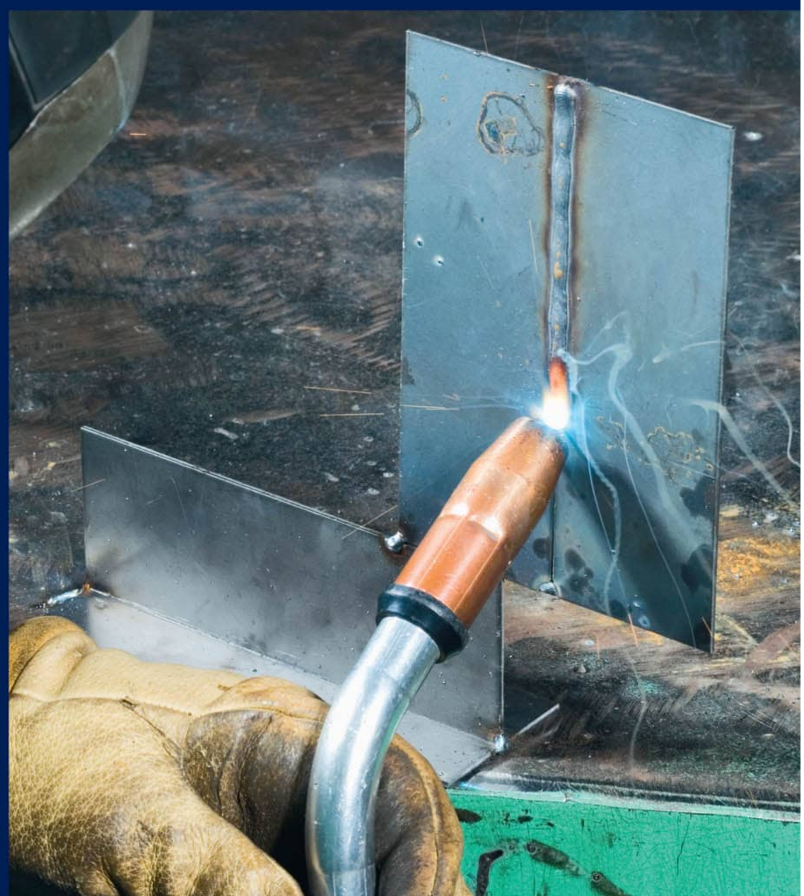
WELDING

EVERYTHING YOU NEED TO KNOW

TODD BRIDIGUM

WELDING



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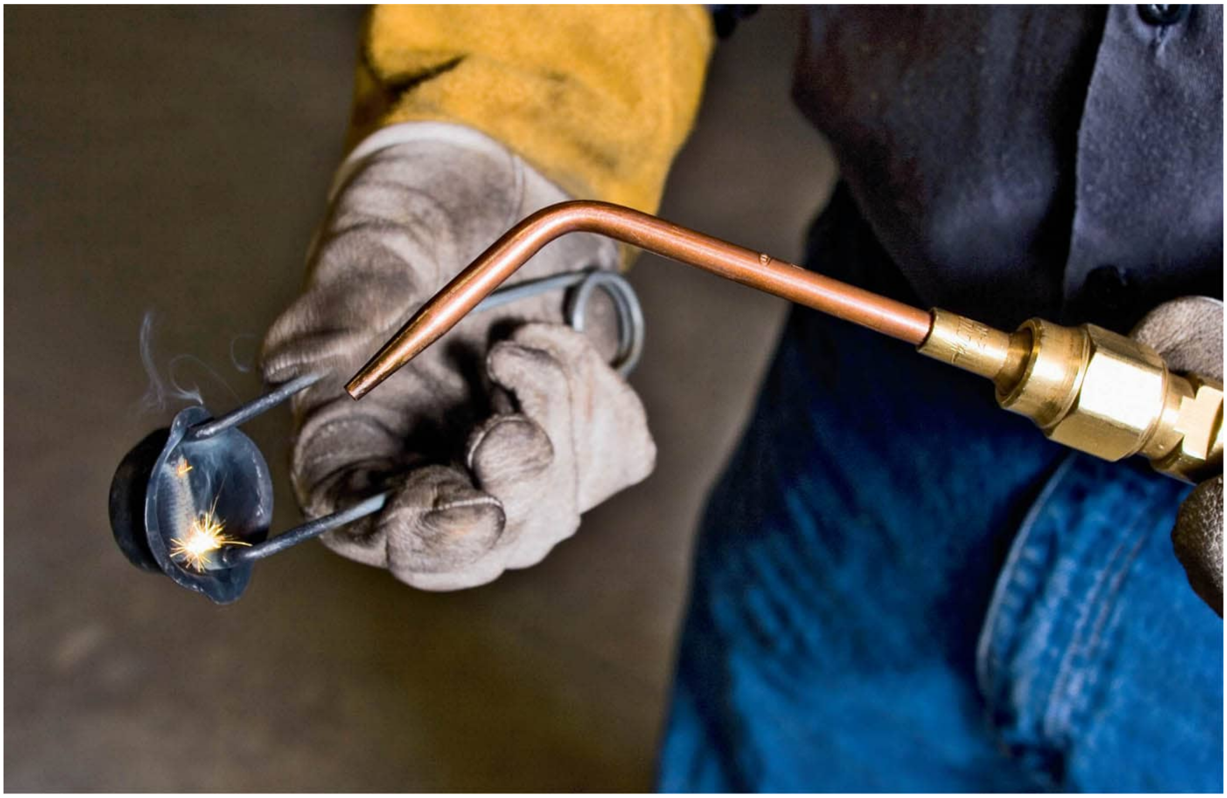

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motorbooks

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CARSON

INTRODUCTION

As a kid, I liked to play with fire. I enjoyed watching one lit match burn an entire matchbook. My first recollection of getting in trouble was when some neighborhood kids and I tried to light a fire in the woods. It's a bummer to be in trouble when you're young. What I didn't know at the time is that playing with fire would become my career.

Most people get into welding because they know someone who welds. Typically, young kids are interested in the same things as their parents or other adults they know—I was lucky that my stepfather was a welder.

Another way to begin is to take a class. Welding has come back to some schools, with courses available to young students. A book, movie, or video game with welding in it may even spark an interest. Finally, social media has given us a window into the welding world like never before, with everyone from beginners to experts posting welding videos online.

If welding is something you want to do, figure out a way to get a torch in your hands. It's like magic once that flame or arc ignites. You can read all the books and watch all the videos you want, but there is no substitute for experience. Adults seem to have cornered the market on experience, but the only difference between young people and adults is adults have lived longer. Even so, adults don't always have all the answers. They make mistakes, too.

Time and experience over the generations have gotten us to the point we are today with welding. Working with metals to make amazing, beautiful, and useful objects goes back thousands of years. We are at the end of a long line of people "playing" with fire and at the beginning of a new era full of advanced techniques and technologies.

Innovation and the disruption it sometimes causes are nothing new. At the beginning of the 1900s the oxygen-and-acetylene torch became widely available. Sales of this new, much hotter torch grew exponentially. Previously, blacksmiths were the ones who heated, shaped, and joined metals. Now that torches had arrived in the hands of many, blacksmiths felt their craft and livelihood was threatened. Other tradespeople, such as railroad workers, used the new torches in their line of work.

Members of the International Brotherhood of Blacksmiths complained to the government. The very first US secretary of labor appointed a group of people to listen to both sides of the issue. Several years went by before the group came to a conclusion. Basically, it came down to how tradespeople are defined. They are not defined by the tools they use but instead by the skills they have.

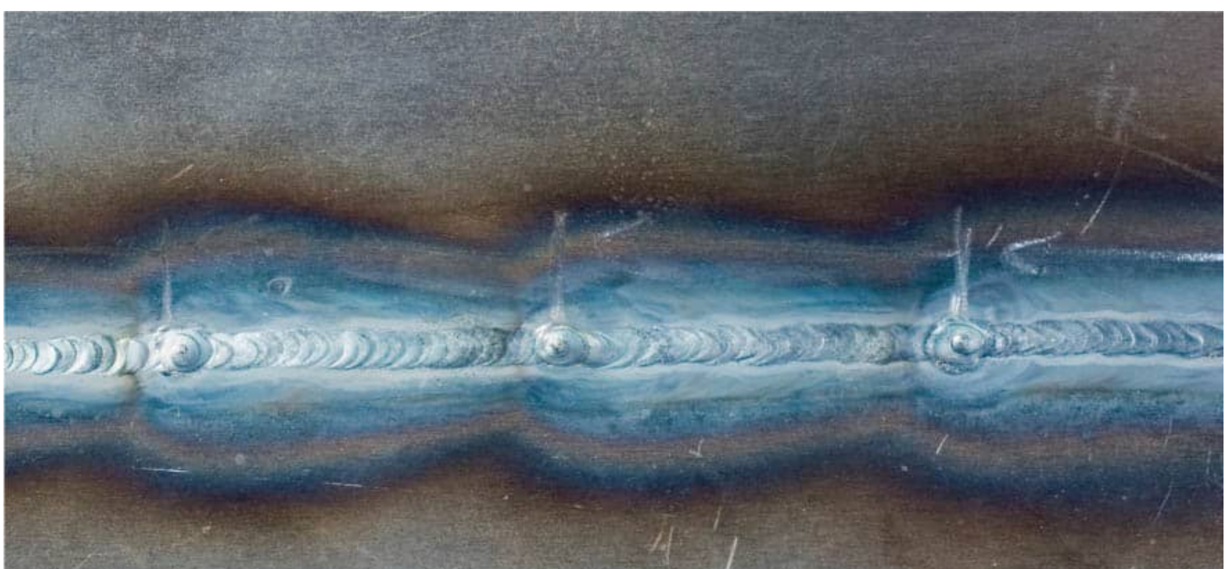
Think of it this way: if you go out and buy an airplane, you don't automatically know how to fly it. Today, anyone can walk into a welding or farm supplier or go online and buy industrial-grade welding equipment. That's the easy part. Knowing how to use the tools safely and effectively takes time and experience. You have to start somewhere, so let's begin our welding journey.

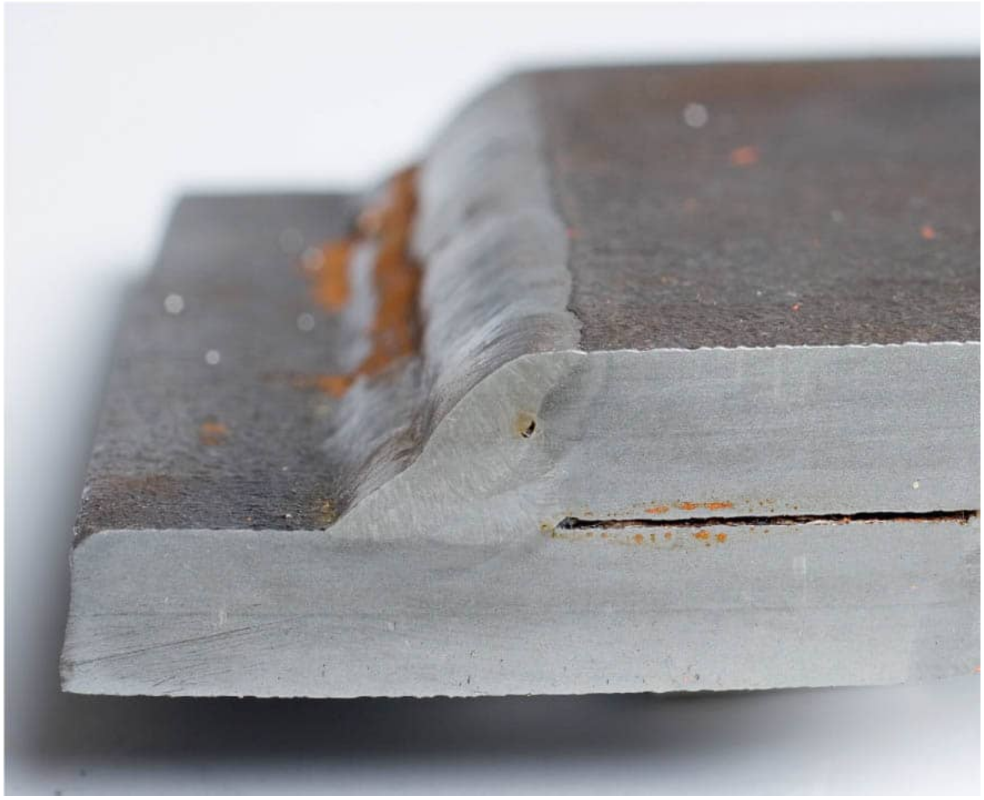
Metal shops are a great place for young people. There is always something new to learn.

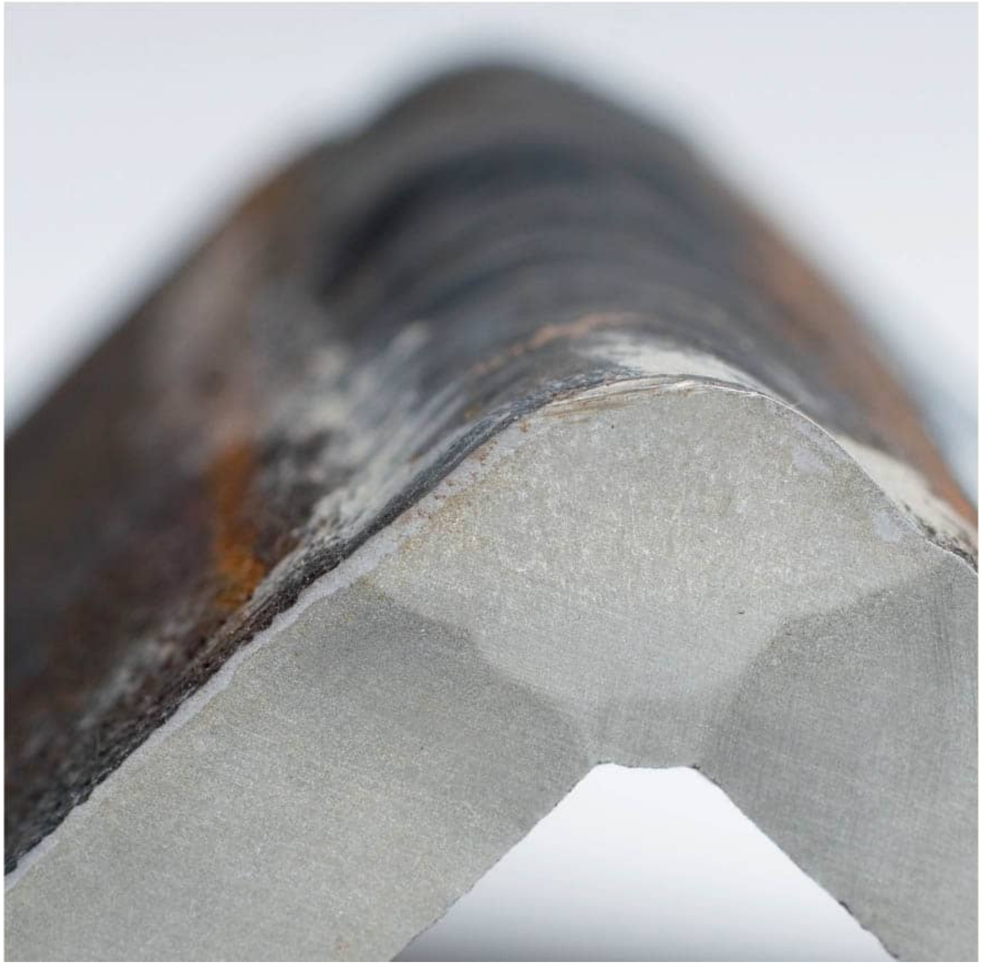

Taking up the torch is worthwhile for anybody interested in making projects built to last.

A GALLERY OF WELDS

Your first welds probably won't be your last. Practice as many different welds as possible.







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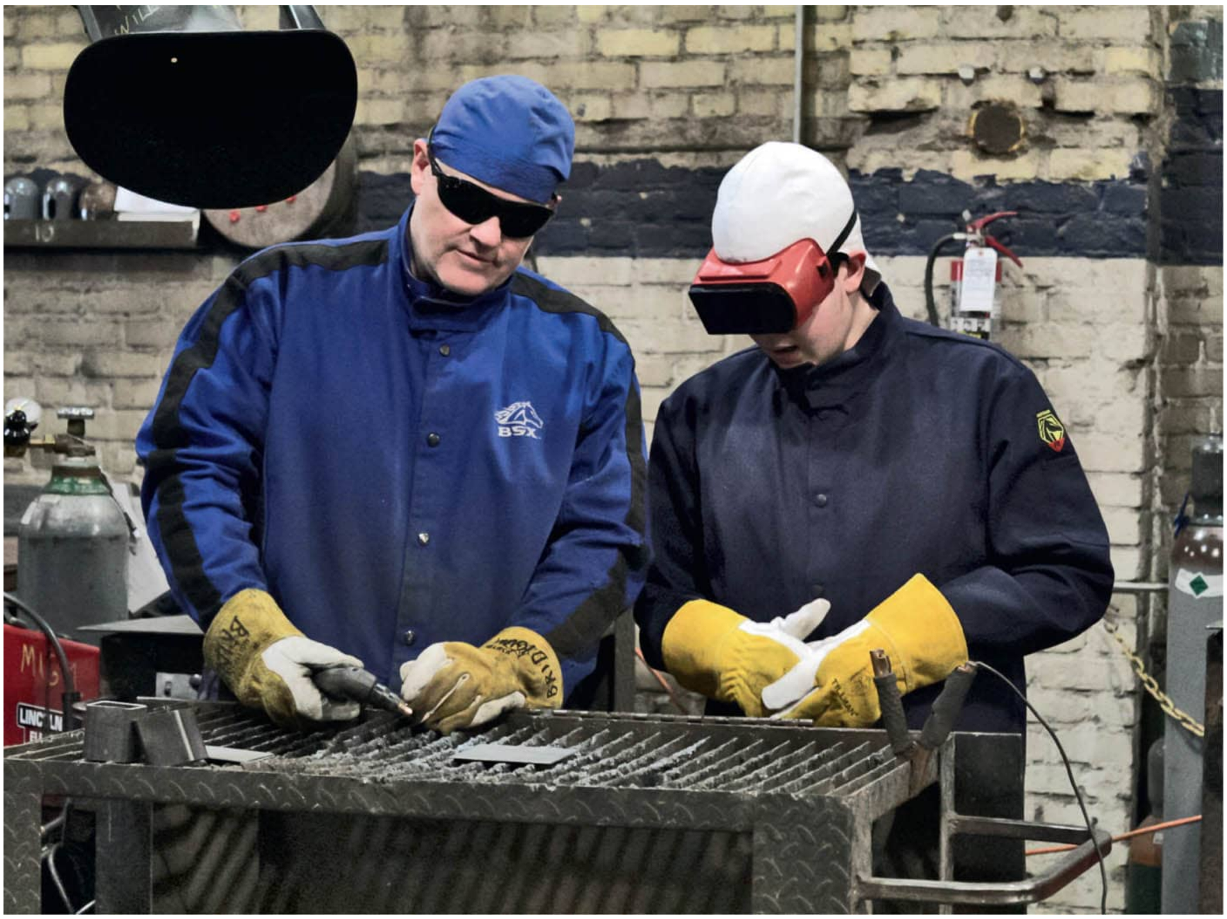
LEARNING TO WELD



Clear communication is important when people work together. Become familiar with the names of tools and equipment for welding and cutting.

In welding, there is an exception to every rule. Woe to the person that tells an experienced welder that they can’t do this or can’t do that. I’ve heard of people using a stick electrode to preheat a metal joint outside in the middle of winter, and I have used a cutting torch to weld and braze thick metals. But is it the best way to do the job?

There is usually more than one way to do a task, and it’s not always a matter of one way being “right” and the other way being “wrong.” Sometimes, different methods work equally well. Other times, one way to do something is better than another. For example, if I need to sweep my kitchen floor, I reach for a broom instead of a paintbrush. Finding the right tool and using it well is a good first step toward success. This means looking at what tools you have to work with and determining what they can do well and, more important, what they do poorly.

WELDING PROCESS NAMES

This book concentrates on some common welding processes found everywhere on earth: gas welding, stick welding, wire feed welding, and TIG welding. Stick, wire-feed, and TIG use electricity to generate heat and are all considered arc welding processes. Gas welding, on the other hand, uses two compressed gases to create a super-hot flame. The combustion, or burning, of these gases is a chemical reaction. For this reason, gas welding is considered a chemical welding process.

These processes have lots of other names because welding has been around for so long. Over the decades, a variety of companies and regions have created their own terms for the same things. It is a good idea to know the various welding process names because different people will use different terms. An old-timer might ask whether you have ever “heliarc” welded before. It would be a shame to say no when you’re an expert with a TIG torch. Here are some common names for the welding processes covered in this book.

TERM USED IN THIS BOOK	ALSO KNOWN AS
Gas welding	OAW (oxygen-acetylene welding)
	Oxy/fuel welding
Stick welding	SMAW (shielded metal arc welding)
	Arc welding
Wire-feed welding	GMAW (gas metal arc welding)
	MIG (metal inert gas) welding
	MAG (metal active gas) welding
	FCAW (flux-core arc welding)
	FCAW-S (flux-core arc welding, self-shielded)
	Innershield
	FCAW-G (flux-core arc welding, gas shielded)
	Dual Shield
TIG welding	GTAW (gas tungsten arc welding)

TERM USED IN THIS BOOK	ALSO KNOWN AS
	TIG (tungsten inert gas) welding
	Heliarc
	WIG (Wolfram inert gas) welding

The first welds, called root passes, were made on this pipe using two different processes: TIG on the right and stick on the left.

Watching an experienced person weld is helpful for learning proper technique.

HOW TO LEARN

Successfully learning to weld has as much to do with the machine as it does with your mindset. Here are a few tips to make the learning process easier. s

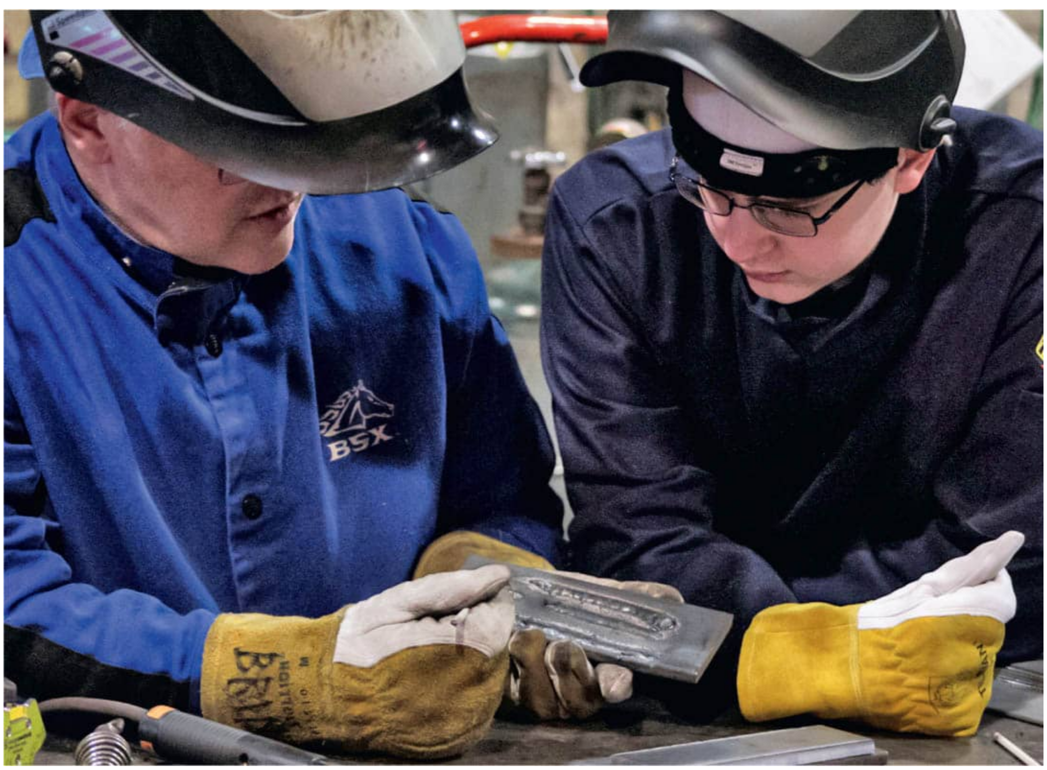
Everyone fails sometimes—even people who have mastered a skill. Empower yourself to figure out what went wrong. It can be very frustrating when things don’t turn out the way you want. Sometimes frustration leads to doing more work, and things get off course when we make the same mistakes over and over. It might be wishful thinking to have things finally come out right. It is natural for people to stick with what they know. In welding, and many trades, it is useful to think first, then act. Accept that you failed. It happens.

Now, take a step back and think about the situation. There are dozens of things that could have gone wrong. What are they? What can you change to help the situation? What new thing can you try? Knowing about the welding or cutting process you are using is helpful. As I said before, understanding what each tool does well and what it does poorly saves time and guesswork.

Machine controls are not universal, but, like controls in cars, they will have things in common. The gas pedal, brakes, turn signals, and gear shift on a car are like amperage, polarity, volts, and wire-feed speed on a welding machine. It is easier to drive a car, or make a weld, if you know how these controls are used.

Check everything for path blockers, job stoppers, and gotchas. These things get in the way of success. Many times when people think they can’t weld, the real cause is a machine or piece of equipment set up improperly. Using too low an amperage with a big welding stick or attaching an electrical work clamp to solid rust should be easy to fix. These conditions have nothing to do with a person’s ability to weld. Don’t be fooled into thinking you have no talent for welding.

You can get feedback on your welding technique in real time when someone watches you weld.

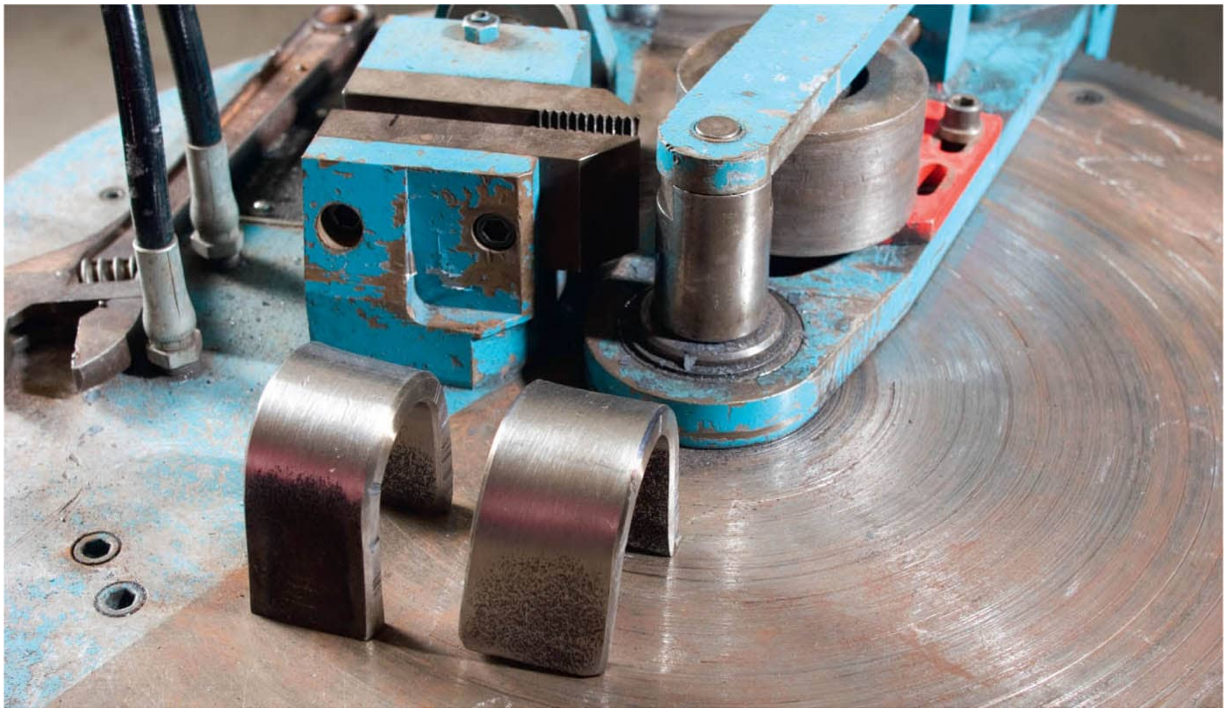


Evaluating welds with a teacher is a great way to learn what went wrong and how to improve.

Know what you’re welding. How thick is the metal? Small differences in metal thickness often mean big changes in what you need to weld it correctly. Thicker metal needs more heat. Thinner metal needs less. What kind of metal is it? Many people start their welding exploration on steel because it has many common uses. If you’re welding a different metal, this may require changes to your setup.

There will be problems. Eventually, something will go wrong with a project or piece of equipment. The key is how you adjust to the problem. For example, what if I’m melting holes through the metal I’m welding? If thinner metals require less heat, how can I make it less hot? Turning down amperage to reduce the heat might be a good start. But if the welding stick doesn’t run smoothly, a smaller electrode or welding wire may be needed. Try making smaller welds and letting the metal cool off between welds. A backing bar made of copper (to draw away the heat) may work. The question to ask is, Out of all these possible solutions, which one will work best? A trip to the store to buy smaller welding electrodes may take too long. Maybe use some steel or wet rags around the weld to draw away the heat, or turn down the amperage to the minimum range for the size of electrode being used. Or travel faster, make smaller welds, and let the metal cool down before welding on it again. Think about what you can do and move forward with your best plan.

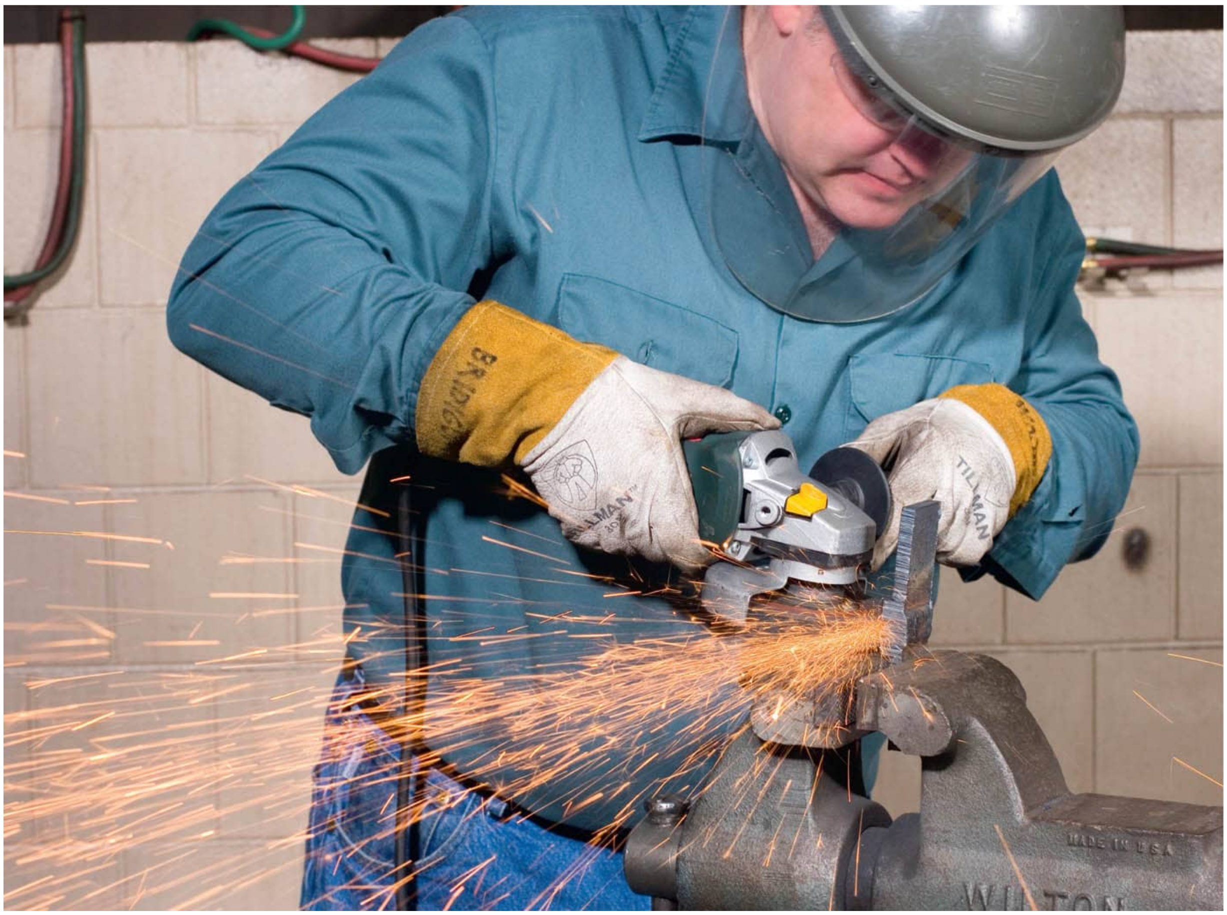
Schools like to call what I just described critical thinking. Many folks call it common sense. Whatever it’s called, practicing these kinds of problem-solving skills will serve you well throughout life. Making mistakes is part of the learning process. Forget other people’s expectations. Everyone learns at their own pace.



Bend testing welds is common in manufacturing and construction work. Welders practice many hours to be ready for these tests.

2

WELDING AND CUTTING SAFETY



Sparks happen in metalworking. Wear protective gear and direct sparks away from people, machines, and flammable materials.

ADULT HELP

The knowledge I've gained working with metals over the years is directly related to the amount of equipment I've damaged and bad parts I've made. In the big picture, a damaged machine or scrap part is not a big deal. The important thing is to learn from your mistakes to avoid making the same mistakes again. A wrecked machine can be replaced. A wrecked body part may never be the same.

The instructor in my first welding class taught us how to use the ironworker, a machine that shears and punches metal. We used this machine for cutting steel plates into smaller practice pieces. One day, I was cutting a piece of metal when it got jammed between the upper and lower blades. I had to use a cutting torch to remove the stuck piece. Unfortunately, the heat from the torch damaged the shear blades. It was my task to remove the blades from the machine. The instructor raised the hydraulic shear, shut off the power, and locked the disconnect switch so the ironworker could not be turned back on. I began working in the tight space. To reach the bolts I had to put my hand in between the blades. Soon, I noticed pressure on my hand —the machine was moving slowly down onto me. Instinctively, I pulled out of harm's way. One at a time, my fingers came out except for the middle one. I had one knuckle left in the machine as the blades closed like a massive pair of scissors. I closed my eyes and yanked, leaving the top of my knuckle on one of the blades. I got lucky. It turned out the ironworker had a leak in the hydraulic system, which caused the blades to fall slowly even though the power was off.

Many safety issues can creep up without you even knowing about them. Arc light can seem harmless until your eyes are burning from overexposure. A small gas leak may seem like no big deal until there is a fire or explosion. Stay alert. Take the time to know about the equipment you are using.

Always wear safety glasses to protect your eyes from flying debris.

Welding is sometimes taught in the pole barn or home garage. A parent or other adult may be the one to help you get started. They will probably give instructions on how things work and what to do. Listen to them. At the same time, remember it is okay to ask questions. It's okay not to know all the answers. Pretending to know the answer can be more dangerous than admitting you don't know how to proceed. All of us are used to watching something happening and copying it. Young children copy what adults do all the time. It can be difficult to see adults make mistakes and not make the same mistakes ourselves. When you hear an adult say "Do as I say, not as I do," believe them. They know they are doing something unwise. Learn from other people's mistakes as well as your own.

WELDING AND CUTTING ENVIRONMENT

One of the best places to weld is outdoors. Ventilation is great outside, so welding and cutting fumes are usually not a problem. However, there are a few things to consider before welding outside.

Avoid welding outside if there is a high danger for fire. Dried grasses and leaves can ignite easily. Stick welding and cutting torches work well in most weather conditions, even in winds up to 40 miles per hour. However, avoid welding with electricity in the rain, and be careful if there is a lot of moisture present, such as a morning dew. Water does not need to be falling from the sky to cause a harmful electrical shock through your body. Puddles on the ground can be just as dangerous. See chapter 7 for more information about avoiding electrical shock.

Welding indoors keeps the welder and workpiece out of the elements. However, garages and pole barns usually hold tools, supplies, machines, and equipment that can be hazardous around welding arcs and cutting torches. Before you start a project, take a moment to look around. Is the space you are working in set up for welding? Are there any hazards? What can you do to reduce the risk of fires or explosions? Here are a few helpful tips.

Fire extinguishers, fire blankets, and first-aid kits are essential for dealing with unexpected emergencies.

