the weld in progress. Produces a poor weld.

**Inclusions**—These are elements and particles that can be introduced into the weld or puddle that create issues with the final weld.

**Inert Gas**—These are noble gases: the unreactive gaseous elements helium, argon, and carbon dioxide.

**Kerf**—This is the width and shape of a cut made by an instrument or tool.

**Lap Joint**—This is a joint between overlapping work pieces.

**Media Blasting**—This is to forcibly clean a surface with pressure using abrasives and forced air, also known as Sand or Abrasive blasting.

**Off Gas**—This is to create an exhaust by heating an element to expel gases.

**Oxyacetylene Cutting**—This is a cutting process using acetylene as the fuel and oxygen as the accelerant to increase flame temperatures to achieve cutting in to metals.

**Oxyfuel Cutting**—This is a cutting process using oxygen as an accelerant to increase the flame of a combustible compressed gas.

**Plasma Cutting**—This is an arc cutting process using a constricted arc flow produced through a small nozzle or orifice, from the electrode to the work piece, by compressed air or inert gas.

**Plate**—These are flat sheets of metal thicker than  $\frac{3}{16}$  inch (5 mm).

**Puddle**—This is the liquefaction of the base metal to form a molten metal pool at the point of heat. Molten pool filler metal is added to create a weld bead.

**Sheet Metal**—This is flat metal  $\frac{3}{16}$  inch (5 mm) or less in thickness.

**Slag**—This refers to oxidized impurities formed as a coating over the weld bead; it is waste material found along the bottom edge of an oxyfuel cut.

**Spatter**—These are small balls or droplets of molten metal ejected from the puddle during the production of a weld. It often fuses to metal.

**Stick**—This is a rod of filler metal covered in flux used in the arc welding process; the term is also used to describe a complete length of milled bar or tube metal.



**Stick Out**—This is the distance the filler metal electrode protrudes from the contact tip in GMAW or MIG.

**Stick Welding**—This refers to shielded metal arc welding.

**Straight Draw**—This is the motion of pulling the weld towards the person conducting the weld.

**Tee Joint**—This is a joint between work pieces meeting at right angle and forming a T shape.

**Wire Feed**—This is the manual or semiautomated rate in which the filler metal is pushed into a weld in progress.

**Toe Out**—This refers to what happens when proper speed or technique is not executed and gravity pushes down on the puddle to form a toe shape when it solidifies into a bead.

**Travel Angle**—This is the proper angle and orientation of the torch tip or gun nozzle moving through a cut or weld. It is also known as the Drag Angle.

# Resources

**For basic information on welding and welding equipment**

**Miller Electric**

[www.millerwelds.com](http://www.millerwelds.com)

**Strong Hand Tools and Build Pro**

[www.stronghandtools.com](http://www.stronghandtools.com)

**Welding Tips and Tricks**

[www.weldingtipsandtricks.com](http://www.weldingtipsandtricks.com)

**Hobart Brothers Company**

[www.hobartwelders.com](http://www.hobartwelders.com)

**For continuing education and welding as a career**

**AWS - American Welding Society**

[www.aws.org](http://www.aws.org)

**CDA Technical Institute for Commercial Dive Welding**

[www.commercialdivingacademy.com](http://www.commercialdivingacademy.com)

**The Fab School**

[www.thefabschool.com](http://www.thefabschool.com)

## Notice to Readers

Read, understand, and follow safety precautions and rules when welding. In addition to general safety rules, also reference the material safety data sheets (MSDS) as provided by manufacturers, as well as the American National Standard (ANSI Z49.1) guidelines available here:

[www.aws.org/technical/AWS\\_Z49.pdf](http://www.aws.org/technical/AWS_Z49.pdf).

# About the Author



Stephen Blake Christena is the owner of Midwest Metal Works in Chicago, IL. MW2 offers custom fabrication services and a learning center for hobbyists interested in MIG welding. Christena teaches small-size courses designed to cover the basics and explore students' projects and interests.



Originally from Flint, Michigan, Christena moved to Chicago in 1998 after graduating from Western Michigan University with a degree in art. During his time at WMU, his primary focus was directed toward metal sculpture, photography, and painting. He opened his first custom metal sculpture studio in August of 1998.



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# Acknowledgments

In loving memory of my mother, Susan Johnson Christena, who passed before her time: you are still my inspiration for life, love, and creativity. I miss you dearly. And to my father, John M. Christena: you are and always have been my hero. Love you, dad.

I would like to thank my brother and sister, Jeff and Amy Christena, for their love and support and for being the wonderful people that they are. I would also like to thank Jerry and Irene Slusarenko: Without your generosity, support, and understanding, none of this could have been possible. Albert LaVergne, my college sculpture professor, thank you for being the most honest man in art. To all the teachers who helped to shape and guild my mind, and to all of my friends and family who make me who I am: Thank you. You know who you are.