1. Sparks can travel up to 35 feet, turn corners, and disappear out of sight. Sparks are especially aggressive when arc welding and torch cutting. Limit the amount of combustibles in the area you are working.
2. Move all flammable materials from the area at least 40 feet away from any welding or cutting. This includes batteries, which can explode from sparks or fire. If you can't avoid welding or cutting near flammable materials, use pieces of sheet metal or fire blankets to deflect sparks

and hot metal. Fire blankets also work well for quickly putting out fires.

3. Always keep a large fire extinguisher around. If there is a greater risk of fire, have a friend stand by and keep a “fire watch” while you do the welding and cutting. It is a good practice to stay in your shop 30 minutes after all cutting and welding is done to make certain a fire is not smoldering somewhere.
4. Whenever possible, weld and cut metals in a wide-open area, away from vents, cracks, and crevices in walls. Sparks can collect in small spaces, smolder, and start a fire without being seen. You can set up fire blankets to cover these areas. Hang three or four fire blankets to create your own welding booth to contain the sparks and hot metal.
5. Torches and plasma cutters do a great job of cutting through metal structures. Think about the consequences of your actions before cutting. Take a minute to ask yourself what will fall after the cut is made. Metal under tension, such as garage door springs, can be especially dangerous when they are cut apart.
6. One of the most dangerous situations is cutting into a drum, barrel, or tank without knowing what’s inside. Even an empty container can be hazardous. Avoid cutting, welding, or doing any “hot work” on containers that may have contained toxic, corrosive, or reactive substances or flammable and explosive vapors.

WHAT TO WEAR

You are responsible for your safety at all times. It is easy to get lazy about safety gear. Recently I was working alone in the shop with a large, hot piece of metal. I leaned over to reach for a tool and felt something warm. I pulled away just in time to see a large hole burned in the front of my shirt. Of course, I was wearing a welding jacket, but I didn’t have it buttoned. I knew better and was a little embarrassed that I wasn’t wearing my jacket properly. Being a little embarrassed is much better than being a lot injured. Now I never forget to fully button up my welding jacket when working in the shop.

There are certain things you don’t want to wear when welding and cutting. Do not wear anything made of nylon or polyester. If I’d been wearing a polyester shirt with my jacket unbuttoned, the hot metal could have melted the shirt onto my skin, causing serious injury. Also avoid loose-fitting clothing or protective gear. A young student was taking a welding class at her high school. She had borrowed one of her dad’s flannel shirts for welding, and the shirt was too large for her. As the student was working, sparks from wire feed welding poured into the sleeve. The spatter built up inside the clothing and started a major fire. The student needed several skin grafts on her torso. Don’t take chances. Sparks can go into any opening. Be sure your welding gear fits properly.

Let’s get dressed for the job, starting at the feet and working our way up.

Welding and cutting is easier to do when you're wearing proper personal protective equipment from head to toe.

FEET

Leather shoes or work boots are a great choice for welding. People working on a farm or in a shop probably already have this type of footwear. Be sure the boots have a rubber sole with a good tread. Avoid shoes with a smooth bottom, which makes it easier to slip and fall. High-top boots do the best job of protecting your feet and ankles from sparks. Low-cut leather shoes work well, too, but be aware sparks and slag can enter through any gap that opens between your pant leg and shoe. Sparks and hot slag always seem to find their way into unprotected areas. No matter what type of footwear you have, be sure your pant leg is long enough to cover the top of the shoe. This helps sparks roll off your pant leg and onto the ground.

LOWER BODY

Wear jeans or work pants, such as those made by Carhartt or Dickies, when welding. Be sure the pants are in good condition and don't have any frays or holes. Holes will let sparks in, and sooner or later they will start a fire. This fire can wick up into your clothing and quickly get out of control. You may not realize there is a problem until you are severely burned. Pant cuffs are another place where sparks and hot slag can collect. It is best to not have any pant cuffs. If cuffs are necessary, be sure to roll the pant cuff to the inside of your leg. Overalls are also a good choice for welding, but check for open pockets that can collect sparks. Close *any* pockets with heavy-duty tape to keep the sparks from going inside.

UPPER BODY

Welding happens right next to your upper body. This is where the sparks, spatter, and heat are most intense. People doing repair jobs wear work shirts for welding. These shirts work great if made from the right materials, such as cotton or a cotton blend, but they may have open pockets that can collect sparks. You can wear welding sleeves over a work shirt to give added protection.

Welding jackets are not very expensive and are great for any job. The jackets are made from fire-retardant cotton. Some come with leather sleeves. Others are all leather for heavy-duty welding. You can wear a jacket over a short-sleeved shirt and button it up to the neck. If you are welding overhead, a shower of sparks can rain down onto your body. A buttoned-up jacket prevents sparks from going down your neck and chest. Welding jackets come in different sizes. Be sure to try them on to get one that fits properly.

Welding jackets are good for medium-duty work and come in different sizes. Be sure to wear one that fits properly.

A hybrid welding jacket with leather sleeves provides more arm protection from heat, slag, and sparks.

An all-leather welding jacket or a leather cape and sleeves with a snap-on bib protects the upper body when doing heavy-duty welding or working overhead.

HANDS

My local welding supplier has a floor-to-ceiling display filled with different types of welding gloves. Welders tend to be very picky about the gloves they use, so manufacturers make a variety of products to suit different needs. Someone doing TIG welding will not need much heat protection, so they can wear thinner gloves. A person doing stick welding needs more protection from hot metal and slag, so thicker gloves do the trick. Pick a welding glove suited for the type of work you will be doing. Sometimes gloves will be labeled “MIG” or “TIG” for the welding process they are designed to work with. Although welding gloves are relatively inexpensive, do not handle hot metal with them. Hot metal will quickly ruin welding gloves, and eventually you will burn your hand. Use a pair of pliers to pick up hot metal.

All welding gloves have two things in common: they are all leather and they have a gauntlet—an extra-long piece of leather to cover your sleeve. The gauntlet protects your wrist from heat and arc light. Cloth, rubber, nylon, or polyester gloves should *not* be worn for welding.

It’s a good idea to have extra gloves available. Do not wear wet, oily, or damaged gloves for welding.

Welding sleeves work well for light-duty welding.

EYES

Your eyes are among the most important parts of your body and among the easiest to protect. Wear safety glasses when welding or working with metals. Cutting sheet metal with tin snips can send a sharp steel fragment flying toward your eyes. I have glasses with gouges in them from this very thing. Stuff flying toward your eyes can happen when you least expect it. Wearing eye protection while metalworking is a must. Most prescription glasses with plastic lenses are made from polycarbonate, which is a strong material with many industrial uses. Side shields are a good addition to regular glasses since sparks, spatter, and slag bounce around in all directions.

Welding and cutting processes also create bright light. A shaded lens in a welding helmet or goggles darkens the light so you can see the welding puddle or cutting line. A tinted pair of safety glasses adds more shade to the shade used for welding, but this might make things too dark to see properly. For this reason, safety glasses should have clear lenses.

It might be tempting to think that sunglasses will work for welding. While sunglasses do a good job of protecting your eyes from the bright sun, they will not protect your eyes from a welding arc. The sun is 92 million miles away from Earth. The electric welding arc, which can be as bright as the sun, is within inches of your eyes. Wear a proper welding helmet and safety glasses. Save the sunglasses for the beach.

Safety glasses, earplugs, and respirators protect you from metalworking hazards such as sparks, fumes, and loud noises.

Face shields deflect sparks away while using a torch or grinder. A #5 shade face shield is on the right.

A clear face shield is great to wear when using grinders for cutting or removing metal. Fiber cutoff wheels are thin and can break easily at high speeds. You can find gruesome photos online of people who did not wear a face shield when using a cutoff wheel. Putting on a clear face shield is an extra step you will not regret.

HEAD

Skullcaps and pipe fitter caps protect the top of your head from sparks and spatter. They also do a good job keeping sweat off your face. Welding hot metal on a hot day with sweat pouring into your eyes is not a fun situation.

Welder skullcaps fit over the head and have no brim. Pipe fitter caps have a small brim to deflect sparks away from the ears. Skullcaps are usually one-size-fits-all and can be found for free or very cheap from welding suppliers. Pipe fitter caps are made for a specific head size, come in a wide range of colors, and are inexpensive. Some of my students make their own welding caps from old pairs of jeans.

A baseball cap turned backward or a bandana works well, too. Just be sure anything you wear is not made from nylon, polyester, or plastic.

#5 SHADE

If you plan to use a torch for cutting, welding, or brazing, a #5 shade provides the best view while protecting your eyes. Shades are numbered from light to dark (a #5 is half as dark as a #10). There is a wide variety of face shields, goggles, and glasses with a #5 shade. For occasional use, goggles and glasses with #5 shades are easy to store. A face shield with a #5 shade protects your face from flying sparks.

ARC WELDING HELMET

Standard helmets with fixed shades work great for welding. The only trouble is you can't see anything through the dark shade until the arc light turns on. All the old-school welders had to learn to tip the helmet, giving a quick nod so the helmet visor slipped down without using their hands. This type of helmet has been around as long as arc welding and holds one shaded lens at a time. Standard welding helmets usually come with a #10 shade, which works well for most types of arc welding. Separate shades from #9 to #13 can be installed in a standard helmet to give the welder a better view depending on the brightness of the arc and the welder's sensitivity to light.

Welding helmet technology has made many advances in recent years. Auto-darkening helmets allow you to see through the shade before welding takes place. Once the helmet is down, the welder can get into position to start the weld without the guesswork involved in tipping the helmet. Usually, people learn to weld faster and easier with an auto-darkening helmet. They cost about four to five times as much as a standard helmet, but that might be worth avoiding the aggravation of tipping the helmet every time you start an arc. Look for an auto-darkening helmet with a variable #9–#11 shade, sensitivity control, and a delay feature. Many helmets also have a #5 shade built in for torch work.

Whatever helmet you buy, be sure to get several extra clear cover lenses. These lenses fit over the shaded lens and take the brunt of the sparks and heat for welding. After a while, they will get scratched, pitted, and a little melted. Being able to see clearly is very important in welding. Have extra clear lenses on hand so you can change it when it becomes too hard to see the puddle clearly.

Standard welding helmets are too dark to see through until the arc is started. Auto-darkening helmets switch automatically to a darker shade when you start the arc.

There are controls inside an auto-darkening helmet you can adjust for different types of welding. Many auto-darkening helmets also adjust for cutting and grinding.

FUMES

When I talk about fumes and welding safety in class, I ask whether anyone has ever gotten sick from welding. Usually, a few hands go up. I ask the students to share their stories. Most didn't know that what they were doing would hurt them. Not every welding situation will be ideal. The important thing is to know about the hazards. Once you can recognize hazardous situations, you can take actions to reduce the risk of personal injury.

Welding and cutting metals creates fumes. These may not be a health issue if the work is done outdoors, but when welding or cutting indoors or in an enclosed space, the fumes can be hazardous. Enclosed spaces are especially dangerous because there is a limited amount of air to breathe. Once the breathable air is gone, people pass out from a lack of oxygen. If this happens, the person is in danger and needs to be rescued from the situation.

Not all welding situations are the same. Certain materials are more dangerous to work with than others. Here are a few things to be aware of.

WELDING PROCESS

Stick welding and wire feed welding with a flux-core wire involve the use of flux and generate a large number of particles. High voltages and amperages generate more heat for welding thicker materials and generate more welding particles due to the increased arc and weld pool sizes. These situations also generate more fumes. Manganese is an ingredient used in flux. Overexposure to manganese can affect the central nervous system, resulting in impaired speech and movement.

METAL COATINGS

Galvanized steel has a rust-resistant zinc coating that creates a harmful vapor when it burns off. Overexposure to zinc, cadmium, copper, or magnesium will make you very sick. You might feel it right away or later that evening. The symptoms are flu like, including nausea, sweating, dizziness, sore throat, and fatigue. Symptoms should subside after a day or two, but those who have had metal fume fever or zinc poisoning will tell you to avoid it in the first place. Drinking lots of milk may help reduce some of the symptoms but will not prevent or cure metal fume fever.

Paint, powder coating, grease, oil, epoxies, glue, and rubber will burn off around the weld and cutting zones, creating a toxic vapor. Protect yourself from these by-products before repairing or modifying parts. Use a fan to blow away the fumes and open a window or garage door. Pay attention to the volume of fumes being generated. A lot of welding and cutting will result in more fumes in the air. Making just a couple of small welds on zinc-coated metal will create a small amount of fumes for a short period of time.

STAINLESS STEEL

Welding stainless steels for prolonged periods of time can be hazardous. Nickel and chromium are added to steel to make it stainless. When welding stainless steel with a flux-based process, such as stick welding or certain kinds of wire feed welding, there is a lot of chromium in the fumes. Exposure to nickel or chromium over time increases the risk of major health problems down the road.

SHIELDING AND FUEL GASES

Be aware of the hazards of using compressed gases in welding. Once the gases displace the atmosphere and there is no more oxygen, you will lose consciousness. In this situation, no half-mask respirator will protect you from fatal consequences. Check for leaks in the system and keep track of the gases you are using. If you get a headache or feel dizzy or nauseous, get away from the area and into some fresh air.

SAFETY RESOURCES

That little piece of paper you get with welding rods, wire, and flux is packed with good information. By law, a material safety data sheet (MSDS) must be provided to those using hazardous products. Every MSDS has sections on general hazards, how the product reacts with other substances, and how to use the product safely.

Take the time to read the owner's manual that comes with any welding equipment. It may not be much fun to read these manuals, but they contain good information about how to use the machine safely and troubleshooting guides outlining what can go wrong and how to fix it.

The American Welding Society (AWS) has several resources for learning about welding and cutting safety. You can stream safety videos and download their publication *ANSI Z49.1 Safety in Welding, Cutting and Allied Processes* for free at www.aws.org. The videos follow the Z49.1 safety standard issued by the American National Standards Institute (ANSI) and are worth watching. Anyone who takes up the torch, wire feed gun, or stick electrode is responsible for educating themselves on the potential hazards. People with a good understanding of the dangers are better able to follow safety guidelines and avoid injury.

Wear a respirator when heating or welding metals that are painted or coated.

3

TOOLS AND METALS

Calipers are useful for measuring the exact size of drill bits to the nearest $^{1}/_{1000}$ (0.001) of an inch.

PRECISION AND PRACTICALITY

How precise a part needs to be is often related to its function. For example, the brush guard on a truck needs to fit the front of the vehicle and the mounting brackets. It should be well made, but it is not necessary that the brush guard have measurements to within less than ⅛ inch of those in the plans. A piston in the truck's engine is a whole different story. The relationship between the piston and the bore in the engine block needs to be very precise and can only be measured properly with a micrometer. It would not be practical to build a brush guard for a truck with extremely accurate dimensions down to $^{1}/_{1,000}$ inch (0.001). On the other hand, having the clearance between a piston and engine bore be more than 0.003 to 0.005 inch would result in an engine that does not run well, if at all. Practicality goes hand in hand with functionality. The most important thing is whether the part you are fabricating or repairing does the job it's meant to do. Sometimes, close enough is good enough, especially if it allows you to move on to the next project and continue working.

RULER BASICS

Rulers and tape measures are usually broken up into common fractions, such as ½, ¼, ⅛, and $^{1}/_{16}$. Look carefully at a tape measure. The different line heights indicate the fractions of an inch. The tallest line in the middle represents ½ inch. The next two tallest lines are ¼ and ¾ of an inch. As the lines get shorter, the fractions get smaller. The next shortest after the quarters are the eighths: ⅛, ⅜, ⅝, and ⅞. Knowing what the different line heights on a ruler or tape measure mean helps you quickly identify which fraction of an inch is being measured.

Some tape measures have fractions printed on them. Most indicate the fractions with taller and shorter lines.

FRACTION CONVERSION CHART

		Decimal	Metric
	1/64	.0156	0.396
1/32		.0312	0.793
	3/64	.0468	1.190
1/16		.0625	1.587
	5/64	.0781	1.984
3/32		.0937	2.381
	7/64	.1093	2.778
1/8		.125	3.175
	9/64	.1406	3.571
5/32		.1562	3.968
	11/64	.1718	4.365
3/16		.1875	4.762
	13/64	.2031	5.159
7/32		.2187	5.556
	15/64	.2343	5.953
1/4		.250	6.350
	17/64	.2656	6.746
9/32		.2812	7.143
	19/64	.2968	7.540
5/16		.3125	7.937
	21/64	.3281	8.334
11/32		.3437	8.731
	23/64	.3593	9.128
3/8		.375	9.525
	25/64	.3906	9.921
13/32		.4062	10.318
	27/64	.4218	10.715
7/16		.4375	11.112
	29/64	.4531	11.509
15/32		.4687	11.906

	Decimal	Metric
31/64	.4843	12.303
1/2	.500	12.700
33/64	.5156	13.096
17/32	.5312	13.493
35/64	.5468	13.890
9/16	.5625	14.287
37/64	.5781	14.684
19/32	.5937	15.081
39/64	.6093	15.478
5/8	.625	15.875
41/64	.6406	16.271
21/32	.6562	16.668
43/64	.6718	17.065
11/16	.6875	17.462
45/64	.7031	17.859
23/32	.7187	18.256
47/64	.7343	18.653
3/4	.750	19.050
49/64	.7656	19.446
25/32	.7812	19.843
51/64	.7968	20.240
13/16	.8125	20.637
53/64	.8281	21.034
27/32	.8437	21.034
55/64	.8593	21.828
7/8	.875	22.225
57/64	.8906	22.621
29/32	.9062	23.018
59/64	.9218	23.415
15/16	.9375	23.812
61/64	.9531	24.209

	Decimal	Metric
31/32	.9687	24.606
63/64	.9843	25.003
1	1.000	25.400

Squares are used to measure 90-degree angles. Combination squares have an adjustable ruler for making layout lines on projects.

MEASURING TOOLS

Many short videos online show how to use various measuring tools. Watch a few of these to get a better idea on the many ways you can use a measuring tool. Tape measures, combination squares, calipers, levels, and lasers are all useful for welding projects.

Bubble levels have liquid-filled chambers with air bubbles that move to the middle when parts are vertical, horizontal, or at 45 degrees.

Calipers can precisely measure parts to within $^{1}/_{1000}$ (0.001) of an inch.

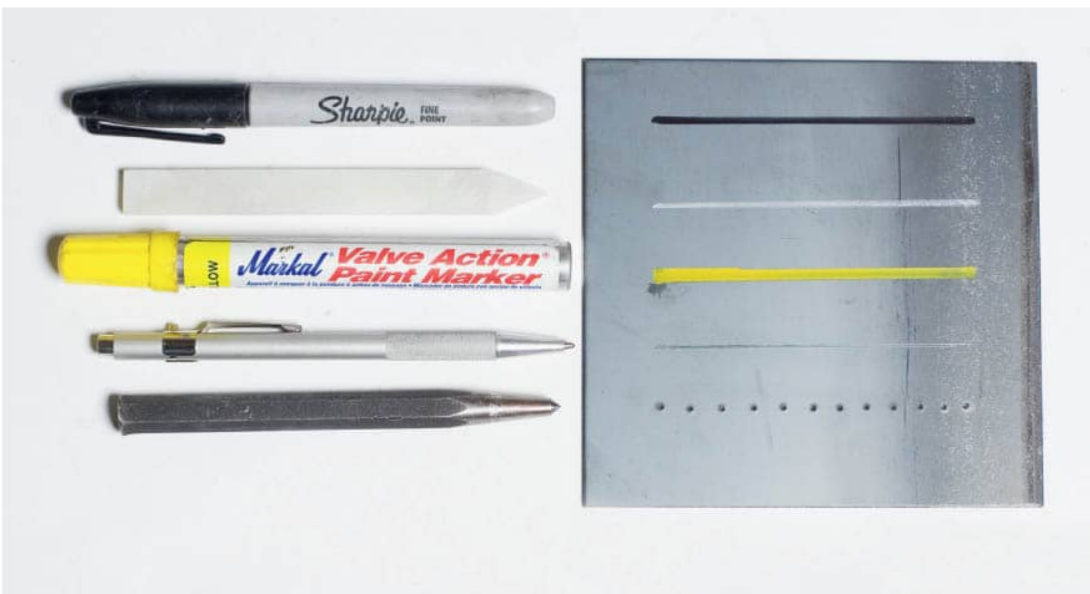
Self-leveling lasers used for fabrication and construction display perfectly horizontal and vertical lines.

Switchable magnets hold steel parts together and are easy to clean because the magnet can be turned on and off.

MARKING TOOLS

Carbide-tipped scribes are commonly used in shops and will mark most surfaces accurately. A center punch can be used for layout and marking spots where parts need to line up. Also, a row of indentations from a center punch is easy to see when following a flat seam in welding.

Soapstone is used with torch cutting because the mark will not disappear when you heat the metal. Sharpie markers work well for layout on clean surfaces, but the marks wear off easily and disappear when the metal is heated. Paint markers come in handy for marking metals or labeling items such as welding machines and helmets for identification purposes.

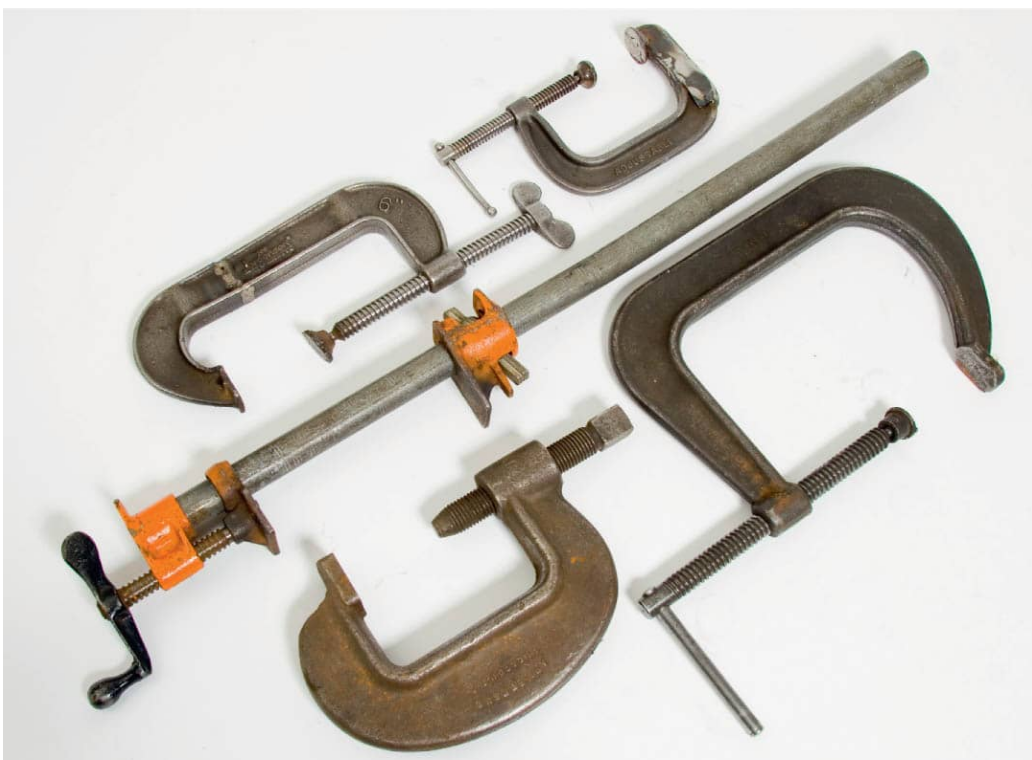


Marking tools can indicate where dimensions are located and label features on a project, such as drilled holes.

HAND TOOLS

C-clamps are widely used in metal fabrication. The quick-adjusting kind is expensive but can save lots of time. Bar clamps are sold with two end pieces that you attach to the correct-diameter pipe. The convenient part is that if you need a longer bar clamp, you use a longer piece of pipe. Vise-Grips are also called self-locking pliers because you can adjust the nob on the handle so that they stay gripped onto a piece of metal. Larger Vise-Grips work well in place of traditional clamps.

Use pliers to pick up metal that has just been welded or to hold small pieces of metal in place when welding. A pair of needle-nose pliers with a wire cutter is very useful for cutting down long filler rods or excess wire on the end of your wire feed gun, and for pushing down sheet metal when tacking to close gaps between two pieces.



C-clamps and bar clamps work well for aligning parts and holding them in place for tack welding.

Pliers and wire cutters are must-have tools for welding. You can use them to safely handle hot metal and easily cut excess wire down to size.

Vise-Grips come in a wide variety of shapes and sizes for general and specialized uses.

DRILLS AND DRILLING

Most home shops have a hand drill available for use in woodworking, masonry, and metalworking situations. Hand drills are not as accurate as drill presses, but you can use them almost anywhere. Drill bits must be made from a harder material than what you are drilling, typically plain high-speed steel (HSS) or HSS mixed with cobalt. Adding cobalt allows the bits to withstand higher amounts of heat and makes them tougher, but these bits also cost more. Typical hardware store bits have a 118-degree angle at the tip, which is fine for cutting through low-carbon steels, aluminum, and copper alloys such as brass. For tougher materials, such as stainless steels, medium- to high-carbon steels, and cast iron, however, a 134-degree tip is best.

Putting a hole in a piece of metal sounds easy, but there are a few important concepts to understand. Although drill bits are made from hard steels, they can become weak when overheated. When the drill bit spins against the surface you're drilling into, it creates friction between the bit and the metal. If there is too much friction, the drilling stops and the bit will likely be ruined. Drilling at a low speed and using lots of cutting oil will help the drill bit do its job and keep it in good shape.

Center punches are useful when drilling into metal. If you center punch the metal first, the drill bit has an indentation to follow. This prevents the spinning bit from wandering, or "walking," away from where the hole should be located. Use low speeds, lots of cutting oil, and firm pressure to drill steel and stainless steel. Use high speeds, a little oil, and light to medium pressure when drilling aluminum. To relieve pressure on the drill bit and reduce friction, it helps to drill a smaller hole first—say, ⅛ (0.125) inch—then increase to the finished hole size with larger drills. Be careful to use light pressure when drilling out a smaller hole with a larger bit. When starting out, the edge of the hole can damage the drill bit.

Precision is important when drilling and tapping. The drilled hole must be an exact size for the tap to cut the threads successfully.

CUTTING TOOLS

Chop saws use fiber or steel wheels with carbide tips. Chop saws with fiber wheels run at a higher speed and are used for cutting carbon steel and stainless steel. Avoid cutting aluminum with a fiber wheel. Chop saws with carbide-tipped steel blades run at lower speeds. Cutting different materials requires changing the steel blade to one designed for that type of metal. Aluminum can be cut on a standard power miter saw with a fine-finish eighty-tooth blade.

Circular saws for cutting metal run at much slower revolutions per minute (rpm) than wood-cutting versions. Otherwise, a metal-cutting circular saw is much like its wood-cutting counterpart. For chop saws and circular saws, you can purchase different blades for cutting different materials. Each blade is rated for a range of thickness.

Band saws are a bit of an investment. Because there are many cheaper tools that cut metal, they may not be a practical choice. Band saws do leave a clean-cut edge without heating the metal. Most can be adjusted to make miter cuts (cuts made at an angle other than 90 degrees).

Finally, a reciprocating saw (such as Sawzall) with a bi-metal blade will easily cut through smaller tubing, pipe, and solid stock.

Metal-cutting chop saws cut a wide variety of structural shapes, including tubing, angle iron, and channel.

Circular saws for cutting metal are portable and work well with a straightedge to guide the cut.

Grinders may have different wheels attached for removing and smoothing metal surfaces.

GRINDERS

A 4½-inch angle grinder is commonly used in metal fabrication shops. Grinders use a variety of discs for different jobs:

- Hard wheels are used primarily for grinding down welds. They remove metal quickly and leave behind a rough surface.
- Sanding discs are less abrasive than hard wheels for smoothing surfaces. They come in a variety of grits. Some are specifically designed to sand aluminum. Sanding discs need to have a backing disc for the grinder, which is usually sold separately.
- Flapper wheels are like sanding discs. They also come in a variety of grits but can last longer than sanding discs and don't require the backing disc.
- Cutoff wheels are great for cutting welds or metal apart. Although they come in a variety of thicknesses, 0.045 to $^{1}/_{16}$ inch is a good range to use.
- Wire wheels and cup brushes are used for removing rust, paint, and mill scale, and for cleaning slag from welds.

The grinder wheels pictured are a knotted wire brush, hard wheel, cut-off wheel, and flapper sanding disc.

Compressed-air tools are designed to do the same tasks as their electrical counterparts. An air compressor is required to run them.

AIR-POWERED TOOLS

A straight-type (180-degree) die grinder with a carbide bit is useful for removing small amounts of metal in tight places, which you otherwise would remove manually with a file. A 90-degree angle-type die grinder can be used with 2-inch sanding and Scotch-Brite discs for smaller, more detailed work.

Steel plates are at least $^{3}/_{16}$ inch in thickness. Flat, square, and rectangular bars come in a variety of sizes.

STEEL

The most popular metal on Earth is steel. It is all around us and key to our daily lives. Humans have been making steel for thousands of years, and it is made mostly of iron and carbon. In modern steels, the quantity of carbon and amount of impurities are closely controlled. The right ingredients make the materials stronger and more predictable to work with.

Steels are not all the same. The steel used for a drill bit has different properties and ingredients than the steel beam holding up the ceiling in a sports arena. Steel is the most recycled material, by volume, of all recyclable materials combined, including paper, plastic, and aluminum. Steel is recycled so much that the steel in a new car could contain some steel from an old Model T car or a demolished skyscraper.

Most people begin learning to weld on steel. Low-carbon and mild steels are inexpensive and easy to weld with oxy/acetylene, stick, wire feed, and TIG. Steels with a medium to high carbon content and steels that have other metals added for strength and toughness—called alloy steels—are not as easy to weld. Take care in selecting the filler metal and in heating and cooling the metal before and after welding.

LOW-CARBON STEEL

Alloy numbers: 1010, 1012
Carbon content: 0.05% to 0.15%
Uses: Many common products, including chains, nails, pipe, screws, and sheets for forming operations (stamped parts)
Note: Easily welded

MILD STEEL (PLAIN CARBON STEEL)

Alloy numbers: A36, 1018CRS, 1022 HRS
Carbon content: 0.15% to 0.29%
Uses: Structural shapes, channel, angle, bar, tubing, sheet, and plate
Note: Easily welded

MEDIUM-CARBON STEEL

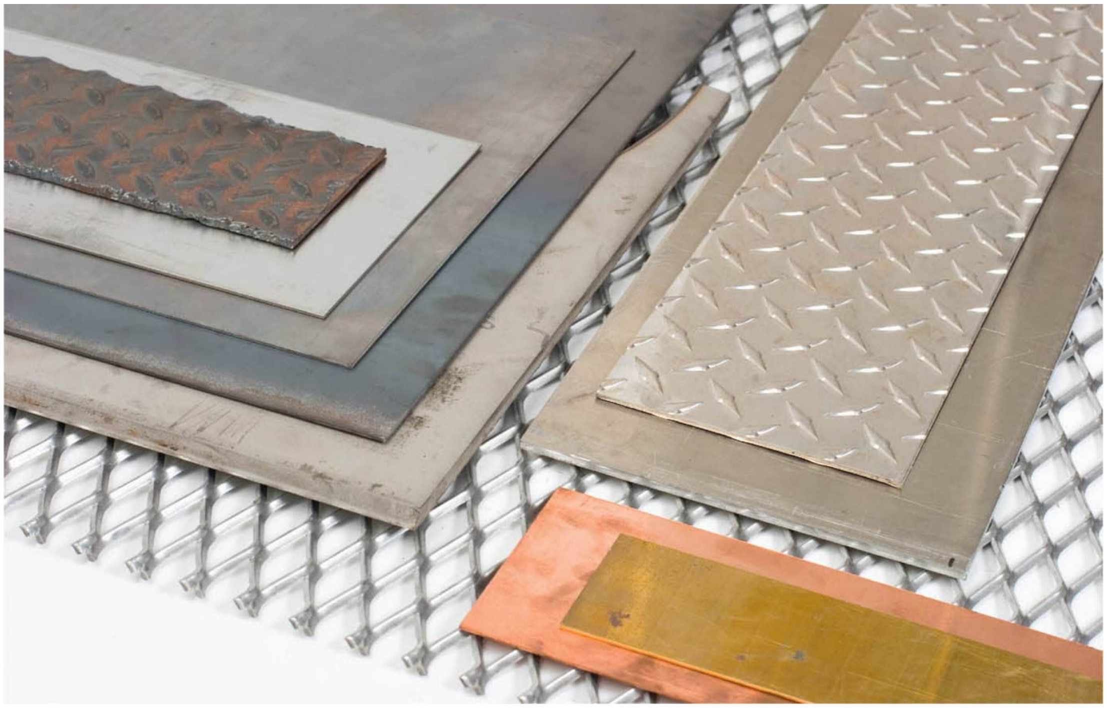
Alloy numbers: 1030, 1040, 1045
Carbon content: 0.30% to 0.59%
Uses: Axles, connecting rods, shafts, and other lathe-turned pieces
Note: Welded by carefully controlling the heating and cooling rates

HIGH- AND VERY-HIGH-CARBON STEEL

Carbon content: high = 0.60% to 0.75%; very high = 0.76% to 1.5%
Uses for high: Dies, car and truck springs, anvils, crankshafts, scraper blades
Uses for very high: Files, woodworking and steelworking tools, chisels, metal-cutting blades, knives, punches
Note: Difficult to weld. A great deal of care is required, including preheating, special electrodes, and welding techniques. Postweld heat treatment is required. Can be brazed.

LOW-ALLOY STEEL (HIGH-STRENGTH STEEL)

Total alloy content including carbon: typically 1.5% to 5%
Uses: Large structural pieces, bridges, boats, truck frames, railroad cars, heavy equipment
Note: Welded carefully with the correct electrode (matching the required mechanical properties) and proper welding procedures



Sheet metals are less than $^{3}/_{16}$ inch thick and come in a variety of gauge sizes. A sheet-metal gauge chart gives actual thickness in inches.

STAINLESS STEEL

Many industries rely on stainless steel equipment to process their products safely. Milk, butter, cheese, and beer are a few examples of foods made using machines that are constructed to 3-A sanitary welding standards. Power plants and chemical manufacturers also use stainless steel pipes and structural shapes in their equipment. Stainless steel is a key metal in delivering much of the energy used today.

Stainless steels contain additional metals, such as chromium and nickel, to increase their resistance to corrosion. However, that doesn’t mean they can’t rust or corrode. In fact, using the wrong welding techniques or a plain-carbon steel wire wheel to clean the metal will make stainless steel corrode just as fast as regular steel.

AUSTENITIC (300 AND 200 SERIES)

Alloy numbers: 304, 304L, 308, 316, 316L
Uses: Food-grade applications such as ovens and vent hoods; 316 and 316L used in structural and marine applications (higher resistance to corrosion)
Note: Easily welded with some care

FERRITIC (400 SERIES)

Alloyed mainly with 11% or more chromium; contains little or no carbon
Uses: Building trim, pots and pans
Note: Least expensive; is considered non–heat treatable and soft

MARTENSITIC (400 AND 500 SERIES)

Alloyed mainly with chromium; typically contains up to 1% carbon
Uses: Knives
Note: Can be hardened by heat treatment; 440C stainless steel is not weldable

Tubing comes in round, square, or rectangular shapes with different outside dimensions and wall thicknesses.

ALUMINUM

Aluminum is a recent addition to metalworking and has grown to be the second-most commonly used metal after steel. A dirtlike substance called bauxite is mined from the earth; it contains aluminum, which is separated by running a huge amount of electrical current through the material. Alcoa is one of the largest producers of aluminum. They are a great resource for information about the metal and its alloys.

1000 SERIES (1100)

Pure aluminum
Uses: Structural shapes, cladding where corrosion resistance is required
Note: Can be welded; low strength

2000 SERIES (2017, 2024-T4)

Alloyed primarily with copper (also magnesium or manganese)
Uses: Aerospace industry
Note: Should not be welded

3000 SERIES (3003)

Alloyed with manganese
Uses: Beverage cans, refrigeration tubing
Note: Can be welded; has a shiny appearance and comes in a mirrored finish

4000 SERIES

Alloyed with silicon
Uses: Primarily as filler metal in welding (4043, 4145) or filler alloy in brazing

5000 SERIES (5052, 5083, 5456)

Alloyed primarily with magnesium (also chromium or manganese)
Uses: Structural applications in sheet and plate form
Note: Can be welded

6000 Series (6061, 6061-T6, 6053)

Alloyed primarily with magnesium and silicon (also copper and/or chromium)
Uses: Structural applications, extrusions, furniture
Note: Can be welded with the addition of a filler metal

7000 Series (7075-T6, 7005)

Alloyed with zinc and other elements
Uses: Aerospace industry, bicycle frames
Note: Heat treatable and high-strength; should not be welded unless the part will receive postweld heat treatment to restore mechanical properties

Pipes carry fluids and are measured by their inside diameter and wall thickness. You can use pipe schedules to identify pipe sizes.

OTHER METALS

MAGNESIUM is used in die-cast parts and components manufactured by machining and stamping. For example, some older lawnmower decks were made from pressed pieces of magnesium. Magnesium has many of the same properties as aluminum, such as high thermal conductivity, and is welded in a similar way.

COPPER was one of the first metals used by early civilizations. It exists in its pure form in nature (like gold and silver do) and does not need to be refined from an ore. Copper is often alloyed with other metals to produce brass and bronze (see below). Copper can be welded using the TIG process but is more often joined by soldering or brazing.

BRASS is copper alloyed with 20 to 40 percent zinc. Certain brasses can also contain tin, lead, and aluminum for specific purposes. Uses for brass include bullet jackets, cartridge cases, musical instruments, and ornamental work.

Tin, aluminum, and beryllium are alloyed with copper to produce **BRONZE**. Zinc may also be present but is not the principal alloying element. Bronze and brass can be arc welded or used as filler alloys in arc welding or braze welding.

IDENTIFYING METALS

Steelyards will have metals organized and categorized for you. But if the piece of metal you are holding came from a flea market, yard sale, or junk pile, how do you know what kind of metal it is? There are several different testing methods for narrowing the possibilities. The function of the part is the first clue: a kitchen knife or tractor rim will be made of a specific type of metal. Second, get familiar with how different metals look. The color, weight, and surface features are all clues, as is the way the interior looks when the piece is fractured. Third, a small magnet will be attracted by most steels, cast iron, wrought iron, and some stainless steels. Fourth, the harder, more brittle metals will be difficult to file or chisel. Finally, metals will throw off different spark patterns when ground on a belt or abrasive wheel and will react to a flame in various ways. Spend some time doing detective work on mystery metals. With a little research, you will become an expert in no time.

STRUCTURAL SHAPES

Structural shapes include angle, channel, tube, pipe, and structural beams (I beams), to name a few. Most shapes are available in steel, stainless steel, aluminum, and other metals.

The only way to get a good idea of the variety of materials available is to visit a steelyard. Spend some time looking around. You’ll be astounded at all the different sizes, shapes, and types of materials there. Structural shapes are available for almost any project. If you need a piece of a certain size for your project, a steelyard will probably have that shape in a variety of dimensions and can cut it to size for you. Be prepared to pay a cutting charge if you need large quantities or accuracy. The “drop” section of a steelyard is a mixed bag of different pieces left over from the cuts made on new material.

Angle iron is made from steel, stainless steel, or aluminum and works well for building brackets, racks, and shelving.

Channels have two legs connected by a web, making them structurally rigid. Frames made with channels are used for trailers and heavy equipment.

4

OXY/FUEL GAS EQUIPMENT AND SAFETY

Be sure cylinders are chained or secured to prevent them from tipping over.

COMPRESSED GASES

Gases for welding and cutting come from many sources. For example, gases from the atmosphere, typically known as “nonliquefied” gases, are processed and separated into individual parts: we get oxygen, nitrogen, argon, and helium from the air we breathe. Liquefied gases include propane and carbon dioxide. The cylinders look the same from the outside, but inside they are filled with liquid instead of gas. The liquid turns back into a gas when it’s dispensed from the cylinder. Each gas has its own use and personality. Some are highly reactive to heat and sparks, some are corrosive, and others burn very easily. There are other useful gases that tend not to burn or react to anything.

Compressed gases provide fire when used in a torch. They also provide pressure, directing the flame to the spot where you need it. For many centuries, artisans used blowpipes to direct a flame where it needed to go. Gently blowing on an open flame, such as a candle, makes it bend. Using a tube can direct the air from someone’s lungs to an open flame to heat a specific spot for hammering, forming, gilding, and other types of metal work. People used bellows and pumps before cylinders of compressed gas became widely available. Now the pressure in a gas cylinder acts like a pair of lungs, blowing the flame where we want it to go.

Larger oxy/acetylene torch setups are usually put on a two-wheel cart to make it easier to move around the work area.

CYLINDER SAFETY

Compressed gases are kept in a steel container called a cylinder or bottle. These gases create a lot of pressure inside the bottle, which is strong but not indestructible. Cylinders have some weak spots and need to be treated very carefully. Here are a few things to remember:

1. The cylinder comes with a cap that protects the valve stem. The valve stem is the weakest part of the bottle. If the bottle tips over without its cap in place, the valve stem can break and let the gas out at high pressure. This will cause the cylinder to act like a rocket, which is very dangerous. Keep a cylinder strapped or chained to a stationary object when using it. When you're finished using the cylinder, put the cap back on. A new bottle has a lot of gas inside, so be sure to secure the cylinder before removing and replacing the cap.

2. Protect the cylinder from extreme weather conditions.

3. Keep oil and grease away from cylinders, especially those containing oxygen. Petroleum products, such as oil, can easily combust when exposed to pure oxygen.

4. Never weld or strike an arc on a gas cylinder.

5. Always read the label on the bottle to know what gas is inside.

6. Try not to drop cylinders or let them roll away from you. Treat cylinders with care.

7. Don't use them as rollers or supports.

8. Avoid transporting cylinders in an enclosed vehicle. Anytime you are in an enclosed space with a gas cylinder, such as in a vehicle, an undetected gas leak can lead to serious problems. If the gas fills the space, it can replace the air you breathe, causing you to pass out—and maybe not wake up.

OXYGEN SAFETY

Oxygen is everywhere. Most of the time, it is our friend. The atmosphere we breathe contains about 21 percent oxygen, which is enough for things to burn in a typical way—such as wood in a campfire. Oxygen in a compressed gas cylinder is 99.5 percent pure, which creates a fire hot enough to burn steel. For example, a cutting tool known as an oxygen lance takes advantage of this fact by burning small steel rods like a Fourth of July sparkler. When lit, this lance can be pushed through solid steel and sever huge metal slabs and castings.

Fires in an oxygen-rich atmosphere spread rapidly and are hard to put out. Even in an area that has slightly more oxygen than our regular atmosphere, such as 25 percent, fires start more easily and get out of control quickly. Treat oxygen with respect. Watch out for leaks, and only use the gas for its intended purpose. Never use oxygen to run pneumatic tools, fill tires, or dust off your clothing or body. Oxygen will saturate the fibers of your clothing or hair and easily catch on fire. Using oxygen to ventilate a space or having an unknown leak in an oxygen cylinder or line can have life-changing consequences.

Oxygen cylinder valves are opened all the way, allowing oxygen to flow into the attached regulator on the left.

Acetylene cylinder valves are opened ¾ to 1 turn. Notice the valve has arrows indicating whether the cylinder is being opened or closed.

FUEL GAS SAFETY

There are many fuel gases, including acetylene, propane, MAPP (a mixture of gases), butane, propylene, natural gas, and even hydrogen. Each fuel gas has a different chemistry, so their flames burn at different temperatures. They also have uses besides welding, such as heating homes and grilling food. The key is to use the fuel gas that best suits the task.

Any fuel leaks can cause a buildup of combustible gas, which will explode with the slightest spark, flame, or arc. Most manufacturers add a chemical to the fuel gas to make it smell bad. It sure stinks, but being able to smell it can save your life.

Acetylene is a little different from other fuel gases because it is a dissolved gas. Since acetylene becomes unstable at pressures greater than 15 pounds per square inch (psi), the cylinder is packed with drywall rock or another material and filled with liquid acetone to keep the gas from exploding when the cylinder is filled. This makes the cylinder heavier than others. If you ever see liquid flames coming from the end of your torch, shut it down. This means acetone is coming out of the bottle instead of gas.

This can happen if a cylinder is lying on its side for too long or if there is no more acetylene gas left in the cylinder.

EQUIPMENT FOR OXY/ACETYLENE OUTFITS

As its name suggests, oxy/acetylene welding uses two gases: oxygen and acetylene. When it comes to combining two dangerous gases such as these two, there is little room for error. Damaged or defective torches can blow up or flame out, causing injury or damage to property. If you buy a used torch at an equipment sale or inherit Grandpa's old torch, get it checked out by a welding supplier! They can clean and test the equipment to be sure it works properly.

You can purchase torch equipment in individual pieces or in sets called outfits that include everything except the cylinders and cart. Equipment comes in different sizes. Someone using a torch inside a building may have to go up a bunch of stairs to get to the water pipe that needs to be soldered. They need a small torch setup that works well for soldering and brazing. Another person might be heating a piece of metal to bend it or cutting apart some scrap pieces of equipment in a pole barn. They need a torch outfit that can be used with larger cylinders and produce more heat. Before buying a setup, think about what you want to do with it. Buying the proper-sized equipment the first time can save you aggravation in the long run. Talk to your welding supplier about your needs.

Finally, take good care of your equipment. The safety and care recommendations for gas cylinders also apply to regulators, torches, attachments, and hoses.

SAFETY FEATURES

Oxy/acetylene torches have specific safety features that anyone using a torch should know about. Color coding identifies the type of gas used for a component. Green is used for oxygen. Red is used for acetylene and other fuel gases. The regulators and hoses should be color coded to identify the gas they are used with.

All connections on the oxygen side have right-hand threads (the common thread type for most bolts and screws, i.e., "lefty loosey, righty tighty). On the fuel gas side, the connections have left-hand threads (i.e., left to tighten, right to loosen). Having different thread connections helps prevent a hose or regulator from being attached to the wrong cylinder. A notch machined into the fitting indicates it is a left-hand thread connection.

Safety devices such as one-way check valves and flashback arrestors are a good investment. Gases mixing in the system can catch on fire inside the regulator or hoses, leading to burned-out equipment or explosions. One-way check valves are usually located between the torch body and the hoses. These valves allow gas to flow in only one direction. Some torch bodies have check valves built in. Flashback arrestors can be installed between the hoses and the regulator. If fire flashes back up the hoses, the arrestors will save the regulator from being damaged.

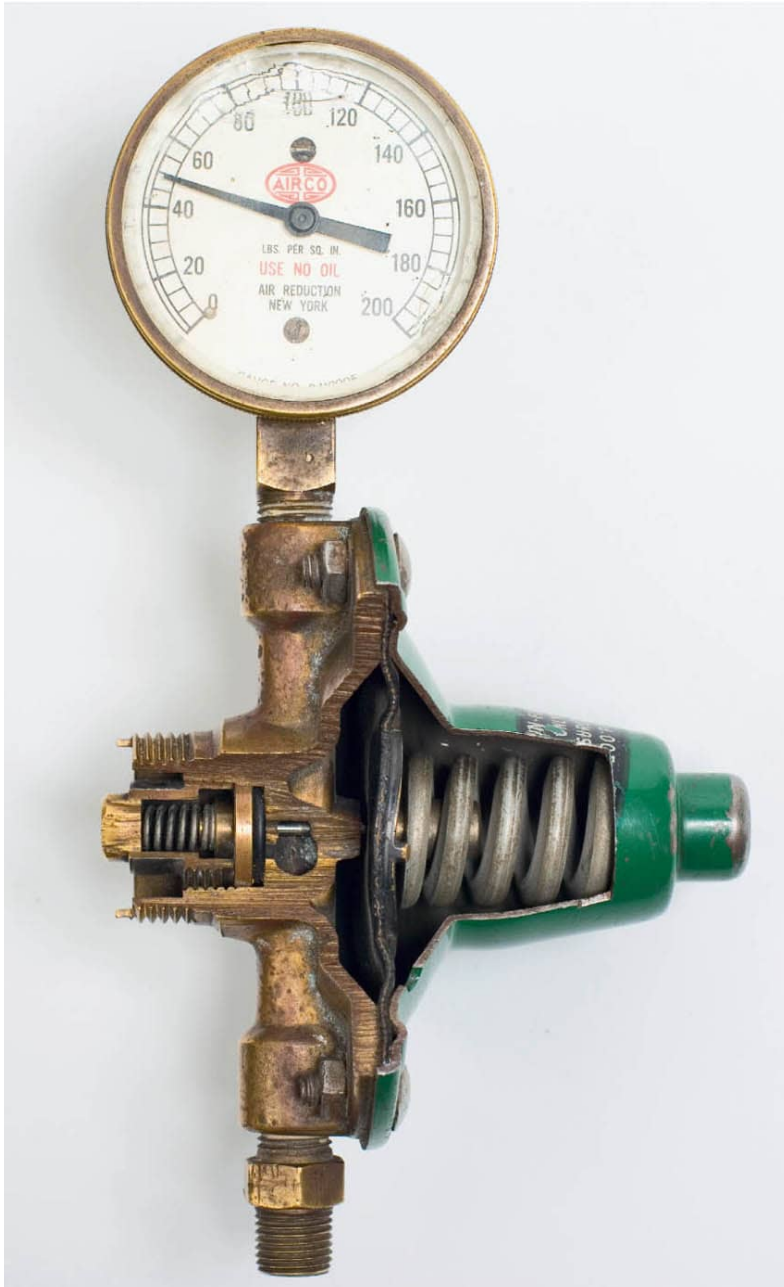
A striker, tip cleaner, one-way check valves, and flashback arrestors are used to keep a torch running safely and efficiently.

Both regulator gauges read 0 pressure, which means there is no gas in the hose and the cylinder valve is closed.

Don't panic if the regulator pressure-adjusting screw comes out. Clean it off as needed and carefully thread it back into place.

REGULATORS

The regulator controls the flow of gas. Gas in the cylinder is under very high pressure. Regulators reduce this pressure inside the hoses. Regulators have two gauges. The high-pressure gauge is closest to the cylinder and tells you how much gas is left inside the cylinder. It's similar to a gas gauge telling you how much gas is left in a car's tank. The low-pressure gauge is just above where the hoses attach to the regulator. This gauge tells you how much gas is in the hoses. This is important because each torch tip and attachment works best at a certain pressure. There is a pressure-adjusting screw in the middle of the regulator. Once the cylinders are open, turn the adjusting screw clockwise for more pressure in the lines; turn the screw counterclockwise to reduce the pressure in the lines. The low-pressure gauge reads how much pressure you add or subtract in the hoses using the adjusting screw.



This cutaway view of a regulator shows the spring that allows gas to flow when the adjusting screw is turned clockwise.

HOSES

A hose connects the regulator to the torch body. Hoses come in different diameters and lengths. There are limits to how long a torch hose can be and still work with the torch tip being used. If you need extra hoses, check to see whether your setup will provide the proper gas flow and pressure for your torch. Having an extra hose around is a good idea in case you accidently cut or burn through a hose. Don't try to repair a torch hose!

TORCHES

Needle valves are one of the most important parts of a torch. These valves control the amount of gas flowing out of the torch tip. Needle valves are like the volume control on a stereo: a small change in the setting can have a big impact on the output. Make tiny adjustments with needle valves. They are precise, and there is no need to overtighten them or use force to close them. Treat them with care.

Different types of torches are made for different kinds of work. If a torch is dedicated to cutting or heating, a good option might be a one-piece torch that connects directly to the hoses. Often, a one-piece cutting torch or rosebud for heating is used with propane for the fuel gas. Propane is less expensive than acetylene, and the bottles are lighter, which makes them easier to move around. Another option is a two-piece setup in which a torch body can hold several different attachments, like welding tips, cutting torches, and rosebuds.

Torches and torch tips come in different sizes. A tip chart is a good way to find out what metal thicknesses your tip was designed to weld or cut. You can find tip charts in the booklets that come with your equipment or online. Search the manufacturer's name first, such as "Smith tip chart" or "Victor tip chart." Searching just the words "tip chart" will show how much money you're supposed to leave for a restaurant server.

When using acetylene as your fuel gas, remember that there is a safe limit to how much gas can come out of the cylinder to supply a torch or attachment. That big rosebud heating attachment might require larger cylinders to work correctly. Check whether buying a larger attachment will require larger cylinders to go along with it.

Welding tips come in different sizes for various metal thicknesses. On the right is a rosebud tip used for heating large areas of metal.

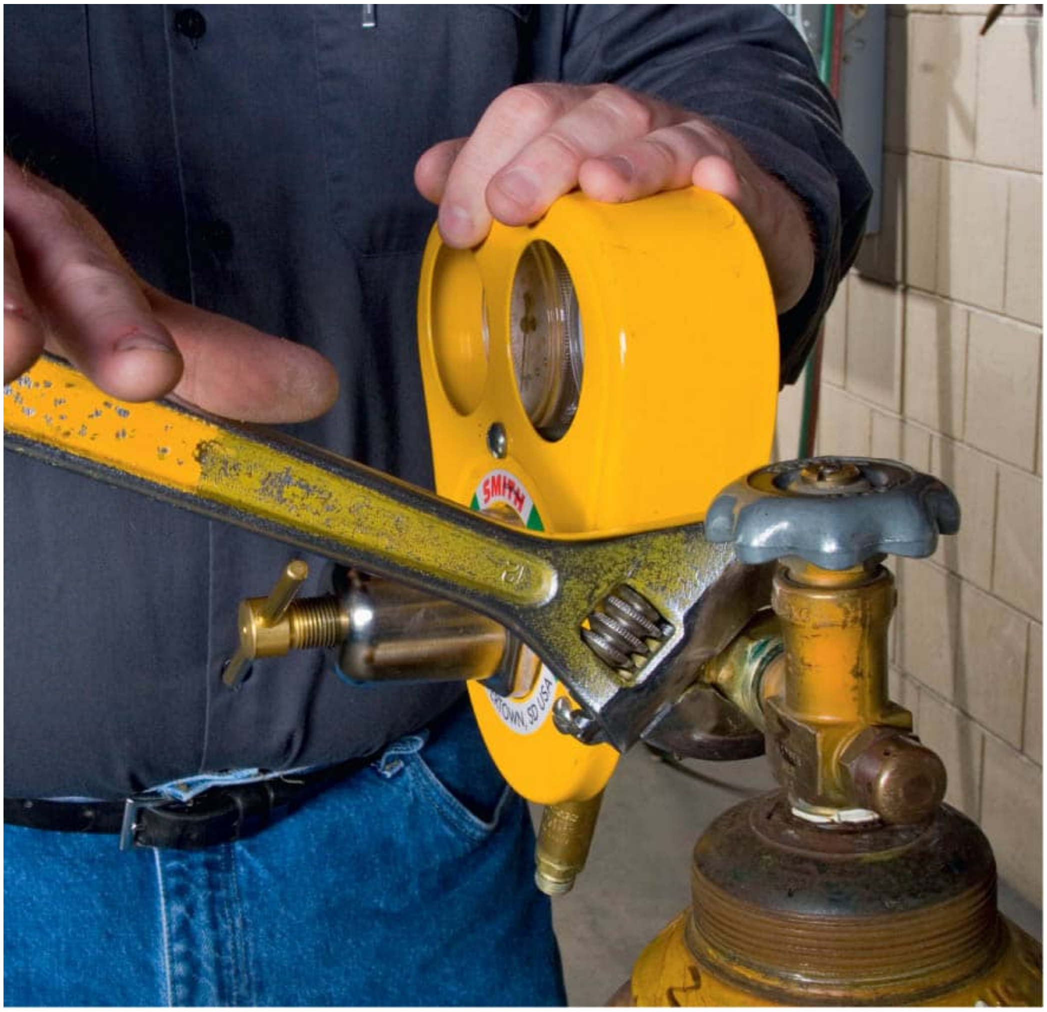
If you suspect there is a gas leak on a torch setup, use some leak-detection solution on all the connections.

Leaking gas will make bubbles appear. You can then clean and retighten the connections.

CHECKING FOR GAS LEAKS

Keeping track of the gases in your torch setup is key to working safely. You need to know how to check for leaks if you smell acetylene or suspect that oxygen is leaking from a loose connection. Even a small leak can release a dangerous amount of gas over time. There are two ways to check for leaks:

1. Follow the startup procedures to pressurize your torch (see next page). Close the valves on both cylinders. Now watch the gauges. If the needles don't move, wait a few minutes. If the high- or low-pressure gauge drops, there is a leak somewhere.
2. Place a few drops of dish soap in a spray bottle of water. Spray the mixture on all connections. Start at the cylinder and work your way down to the torch. If bubbles appear at a connection, you have a leak. Bleed the system (see "Startup and Shutdown Procedures" on the next page) and examine the connecting nuts and screw threads for damage. Use a wrench to tighten any leaking connections. If the leak continues, do *not* use the equipment. If the connection between the cylinder and regulator is leaking, you might need to get a new cylinder. If the leak is on a connection to the regulator, hoses, or torch, take the equipment to a welding supplier for repair.



Use care with wrenches. Most fittings are made of soft brass and can easily be damaged.

Be sure all the fittings are snug. Any loose connection can leak gas and start a fire.

STARTUP AND SHUTDOWN PROCEDURES

There is more than one way to start up and shut down a torch. I teach the following method to my students because it gives an accurate pressure. When the needle valves are open, you can turn the pressure-adjusting screw and see the change in gas pressure on the low-pressure gauge of the regulator. Just remember to close the needle valves as soon as you are finished adjusting the pressure. This method also purges the hoses so there are no mixed gases in them when you light the torch.

For an easy reminder on how to start up and shut down a torch, just remember “A before O”: do everything with the acetylene side first and the oxygen side second.

Stand to the side of any cylinder or regulator when opening a cylinder valve.

As you turn the regulator adjusting screw clockwise, watch the low-pressure gauge to see how much gas is entering the hoses.

STARTUP

1. Check the valves. Make sure they are closed.
2. Check the pressure-adjusting screws on the regulators. Make sure they are backed out or loose.
3. Standing to the side of the regulator, open the fuel gas cylinder ¾ to 1 turn. The high-pressure gauge on the regulator should pop up and read how much gas is left.
4. Open the fuel gas needle valve on the torch ½ turn.
5. Turn the pressure-adjusting screw on the red fuel gas regulator clockwise. Read the low-pressure gauge. Set the pressure for the tip you are using.
6. Close the fuel gas needle valve on the torch.
7. Standing to the side, slowly open the oxygen cylinder valve a little bit, then open the cylinder valve all the way.
8. Open the oxygen needle valve on the torch body ½ turn.
9. Turn the pressure-adjusting screw on the green oxygen regulator clockwise.
10. Read the low-pressure gauge. Set the pressure for the tip you are using.
11. Close the oxygen needle valve on the torch body.

Use only a striker to light a torch. Fire from matches or lighters can react violently with high-purity oxygen.

The gases are now ready to be lit. Here are a few pointers when lighting a torch:

- Use only a striker to light a torch. Never use matches, lighters, hot metal, or another torch.
- Hold the striker to the side of the tip when igniting the fuel gas. Do not cup it over the tip.
- Open the fuel gas needle valve on the torch body slightly and ignite the acetylene.
- Always keep track of where your torch is pointed. Be certain to point it away from any flammable objects, gas cylinders, hoses, regulators, and people.
- Adjust the acetylene needle valve on the torch body until you have the amount necessary for the volume of heat required for the job.
- Slowly open the oxygen valve and adjust to the required flame.

Leaving oxygen and acetylene under pressure in the hoses is a potential hazard. When you finish using a torch, be sure to bleed the lines.

SHUTDOWN

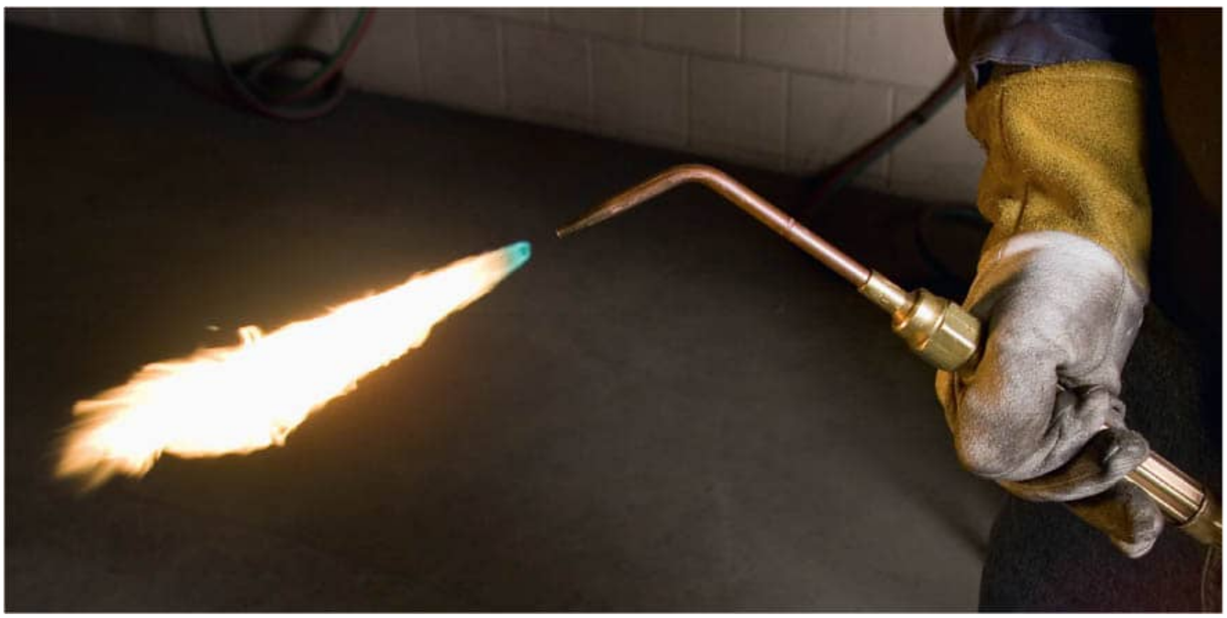
Shutting down the torch bleeds the lines of pressurized gases.

1. Close both gas cylinder valves.
2. Open the fuel gas valve on the torch body to bleed the gas from the hose. Watch the regulator gauges and make certain both drop to 0.
3. Open the oxygen valve on the torch body to bleed the oxygen line. Both the low-pressure gauge and high-pressure gauge should drop to 0.
4. Turn the pressure-adjusting screws counterclockwise until they are loose.

TYPES OF FLAMES

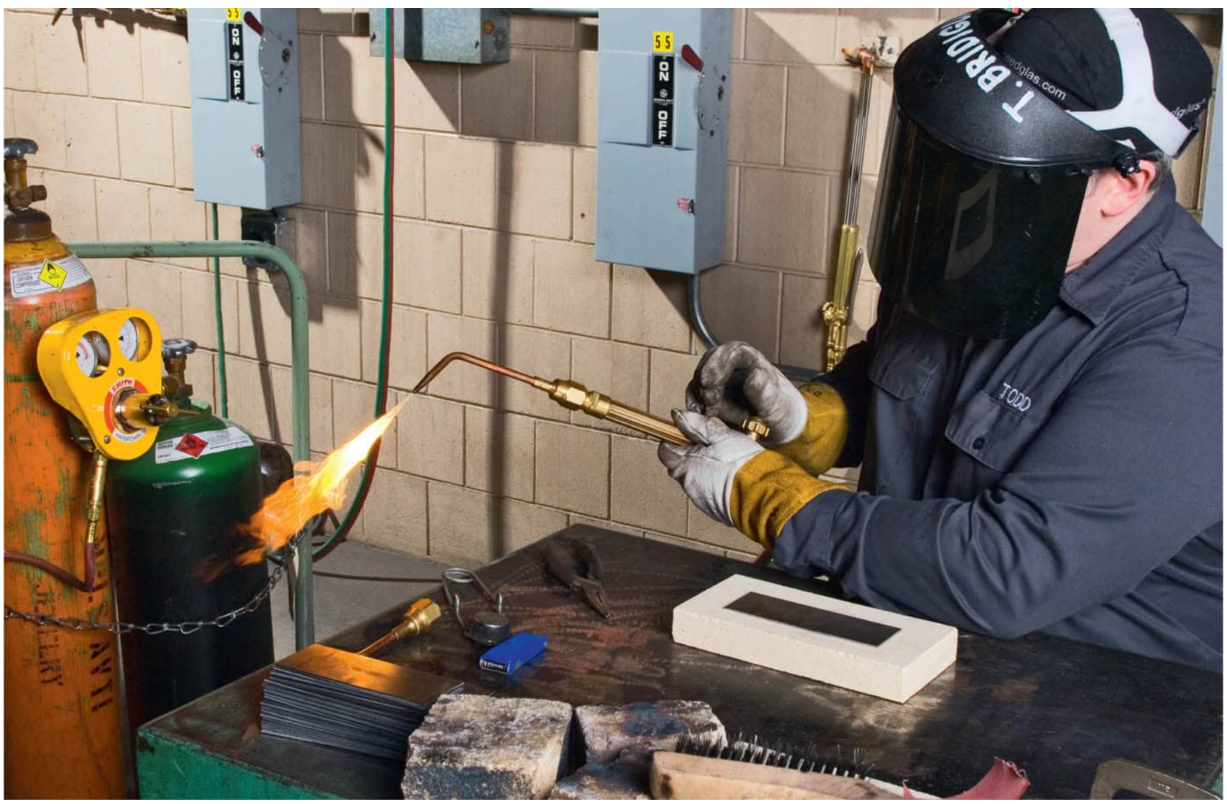
After lighting the torch, adjust the amount of acetylene for the tip size and amount of heat needed. The acetylene will burn with a bright orange flame. If you turn up the acetylene too high, the torch will snuff itself out when you add the oxygen. If this happens, shut down the needle valves and try again. It might take a few tries to get the feel for how much acetylene to add in the beginning. One clue to look for is the acetylene flame jumping away from the tip. If the acetylene flame does not burn at the end of the tip, there is too much acetylene and too much turbulence for the torch to handle.

Once you have the right amount of acetylene, add some oxygen to the mix. This will cause the flame to change color. Oxy/acetylene flames are identified by "reading" their three parts: the cone, feather, and envelope. As you add or subtract oxygen with the needle valve, the flame will be carburizing, neutral, or oxidizing.



If the orange flame jumps off the end of a torch tip, there is too much acetylene flow for the tip you are using.

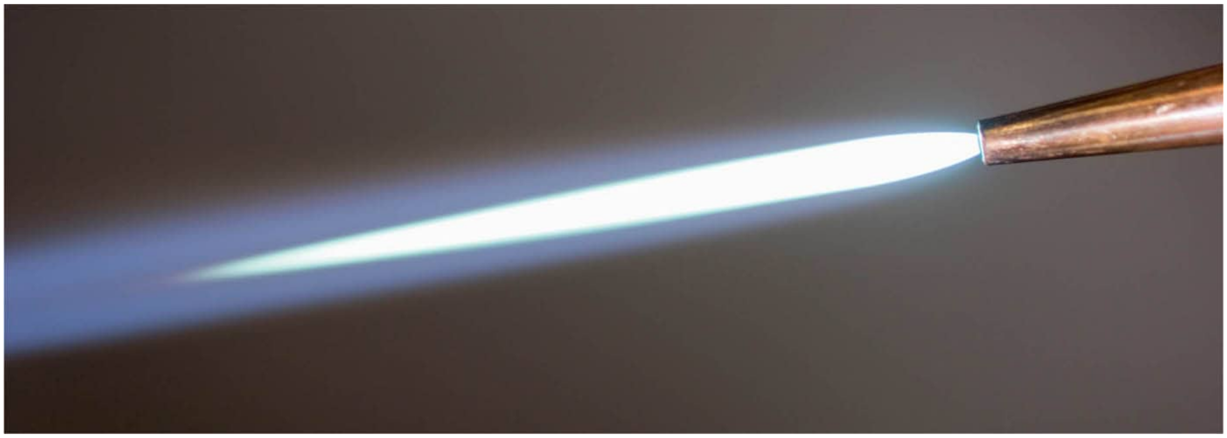
Adjust the acetylene gas first before adding oxygen to control the volume of heat in the oxy/acetylene flame.



Wearing a #5 shade, like the one on this face shield, provides a clear view of the oxy/acetylene flame.

CARBURIZING FLAME

A flame with a cone, feather, and envelope is a carburizing flame. This is the only flame in which all three parts are visible. Carburizing flames have too much acetylene gas in the mixture. Turn up the oxygen gas to achieve a neutral flame. Sometimes a carburizing flame is used on purpose for brazing and soldering because of its lower temperature. Carburizing flames tend to make metals more brittle.



A carburizing flame is easy to identify because the feather is always visible.

NEUTRAL FLAME

As you add oxygen, the feather will become smaller. A neutral flame happens at the point at which the feather meets the cone and they combine. Only the cone and the envelope are now visible. A neutral mixture of oxygen and acetylene completely burns off both gases. A neutral flame is used in most gas welding and cutting applications.

A neutral flame has a light-blue cone next to the tip and a darker blue envelope. The feather can no longer be seen.

OXIDIZING FLAME

This occurs when there is too much oxygen in the gas mixture. The cone and envelope will be shorter, and the flame will hiss louder. Typically, an oxidizing flame has no useful purpose in welding or brazing. Turn the oxygen needle valve clockwise to reduce the amount of oxygen until the feather reappears. Then remix for neutral.

TORCH POPPING AND LOOSE FLAMES

When a torch backfires, the flame goes out with a loud pop or series of pops that sounds like a string of firecrackers going off. This is the sound of the gases exploding inside the tip. A backfiring torch usually sends sparks of molten metal from your puddle flying everywhere. Torches pop out for many reasons:

1. The welding or cutting tip is too hot. Welding or cutting for a long time, getting too close to the metal with the torch, and working in the corner of a piece of steel can all cause the tip to overheat.
2. The regulator pressure is incorrect for your torch tip.
3. The tip accidentally touches the work.
4. Little pieces of spatter build up inside the tip. Use a tip cleaner to clean the torch tip and allow the gases to flow properly.

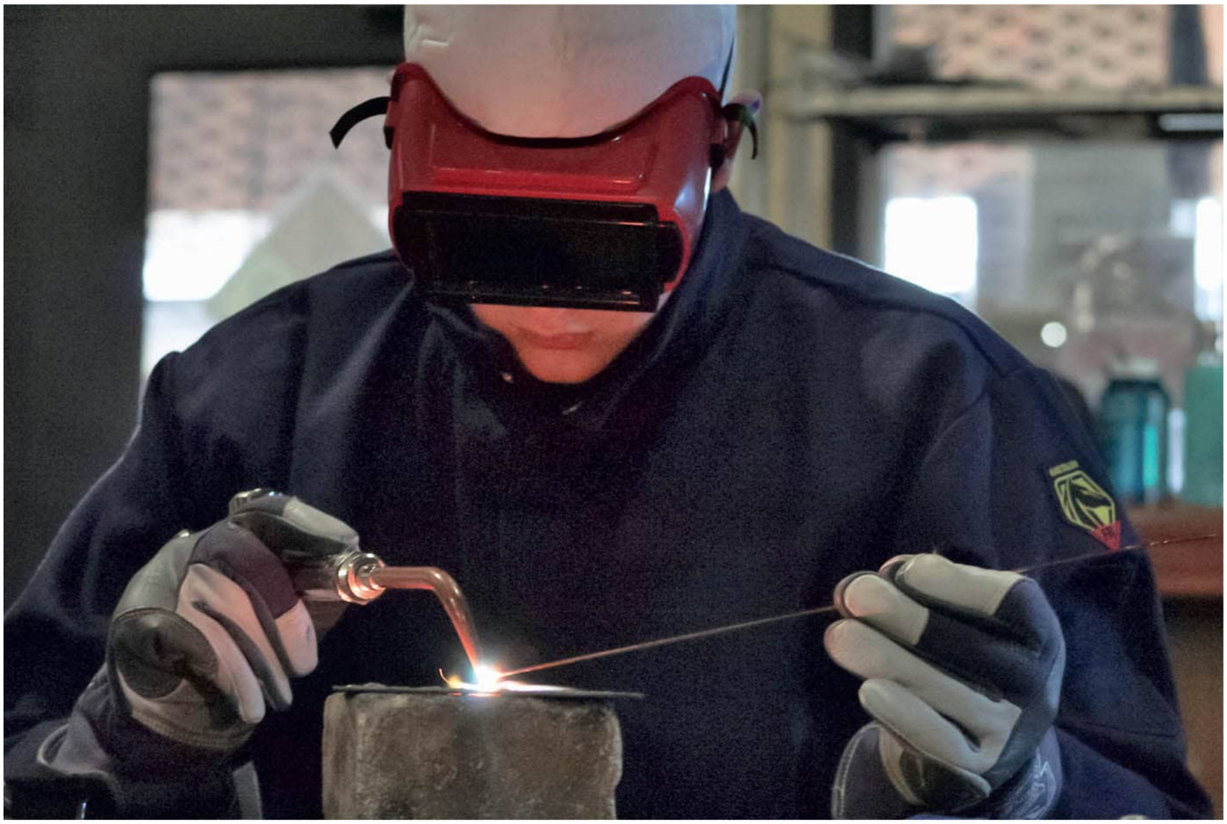
The flame should always exit the torch tip *only*. If a flame exits anywhere else, shut down the torch. Loose flames are a sign of trouble. Bleed the lines and check all the connections. If any are loose, tighten them down. Even the connection between the copper tip and brass nut on a welding tip or between the torch body and cutting tip on a cutting attachment can come loose.