*“I believe in teaching through example. A strong work ethic with good discipline in the pursuit of personal growth is the best way to discover your own voice. Good skills are like good grammar, they are the foundation of effective communication.”*

—Albert LaVergne

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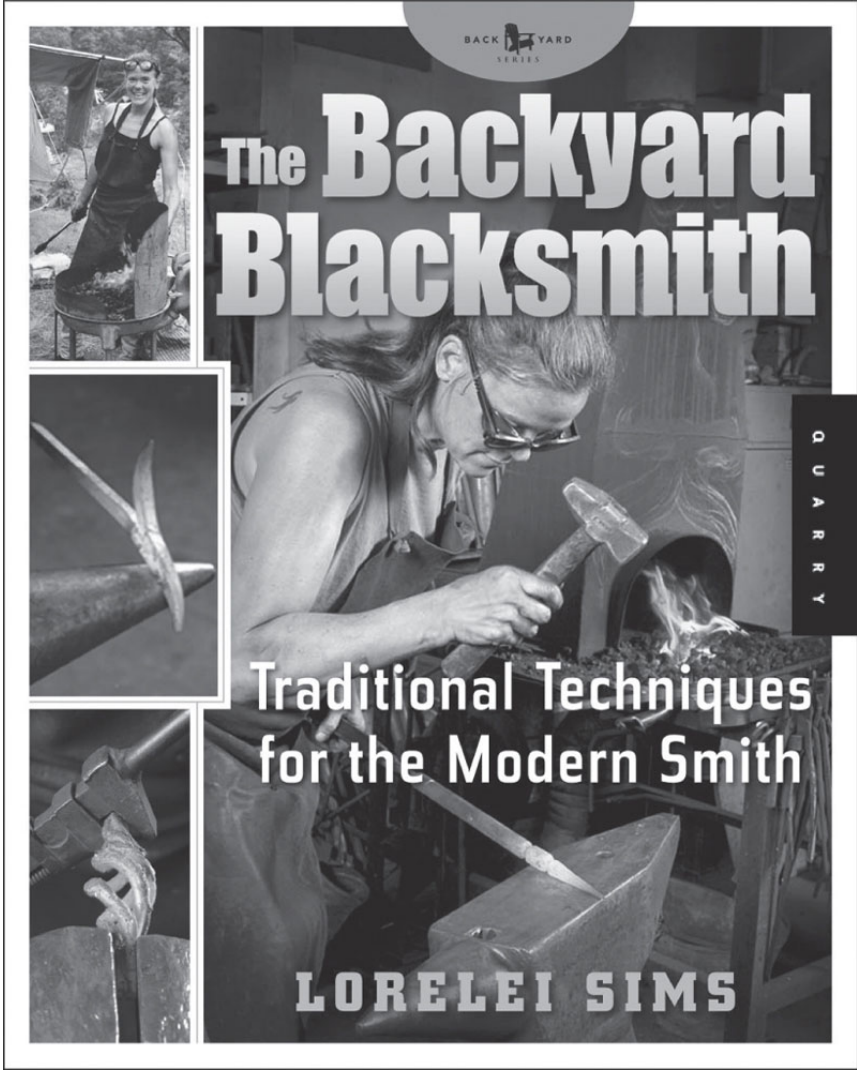
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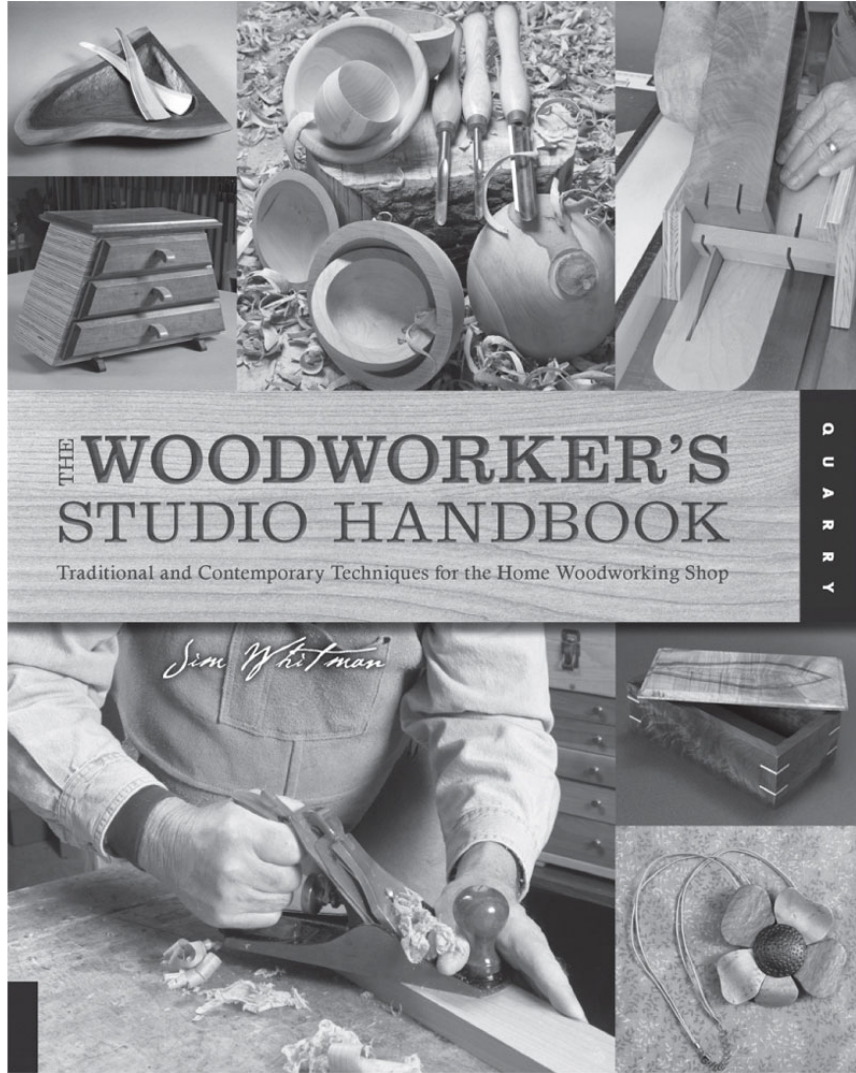
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Dedicated to my parents, John and Susan Christena: I am a true cultivation of all that you have taught me, guided me, and blessed me with. You are my heroes.

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