Flashback occurs when mixed gases burn inside the torch tip. It is easy to identify because of the shrill hissing and squealing sound. The tip will glow orange and begin building pressure in the torch higher than in the hoses. Eventually, flashbacks will burn back into the system, damaging equipment and possibly exploding. If a flashback occurs, shut the needle valves immediately and determine the cause. Flashbacks have many of the same causes as backfires and can be prevented. The following conditions can cause torch starvation, which in turn will overheat the torch, causing a flashback:

- Restrictions in the gas lines
- Extreme lengths of small-diameter hoses
- A torch tip placed directly on the metal
- Improper gas pressures for the tip or attachment being used
- Damaged or mishandled (overtightened) needle valves
- Improper seating of the acetylene cylinder valve

5

GAS WELDING, BRAZING, AND SOLDERING



Wear a #5 shade when torch welding to see the molten puddle clearly.

HOW GAS WELDING WORKS

Often people think of welding, brazing, and soldering as the same thing. They are similar in that you melt metal to join two pieces together. In brazing and soldering, however, only the filler metal is melted. Welding is different because more heat is used to melt everything together. The filler metal and the base metal are heated until they turn into a liquid. The liquid pool that forms on the base metal is called the puddle. Using the torch to move the puddle, making it bigger or smaller, and adding filler metal are the fundamentals of welding.

In welding, the filler metal is usually matched to the base metal. Using a steel filler rod to weld steel sheets together is common. There are filler rods for gas welding, but TIG welding filler rods work just as well. A spool of welding wire will work too. Just unspool what you need and cut it off with a wire cutter. It may help to straighten it a little before welding.

Oxygen and acetylene are the gases used for welding steel. Oxygen combined with another fuel gas, such as propane or natural gas, is good for cutting and heating, but the flame temperature is not high enough to create a small molten pool on steel. Oxy/acetylene is rarely used in the manufacturing industry because it is slower than arc welding, but gas welding is a great way to learn how to weld because you can see the puddle clearly as you move it with the torch. Working slowly allows the welder to make small changes as they go.

Buying an oxy/acetylene torch allows a person to weld, braze, cut, and heat—all without electricity. Different tips are required for each process, but there is some crossover. The oxy/acetylene tip for welding is also used for brazing. A cutting torch tip is used primarily for cutting steel, but a cutting torch can also be used for welding and brazing with caution. The torch operator must be careful not to press the cutting jet lever; otherwise, a stream of pure oxygen can gouge or cut through in an instant what is supposed to be joined. Heating can be done with a welding or cutting tip in a concentrated area. This is good for heating up metal, making it easier to bend. A rosebud tip is the best choice for heating large areas. Metal is commonly heated before and after welding and to remove moisture from a joint.

Welding into corners, as shown on this T joint, requires more heat than welding other joints.

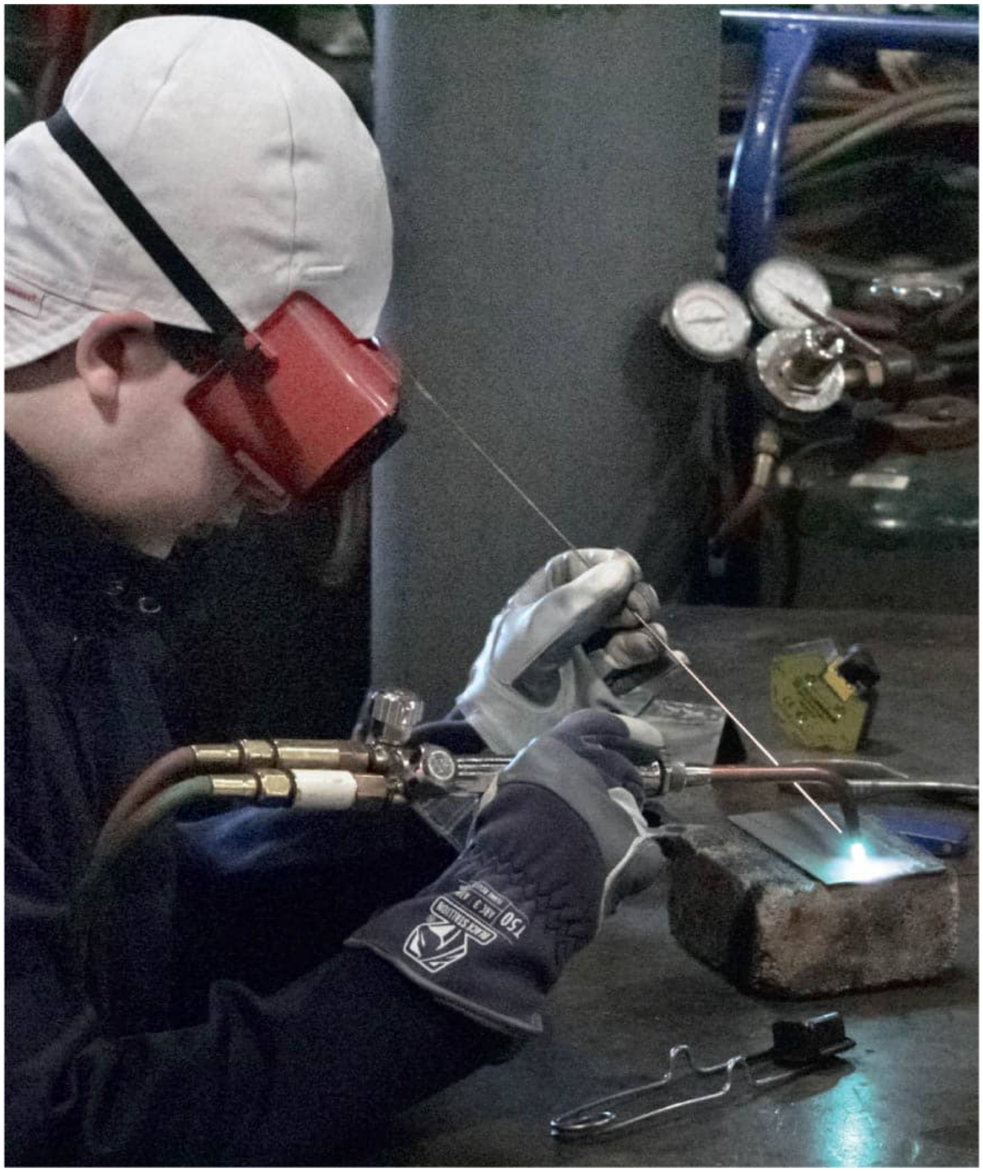
GAS WELDING TECHNIQUES: DASH

Four main factors determine how a weld will turn out: distance, angle, speed, and heat (DASH). Paying attention to these four things at the same time is difficult, but the slow speed of gas welding helps the beginner manage the torch. If you get these four things right, you will have a good weld every time. If you get one of them wrong, your weld may or may not turn out. Two or more incorrect, and there is no hope of success.

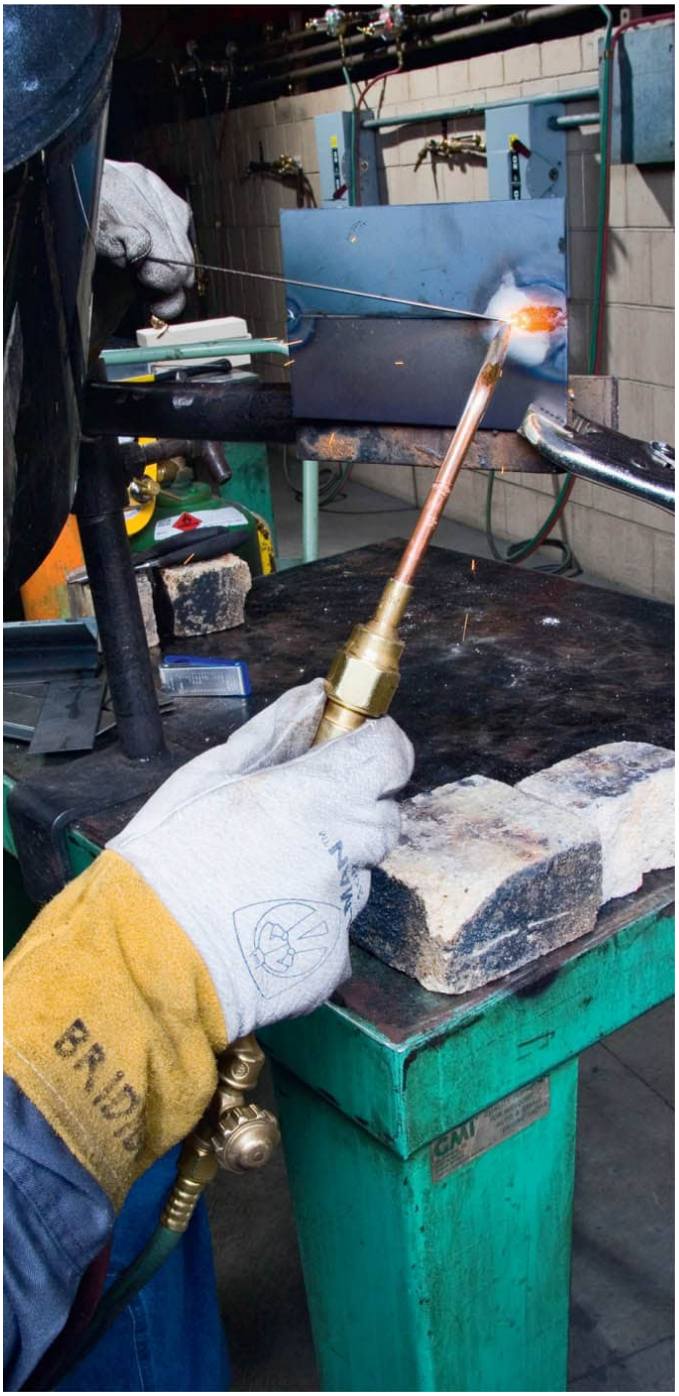
DASH changes depending on the welding process, thickness of metal, joint design, and welding position. For oxy/acetylene welding, there are many relationships between the factors to consider. Keep these relationships in mind when welding. The better you understand them, the better your chances for success.

One other thing: try to relax and get comfortable. Position your arms and body so you don't need to strain. The more you can support yourself when welding, the better. Tired hands, arms, legs, and body make it difficult to concentrate. This is true whether you are welding in a shop or repairing equipment outdoors.

Adjust the amount of acetylene first for the required heat, then add oxygen to the flame.



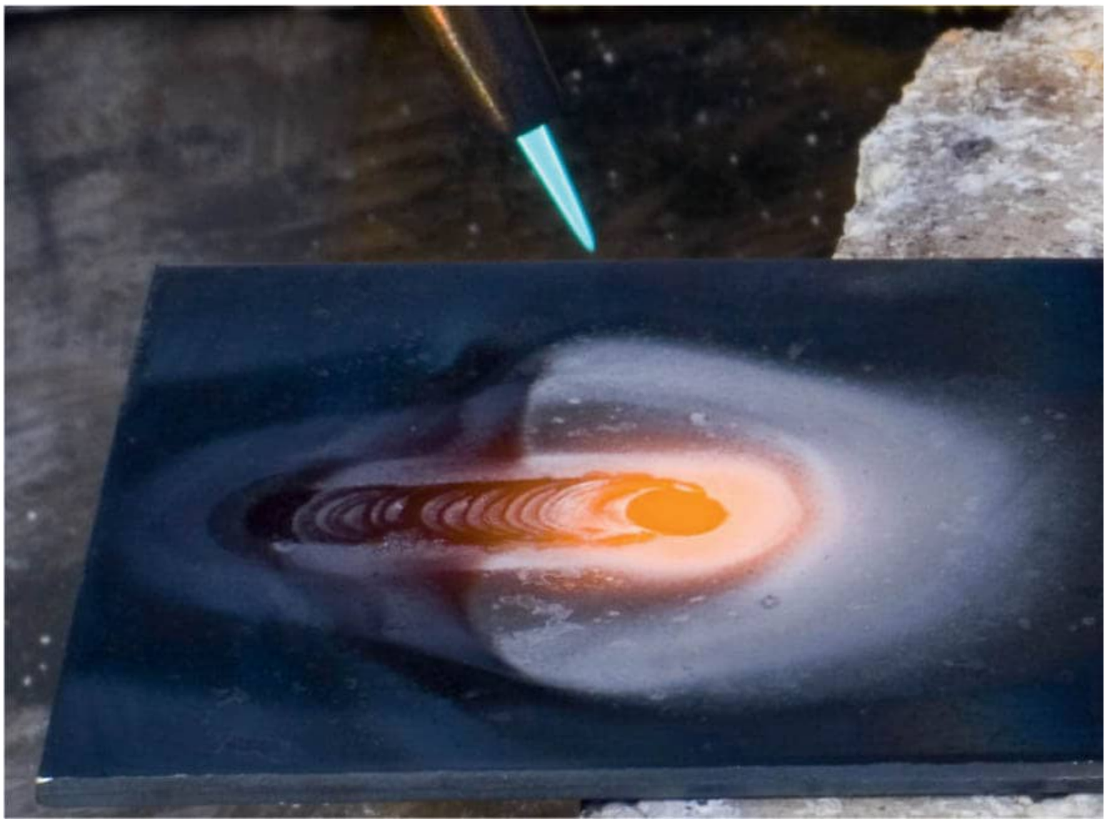
Practice moving the puddle with your torch first, then try adding filler metal to the weld pool.



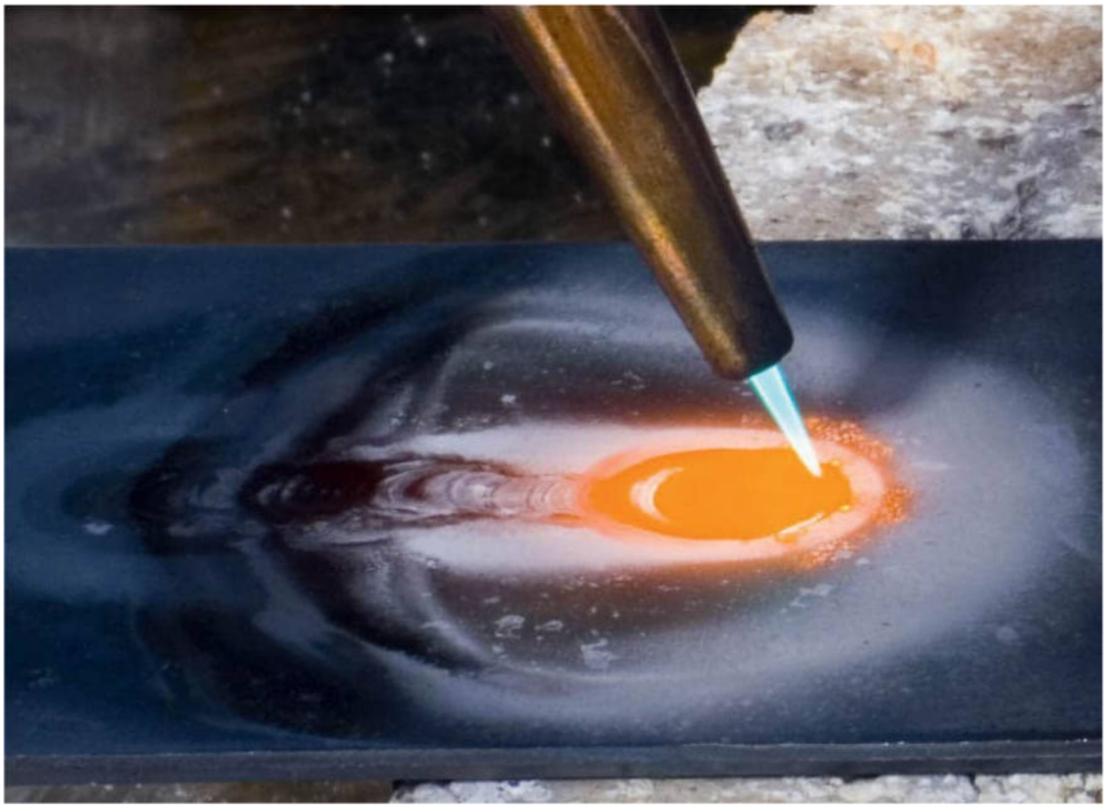
Brace your arms and hands wherever you can to stay steady. This is especially challenging when the weld is not flat on a table.

DISTANCE

The tip of the neutral flame cone should always be ⅛ inch from the metal. Keep this distance consistent throughout the weld. Get familiar with what ⅛ inch looks like. Find a piece of metal that is ⅛ inch thick and put it next to your flame. Little changes make big differences. A flame is not as effective if it is close but not close enough, such as ½ inch away. Don’t pull the torch back to reduce the heat—remove the flame completely if things get too hot.



This torch is too far away from the steel. The cone needs to be about ⅛ inch from the metal.



When the cone is the correct distance from the metal, it is easier to move the puddle on the plate.

ANGLE

The heat will go where you point the torch. Two angles help you keep track of where the heat is going. *Travel angle* is the angle the torch is held parallel to the weld joint. *Work angle* is 90 degrees or perpendicular to the weld, as when the torch is tilted side to side. A steep travel angle occurs when the flame is pointed more toward the workpiece. This will put more heat into the metal. A shallow travel angle happens when the flame is pointed less toward the metal. This causes more heat to bounce off the workpiece, reducing the heat going into the base metal.

Use a push technique for oxy/acetylene welding: point the torch in the direction of travel.

If the torch angle is directed toward one piece of metal and not the other, only one side of the joint will melt.

Traveling too slowly on thin metal can cause burn-through, creating a hole in the metal.

When adding filler metal, keep the rod close to the cone so it remains hot, which makes it easier to dip into the puddle.

SPEED

How fast you should move the torch depends on what the molten puddle is doing. If the puddle disappears, that means the heat was removed. Moving too quickly or changing direction suddenly causes this type of problem. Slow down, work with the bead, and watch what it does. Read the puddle. If it spreads out and gets too big, speed up. Pay attention and adjust to what you see. Once you start welding, a consistent travel speed will help put a uniform amount of heat into the base metal along the weld joint. Look for a bead width from ¼ to $^{5}/_{16}$ inch.

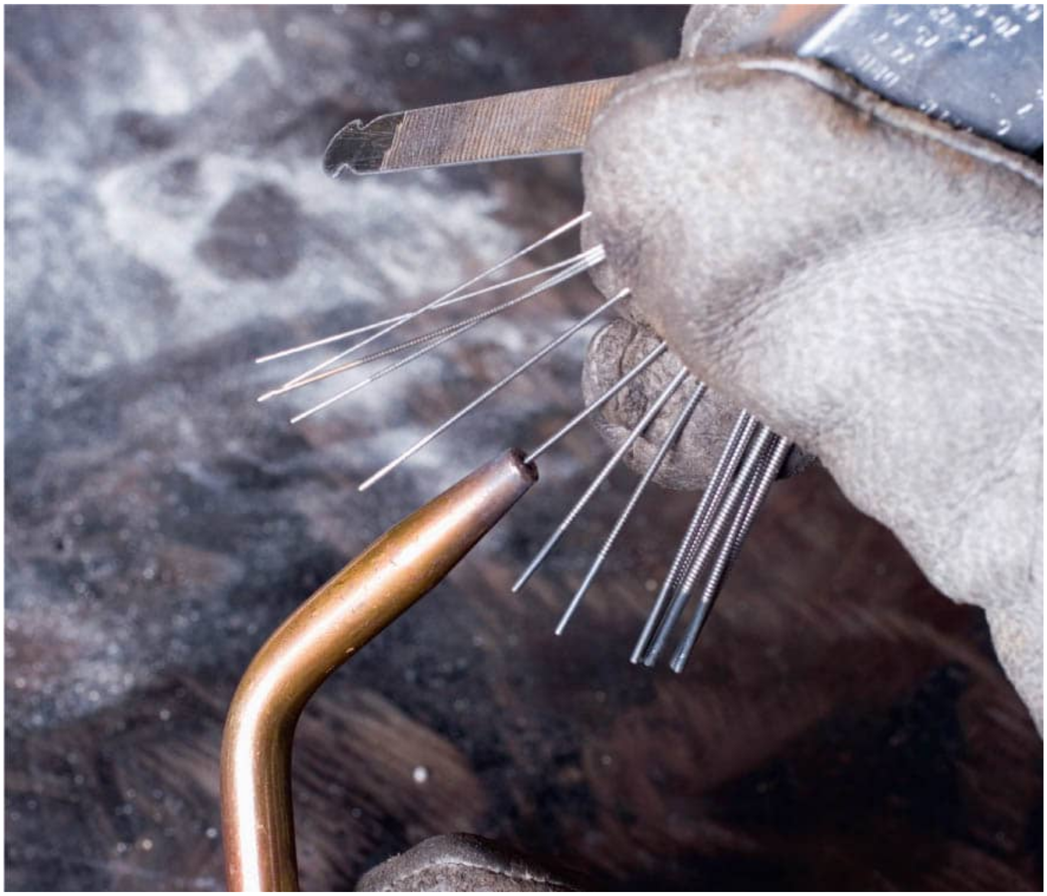
HEAT

The volume of heat in oxy/acetylene welding depends on the size of the tip you are using and the amount of acetylene in the gas mixture. Adjust the gas mixture to change the amount of heat. If adjusting the acetylene is not enough to achieve the amount of heat you need, then you might need a different tip size. Heat also changes because of the other parts of DASH. Even though holding the flame farther away will cool things down, it's best not to use distance to control heat input when welding with oxy/acetylene. Keep a consistent distance. Torch angle will determine where the heat goes. Incorrect torch angles will direct heat where it is not needed, such as one piece of metal in a joint and not the other. Both pieces of metal need to be hot enough to melt. Otherwise, you could be melting filler metal on top of base metal, like icing on a cake. Remember the base and filler metals need to melt together for the weld to be strong. Finally, the faster you go, the less time the flame has to heat the metal. The slower you travel, the more time the flame has to get things hot—maybe too hot.

COMMON GAS WELDING PROBLEMS

Gas welding is a good way to join sheet metals less than ¼ inch thick. One common mistake is trying to weld a thick piece of sheet metal with a tip that is too small. Matching the welding tip size to the thickness of metal will create enough heat to form the puddle in a short amount of time, usually less than 30 seconds. If you are welding a piece of metal and a minute goes by without a puddle forming, the metal is probably too thick for the tip.

Gas welding tips are prone to getting dirty from weld spatter and can easily overheat and pop out or backfire. Have a tip cleaner on hand to scrape the soot off the end of the tip. Use the correct-size reamer to clean out the hole where the flame exits. Don't force a reamer into the torch tip; it is likely to get stuck and break off. Don't overclean a tip, either. Once the hole becomes misshapen or too large, the tip will no longer hold a proper flame. See "Torch Popping and Loose Flames" in chapter 4.



Use a tip cleaner to remove soot and debris so the flame works properly.

The amount of acetylene in a neutral flame determines the volume of heat. A small campfire made from twigs and branches burns at the same temperature as a large bonfire made from big slabs of wood. The difference is the amount of fuel in the fire. The bonfire has more fuel and throws out more heat. While we can sit close to the small campfire, we need to back away from the bigger fire because it has a larger volume of heat. Acetylene works much the same way. The more acetylene in a flame, the more heat it will produce. If the molten puddle is not forming on a thicker piece of metal or if a T joint requires more heat, you can add more acetylene to the flame. If you are welding thinner metal, you can reduce the amount of acetylene for a smaller amount of heat. Whatever the amount of acetylene you use, it is important to add enough oxygen to the mix to achieve a neutral flame.

If the torch burns through the metal right away, try using less acetylene or switch to a smaller tip.

HOW BRAZING AND SOLDERING WORK

Brazing and soldering are different from welding in two ways. First, the only metal that melts in the brazing and soldering processes is the filler metal. If the pipe, tube, or sheet melts, that means the heat is out of control. Second, the filler metal is usually different from the base metal. A filler rod made of silver, copper, and zinc can braze steel, stainless steel, copper, brass, and other dissimilar metals. This is a reason why the filler metal for brazing and soldering is also called a filler alloy. An alloy is a mix of different metals. Common soldering alloys are 50 percent tin/50 percent lead, 95 percent tin/5 percent antimony, and silver-bearing soft solder, which is 96 percent tin/4 percent silver. Common brazing alloys are silver braze (also called silver solder), which is mostly silver with copper and zinc, and Sil-Fos, which is mostly copper with some silver and phosphorous. Sil-Fos brazing rod is unique because it does not require flux.

It's not surprising that soldering and welding are thought of as the same thing. In fact, the Spanish word for welder is *soldador*. Soldering *is* different from welding but is basically the same as brazing. The big difference is that soldering happens at a lower temperature than brazing, usually lower than 840°F (449°C). That may be very hot in most circumstances, but it is a low temperature when joining metals.

Tools for soldering include flux, solder, sand cloth, a wire brush, and a tool for deburring the tube after it is cut.

The filler alloy used for soldering has a much lower melting point than metals for brazing or welding. Flux (see below) is also designed to flow over the base metal with less heat.

A wide variety of gases and torches are used for brazing and soldering. MAPP gas, propane, and butane torches put out enough heat to melt most filler alloys. These fuel gases can be combined with pure oxygen, such as with an oxy-propane torch, which can use different attachments for brazing, cutting steel, and heating metals. Often, however, torches for brazing and soldering are used with regular air instead of pure oxygen. There is enough oxygen in air to support the combustion, but because it is mixed with other gases, the flame temperature is lower. This is good because the torch should melt only the filler alloy and not the base metal.

Soldering and brazing have advantages over welding in certain situations. They are great ways to join metals without the high heat of welding. Some metals, such as cast iron and tool steels, are difficult to weld because they tend to crack after being heated to a high temperature. The cracking usually happens when the workpiece is cooling down. Other metals, such as copper, can become very weak after welding. Soldering joins copper tubing at a low temperature and keeps it rigid while making a watertight seal.

Tools for brazing include flux, brazing alloy, sandpaper, a wire brush for cleaning the inside of the tube, a tube cutter, and a reamer for deburring.

Torches for soldering and brazing are available at most hardware stores. Here, a MAPP gas torch is used to solder a copper fitting.

There are other circumstances in which welding is the best choice. If the metals being joined will be under high mechanical stress or used in a place where they will be very hot—for example, as part of an engine exhaust—then welding could be a better option. Dirty metals that cannot be completely cleaned and joints with big gaps are also better joined by welding than by brazing or soldering.

BRAZING AND SOLDERING TECHNIQUES

FIT-UP

It is important to keep a small space between parts being brazed together. The gap should be about the thickness of a sheet of notebook paper. This tiny space is where the braze alloy will flow. It is very difficult to measure this space without a caliper. If the pieces easily slip together, the space should be about right. If a joint is forced tightly together, the braze has nowhere to go and will not hold.

CLEANING

Use a solvent or degreasing product to remove any oil or grease from the metal. Then, you must clean the metal again with sand cloth or a wire brush both inside and outside. The metal surfaces should look bright and shiny. Clean all the parts where they come together and a little beyond where they overlap.

FLUX

Flux is like primer on a car. Primer is applied first to help the paint stick. Flux is similar in that it helps filler alloy stick to the metal being brazed. You need to apply the correct flux in the correct amount. Read the label on the container—it will say whether the flux is for brazing or soldering. Coat all the mating surfaces with flux. This is easy to see if the tube has just been cleaned and the metal is bright. If you add too little flux, the heat from the torch can burn it off before everything gets hot enough for the filler alloy to melt. Adding too much flux can clog and corrode the inside of a tube.

HEAT

Once you complete the prep work, you can put heat from a torch to the joint. Keep the torch at a consistent distance from the tube. The flame cone can be right next to the metal or held back a little so the envelope of the flame wraps around the tube. Keep moving the torch around to all sides to heat the tube evenly. What matters most is the amount of heat that is put into the part being brazed or soldered. There is what I refer to as a window of heat, in which everything can go right. If the parts being joined get too hot or are not hot enough, brazing or soldering will not happen. Keep in mind that different metals take different amounts of heat to reach the correct temperature range. A small copper water line will need much less time under the flame than a broken steel handle on a piece of machinery.

Be sure to move the torch around the tube to heat all sides evenly before adding the filler alloy.

JOINING

At the right temperature, the flux will spread out, forming a coating over the metal. Once the flux melts, it's time to start testing whether the base metal is hot enough to melt the filler alloy. Touch the rod to the part. The rod should melt and flow onto the metal when the temperature is right. When everything goes well, the solder or braze metal will flow into the joint.

Put a short bend in the soldering rod to make it easier to tell how much solder you are adding to the joint.

DEWETTING: A COMMON PROBLEM

The most common time brazing and soldering fails is when the filler alloy does not flow completely onto the metal being joined. This condition is called nonwetting or dewetting. Basically, the filler does not go where it should because something has gone wrong with the prep work or with heating the metals. The filler alloy might even flow out on most of the part, but if you miss a spot, the dewetted part will leak. This is because the filler alloy has not filled one area of the tube, creating a path for the fluid to come out. If dewetting happens, there is nothing you can do except start over. The parts can be reheated and pulled apart, recleaned, and refluxed. Here are some tips for avoiding dewetting:

Silver brazing is a good process to use for joining brass fittings to copper tubing.

1. Be sure to clean the whole surface of both pieces to be joined. Take the time to inspect your work carefully.

2. When you have cleaned the metal with a solvent and brushed it until it is bright, that is the best time to apply the flux. Newly cleaned parts can quickly get dirty again with soil or grease. Even the oil on your fingers can contaminate the metal. Avoid touching clean parts.
3. Carefully apply the flux over all the surfaces to be joined. Filler alloy will flow around any missed spot instead of over it.
4. Be sure to apply the correct flux. The brazing process is too hot for soldering flux to work. Soldering is not hot enough to melt brazing flux.
5. Be sure to apply enough flux for the high heat of brazing. If you apply too little flux, it will burn off before the parts are hot enough for the filler alloy to flow. Put a little extra flux on the outside of the tube.
6. Keep your heat in the window. If the filler alloy does not melt, your parts need more time under the torch flame. Just a few more seconds might raise the temperature enough for soldering or brazing to happen. Test the heat with your solder or braze rod often.

6

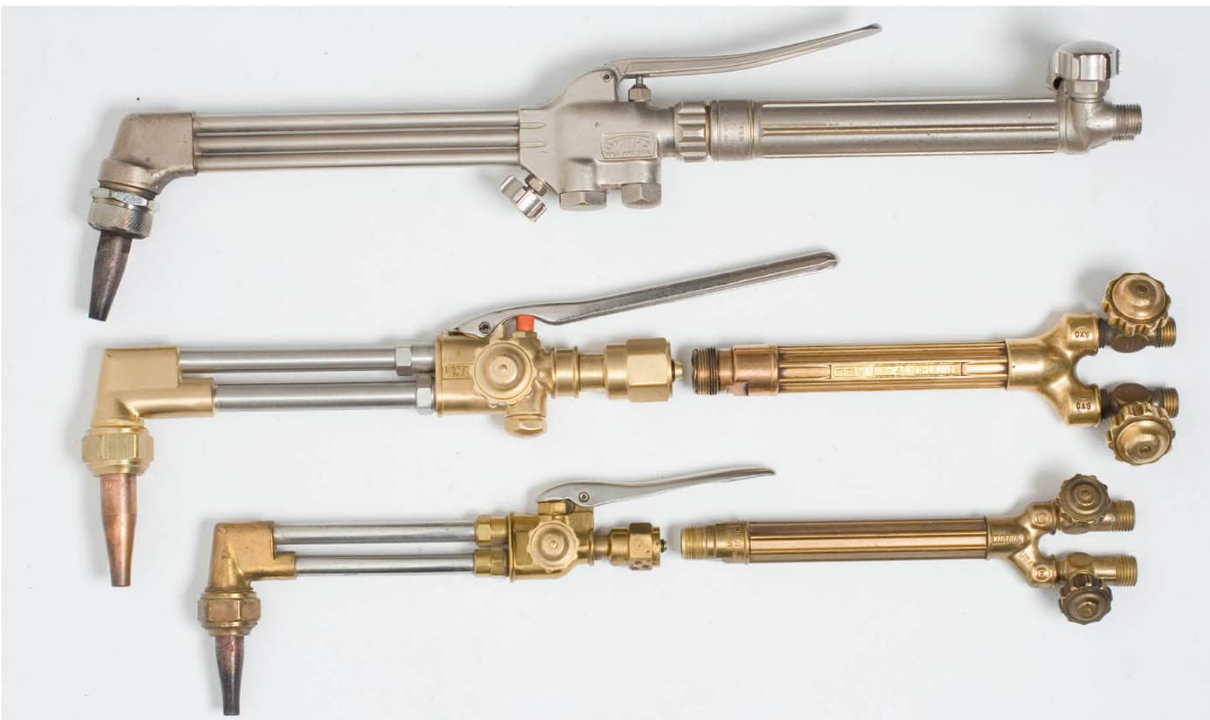
TORCH AND PLASMA CUTTING

Cutting steel creates lots of sparks. Keep track of where they are going and avoid directing sparks toward flammable materials.

HOW TORCH CUTTING WORKS

It is easy to imagine taking a super-hot flame and melting two pieces of metal together. However, melting metal is different from cutting it. Cutting is more exact.

Humans have used high-purity oxygen to burn metal for centuries. In the late 1800s, a torch was developed that could cut a large hole in a ¼-inch steel plate. Banks and companies that made safes and vaults now had a lot to worry about! Around this same time, someone tried to cut open a vault with a torch hidden in a suitcase. The small cylinders didn't hold enough gas to finish the job, so the would-be thief left empty-handed.



Cutting attachments come in a variety of sizes and connect to the matching torch body

High-purity oxygen (95 percent or higher) burns almost anything. Keep this in mind when you are using any torch—your clothes and body are combustible. A fire is a chemical reaction that happens when fuel and oxygen reach a high enough temperature to combust. Burning steel with oxygen is a little different. First, the steel needs to be hot enough, around 1,500°F (815°C). It will turn a bright cherry red, almost orange. The preheat flames in a torch tip make this happen before the cutting begins. Next, a cutting jet lever on the torch sends a stream of high-purity oxygen out of the cutting tip. Then, the steel combusts. The oxygen instantly oxidizes the metal. Oxidation is a chemical process that usually happens in slow motion. Raw steel, if left outside, will rust. The rust is the iron combining with oxygen in the surrounding air to create oxidized metal. Just like preventing the slow-motion rusting process, anything that interferes with the torch's oxygen stream will slow the cutting, make poor-quality cuts, or not cut through the metal at all.

Propane is a common fuel gas used for torch cutting. Acetylene fuel gas is also used for cutting and is more versatile because it can also be used for welding, brazing, soldering, and heating. The fuel gas is combined with high-purity oxygen to increase the heat of the flame and allow for the cutting of steel. Torches and torch tips may vary depending on the fuel gas being used. (Refer to chapter 4, "Oxy/Fuel Gas Equipment and Safety," for more information on gases, cylinders, regulators, and torches.) Cutting tips are different from welding or heating tips. They deliver the right amount of oxygen for cutting to an exact place on the steel. Pressure settings for torch tips will be different, too. A similar amount of acetylene is used for cutting as for welding, but a lot more oxygen is required to cut metal. For example, a Victor #2 welding tip works at 5 psi of acetylene and 5 psi of oxygen. A Victor 1-101-1 cutting tip works with 5 psi of acetylene and 30 psi of oxygen. Refer to a torch tip chart to find out what gas settings are required.

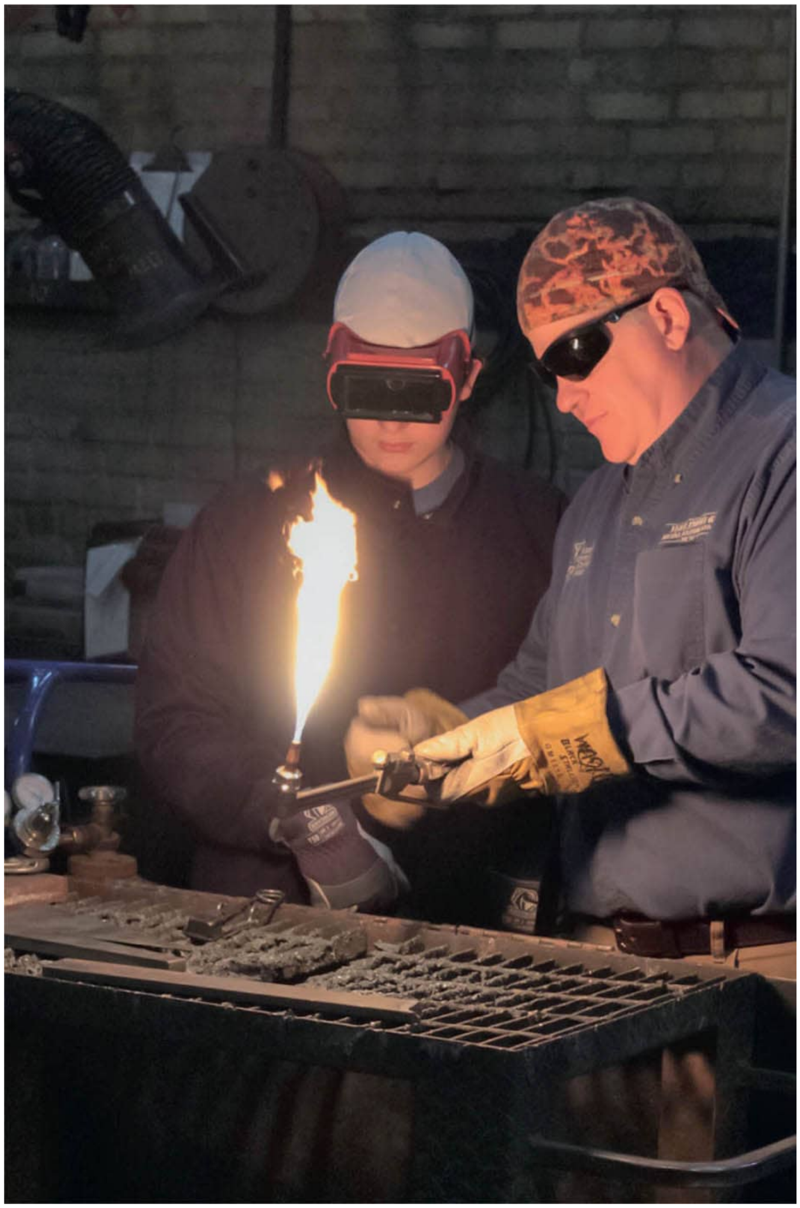
Cutting tips usually have their size stamped on them. You can use a variety of tip sizes with the same torch.

TORCH CUTTING TECHNIQUES

Once the torch outfit is pressurized, the torch is ready to light. Always use a striker for lighting a torch. Lighting a torch with a lighter, matches, or hot metal is dangerous and can lead to injury. It is also a good idea to keep lighters and other flammable materials out of your pockets. Torch cutting produces a lot of sparks that go everywhere, including into pockets, cuffs, and shoes.

Turn on the acetylene, then light the gas with your striker. There should be a bright orange flame. Turn up the acetylene so that the flame feathers out. The more acetylene you add, the larger the preheat cones will be when you add oxygen to the mix. Larger preheat flames are usually better because cutting can go faster with more heat. Slowly mix in the oxygen and watch the flame change. Seeing the different parts of the flame is a lot easier with #5 shade goggles; I recommend wearing a pair when cutting. Once the feather meets the cone, push down the cutting jet lever completely. The feather might jump off the cone. If this happens, add a little more oxygen so the preheat cones are sharp and well defined. Neutral preheat flames will do the best job of heating the metal before and during a torch cut.

An oxygen jet leaves small grooves in the cut metal, which you can polish out with a grinder.



After lighting the torch with a striker, add enough heat by turning up the acetylene until the orange flame feathers out.

Get comfortable with the torch. Thick gloves and a welding jacket will help because the torch and metal can get very hot quickly. Make practice cuts on some scrap metal. Watch what the stream of pure oxygen does to the metal. The steel being cut turns into something called dross or slag. It is common for some dross to stick to the back of the metal being cut. Watch what the dross does. If it comes back up to the surface of the metal, it means you have not cut all the way through. See "Common Torch-Cutting Problems" on this page for more information.

Cutting with a torch has things in common with welding. The preheat flames need time to do their job—you can only cut as fast as the preheat flames allow. Try to use a smooth, steady motion while keeping the torch at a consistent distance from the metal. The preheat flames need to be about ⅛ inch away. If they are too far away, the metal will not preheat correctly, and cutting will be erratic or stop completely. If this happens, release the cutting jet lever. Take the time to get comfortable and be sure you can clearly see what is happening.

With the cutting jet lever pressed down, a feather appears, indicating a slightly carburizing flame.

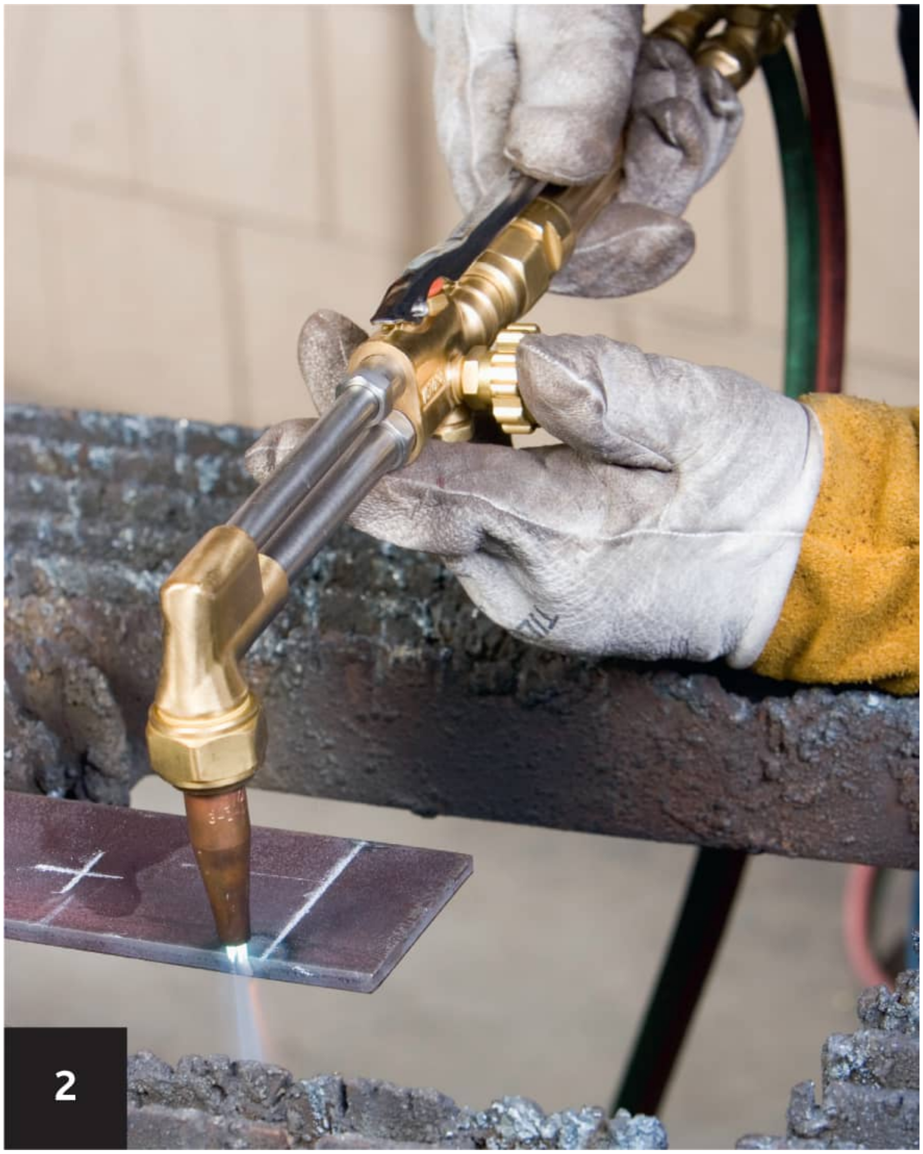
Hold the cutting jet lever down and adjust the oxygen until the feather combines with the cone. This is a neutral flame.

Right-handed people typically use their right hand on the cutting jet lever and their left hand to support the torch.

Use soapstone to mark the metal to be cut. Soapstone holds up well under the heat of the torch and is still visible at 1,500°F (815°C). To make straight cuts, use a straightedge made from angle or bar stock. Clamp metal straightedges to a workpiece as a cutting guide. You can weld handles onto straightedges and other cutting guides to make them more portable. This is useful when cutting large or oddly shaped pieces.

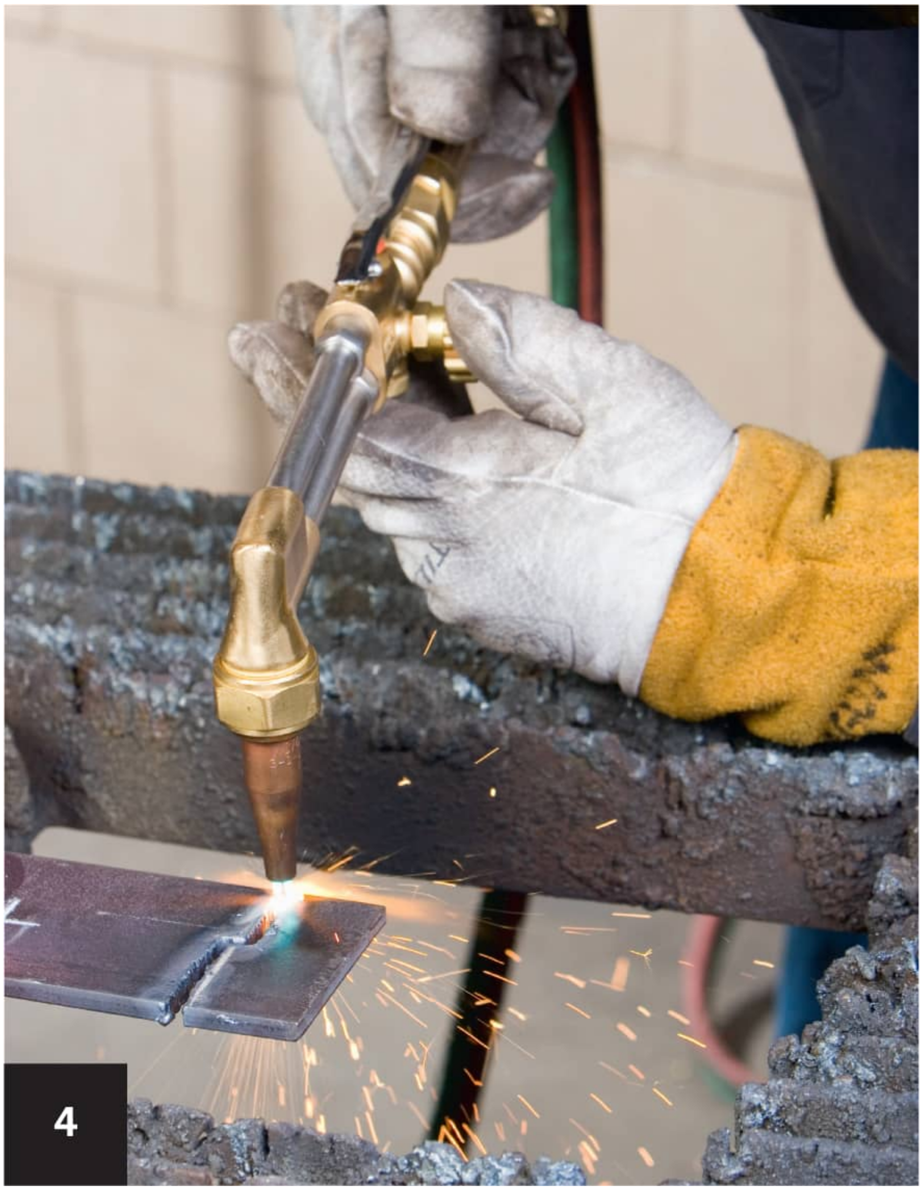
Resting one arm on the table for stability is easier with thick gloves and a welding jacket providing protection from the heat.

A combination square works well for laying out cut lines with soapstone.



Preheat the edge before cutting. Apply heat until the steel turns red-orange.

Push the cutting jet lever all the way down and begin moving the torch. Try to maintain a consistent distance and speed while cutting.

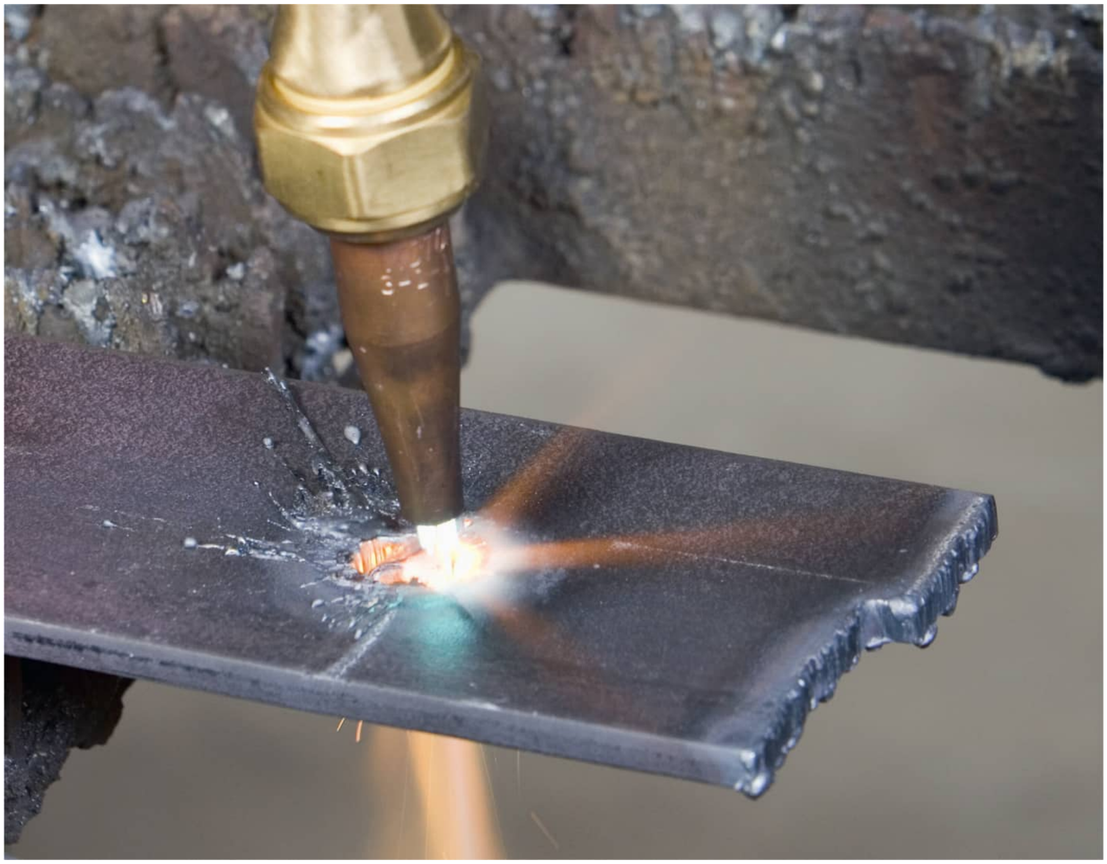


The metal should fall away when the cut is complete. Be careful—metals cut with an oxy/acetylene torch are usually very hot.

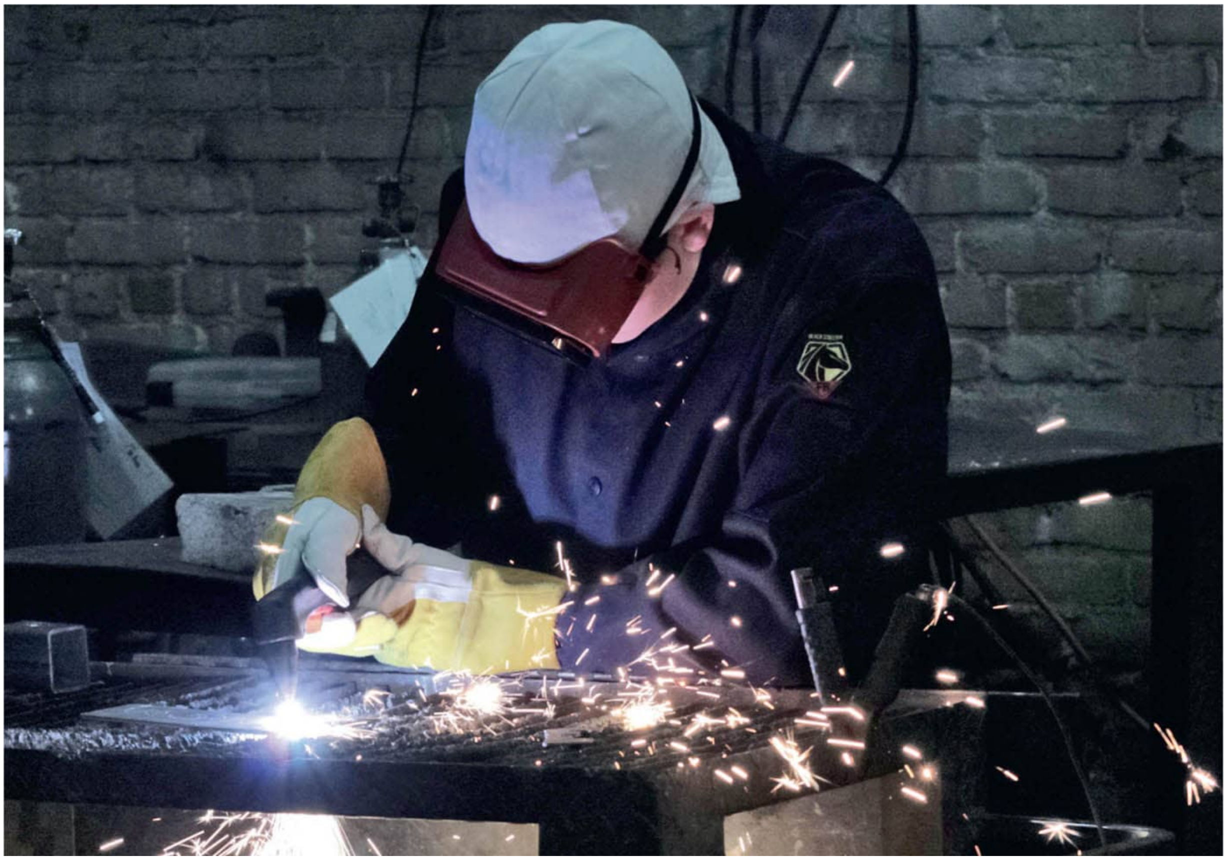
This straightedge made from 1½-inch pipe works well for holding the torch at an angle to cut bevels.

COMMON TORCH CUTTING PROBLEMS

Cutting thick steel plates with a small torch outfit doesn't work very well. Know what size cylinders, regulators, torches, and torch tips you need for the work you are doing. It is a good idea to have a variety of torch tips on hand for different situations. A Victor 1-101 #000 tip will do a good job cutting through ⅛-inch sheet metal, while a 1-101 #2 tip is rated to cut through 1-inch-thick plate. It might also be necessary to have larger cylinders and hoses and a higher-capacity torch body.


When cutting holes, keep the torch in motion as you press the cutting jet lever to avoid slag clogging the tip.

Torch cutting this hole for a bolt took much less time than drilling would have.



Plasma torches cut a wide variety of metals, including plain carbon steel, stainless steel, aluminum, copper, and brass.

Cutting tips get dirty when cutting metal. Slag, sparks, and small bits of metal get stuck to the end or get into the oxygen jet hole. Use a tip cleaner on a regular basis to clean the preheat holes and the center hole where the oxygen jet flows. Debris in the tip can throw a cutting jet out of whack, making it spin or shoot off to one side. Eventually, torch-cutting tips wear out. The holes become misshapen and can no longer hold a good flame or jet, making a good cut nearly impossible.

There are several reasons why a torch will not cut all the way through a piece of metal. Sometimes, it is a technique problem, such as going too fast or holding the torch too far from the steel. Other times, it is an equipment problem, such as not setting the oxygen pressure high enough or having preheat cones that are too small. Whatever the cause, stop working if you see dross coming up through the cut. Release the cutting jet lever and take a moment to see what is going on. You may need to clean the tip, get more comfortable, or adjust the gases. If any part of the cut is all the way through, you can restart in the cut by preheating again to cherry red. Another method is to make another cut right next to where the dross came up in the first attempt. It will be better to have things start working right again than to get frustrated and struggle through a slag mess. Finally, check what type of metal you are cutting. Oxy/acetylene torches do a great job of cutting through steel, but not much else. Metals such as aluminum, brass, and stainless steel can be melted apart with a torch with a lot of heat, but it will leave very rough edges.

HOW PLASMA CUTTING WORKS

Developed in the 1950s, the plasma arc is a “newer” process in the world of welding. Plasma cutting uses electricity and compressed air to create a super-hot blue fire. The plasma arc can reach 30,000°F (16,600°C), which is hotter than the oxy/acetylene flame and most welding arcs.

Plasma is air that is charged with electricity. In nature, this happens in the air that surrounds a lightning bolt as it travels to the ground. In plasma cutting, the parts of the torch and pressure of the gas cause air and electricity to combine into plasma. The blue column of plasma is hot enough to liquefy metal while the high-pressure gas blows it away. In fact, you can cut any electrically conductive material with this type of torch.

Plasma-cutting machines are specialized for cutting only. They require compressed air to work properly. The air compressor can be built into the plasma-cutting machine or a standalone unit. Standalone air compressors are handy for running pneumatic tools and filling tires, too, so many people already have one. Make sure the compressor’s output is high enough to maintain the plasma arc you are using.

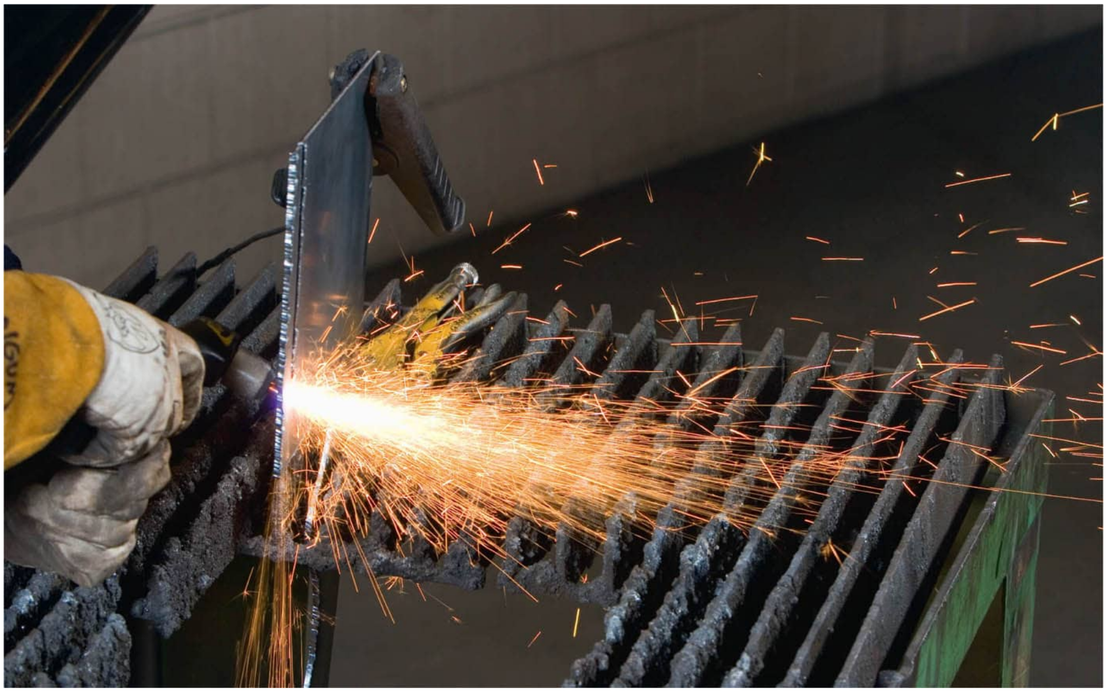
Light-duty plasma cutting machines like this one are used to cut sheet metals less than $^{3}/_{16}$ inch thick.

Plasma-cutting machines also need an electrical circuit to power the plasma arc. This requires a work connection, which is a clamp connected by a wire to the machine. The electricity flows through the torch to the piece of metal being cut and back to the machine through the work clamp. Be sure the work clamp, also called a ground clamp, is connected to clean metal.

Once the machine has power, you can set the amperage and air pressure. Air pressure is typically 70 psi. Amperage depends on the thickness of metal you are cutting and the machine capacity. I like to set the amperage on the high side of the range, often as high as it will go. This creates a hotter plasma arc, so I can travel faster. If the machine is set under 40 amps, the torch tip can touch the base metal while cutting. If you use more than 40 amps, a standoff or drag shield will keep the tip away from the metal so the surfaces don’t stick together. You can also hold the plasma torch ⅛ to ¼ inch from the metal being cut. Anyone who has practiced some welding or torch cutting will be skilled at maintaining the right distance.

A compressed-air hose connects to the back of the machine. Compressed air is electrified, turning it into plasma for cutting.


This plasma torch uses less than 40 amps, so the tip can be placed directly on the metal being cut.



Plasma cutting works in all positions. Practice cutting on both flat and vertical pieces.

PLASMA CUTTING TECHNIQUES

Plasma cutting puts much less heat into the metal than torch cutting. There is no need to preheat the metal when plasma cutting. The plasma arc usually burns through the metal right away. You want to be comfortable—brace your arms so that you can make long, steady cuts. Straightedges help make smooth cuts as well. The same ones used for torch cutting can be used with plasma cutting. Wear a shaded lens meant for the job. Sunglasses are useful for shading your eyes from the sun but are not meant for working with torches and arcs. I wear a #5 shade for plasma cutting. Make a few practice cuts on scrap metal before cutting on something important. Practice on the same thickness of metal as your project. Cutting thicker metals requires more heat and slower speeds than cutting thinner metals.

Practice the cutting motion. Hold the torch with the arc off and try to mimic real cutting. See whether you can hold the torch close to your cut line the whole way and go slowly. If needed, reposition your arms and body to get comfortable and hold steady. Once you’re at the start of the cut, pull the trigger and go. As you guide the torch along, watch as the plasma arc vaporizes the metal. At the end of the cut, release the trigger to turn off the arc. It may be necessary to stop and restart a few times on longer cuts. You can restart the cut at the same place you ended, or you can come in from an edge if it is more comfortable to restart that way.

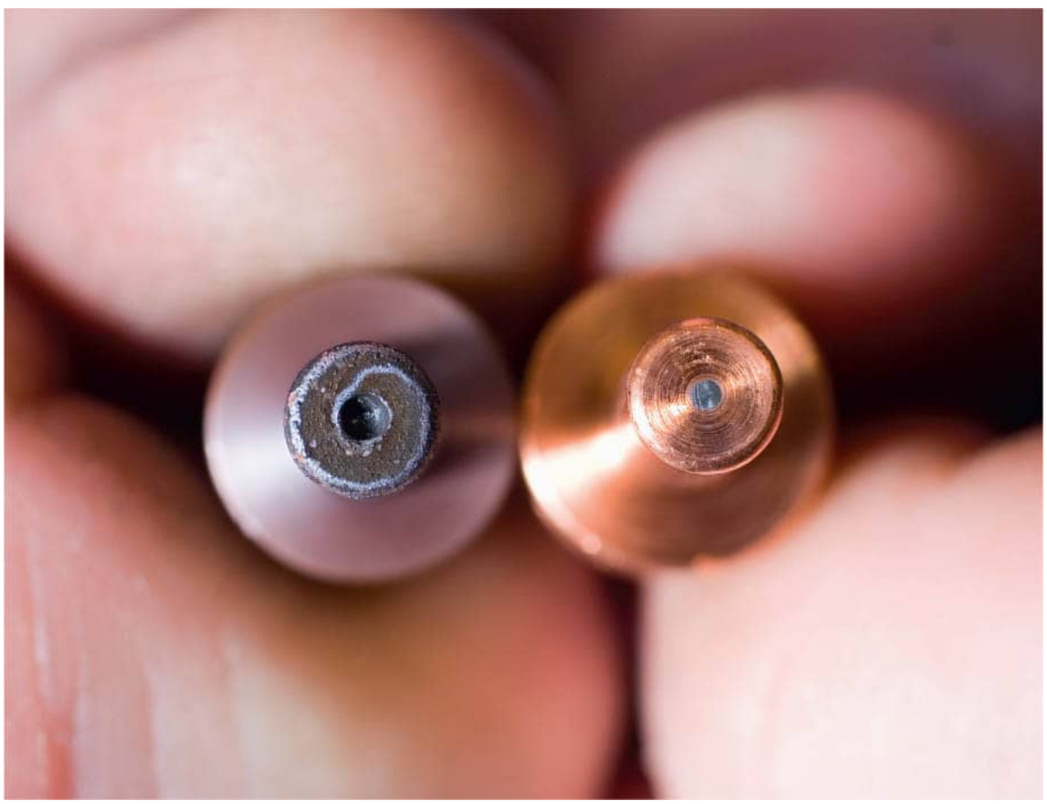
To make a cutout in the center of a piece of metal, begin by tipping the torch slightly to the side. If you hold the torch straight up and down, it is likely the slag shooting out of the cut will contaminate the torch parts. On thicker metals, it takes time for the plasma to pierce the metal. Holding the torch at an angle allows the slag to blow off sideways, away from the torch. This is also a good technique to use for making interior cuts with an oxy/acetylene torch.

COMMON PLASMA CUTTING PROBLEMS

Parts of the plasma torch wear out with use. Eventually, the electrode gets pitted beyond $^1/_{16}$ inch and the tip becomes oval-shaped instead of a perfect circle. Torch parts wear out faster or slower depending on what you are cutting and how. Long, steady cuts make torch parts last. Making cuts with the arc turning on and off a lot will shorten the life of the tip and electrode. Another problem is water or moisture in the compressor and hoses. This greatly reduces the working life of the torch parts. Torch parts are expensive. Take time to bleed any water from the system before cutting. Have extra torch parts available if something wears out completely; this allows you to finish a job that would otherwise be delayed if you had to go buy the part you need.

It is common for the plasma arc to not cut all the way through the metal. This may be because more heat (amps) and air pressure are needed. Other reasons include fast, erratic torch movements and the plasma torch being held too far away. The plasma torch needs time to do its work, although it usually cuts faster than oxy/acetylene. As in torch cutting, the dross will come up through an incomplete cut. Unlike the oxy/acetylene torch, however, the plasma torch can cut back through the dross. Slow down your cutting speed, keep the plasma arc on, and cut back over the uncut areas. Metals that are painted, dirty, or rusty are not ideal for plasma cutting. If you must cut dirty or rusty metal, cut with the cleanest side facing up. Sand a small area clean on the metal so that the work clamp has a good electrical connection.

Torch tips and electrodes wear out during the cutting process. Replacing them often is part of the expense associated with plasma cutting.



Electrodes that are pitted more than $^{1}/_{16}$ inch should be replaced.

7

ARC WELDING BASICS

Take the time to become familiar with machine controls so that you can adjust the settings effectively.

ELECTRICITY: A POWERFUL TOOL

It's hard for us to imagine what life would be like without electricity. After electricity was discovered, the next step was to make it useful for everyone. It took Thomas Edison many attempts to invent a practical, long-lasting lightbulb. Once people had the lightbulb in their homes, large electrical networks were built to meet the demand for electricity.

In the late 1800s, arc welding applications were invented and used in industry. Arc welding remained mostly in shipyards, factories, and construction sites. In the late 1920s, flux-covered arc welding electrodes became widely available. Around this time, N. C. Miller produced the first welding machine that would operate from a home electrical supply.

CURRENT, CIRCUITS, AND POLARITY

Old-fashioned lightbulbs have a small wire inside called a filament. When electricity flows to the bulb, it heats the filament until it glows. The filament gets hot because a large amount of electricity is flowing across a very small area. This creates resistance in the circuit. Resistance creates heat, and the heat creates light.

VOLTAGE	AMPERAGE
Force that causes electrical current to flow in a circuit	Amount or rate of electrical current that flows in a circuit

This older stick machine has two meters indicating the actual voltage and amperage while the weld is being made.

In welding, resistance is also created in the circuit, except instead of a thin filament there's a small gap. The gap is small enough that the circuit is not interrupted because electricity can "jump" across it. As it crosses, it creates an electric arc, making welding possible. The electric welding arc has been measured at over 10,000°F (5,500°C)—hotter than the surface of the sun.

When electricity leaves the power source, flows through the cables, and returns to the power source, this path is known as a circuit. In welding, the circuit must be complete for the arc to stay lit. If the gap is too large for the electricity to cross, or if there is a loose connection, the welding arc cannot be made.

AC/DC

In arc welding, electricity is generated by a power supply and sent through cables called welding leads. Electricity always flows from negative to positive. “Negative” and “positive” describe the electrically charged poles. In direct current (DC), the current flows in one direction. The way the welding leads are hooked up to the welding machine determines which way the current travels through the electrode holder and work clamp. This is known as polarity. There are two types of polarity:

DIRECT CURRENT ELECTRODE NEGATIVE (DCEN): STRAIGHT POLARITY

If the cable attached to the work clamp is connected to the positive terminal and the electrode holder is attached to the negative terminal, the electricity will flow straight down the electrode, across the arc gap to the base metal, and back to the work clamp and machine. Most of the heat is concentrated in the base metal.

DIRECT CURRENT ELECTRODE POSITIVE (DCEP): REVERSE POLARITY

If the cable attached to the work clamp is connected to the negative terminal and the electrode holder is attached to the positive terminal, the electricity will flow through the base metal first, “jump” across the arc gap to the electrode, and continue up the electrode and back to the machine. Most of the heat is concentrated in the electrode.

In alternating current (AC), as the name implies, the charge at the power source alternates between the positive and negative poles. This type of current (amperage) switches directions between the two poles of positive and negative electrical charge every $^{1}/_{100}$ or $^{1}/_{120}$ of a second. Therefore, one full cycle of AC takes place either 50 or 60 times a second, which is a frequency of 50 or 60 hertz. People who use alternating current to weld will notice a vibrating noise and a flickering arc.

Some machines require the welder to change the leads when switching between DC electrode positive and DC electrode negative.

Since AC current rapidly changes polarity, it doesn’t matter how these leads are connected to the machine.

Switching between AC and DC happens with the push of a button on this TIG welding machine.

ARC LIGHT

Think of the electric arc as a small sun producing a lot of heat and emitting a blinding light. Arc light contains ultraviolet (UV), infrared (IR), and visible light, making it very intense. A shaded lens is required when arc welding. These lenses are so dark you can't see through them without the light of the arc.

Specific hazards are associated with arc light. Blindness is not one of them. The idea that arc light will make you permanently blind is a common misconception (along with the myth that you cannot wear contacts while welding because they will melt to your eyes). The real danger from arc light is a condition known as arc flash. Think of arc flash as a sunburn on the surface of your eyeball. As is the case with a sunburn, arc flash happens when your eyes are exposed to the light for an extended time. If you step outside for a moment and then go back indoors, you won't be sunburned. Stay outside all day without protection and you'll burn for certain. You need not look directly at the arc light to suffer arc flash.

Shaded lenses protect your eyes from the bright arc light and provide a clear view of the weld puddle.

Fortunately, arc flash is not permanent and will not cause blindness. It is very uncomfortable but will not hurt right away. Instead, hours after welding, it will feel like someone poured sand in your eyes. Only time will heal the surface of your eyes. It is best to avoid arc flash in the first place by doing the following:

1. Pick the proper shade lens for the type of work you are doing. Avoid looking at the arc or flash unless equipped with the appropriate lens. The proper shade depends upon the type of arc welding and the size of the electrode you are using. A minimum of #9 shade should be used for arc welding. If you see spots in front of your eyes after welding, your shade is not dark enough—use the next higher shade number. See chapter 2 for more information about shaded lenses and welding helmets.

2. Be sure your helmet is in good condition. Cracks and holes allow arc light in and can lead to arc flash. Remember: you don’t need to look directly at the light to get burned.
3. Caution others about watching the arc light without proper eye protection. People are attracted to the bright light, especially children and pets. Protect others by using light-blocking curtains, making anyone who is watching you work wear a welding helmet, or keeping them away from the area.
4. Wear protective clothing to protect your skin from intense rays. Any exposed skin can be burned by IR and UV light. Avoid wearing white clothing while arc welding because it will reflect the arc light up onto your face.

ELECTRICAL SHOCK

Remember that electricity will always find and follow the path of least resistance. If you are arc welding in perfectly dry conditions, your risk of being shocked is minimal. However, when water becomes a factor, it is possible to get hurt. One early morning, a farmer dragged his welding leads across a grassy field to a tractor that needed some repairs. He lay down underneath the tractor, dropped his helmet, and struck an arc. At that moment, he experienced a sharp jolt of electricity from a low-voltage shock. The dew on the grass was enough moisture to send the electricity on another path. Fortunately for him, this incident tripped the breaker switch in the fuse box, saving his life.

It takes less than 1 ampere to kill a person. Since the amperage used in arc welding is considerably higher than that, follow these safety practices:

1. Keep gloves, clothing, and feet dry to avoid electrical shock. If there is a chance the gloves you are wearing will get wet, have several pairs handy so you can easily change to a dry pair.
2. Don’t weld in the rain.
3. Make sure cables and welding lead connections are in good condition and free of cracks.

4. Connect your work clamp close to the welding area. This allows the electricity to flow through the base metal and the work clamp in the shortest possible distance.
5. Be extra careful. The risk of electric shock is much greater when using alternating current (AC).
6. Using high-frequency AC waves with TIG power sources can also cause electric shock. Position the work clamp so that your body is not in the path of the welding circuit.
7. Always disconnect the power from any arc welding machine *before* changing the leads, opening protective covers, or servicing the equipment.

CHOOSING THE RIGHT WELDING MACHINE

Spending the money to purchase welding equipment is a big financial decision for most people. The best equipment to buy will be unique to each situation and will depend on different factors. Here are a few questions to consider.

Q: AM I WELDING INSIDE OR OUTSIDE?

A: Any of the arc welding processes work well indoors. For arc welding outdoors, stick welding or wire feed welding with a self-shielded fluxcore wire works best. Smaller inverter-type welding machines can be plugged into a regular outlet, so you can use a generator to provide power anywhere. An engine-driven machine will also work, but these are more expensive to purchase.

Q: WHAT TYPES OF METAL AM I WELDING?

A: TIG welding with AC/DC current is the most versatile and least expensive process; you can use it to weld almost anything. Wire feed is almost as versatile as TIG, but welding metals such as aluminum and stainless steel requires different types of welding guns and shielding gases. Stick welding is the most limited, working well for steel, stainless steel, and copper alloys, such as bronze.

Q: AM I WELDING THICK PLATE, THIN SHEET, OR BOTH?

A: Any of the arc welding processes will weld both thin sheet and thick plate. Welding thicker metals may require a more powerful a machine. The “size” of a welding machine is expressed by the output capacity in amperage:

- 150- to 200-amp machines used for light-duty welding and repair work on metals from sheet metal to ⅜-inch-thick plate
- 250- to 300-amp machines are typically used in manufacturing shops for welding sheet metal and thick plate
- 400- to 600-amp machines are used at construction sites for heavy-duty welding of large beams, containers, and pipes greater than ¼ inch thick.

A spool gun is available for this wire feed machine to weld aluminum. In addition, a 100 percent argon shielding gas is required.

This constant-current TIG welding machine can also be used for stick welding.

Many machine manufacturers provide a thickness range for welding in the machine's description or specifications. Keep in mind that the larger-capacity machines will require more electricity to run, which means a 220/240-volt connection is needed. This type of connection is different from the standard household outlet.

Q: HOW MUCH WELDING AM I DOING?

A: Wire feed MIG welding was developed for high-speed production welding. It is possible to use stick and TIG to weld most of the same metals together, but it usually takes more time. Building one trailer or making repairs occasionally is very different from production welding in which a machine might be running most of the day, every day. Production-type welding machines usually have a higher amperage output and longer duty cycle. Duty cycle is the amount of time you can run the welding arc before the machine needs to shut itself off and cool down. Welding machines for the home and the farm are not used as often. A machine with a lower amperage capacity and shorter duty cycle can do the job for much less money.

TYPES OF MACHINES

Welding machines produce electrical current in different ways depending on how they are built. The welding process you choose—stick, wire feed, or TIG—will have specific arc characteristics, and your machine must be capable of producing that type of arc. Welding machines are broken into three categories: constant current (CC), constant voltage (CV), and a combination of both (CC/CV).

STICK AND TIG

Constant-current (CC) power sources are used for both stick and TIG welding. This type of welding machine may provide alternating current (AC) only, direct current (DC) only, or both AC and DC. Some CC machines are designed specifically for stick welding, while others are designed for TIG. Newer CC machines are usually able to do both.

WIRE FEED

All wire feed welding processes require a constant-voltage (CV) power source. Constant voltage, also known as constant potential, is used in welding with both solid and flux-core wires in metal inert gas (MIG) and flux-core arc welding (FCAW). This type of machine will hold the voltage constant while the amperage can vary. See chapter 9 for more information on the different kinds of wire feed welding.

Voltage and wire feed speed are set on a constant-voltage machine for MIG welding.

A light-duty wire feed machine uses small-diameter wires to weld thin pieces of sheet metal.

MULTIPROCESS

This type of welding machine with both CC and CV comes the closest to "doing it all," providing the most versatility in welding. You can use these machines with any of the arc welding processes discussed in this book. Multiprocess machines can cost more and sometimes require an additional wire feeder unit to perform MIG and FCAW.

TRANSFORMER

This type of CC machine only produces alternating current (AC). This is the base model for stick welding because it is the least expensive and takes less electricity to run than other options. Commonly called a welding transformer, it runs on single-phase power. In terms of electrical equipment, a transformer changes the voltage levels of alternating current.

TRANSFORMER-RECTIFIER

This type of power supply is available in CC, CV, and CC/CV types. A welding rectifier has a transformer coupled with a rectifier, a device that changes AC into direct current. Transformer-rectifiers can produce both AC and DC for welding. This type of “older” conventional machine is larger and heavier and uses more electricity than an inverter (see below). There are still a lot of these machines around because they were built to last and can often be repaired.

INVERTER

An inverter changes DC into high-frequency AC current and produces both AC and DC for welding. It can be CC, CV, or CC/CV. Inverters have gained popularity because the machines are smaller and lighter and use less electricity than transformer-rectifiers. Many inverter-type welding machines plug into a regular household 110/115-volt outlet, making them convenient to use. Most inverters have voltage sensing, meaning the machine analyzes the power available and adjusts the power to the welding arc.

MIG, TIG, and stick welding with direct current are all possible using a multiprocess machine. This one plugs into a household outlet.

GENERATOR

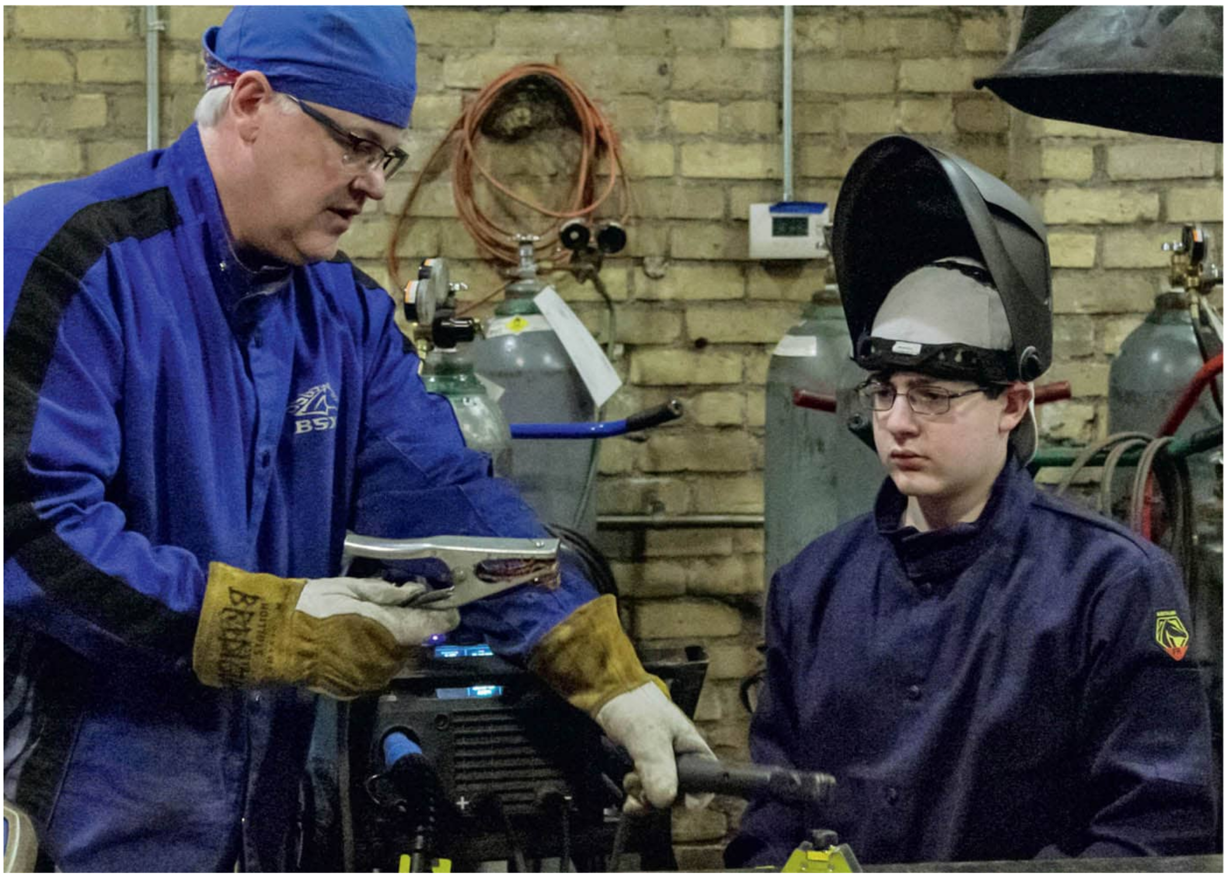
When there is no electricity available for arc welding, an engine-driven generator (running on gas, diesel, or propane fuel) can provide the electric current. Basic models of this machine produce only DC current. More expensive machines produce both AC and DC and have excellent arc characteristics. Engine-driven machines need proper routine maintenance and are designed for outdoor use. The noise and fumes from welding and engine exhaust are not suitable for indoor use.

Transformer-rectifier welding machines are big and heavy. Fabricating a frame with wheels makes it easier to move around.

Many inverters come with different electrical plugs that can be changed depending on what type of outlet you are using for power.

8

STICK WELDING



Connect your work clamp to clean, bare metal for a strong and stable welding arc.

HOW STICK WELDING WORKS

Stick welding was the first arc welding process to become widely available. It does a great job welding almost any kind of steel—stick welding and steel were meant for each other. Before stick welding, people used the carbon arc welding and bare metal arc welding processes to weld metals together with electricity. The heat was higher, and it was much faster than oxy/acetylene welding, but there were two drawbacks. One was the additional carbon that was deposited in the weld from the electrode. Adding carbon to steel makes it harder and more brittle. Another was that without flux, elements in the air, such as nitrogen and oxygen, contaminate the weld, making it weak.

Keeping air away from the molten metal is critical to making a strong weld. Stick welding steel with a flux-covered electrode results in strong joints that can withstand a lot of force. This greatly expanded welding's contribution to society. The manufacture of ships, railroads, pipelines, bridges, buildings, mining and farm machinery expanded and improved.

As the flux coating burns in the electric arc, it turns into a slag that covers the weld bead.

Experiment with amperage settings: watch what happens to the arc when you increase or decrease the amps.

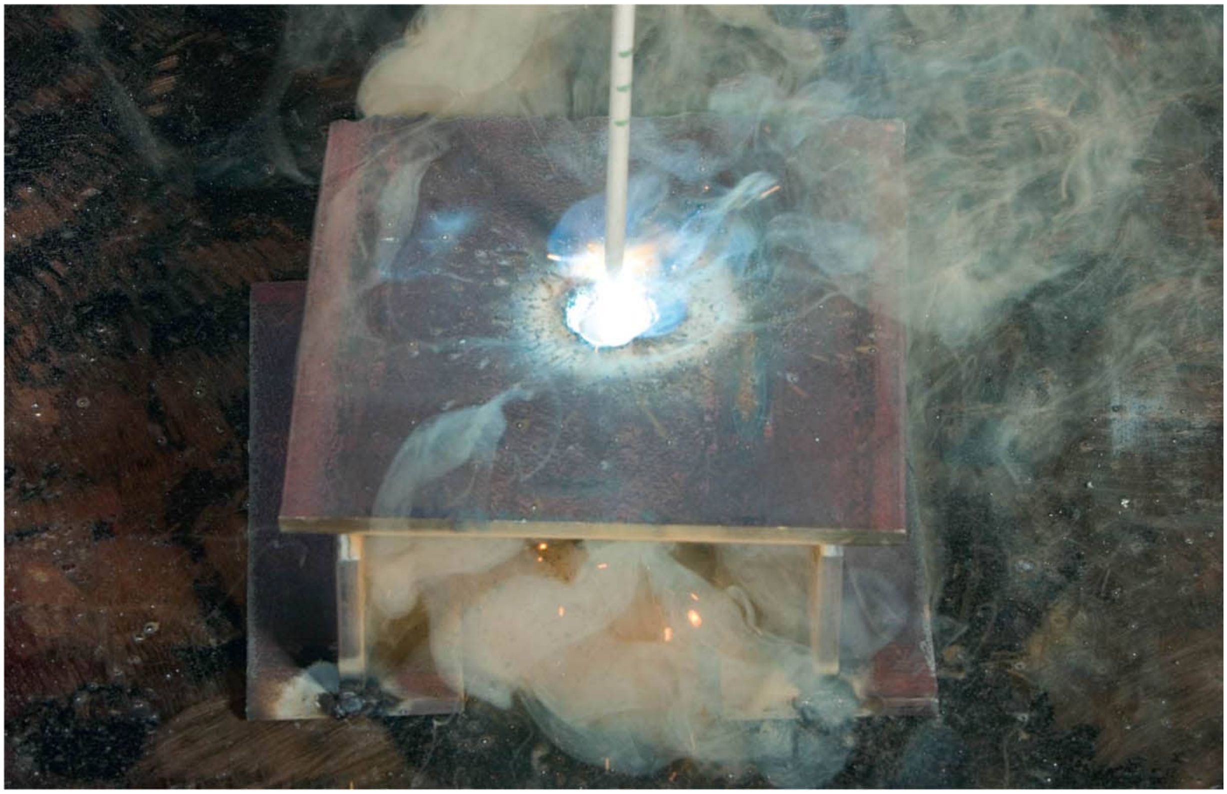
The key to stick welding is the flux coating on the outside of the electrode. When electricity passes through the electrode, the arc melts the metal and flux as it moves along the joint. Flux protects the molten puddle as the bead is being made and then turns into a slag coating. Typically, the slag is chipped off after welding or before a new weld is started. Over the years, different flux coatings have been invented for different needs.

The amount of electricity sent through the electrode is critical. The electrical current is measured in amperage and is set on the machine. Amperage determines the amount of heat. The right amperage setting depends on the type and size of the electrode. There are many apps and online calculators to help figure out how to get started. For example, the calculator on the Miller welding company website (millerwelds.com) will ask what type of metal you are welding and what electrode you are using. You need to know the type and size of the electrode being used for the setting to be accurate. These calculators and apps give approximate settings. Each welding situation is different. The metal thickness and welding position make a big difference in the amount of heat needed to make the weld. You can use more heat for thicker metals or welding in a flat, horizontal or overhead position. Less heat is used for thinner metals or welding in a vertical position. See chapter 12 for more information.

MACHINE CONTROLS

Stick welding machines are the simplest type of arc welding equipment. There is a power source with two cables that plugs into an outlet. These cables are called welding leads. How the electricity flows in the welding leads determines the polarity being used. Most stick welding uses either alternating current (AC) or direct current electrode positive (DCEP). Know how to switch the current on your machine. On some power sources, you can change the polarity using a button or switch. Others require that you change the leads to different terminals with a quick-connect or lug-type connection.

Older welding machines have a high/low amperage switch and a dial for final adjustments.



When amperage is set too high, the arc light appears brighter and the welding rod “digs” into the plate.

Amperage is set directly on the machine, usually with a dial. On a machine with a digital display, you can make exact amperage settings. On machines without a digital display, use the numbers around the dial for reference. Take the time to adjust the amperage by welding on pieces of scrap metal. Watch the arc and weld puddle as you test different amperages. It is good practice to see what a smaller, dimmer “cold” arc and a larger, brighter “hot” arc look like. That way, when you weld something important, you can determine whether more or less heat is required.

Machines equipped with an arc control feature can be fine-tuned. Also called arc force or slope control, this feature changes the characteristics of the welding arc. A “soft” setting (on the low end) decreases the amount of current in relationship to voltage. The arc is quiet, with less penetration into the base metal. Turning the arc control to maximum increases the amount of current in relationship to voltage. The result is a “harsh” arc with digging characteristics and deeper penetration for thicker metals. “Hot start” is a machine control that can help with starting the arc and weld bead. Striking an arc can be tricky. A hot start delivers more amps for a short time making it easier to begin welding and providing better fusion at the start of a weld.

CABLES (LEADS)

Stick welding cables, or leads, vary in length depending on the job. Multiple cables can be attached to each other with connectors that twist together. If the welding machine is close to the work, you can use 12- to 15-foot leads. If the work is farther away, such as on the roof of a building, you will need longer leads, such as 100 to 200 feet. Keep in mind that long cables cause more resistance in the circuit: the longer the leads, the more the amperage will drop. Large-diameter welding cables are needed to maintain the correct amperage and deliver the right amount of heat to the weld. Refer to a welding cable size chart to find the correct size for the length of welding leads you plan to use.

The welding leads connect to the electrode holder and work clamp. This connection can become loose with time and use, which can cause the welding arc to be weak and unstable. Keep your leads in good condition. Cracked or missing insulation increases the chance of electric shock, especially if water is present. The copper wires in the cable are very fine and can be crushed or kinked, creating a bottleneck in electrical current. Using leads that are too small for length or amperage can also be a problem. These circumstances will cause a buildup of resistance in the circuit, overheating the equipment.

An electrode holder, sometimes called a stinger, attaches to the end of one of the welding leads. Welding rods are clamped into the holder. This transfers the electricity between the cable and electric arc where the welding occurs. Electrode holders are sized depending upon the amperage used. If the electrode holder becomes hot or the ends of your copper cables are discolored, either the electrode holder is undersized or the welding leads are too long or too small. Insulators on the outside of the electrode holder prevent arcing when you set the holder down on an electrically “hot” piece of metal, such as a worktable. Replace any insulating piece that becomes worn out. The handle of an electrode holder is spring-loaded, opening and closing to clamp onto a welding rod. This spring-loaded release lever is helpful when you need to let go of an electrode quickly—for example, when it is stuck to the workpiece. After welding, always remove the electrode from the holder to avoid unintentional arcs.

A work clamp, sometimes called a ground clamp, attaches to the other welding lead. It then connects to the part being welded or to a worktable where smaller pieces are welded. The electrical circuit needs the work clamp to transfer electricity between the welding arc and welding machine. Connect your work clamp to bare metal. If the metal is rusty, dirty, corroded, or painted, sand off an area of bare metal for the work clamp. Otherwise, contaminants between your clamp and the base metal will impede amperage flow, destabilizing the welding arc. It is best practice to always connect your work clamp securely to the table or the project you are welding.

Placing welding rods at different angles in an electrode holder makes it easier to maintain the correct angle.

Electrode holders and work clamps connect the electrical circuit to the part being welded.

ELECTRODES

Also known as welding rods or sticks, electrodes have a metal core with a flux coating on the outside. Without flux, the weld would be full of holes, weak and brittle. The flux coating performs the following functions in welding:

1. Acts as a cleansing and deoxidizing agent in the molten weld pool.
2. Creates a shielding atmosphere by releasing carbon dioxide (CO_2), protecting the molten pool from contamination.
3. Forms a slag coating over the semi-molten metal to further protect it from the atmosphere.
4. Stabilizes the welding arc.
5. Improves fusion into the base metal.

6. Determines the type of welding current that can be used for welding: AC, DCEP, or DCEN.

Many welding rods are defined by the type of flux they have. The flux ingredients determine how the electric arc behaves and how the weld turns out. Most rods have numbers printed on them. These numbers from the American Welding Society (AWS) classification system are used so there is a general understanding of what results a welder can expect from a welding rod or wire. There are several good online resources to learn more about the AWS classification system. Remember: these numbers do not indicate the size of the electrode, nor is the size printed anywhere on the electrode. Use a ruler to measure the bare metal end to find out the size. Knowing the size and type of electrode is critical to setting the correct amperage to set on the welding machine.

Chipping hammers and wire brushes are used to remove slag from a bead. Wear safety glasses when you do this—slag can be very hot after welding.

In stick welding, electrodes become part of the finished weld bead. The type of welding rod you use will influence the strength and mechanical properties of the finished weld. Before you begin a project, identify the base metal you are using and select an electrode recommended for that metal. Even the most experienced welder is not expected to know all the electrodes available today. Ask a welding supplier or do some research to save time and money and provide peace of mind. Brand-name electrodes generally have a track record for high quality. Examples include Fleetweld and Excalibur from Lincoln and Sureweld and Atom Arc from ESAB.

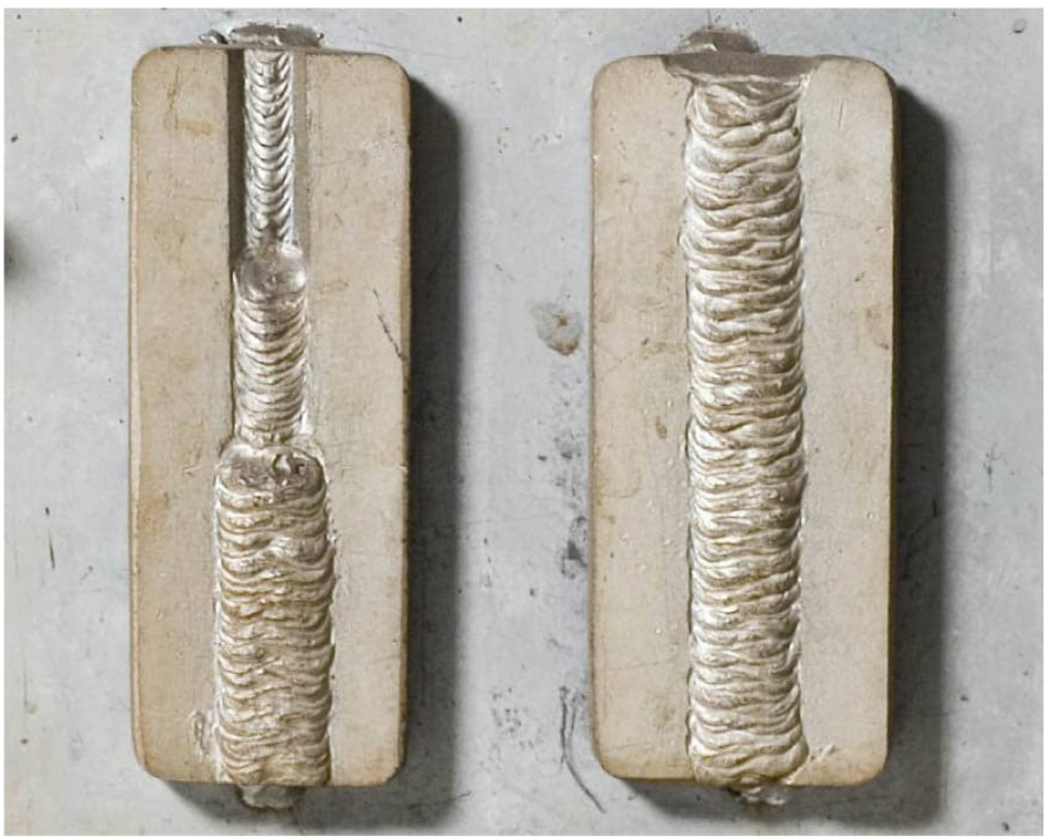
THE FOLLOWING TYPES OF RODS ARE COMMONLY USED FOR WELDING MILD STEELS

E6013
Clay-based (rutile) flux
General purpose, easy to use, smooth bead appearance
Low arc penetration
Used with both AC and DCEP current
Can be used on sheet metal with DCEN
E6010
Paper-based (cellulous) flux
Welds through light to moderate amounts of rust, dirt, and paint
Rough bead appearance with little slag
Deep penetration with fast-freeze characteristics (quickly solidifies)
Used with DCEP current
E6011
Paper-based (cellulous) flux
Same characteristics and uses as 6010 but with slightly less penetration
Used with both AC and DCEP current
E7018
Limestone (potassium carbonate) flux
Also known as low hydrogen
Outstanding crack resistance, smooth bead appearance
Joins a wider range of carbon steels than any other electrode
Typically used with DCEP current
E7018 AC rod has additional stabilizers in the flux for better results with alternating current

Flux-coated welding rods have a bare metal end, which is placed in an electrode holder to conduct electricity.


A 6013 electrode was used to make multiple weld beads in a T joint. Each weld pass is layered so that it overlaps the previous beads.

6010 and 6011 welds can have a stacked coin appearance using the whip technique.



The weave technique is used to make a wider weld. Here, a 7018 electrode was moved side to side, adding more filler metal in one pass.

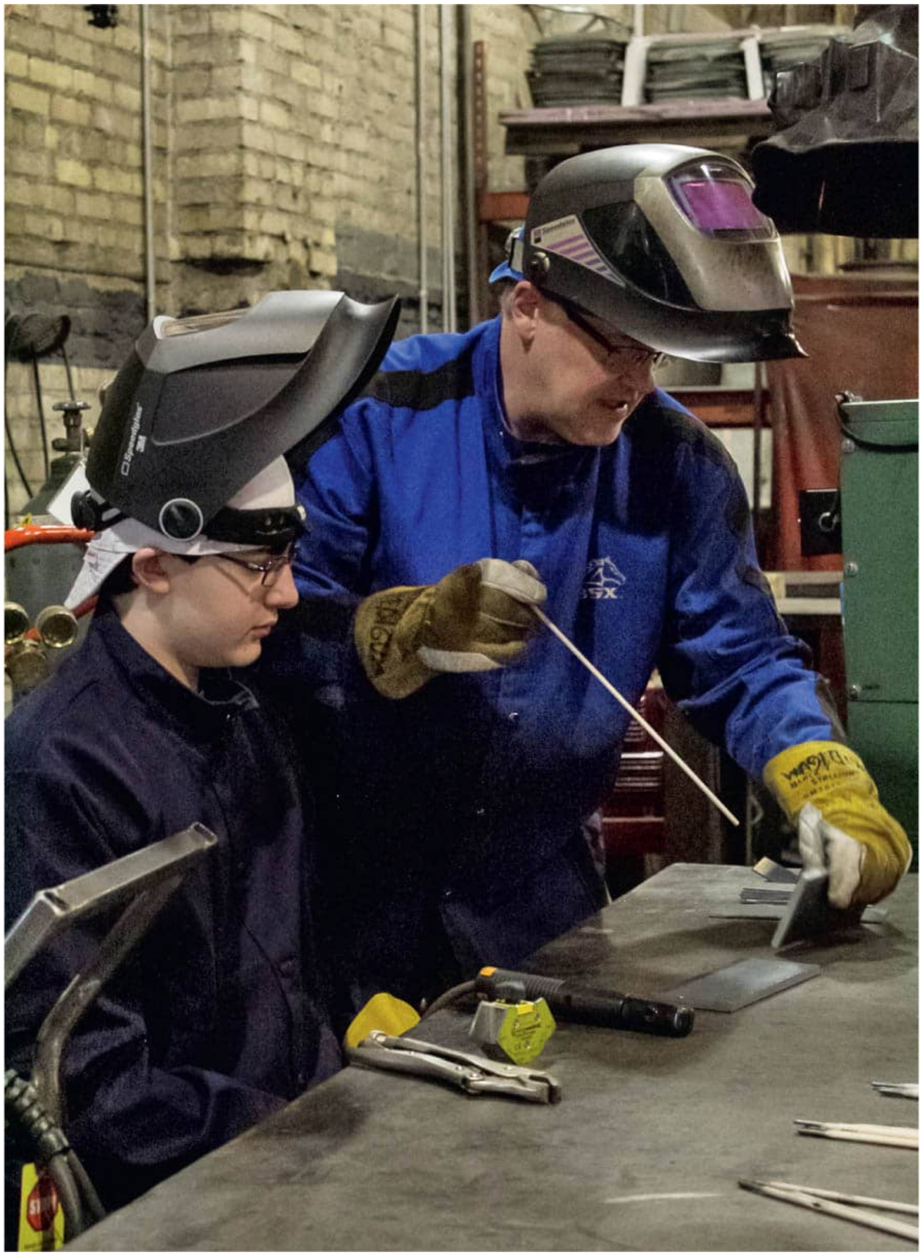
Each type of electrode comes in a variety of sizes. Electrode size is measured by the diameter of the bare metal end—don’t measure the part with the flux. Two welding rods can look like they are different sizes because of their flux coating but really be the same size when measured properly. Have a variety of electrode sizes available to weld different thicknesses of metal. The most common sizes are $^{3}/_{32}$ inch, ⅛ inch, and $^{5}/_{32}$ inch. An electrode diameter equal to or less than half the thickness of the base metal will make the heat input more controllable. Never use an electrode whose diameter is greater than the thickness of the base metal.

Another limiting factor may be the output capacity of the welding machine. Large-diameter electrodes require machines that can deliver a high amperage to the arc. One advantage of stick welding is that you do not always need a large welding rod. Even a light-duty stick welding machine with a 150-amp capacity has enough heat to run a ⅛-inch E7018 electrode capable of welding thicker plates of steel.

Electrodes can be bent for making short welds around sharp turns or in hard-to-reach places.

STICK WELDING TECHNIQUE: DASH

As in gas welding, the four main factors in welding technique are distance, angle, speed, and heat (DASH). If you get these four things right, you will have a good weld every time. Keep these in mind when practicing your welds. Your chances for success are far greater if you can consistently control all components of DASH at the same time. This is one reason why it takes some skill to become a good welder.

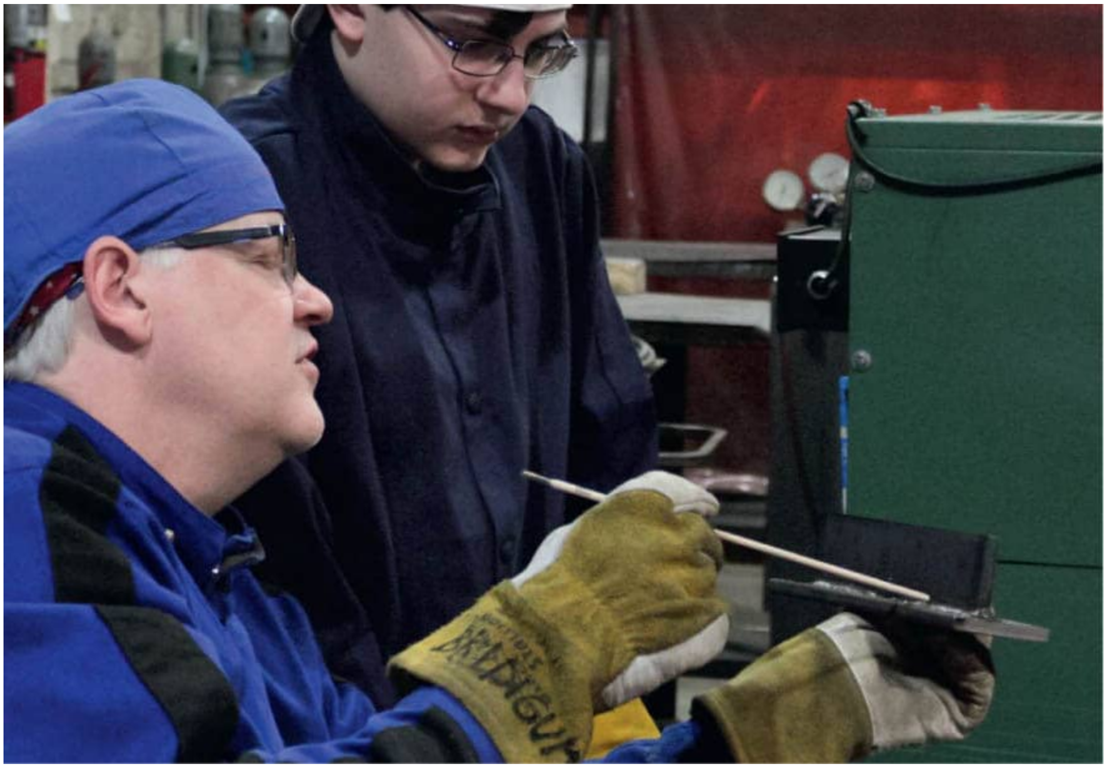


Plan your work. Think about electrode angles and welding positions before striking an arc.

DISTANCE

In stick welding, distance is your arc length (arc gap). Using the correct arc length maintains the balance between amperage and voltage and allows complete fusion to take place. Never pull back the welding rod if you need to cool things down. Pulling the rod too far away will spread out the arc and make a bad-looking weld every time. The tip of your welding rod should always be at a distance slightly smaller than the electrode's diameter—for example, if you are using a ⅛-inch-diameter electrode, an arc gap of a little less than ⅛ inch is ideal. This is a lot closer than it first appears. The welding rod is so close it is almost touching the metal. Maintaining this distance throughout the weld is difficult because as the electrode burns, it is being consumed, getting shorter. Often, beginners are too far away from the base metal, so I tell them to "push down" with the electrode to maintain the proper arc length.

Gauge the amount of arc light between the rod and the base metal as one way of maintaining the proper distance.



It helps to look at your welds with someone who can give advice on improving your technique.

ANGLE

Heat from the welding arc and filler metal is directed by the electrode angle. Penetration into the base metal will change depending on the angle at which you hold the electrode. Think of a garden hose spraying water in a muddy backyard. Holding the hose at a shallow angle relative to the ground will make a small dent, but most of the water bounces off in a spray. If you direct the hose at a steep angle, the water will penetrate farther into the ground. A stick welding electrode is similar, except you are spraying metal instead of water. Angles used in stick welding will determine the amount of penetration into the base metal, and where the heat is placed in the joint. When your electrode angle is incorrect, the heat will be directed to only one part of the joint and not the other, making a much weaker weld.

Proper electrode travel angle is almost 90 degrees to the piece being welded. This allows the arc to better penetrate the metal.

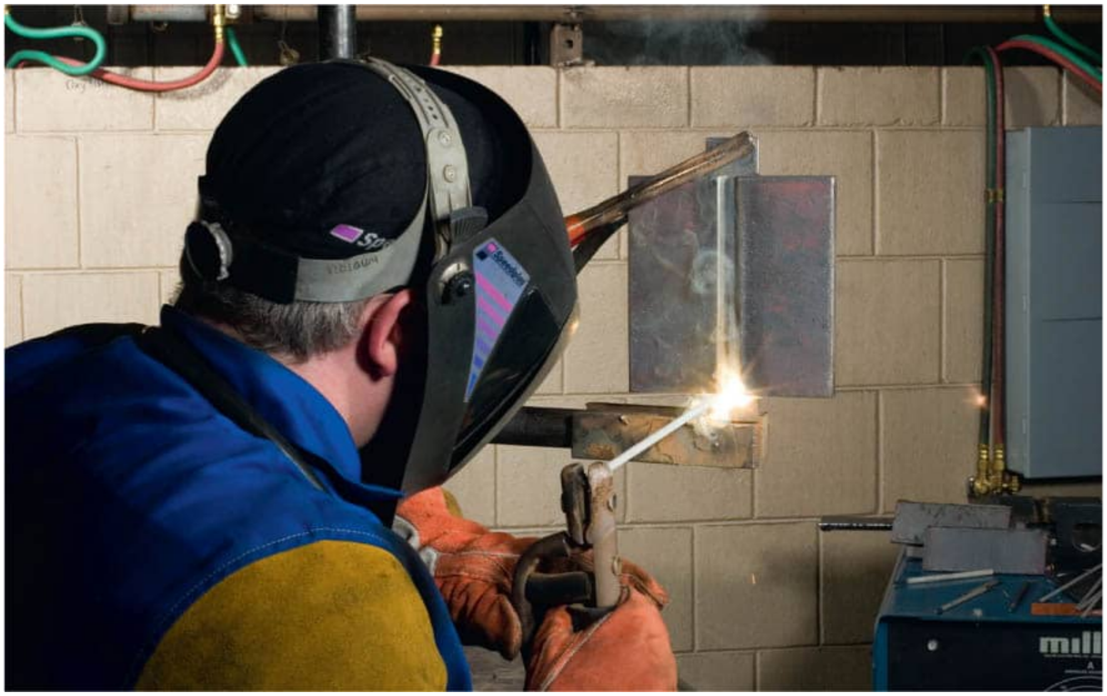
Shallow electrode angles cause the arc to bounce off the metal with little penetration.

SPEED

The key to creating uniform weld beads is a consistent travel speed. Any small variation in speed, such as skipping ahead or using rapid circular movements, will show in the final weld. Traveling too fast will result in shallow penetration into the base metal and a lack of adequate fusion. At a high-enough amperage, a weld bead made too quickly can have a good appearance but will lack strength. To travel at a consistent speed, get comfortable and steady. Faster travel speeds put less heat into the base metal and deposit less filler metal, making the bead smaller. Slower travel speeds put more heat into the base metal and build up the bead.

HEAT

The amount of heat depends upon the amperage being used. Most electrodes will work with a variety of amperages. This is helpful when the weld is too cold or too hot. It is easy to change the heat setting 5 to 10 amps at a time until the welding rod is running right. Even though electrodes work over a wide range of amperages, welding at the upper or lower limits of a particular size welding rod may cause problems in the final weld. Instead, if you find yourself at the limit of what a particular electrode can handle, it’s better to use a larger or smaller diameter to increase or decrease the amount of heat required.



Stick welding vertically requires less heat than welding horizontally. Turn down the amperage until the weld puddle stays in the joint.

COMMON STICK WELDING PROBLEMS

It will not matter how good your welding skills are if you are using the electrodes and equipment incorrectly. Asking someone to weld 0.030-inch-thick metal with a ⅛-inch-diameter electrode is like asking a musician to play the piano with a broken hand—it will be difficult or impossible to do well. Most important is to relax and get comfortable.

Remember ABC: always be comfortable. Rest your arm on the table. Brace your body against a solid object. Keep your elbows tucked into your sides and sit down when possible. Wear the proper personal protective equipment (PPE) so you're safe from and not distracted by the sparks. When you are familiar and comfortable with the process, your chances of making great welds improve dramatically.

Below are some common problems you might encounter, their usual causes, and how to solve them.

UNABLE TO STRIKE AN ARC

- Electrode not in holder correctly—put bare metal end into electrode holder
- Ground not connected to table or part being welded—connect ground clamp
- Ground connected to paint or rust—sand off a clean spot
- Amps set too low—turn up amps on the machine or switch to a smaller electrode
- Welding circuit interrupted—remove anything that does not conduct electricity

WELDING ARC IS ERRATIC

- Electrode held too far away—get closer
- Loose connection—check all connections to machine and on welding leads
- Wrong polarity—switch to DCEP
- Metal dirty—clean metal where you are welding

WELDING ARC IS TOO HOT

- Wrong amperage used for the type of flux on the electrode—make sure amperage setting matches manufacturer recommendations
- Welding electrode too small—switch to one size larger
- Traveling too slow—don't stay in one place too long

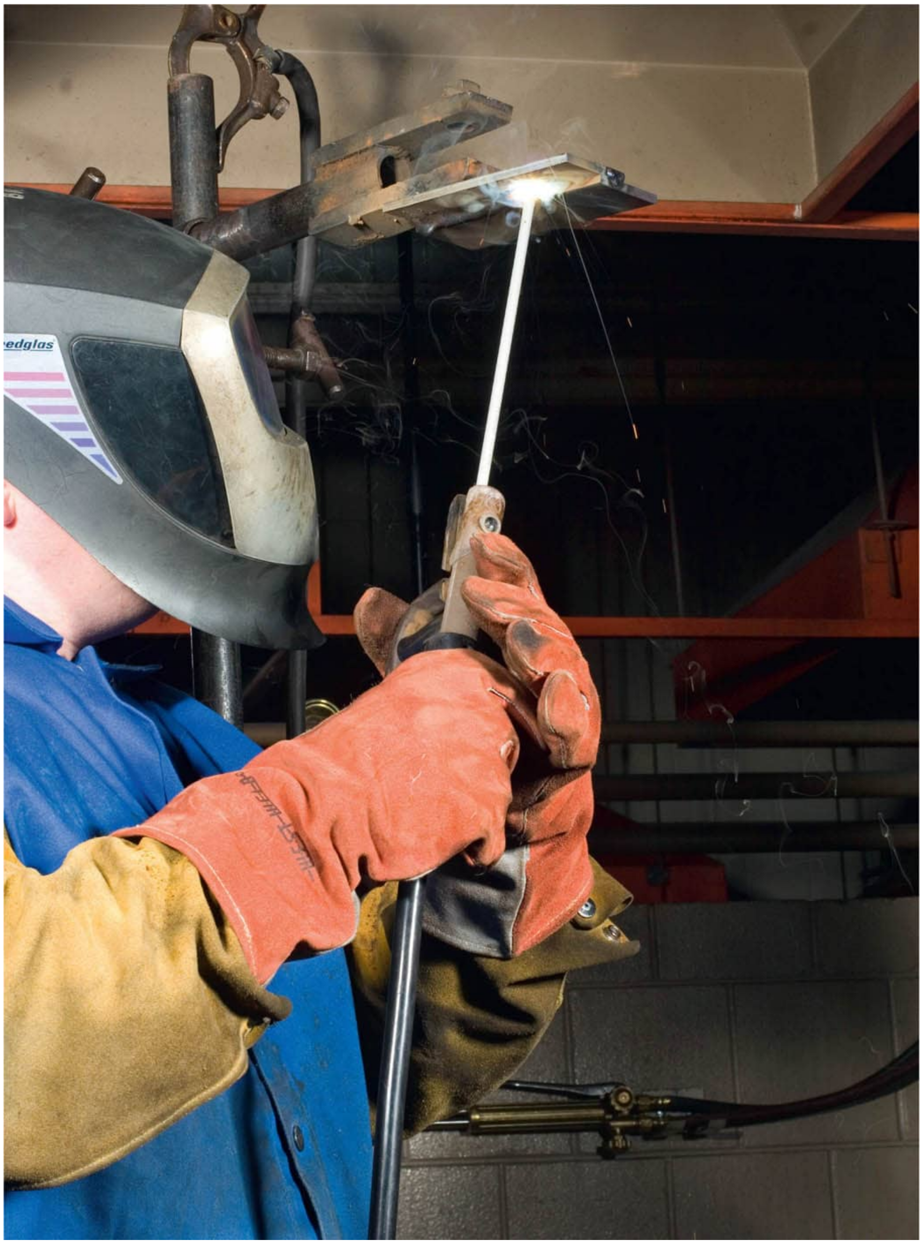
BEAD IS NARROW AND NOT UNIFORM (IRREGULAR)

- Push down, slow down—get closer and travel slower
- Welder not comfortable—remember ABC
- Not reading the puddle—watch the weld and adjust to what is happening

SLAG INCLUDED IN WELD BEAD

- Amps too low—turn up amperage
- Electrode too far away—get closer
- Metal dirty in weld joint—clean metal where you are welding
- Electrode held in one place too long—don't let slag build up under the rod

Beads from top to bottom: amps too low or too high; arc too long; incorrect angle; bead correct with uniform width and even ripples.



Be as comfortable as possible in awkward positions. Keep your arms close to your body and lean on a fixed object to stay steady.

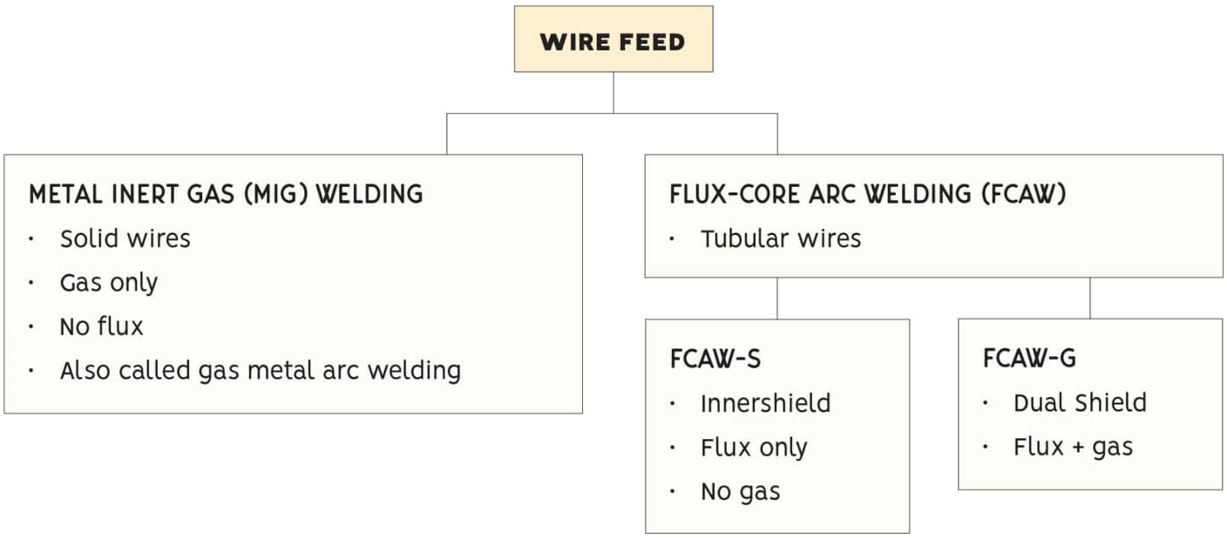
9

WIRE-FEED WELDING

MIG welding is a popular process because it's semiautomatic, which makes it easier to learn.

WIRE-FEED FAMILY TREE

There are many types of wire-feed welding. MIG and flux-core welding are the two main types used today.



MIG WELDING

The metal inert gas (MIG) welding process was discovered in the late 1940s. Its key to success was using a shielding gas instead of flux to protect the bare metal wire and weld from contamination. Shielding gases were first used in TIG welding. Bare metal electrodes were used before modern stick welding with little success—the welds were unprotected from the surrounding air and absorbed oxygen, nitrogen, and water vapor, making them weak and brittle (especially steel). With MIG welding, a shielding gas is used to protect the weld, and the bare metal electrode wire makes continuous welds.

Early on, MIG welding was used to join aluminum, stainless steel, copper, and copper alloys, such as bronze. The argon gas used for MIG was expensive at the time, so the process was limited. Despite the cost, however, MIG welding is credited with increasing the use of aluminum in ships, vehicles, and buildings. Applications greatly expanded for wire feed in the 1950s when carbon dioxide was used as a shielding gas for the first time. Carbon dioxide is cheaper than argon. Welding machines were modified to produce a current that welders could set precisely over a range of heat settings. This improved weld quality. MIG was established as the “go-to” process for making high-speed, continuous welds on most metals. Today, MIG welding still uses argon and carbon dioxide shielding gases and solid welding wires.

FLUX-CORE ARC WELDING (FCAW)

You can think of the flux-core wire as an "inside-out" stick welding electrode. Instead of the flux coating on the outside, the wire has the flux inside of it, wrapped in a steel tube called a sheath. Flux benefits welds because it stabilizes the arc, acts as a deoxidizer, and becomes slag that protects the molten pool as it solidifies. A flux-core wire was combined with carbon dioxide shielding gas to produce welds on steel similar to stick welding. The wire-feeding process became more automated, reducing the cost of welds.

The next process improvement was the creation of a flux-core welding wire that did not need a shielding gas. In the late 1950s, the Lincoln Electric company developed self-shielded wires called Innershield. Special metals were added to the flux ingredients to create a shielding vapor. The shielding vapor is strong enough to work on its own, protecting the weld as it is being made. Flux-core arc welding with a self-shielding wire is popular today when outdoor welding is required.

HOW WIRE-FEED WELDING WORKS

The welding wire is wound on a spool and fed into the weld pool by motorized drive rolls. As the drive rolls turn, the wire electrode is continuously fed into the welding arc and becomes part of the weld. Wire-feed welding machines provide constant-voltage (CV) welding current. Like in other arc welding processes, electricity flows between the welding gun (torch), the metal being welded, and the work clamp. Unlike other processes, wire feed is semiautomatic because the machine makes slight adjustments to the heat as a weld is made.

Parts of a wire-feed welding system include a CV power source, wire-feeder unit, spool of wire, gas cylinder, flow meter, welding gun, and work clamp.

MODES OF METAL TRANSFER

MIG WELDING (SHORT CIRCUIT)

Often, welders set their welding machines by sound. The sizzling "bacon frying" sound in MIG happens when the volts, wire-feed speed, and shielding gas are all set correctly. The sound you hear is the short-circuit transfer of the welding wire as it melts and becomes a bead. In short-circuit transfer, the wire touches the metal. When the wire contacts the metal, the electrical resistance causes the wire to heat up and "pinch off." The heat of the arc fuses some of the wire to the base metal. Since the machine is automatically feeding, the wire is fed back into contact with the metal. Another droplet of wire is pinched off and deposited. This process happens very quickly, about twenty to two hundred times per second depending on the machine settings and amount of wire stickout (distance between the gun and the base metal).

Since the arc is not continually "on" during short-circuit transfer, the weld puddle is small and relatively cool. Therefore, MIG welding is useful for welding thinner-gauge metals ($^{3}/_{16}$ inch or less), filling joints with gaps or poor fit-up, and welding in vertical and overhead positions. However, you can also weld thicker metals successfully with short-circuit transfer using proper joint design, a machine with a higher output current, and good welding technique.

Short-circuit MIG uses a solid wire and shielding gas, making the weld easy to see.

FLUX-CORE ARC WELDING WITH A SHIELDING GAS (FCAW-G)

It may not make sense that a welding process would need both a shielding gas and a flux to protect the weld bead. Why not use one or the other? The answer is the first flux-core electrodes did not have enough flux to properly shield the weld pool. The thin flux coating was useful because it stabilized the arc. This allowed welders to use higher voltages so more liquid metal could transfer across to the weld pool. With a solid MIG wire, as voltages increase, an erratic arc is created with lots of spatter. However, in FCAW, the flux stabilizes the arc so a globular transfer can take place. Droplets are pinched off the end of the flux-core wire and transferred to the base metal through the continuous arc stream. The flux turns to slag, which helps slow the cooling rate and protects the hot weld bead. This means you can make bigger welds faster and more cheaply when welding thicker plates of steel. Gas-shielded flux-core welds can be made in any position, including vertical and overhead. FCAW-G is still used today in structural steel fabrication shops where large parts are welded indoors.

Gas-shielded flux-core wires work well for welding steel plates. After welding, a slag coating covers the bead.

Self-shielded flux-core wires create a shielding vapor around the weld. No shielding gas is used with this type of wire.

FLUX-CORE ARC WELDING WITH SELF-SHIELDING FLUX (FCAW-S)

FCAW-S and FCAW-G use tubular wires. First, a flat metal strip is formed into a U shape to make the wire. Then, a powdered flux is poured in and the wire sheath is closed up, giving it a flux core. The flux ingredients and chemical composition determine whether the wire is used with or without a shielding gas. Aluminum and magnesium are added to the flux core of self-shielded wires. These metals react and combine with oxygen and nitrogen in the air, protecting the weld. Never use a shielding gas with a self-shielded electrode! The resulting weld will trap high amounts of aluminum, making the weld brittle and more likely to crack. The metal transfers across the arc in droplets similar to FCAW-G wires. Self-shielded flux-core wires are great for outdoor use on a wide variety of metal thicknesses, from sheet to plate. This type of wire-feed welding works for general fabrication or repair work on zinc-coated steels as well.

MACHINE CONTROLS

Direct current electrode positive (DCEP) is always used for MIG welding with a solid wire. That means the gun cable (welding lead) is attached to the positive terminal and the work clamp is attached to the negative terminal. DCEP is also used with most gas-shielded flux-core wires. Self-shielded flux-core wires usually operate using direct current electrode negative (DCEN). Refer to the wire manufacturer’s specifications for the recommended polarity. AC is not used in MIG or FCAW.

VOLTAGE

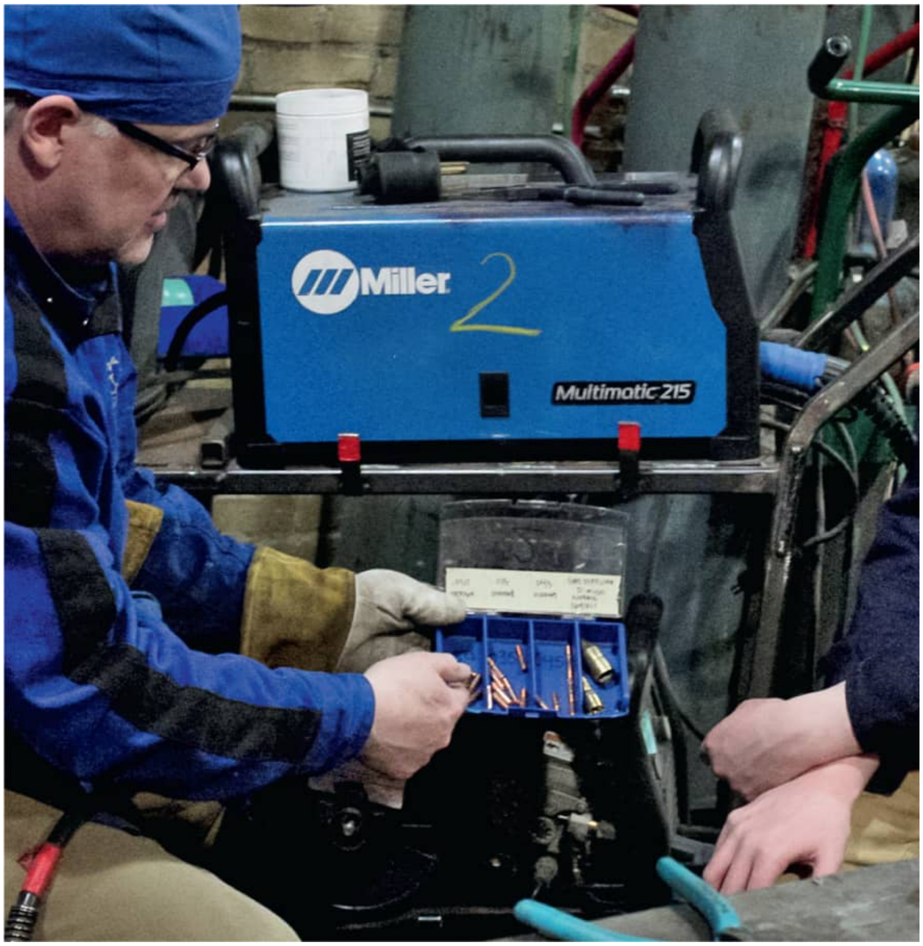
Wire-feed welding uses a constant-voltage (CV) power source. Unlike constant-current (CC) machines used for stick and TIG welding, CV machines have a control for setting voltage. Although voltage is the force behind amperage, it is useful to think of it as functioning like amperage, controlling the amount of heat. The arc length is self-regulating in a CV power source, meaning the machine adjusts automatically for variations in wire stickout and distance from the gun to the weld.

WIRE FEED SPEED

With a CV power source, the amount of amperage is determined by the wire-feed speed (WFS). WFS is the rate at which wire is being fed to the weld pool. Although amperage is the amount of current flowing in the circuit, it is useful to think of wire-feed speed as an adjustment made secondary to voltage. WFS is measured in inches per minute (ipm)—the length of wire fed in 1 minute. Machines with an “inch” button will feed wire without gas flow or electrical output, which is useful when installing a new spool or clearing misfed wire.

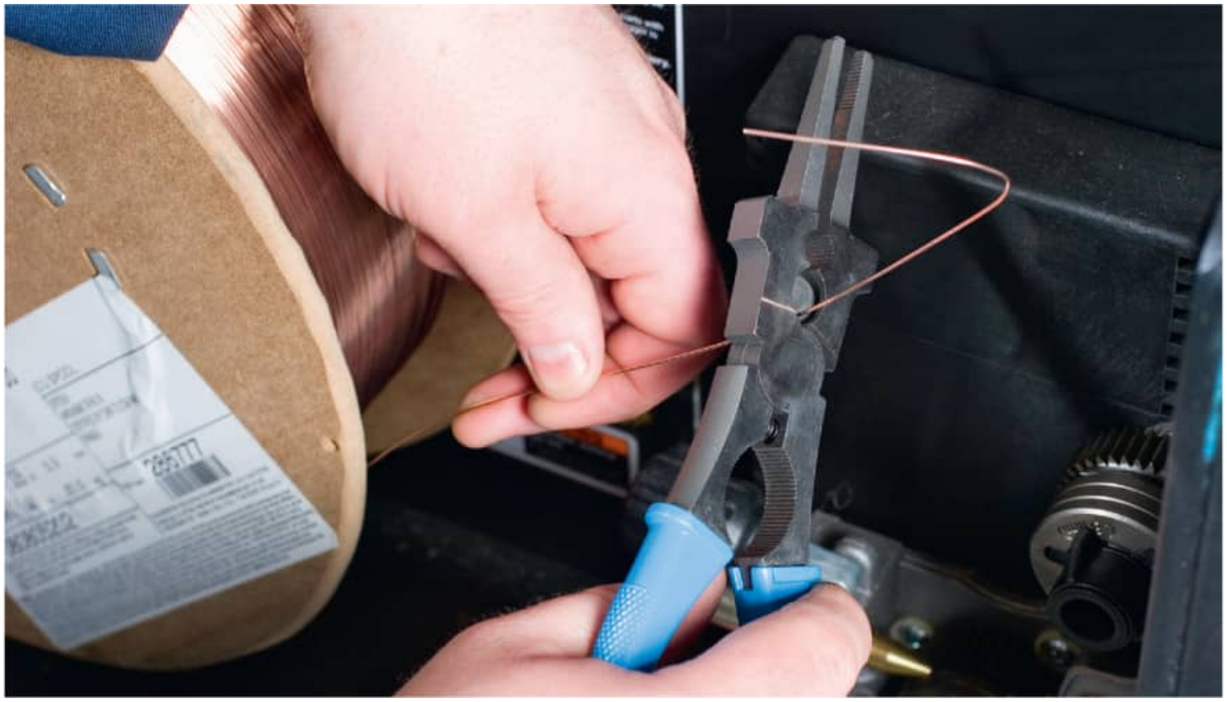
Miller (millerwelds.com) has a good weld setting calculator for MIG and flux core. Enter the type and thickness of metal you are welding to find a working range for voltage and wire-feed speed. Keep in mind that machine settings may vary depending on the shielding gas used. For a more detailed approach, look at the voltage and wire-feed speed recommendations from the wire manufacturer. Once you find a good setting, write it down. Next time you need to make a similar weld, you will not need to “reinvent the wheel.”

Two controls are used to adjust heat for wire-feed welding. This machine is set at 16.4 volts and a wire-feed speed of 203 inches per minute.

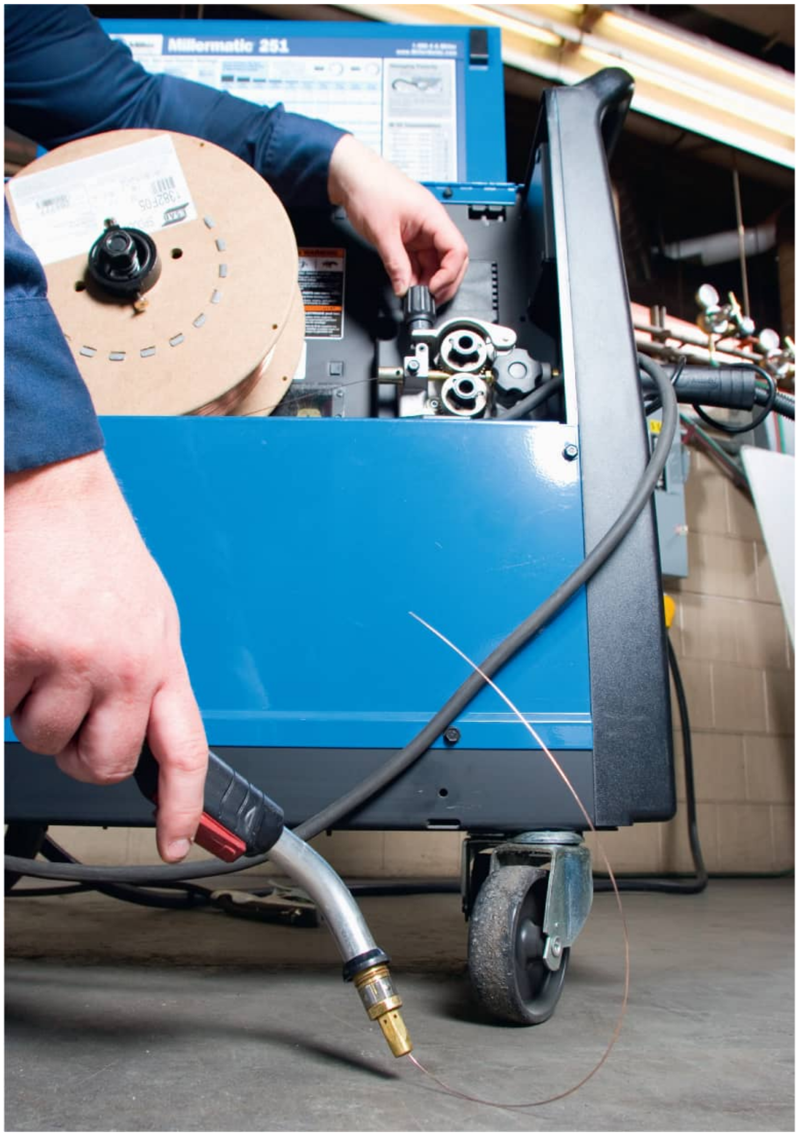


Match the contact tip and wire sizes. Have extra wire-feed gun parts available to replace any that become worn or damaged.

There can be many reasons why a wire feed machine is not running right or the weld bead is poor. Not having the correct voltage and wire feed speed is just one of them. Make sure the machine is set up correctly before trying to make fine adjustments with the controls. See "Common Wire-Feed Welding Problems" on this page for more information.



Bends or kinks in a wire will cause feeding problems. Remove any bent sections before feeding wire through the drive rolls and gun cable.



Drive-roll tension is adjusted by feeding the wire against a nonconductive surface. Increase tension until the wire stops slipping.

GAS FLOW

Shielding gas flow rates are measured in cubic feet per hour (cfh). Flow rates are set on the regulator/flow meter. Setting the proper flow rate is very important. A low shielding gas flow rate will not shield the molten puddle adequately and is more sensitive to air or gun movement. A flow rate set too high will create turbulence that causes air to be pulled in from the atmosphere.

The top of the ball indicates a flow rate of 35 cubic feet per hour. A valve is used to adjust the flow rate.

- For short-circuit transfer with MIG, a flow rate of 25 to 30 cubic feet per hour is adequate.
- For globular transfer with a gas-shielded flux-core wire, a flow rate of 35 to 45 cubic feet per hour is necessary because the arc is larger and hotter, and more stickout is required.

Regulators and flow meters mostly do the same job. A flow meter has a glass tube and ball that indicates the gas flow rate in cubic feet per hour.

Open cylinder valves slowly to avoid damaging regulators and flow meters.

Wire feed gun cables have a liner that can be damaged if the cable is bent or tightly coiled.

WIRE FEED GUN

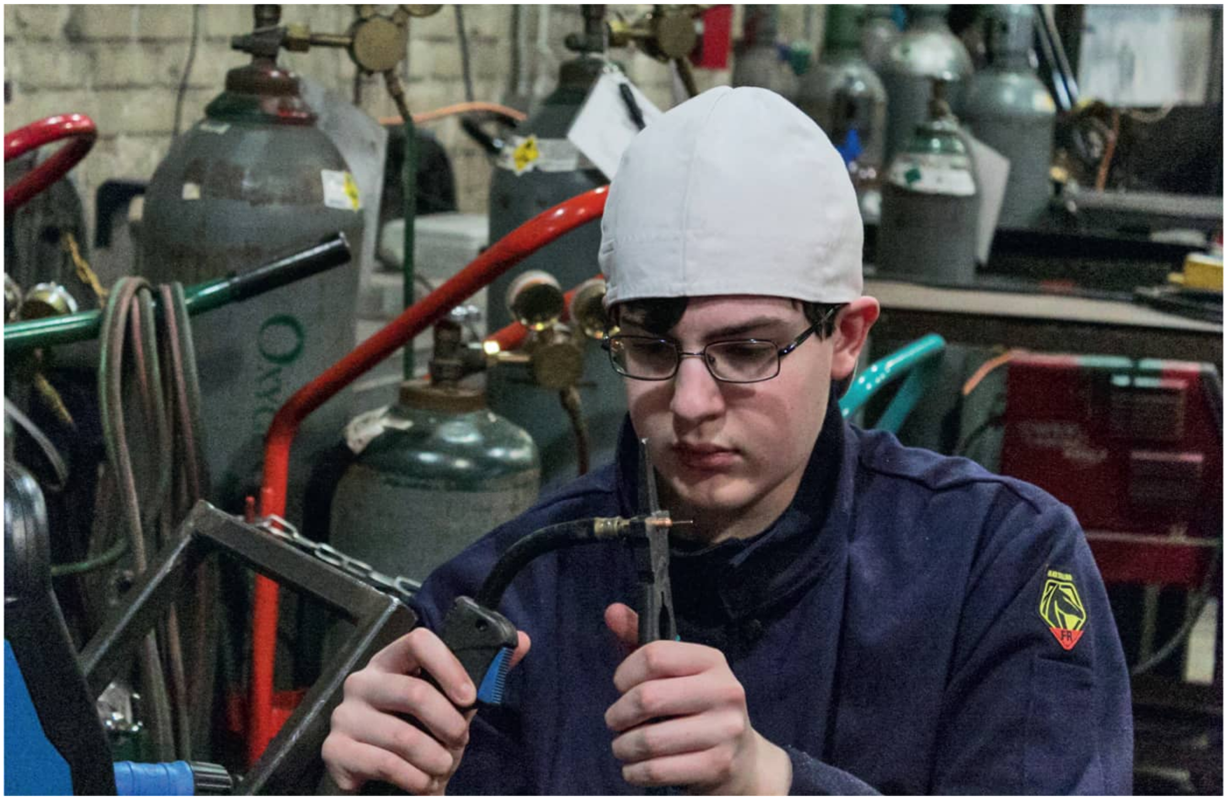
The torch used in wire feed welding is commonly referred to as a gun. The gun carries the welding current, shielding gas, and wire to the weld pool. When you depress the trigger, it sends a signal to the machine to begin feeding an electrified wire surrounded by a flowing gas. Keep your gun in good condition, and keep replacement parts and consumables on hand so small problems don’t become major setbacks. Contact tips are especially important because they transfer the welding current to the wire. Replacing contact tips when they become out of round or full of spatter will help stabilize the arc, making it easier to wire feed weld.

Wire feed guns are either air cooled or water cooled. Water-cooled guns are used in high-heat and high-deposition welding with 200 amps or more. These amperages are not typical for most welding projects you will do in a small shop. Air-cooled guns are more common, lighter, and less expensive. Guns are rated for the amperage required for welding. For example, a Tweco #2 gun is rated for 200 amps. The gun supplied with a machine should be the proper size for the maximum output voltage and work for most welding situations.

Many guns will work for wires that don’t require a shielding gas. If you use a self-shielding wire, you can remove the nozzle for a better view of the weld pool. Specialized guns are made for welding with large-diameter FCAW-S wires. These guns have a metal shield built in to protect the welder’s hand from high heat.

Nozzles, contact tips, insulators, and diffusers are all parts of a wire feed gun that you can easily replace when needed.

With the nozzle removed, the insulator, diffuser, and contact tip are visible. Tighten any of these parts if they become loose.



Contact tips electrify the welding wire. Replace worn-out tips to improve electrical connection and arc stability.

WIRE FEED WIRES

Wire feed is broken down into categories according to the wire type. Solid wires are used in MIG welding. Tubular wires are used in FCAW. Welding wires are identified by the American Welding Society (AWS) classification number as well as the brand name from the manufacturer. Here are some common wires used for different types of wire feed welding.

Typical wire sizes are 0.023-, 0.030-, 0.035-, and 0.045-inch diameters. Wire diameters are given as decimal inches to the thousandths place. The larger the wire, the greater the amount of electricity that can flow across the welding arc. A smaller-diameter electrode will have less amperage capacity and heat. Thicker metals, requiring more heat for proper fusion to take place, should be welded with larger-diameter electrodes. The amperage output capacity of a machine determines what wire sizes you can use with it and what thickness of metals you can weld.

ER70S-6—ESAB SPOOLARC 86
Mild steel
For MIG welding most steels in all positions using DCEP
Contains high levels of manganese and silicon for powerful deoxidizing characteristics
Can weld over moderate amounts of rust, scale, and dirt on metal surfaces
Used with 100% carbon dioxide (CO_2) or argon (Ar)/CO_2 shielding gas mixes
Low spatter, good bead appearance on sheet metals
E71T-1—ESAB DUAL SHIELD 7100 ULTRA
Mild steel
For flux-core arc welding with a shielding gas (FCAW-G) in all positions using DCEP
Used indoors on thicker steel plates
E71T-11—LINCOLN INNERSHIELD NR-211-MP
Mild steel
For flux-core arc welding without shielding gas (FCAW-S) in all positions using DCEN
Used outdoors for metal up to $^{5}/_{16}$ inch thick using 0.030-inch and 0.035-inch wire sizes
E71TG-G—LINCOLN INNERSHIELD NR-212
Mild steel
For flux-core arc welding without shielding gas (FCAW-S) in all positions using DCEN
Used outdoors for metal up to ¾ inch thick using 0.045-inch and larger wire sizes
ER5356
Aluminum
Recommended for spool guns
Harder wire is easier to feed
ER308L
Stainless steel
Used with a tri-mix gas
L indicates a low carbon content to help prevent weld corrosion
E308LFC-O
Stainless steel
Self-shielded flux-core welding wire

Shielding gas is not used

SHIELDING GASES

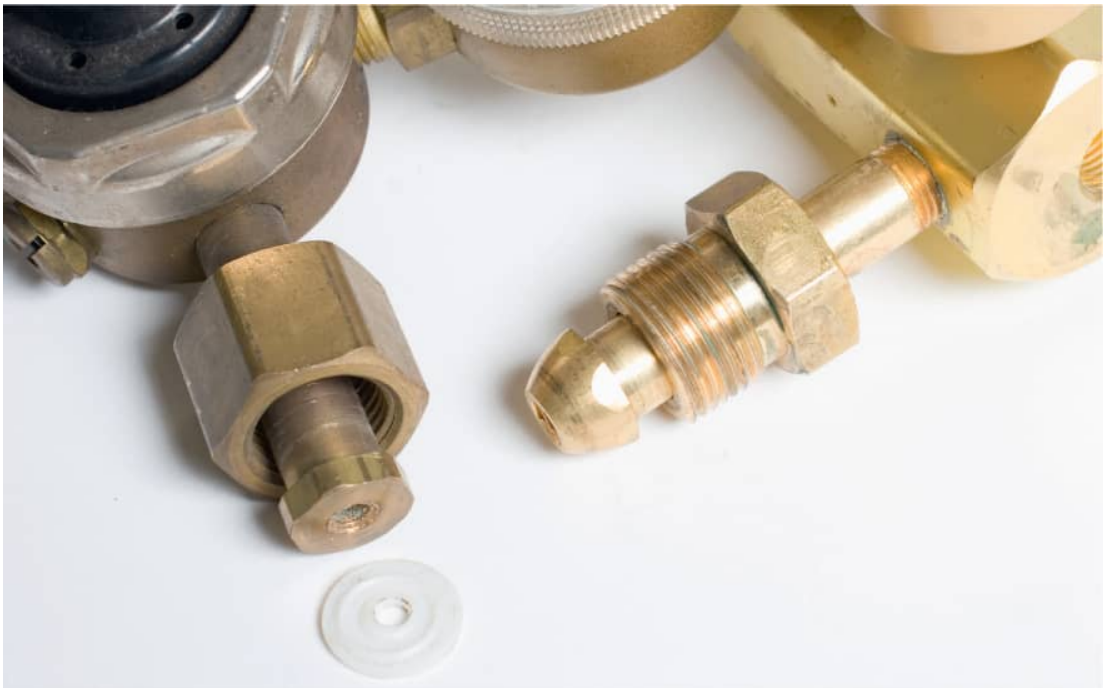
Compressed gas cylinders can be very dangerous and should be handled with care. See here for more information on cylinder safety. The single most important rule in selecting the type of shielding gas is to match the gas to your wire. Wire manufacturers give recommendations on which type of shielding gas to use with their wires.

Read the label on a cylinder to know what gas is inside. This cylinder contains C25 shielding gas.

MIG WELDING (SHORT CIRCUIT)—MILD STEEL AND FLUX CORE ARC WELDING DUAL SHIELD (FCAW-G)—MILD STEEL
Pure carbon dioxide (CO_2) is the least expensive and penetrates farther into the base metal; produces more smoke and fumes than C25; finished weld has a rougher appearance
C25 (75% argon/25% carbon dioxide) is more expensive and has slightly less penetration than 100% CO_2; finished weld bead has a smoother appearance; for FCAW-G with C25 shielding gas, lower the voltage by 1–1.5 volts
MIG WELDING (SHORT CIRCUIT)—STAINLESS STEEL WIRES
Mix of argon (Ar), helium (He), and carbon dioxide (CO_2) is used in various quantities, sometimes called a tri-mix shielding gas; a typical tri-mix gas has 90% He, 7.5% Ar, and 2.5% CO_2
MIG WELDING—ALUMINUM WIRES
100% Ar used on metals up to ½ inch thick
Ar-He mix used on aluminum over ½ inch thick

REGULATORS AND FLOW METERS

A shielding gas is always used for MIG welding and FCAW-G. A regulator or flow meter should be matched to the type of gas being used. Some regulators can be used with multiple types of gases, while others are designed for a specific type of gas, such as carbon dioxide. Carbon dioxide regulators are designed not to freeze up from the cold temperatures associated with recompressing liquid carbon dioxide into a gas. Flow meters are typically combined with regulators, indicating the exact flow of shielding gas in cubic feet per hour.



Flow meters used for carbon dioxide need a nylon washer to create a leakproof seal with the cylinder.

Keep gun angles close to 90 degrees from the metal and direct the heat to both parts of the joint.

WIRE FEED WELDING TECHNIQUES: DASH

Become familiar with all the controls on the machine you are using. Although wire feed welding is easier than other processes, it can be very frustrating when the machine is not working right. Take a few minutes to experiment with different voltage and amperage settings. If problems persist, see "Common Wire Feed Welding Problems" on this page for possible solutions.

Starting a bead with wire feed is easy. Steady your body by resting your arms on the table or bracing yourself against a solid object. Use two hands on the gun. Relax and get comfortable so you can guide the gun in a smooth motion. Pay attention to the end of the wire feeding into the weld pool. If you are having a hard time seeing the puddle, adjust the position of your head, not the gun angle, to get a clear view. Place the wire where you want to begin, then pull the trigger.

A wire feed gun can be pushed, pointing in the direction of travel, or pulled (dragged) in the opposite direction of travel. Pulling a wire feed gun results in deeper penetration into the base metal and a convex weld bead. Some flux-core wires work best when the gun is pulled. Pushing the gun flattens out the weld bead and results in less penetration. Pushing is used to weld thinner pieces of metal with short-circuit transfer.

DISTANCE

Wire feed welding machines are self-regulating. This means the distance between the gun and base metal, called stickout, does not have to be exact in order to make a good weld. As stickout increases, preheating in the welding wire also increases, so the machine automatically adjusts by lowering the amount of current. As stickout decreases, the machine increases the amount of amperage to compensate for the increased rate of wire burn-off. Either way, the machine is making these slight adjustments very quickly.

There are limits to stickout. Too much stickout increases voltage and lowers amperage. This tends to destabilize the arc, causing excessive spatter, poor heat control, and insufficient penetration. A long stickout also puts an excessive amount of preheat into the wire, increasing the rate of filler metal deposited into the weld. This results in a lack of fusion between the base and filler metal. Too little stickout results in the wire burning back and fusing to the end of the contact tip.

The amount of acceptable stickout can vary depending on the wire feed process:

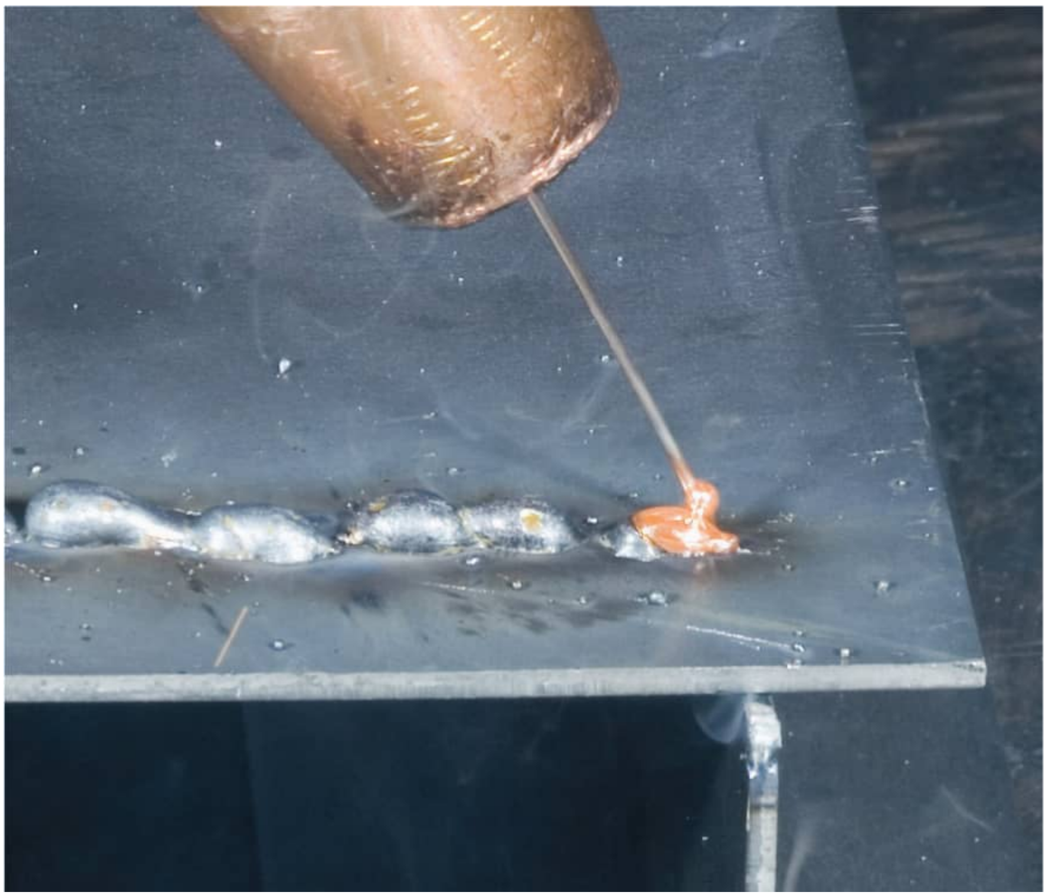
- Short-circuit transfer: ¼ to ½ inch
- FCAW-G: ⅝ to ¾ inch
- FCAW-S: ½ to 1 inch

ANGLE

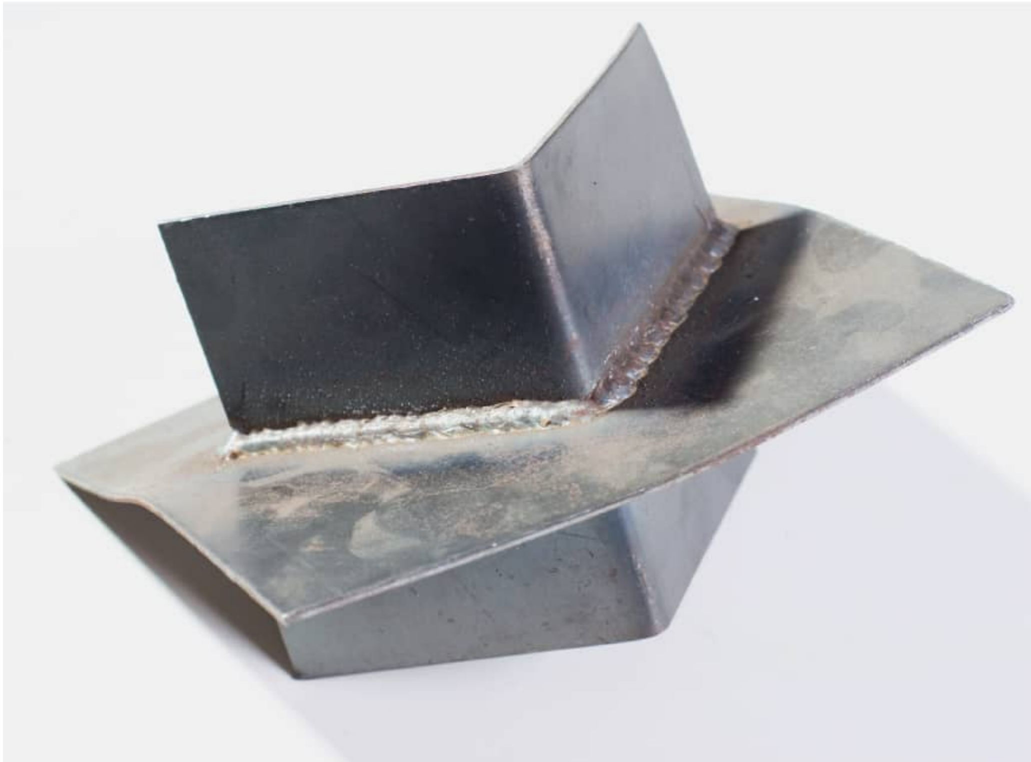
Gun angle directs the heat of the welding arc, filler metal placement, and shielding gas flow. Extreme gun angles cause undercut and compromise the flow of shielding gas. (Undercut is a small groove next to the weld.) Proper work and travel angles will vary depending on the joint design and welding position. When welding two pieces of metal, keep the gun at the same work angle to each piece—avoid tipping the gun toward one side of a joint and away from the other. Move your head to different locations until you have a clear view of the wire feeding into the molten puddle.

SPEED

Two different speeds are involved in wire feed. The wire feed speed is set on the machine in inches per minute. Travel speed is determined by the person manipulating the gun. Overall, travel speeds are faster in wire feed welding than in other processes. It is easy to “miss” the joint with wire feed because everything happens quickly. Use the end of the wire as a guide and keep an eye on where the weld pool is going. A fast travel speed will result in a small weld bead and lack of fusion into the base metal. A slow travel speed will build up too much heat and filler metal in one area. Small circular or zigzag motions can be used for wire feed welding. Keep all motions small and tight; sudden movements can cause undercut.



Too much wire stickout decreases heat, causing the weld bead to become narrow and lumpy.



Practice welding around corners to improve welding technique.

Seeing sheet metal glow orange on the back side of a weld is a good indication that you are using enough heat.

HEAT

How much heat you need for welding depends on the amount of amperage at the welding arc. Since wire feed welding uses a CV power source, the level of voltage can be adjusted. It may help to think of adjusting the level of heat by making changes to the voltage setting first and then adjusting the wire feed speed to match the voltage being used. Too much voltage can cause burn-through. Too much heat causes unnecessary distortion in the workpiece. Too little voltage results in a lack of fusion between the base metal and filler metal. Lack of fusion causes a welded joint to come apart under load.

Drive rolls, inlet guides, and gun liners are important parts of a wire feed system. A 1-pound spool of aluminum wire is used with a specialized spool gun.

COMMON WIRE FEED WELDING PROBLEMS

There are many parts in a wire feed system, and the more parts there are, the more things can go wrong. Each wire feed problem can have multiple causes. It may seem overwhelming at first. Effective troubleshooting is a useful skill and requires some knowledge of the welding process and the machine you are using. Troubleshooting wire feed problems gets easier with time and experience.

ARC IS ERRATIC

- Incorrect machine settings—adjust voltage and wire feed speed
- Loose or worn contact tip—replace with a new one
- Contact tube recessed too far into nozzle—adjust contact tip close to flush with the gun nozzle
- Dirty or coated metal—clean rust, dirt, and paint from weld joint
- Work clamp issues—clean off metal for a good electrical connection
- Shielding gas issues—check for proper flow rate and any loose connections or holes in hoses
- Wrong type of gas—check that you are using the correct gas for the welding wire
- Wrong polarity—be sure to use the correct polarity for the welding wire
- Loose welding lead connections—check gun and work cables and tighten if needed

IRREGULAR WIRE FEEDING

- Drive-roll tension too loose—adjust tension screw
- Gun cable liner kinked, clogged, or worn out—replace gun cable liner
- Kinked or rusty welding wire—unroll damaged area until wire looks new or replace spool

BIRD NESTING (THE WIRE GETS TANGLED IN THE MACHINE DRIVE ROLLS AND STOPS FEEDING)

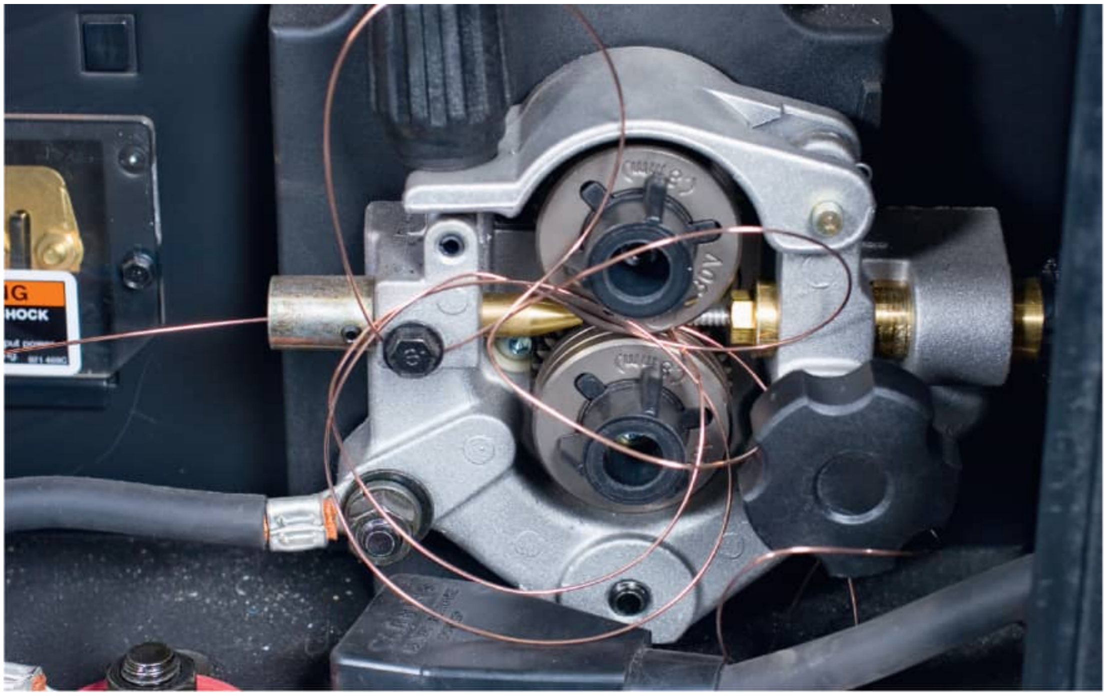
- Drive-roll tension set too tight—loosen tension screw
- Drive rolls wrong size—check that the drive rolls match the size of wire being used
- Drive rolls misaligned, worn, or damaged—adjust alignment or replace drive rolls
- Gun or gun cable clogged—disassemble and remove dirt, dust, or slag
- Gun cable kinked or coiled tightly—keep gun cable as straight as possible when welding
- Wrong wire feeding system—softer wires (such as aluminum) and long gun cables require a different feeding system

WELD CONTAMINATED BY ATMOSPHERE

- Shielding gas blown away—check for drafts, fans, or windy conditions
- Incorrect shielding gas flow—adjust flow rate for welding being done
- Gun too far away from weld pool—get closer to reduce stickout
- Contact tube not centered in nozzle—replace worn gun components
- Empty gas cylinder—replace with full cylinder
- Leaks in gas lines, including regulator and gun—check for leaks and fix as needed
- Broken gas solenoid—send machine out for repair or purchase new machine

Replacing a contact tip is easy: remove the nozzle, unscrew the worn-out tip, and replace it with a new one.

Loose connections in a shielding gas system can bring air into the weld area, causing small holes in the bead (called porosity).



Problems with a wire feed system can lead to “bird nesting,” in which wire gets tangled in the drive rolls.

10

TIG WELDING

Learning to TIG weld takes time, practice, and patience.

HOW TIG WELDING WORKS

TIG welding machines and stick welding machines have a lot in common. Both use constant current to deliver electricity to a welding arc. Amperage, which determines the amount of heat going to the weld, is set on the machine. The main difference is that in TIG welding there is no flux-covered rod and the electrode does not become part of the weld.

The need for TIG welding came about in the late 1930s when an airplane designer wanted to develop an all-welded airplane frame. An all-welded airframe has many advantages, including reduced cost and weight. But this kind of airplane would require a new way to weld magnesium. The welds needed to be strong and crack resistant. There is little wiggle room for bad welds when you're flying thousands of feet above the earth.

A flux coating would contaminate the welds on magnesium. Therefore, the stick welding electrode was replaced by a tungsten electrode. Tungsten has a high melting point and does not melt when exposed to arc welding temperatures. Because it does not melt, it does not become part of the finished weld. Instead, a filler rod is used to add metal to the welded joint. The flux coating on a stick welding rod was replaced by a shielding gas. The first shielding gas to be used was helium, which is why TIG welding is sometimes referred to as heliarc. Shielding gases do the same job as the flux: they protect the weld while it is a liquid puddle by keeping out oxygen, nitrogen, and water vapor.

While TIG and stick welding are related, they each have their own traits. Stick welding is good for working outdoors in windy conditions and welding metals that cannot be cleaned thoroughly. Try this with TIG welding and there will be problems. TIG welding requires clean metal and a place where the weld is protected from wind. However, TIG welding is a popular precision welding process because it can weld both sheet metal and thicker plate. It is great for fabrication projects such as building a motorcycle frame. But it may not be the best choice for repairing equipment outdoors.

You can use a TIG torch to fuse metals together without using a filler rod. This is called an autogenous weld.

These Dinse-type connectors twist into place. DCEN is used when the torch is negative and the work clamp is positive.

MACHINE CONTROLS

TIG welding uses a constant-current (CC) welding machine. The same type of current is used for stick welding, so many machines can do both TIG and stick welding. Amperage is set on the machine to control the amount of heat needed to make a weld. Direct current electrode negative (DCEN) polarity is used to TIG weld all types of metals except aluminum and magnesium. Electricity flows straight down the tungsten electrode, across the welding arc, and into the metal. With DCEN, most of the heat is concentrated in the metal—which is good because if the electricity were flowing the other way, the heat would melt the tungsten.

Alternating current (AC) is typically used for TIG welding aluminum and magnesium. AC does a good job breaking up the oxide layer on the surface of these metals. This happens when the electrode switches to the positive polarity in the AC cycle. By switching back and forth between EP and EN polarities, AC current keeps the tungsten electrode at a lower temperature, preventing it from melting away.

HIGH FREQUENCY

There are several ways to start a TIG welding arc. Scratch start and lift start are ways you can start the arc using direct current and are similar to striking an arc with a stick welding rod. Some TIG machines have a high-frequency (HF) control. With HF, you can start an arc without the tungsten touching the base metal. A remote-control foot pedal or torch-mounted switch is used to start the arc. Newer machines change the high-frequency setting automatically depending on which type of current is selected, AC or DC.

TIG power sources can have many different controls. This machine is set for 120 amps, which is enough heat to weld ⅛-inch-thick metal.

Remote start controls, such as foot pedals, are used to establish the arc and to increase or decrease the amount of heat.

POSTFLOW

Many TIG machines have a postflow setting that keeps the shielding gas on after the arc is off. Postflow is important because it continues to shield the molten weld pool as it solidifies at the end of a weld. Postflow also protects the white-hot tungsten electrode from being contaminated. Set 1 second of postflow time for every $^{1}/_{100}$ (0.010) inch of tungsten. For example, if the diameter of your tungsten is $^{3}/_{32}$ (0.093) inch, set postflow between 9 and 10 seconds.

The same TIG welding techniques—distance, angle, speed, and heat—are used for welding almost any metal, including aluminum.

AC CONSIDERATIONS

There is an oxide layer present on aluminum and magnesium that can make it difficult to weld. Alternating current is used to break up the oxide layer. The DCEP part of AC provides a cleaning action that helps remove oxides from the surface of the metal. If you are using AC to weld aluminum or magnesium, there are additional machine controls you can use.

AC BALANCE

AC balance changes the amperage output on the straight polarity side (negative pole) and reverse polarity side (positive pole). The output can be changed to favor one pole over the other. For example, a 90 percent negative and 10 percent positive balance will create a narrow arc with more penetration into the base metal and little cleaning action on the surface. A 60 percent negative and 40 percent positive balance will make the welding arc wider and less stable. There will be less penetration into the base metal, but more time spent at the positive pole creates cleaning action on the surface of the base metal.

AC FREQUENCY

Inverter-type welding machines can compress the AC wave so that the time between each cycle of AC (frequency) is very short. One wave of high-frequency AC is used in a circuit to keep the arc going through the "zero value." Another AC wave gives the arc a great amount of stability. With some inverter power sources, the frequency of the AC wave is adjustable. As AC frequency increases, the arc becomes more focused and the molten pool becomes narrower.

TUNGSTEN ELECTRODES

Tungsten electrodes have color-coded ends so the electrode can be easily identified. Most manufacturers use the same color-coding system, but some may use their own. Consult the AWS classification if you are uncertain about the alloying element in a tungsten electrode. Here are a few common examples.

Common tungsten sizes are $^{1}/_{16}$ inch, $^{3}/_{32}$ inch, and ⅛ inch. Each size needs matching torch parts to fit properly. If you plan on using different sizes of tungsten, remember to have the correct sizes of torch parts ready for use.

Tungsten electrodes usually come in packs of ten. Torch backs and ceramic torch cups come in different sizes and lengths.

RED

- Tungsten with 2% thorium added
- Great for DC TIG welding
- Will hold a sharp point at high amperages

GREEN

- Pure tungsten (nothing added)
- Used only for AC TIG welding at lower amperages
- Will not hold a point

GRAY

- Tungsten with 2% cerium added
- Works well for AC and DC TIG welding
- Can hold a pointed or balled end

Torch components include a cup to direct the shielding gas, inner and outer collets that hold the tungsten in place, and a torch back.

Tungsten grinders have a diamond wheel and guides for making a perfect cone-shaped point.

Before TIG welding with DC current, a tungsten electrode should be ground to a point. There are several tools you can use to grind a piece of tungsten:

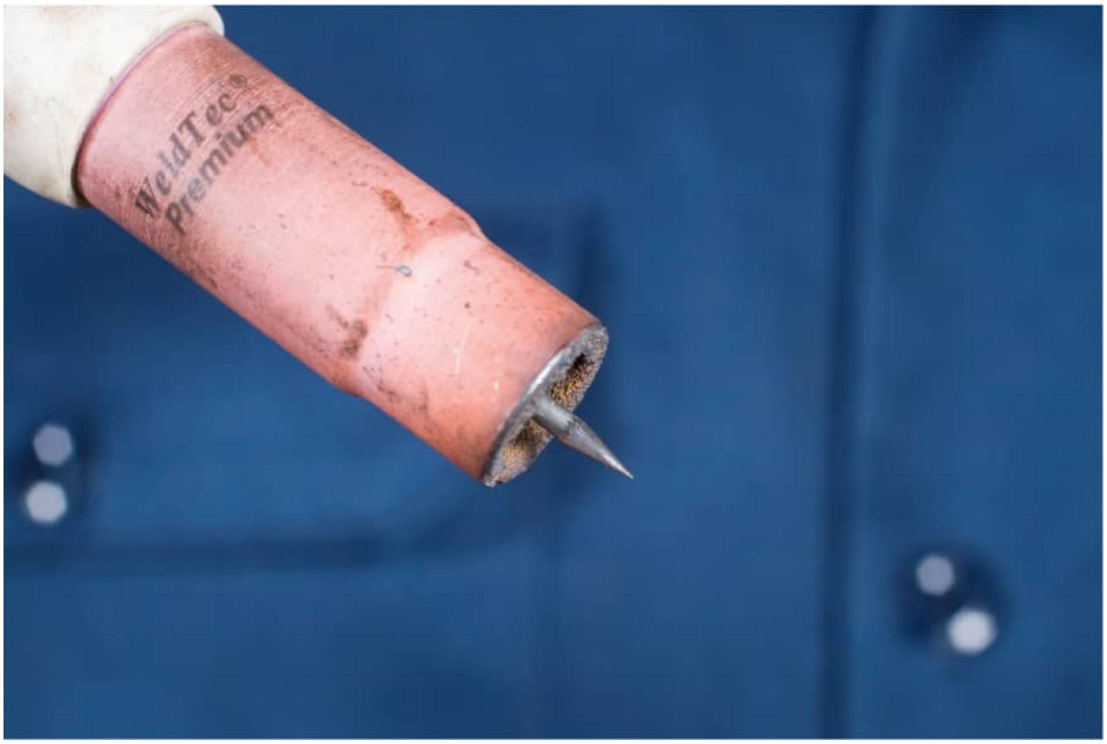
1. A machine specifically for grinding tungsten (these come in different sizes and use a diamond wheel to grind the metal; the tungsten is inserted into the machine and held at specific adjustable angles)

2. A pedestal grinder with a stone wheel used for tungsten only

3. A belt sander

If you have a portable drill, you can put the tungsten in the chuck and turn it at a low speed. Otherwise, you will need to rotate the tungsten by hand in order to create the desired cone shape at the end. Use light to medium pressure when sharpening. If you use too much pressure, the tungsten will heat up from the friction and turn blue, reducing its performance.

It is important to know that electricity flows on the outside of the tungsten electrode. For this reason, the grinding marks should always be “in line” with the length of the tungsten—that is, grind lengthwise. If you sharpen a piece of tungsten at 90 degrees to your abrasive wheel or belt, the grinding marks will circle around the tungsten rod. The electricity will follow the grinding grooves in the tungsten. Circular grooves cause the arc to spin off the end, making it less stable and less focused.



Adjust the tungsten in the torch so that the pointed end is just past the ceramic cup.

Long tungsten stickouts can be a problem because the shielding gas no longer protects the weld pool.

Once the tungsten is sharp, keeping it that way is a challenge. Anytime you touch the electrode to the work, both the base metal and tungsten become contaminated. The tungsten should be resharpened when this happens. If the end of the tungsten is completely messed up, use two pliers to break off the end, then resharpen.

When TIG welding with AC, a ball usually forms on the end of the electrode. You can grind gray-coded tungsten to a point first before using it with AC. With inverter-type welding machines, the action of the current will ball the end slightly or not change the shape at all. If the ball becomes large from too much current, switch to a larger-diameter tungsten or a different tungsten alloy.

Air-cooled and water-cooled torches contain small parts. Be careful not to bend or overtighten the components.

TORCHES

A wide variety of tungsten sizes can be used with every torch. However, if you plan on using different tungsten sizes, you will need to have the correct torch parts for each diameter. The torch cup, inner collet, and outer collet (diffuser) are specific to the diameter of tungsten being used.

Gas lenses are a popular torch add-on for TIG welding. These make TIG welding easier because they make shielding gas coverage more even, allowing the tungsten to stick out further. Clear torch cups allow better visibility of the weld puddle as it is being made.

Smaller TIG welding machines will have an air-cooled torch. Air-cooled torches are typically used with currents less than 200 amps. However, they may not work for long periods of "arc on" time, even at less than 200 amps. If the heat of the arc makes the torch too hot to handle, reduce the welding time or switch to a water-cooled torch. Water-cooled torches use a pump and reservoir in a closed system to circulate coolant through the torch. Water-cooled torches are smaller and lighter and can withstand a lot of "arc on" time at high amperages. Machines equipped with a water-cooled torch and pump system are significantly more expensive.

Filler rods are made from different metals and have a variety of uses. Some steel rods have a copper coating to prevent rust.

FILLER RODS

Filler rods are used to add weld metal to the joint for reinforcement, making it stronger. The filler metal is selected based upon the type of metal being welded. Filler rods are identified by a set of letters and numbers, which describe the type of alloys contained in the rod. The AWS classification system for filler rods is used to describe the ingredients in the rod and how strong the resulting weld should be. Common filler rods used in TIG welding include the following.

ER70S-2—MILD STEEL

- Contains silicon and manganese deoxidizers, which help remove impurities from the weld
- For welding all grades of carbon steel

ER308L—STAINLESS STEEL

- For welding 304, 308, 321, 347 stainless steels
- *L* indicates a low carbon content to help prevent weld corrosion

ER4043—ALUMINUM

- For welding the widest variety of aluminum alloys

SHIELDING GASES

A shielding gas protects the molten weld pool from atmospheric contamination. The air we breathe contains elements such as nitrogen, oxygen, and water vapor that molten metal can rapidly absorb. If these elements are absorbed, the weld will be brittle and porous. TIG welding always uses a shielding gas. Shielding gases are stored at very high pressures in compressed gas cylinders. Be familiar with the hazards related to storing, handling, and using these cylinders. See here for more information on cylinder safety.

Argon is the go-to shielding gas for TIG welding. Argon gas is used to weld almost any metal with both DC and AC current. There are other shielding gases used in TIG welding, including argon-helium mixes and argon mixed with small amounts of hydrogen or nitrogen for specialized welding applications. Do not use C25 or other gas mixes used for wire feed welding. Base metals welded with TIG will be contaminated if exposed to carbon dioxide or oxygen.

Shielding gas flow rates are measured in cubic feet per hour (cfh). For TIG with straight argon, a flow rate of 15 to 20 cfh is usually adequate. If the shielding gas flow rate is too low, it will not provide enough coverage over the molten puddle. This is especially true when longer tungsten stickouts are used. If the flow rate is set too high, turbulence from the gas stream can aspirate air, sucking in oxygen and nitrogen, which will contaminate the weld.

The flow meter gauge indicates there are 650 pounds per square inch (psi) of argon gas left in this cylinder.

Use the adjustment knob on the regulator to set gas flow. The ball indicates a flow rate of 15 cubic feet per hour.

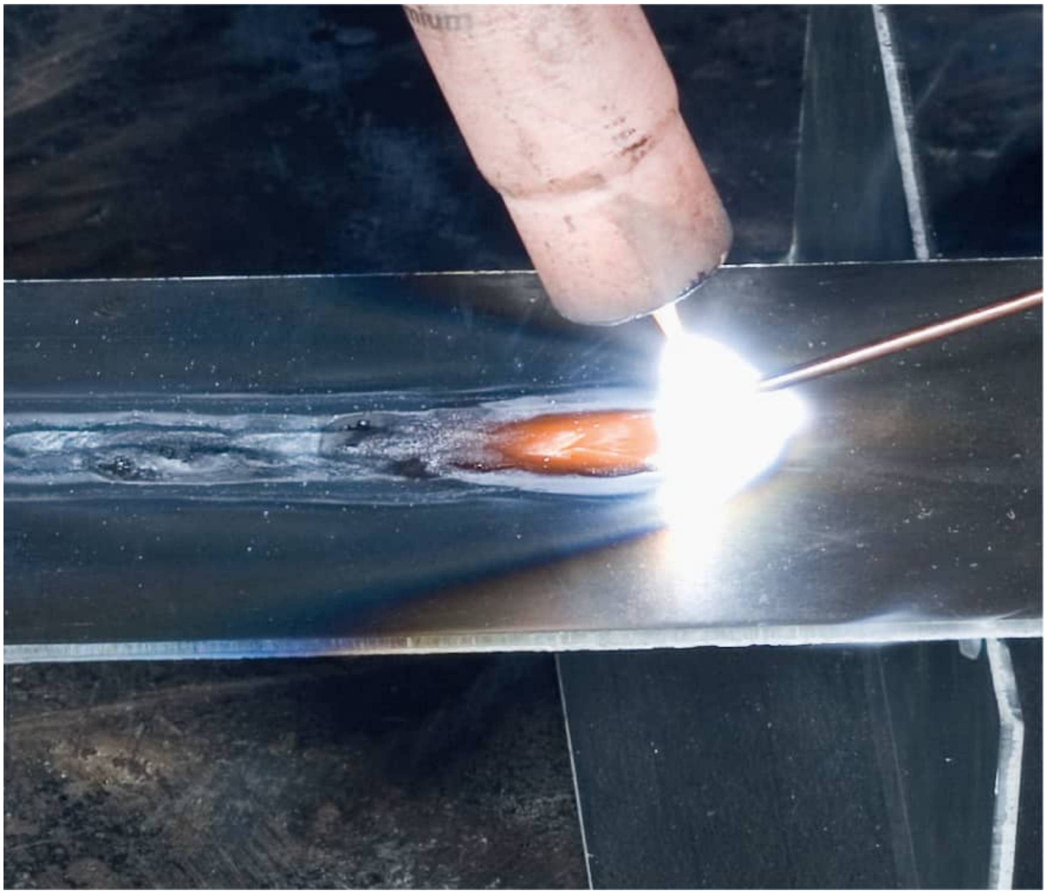
TIG WELDING TECHNIQUES: DASH

In TIG welding, one hand holds the torch, the other hand holds a filler rod, and in many cases a foot-operated switch controls the amperage. Start off using only the torch and foot pedal. Add the filler rod once your foot controlling the amperage is coordinated with your hand manipulating the torch. The techniques for pushing a puddle and adding filler rod are similar in gas welding and in TIG. Like an oxy/acetylene welding tip, the TIG welding torch is pushed. Travel in the direction your torch is pointed (forehand technique). The relationships between distance, angle, speed, and heat are critical in all welding processes, and especially TIG. If you manage these four factors correctly while running a bead, it will turn out right. As always, each part of DASH influences the other, so keep this in mind to increase your chances of making a great weld.

Some flow meters work with different gases. Be sure to read the correct scale for the type of gas you are using.


Once you begin using a filler rod for TIG welding, get comfortable. Rest your arms on the table or work surface to stay steady.

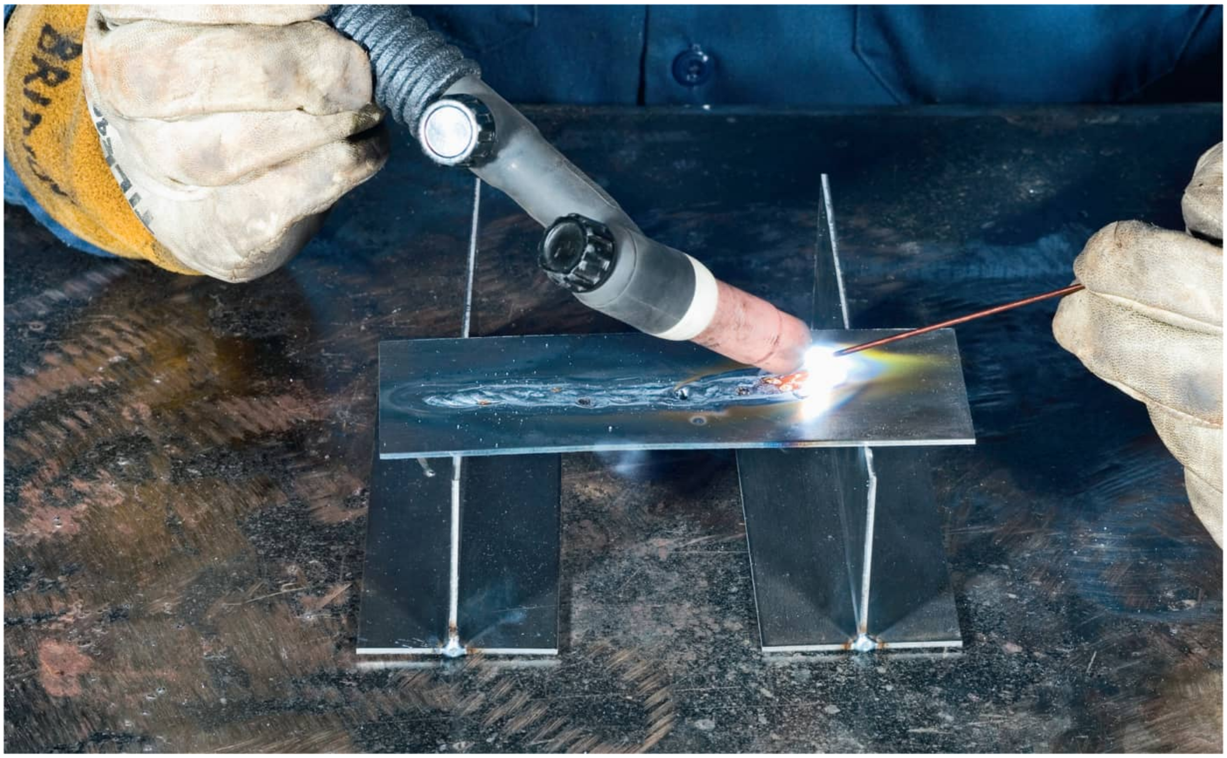
Start to learn TIG welding by holding only the torch and fusing two pieces of metal together.



Holding the torch too far away from the metal causes the arc and molten puddle to spread out.

DISTANCE

Keep the tip of your electrode as close to the base metal as possible without touching it. The optimum distance (arc length) is about $^{3}/_{32}$ to $^{1}/_{16}$ inch, which is very short. Distance should remain consistent during the entire weld. Raising the TIG torch will cause the arc to spread out, making a wider molten pool. A shorter arc length will focus the arc, making the weld pool small. As in other welding methods, do not change the distance to change the amount of heat. Only change distance to increase or decrease the size of the molten puddle.



Holding the torch at the wrong angle distributes the heat unevenly and makes it difficult to add filler metal to the weld pool.

ANGLE

Travel angle is the angle at which the torch is held in line with the weld joint (length). Work angle is the angle of the torch perpendicular to the weld joint (side to side). Using the correct work and travel angles will direct the arc into the root of the joint. Torch angle determines where the heat is placed. An incorrect torch angle directs heat where it is not needed, such as to a thinner section of metal or one side of a weld joint and not the other. The travel direction should be a forehand technique, pushing the torch. Adjust the torch angle to manage and direct the molten puddle.

The heat input in the base metal will change depending on your torch angle. Steep angles direct the heat of the arc toward the workpiece and increase the amount of penetration into the base metal. Shallow angles (less than 45 degrees from the base metal) are not recommended since the arc spreads out and less heat is applied to the base metal. When shallow torch angles are used, the rod tends to get drawn onto the hot tungsten instead of the molten puddle.

SPEED

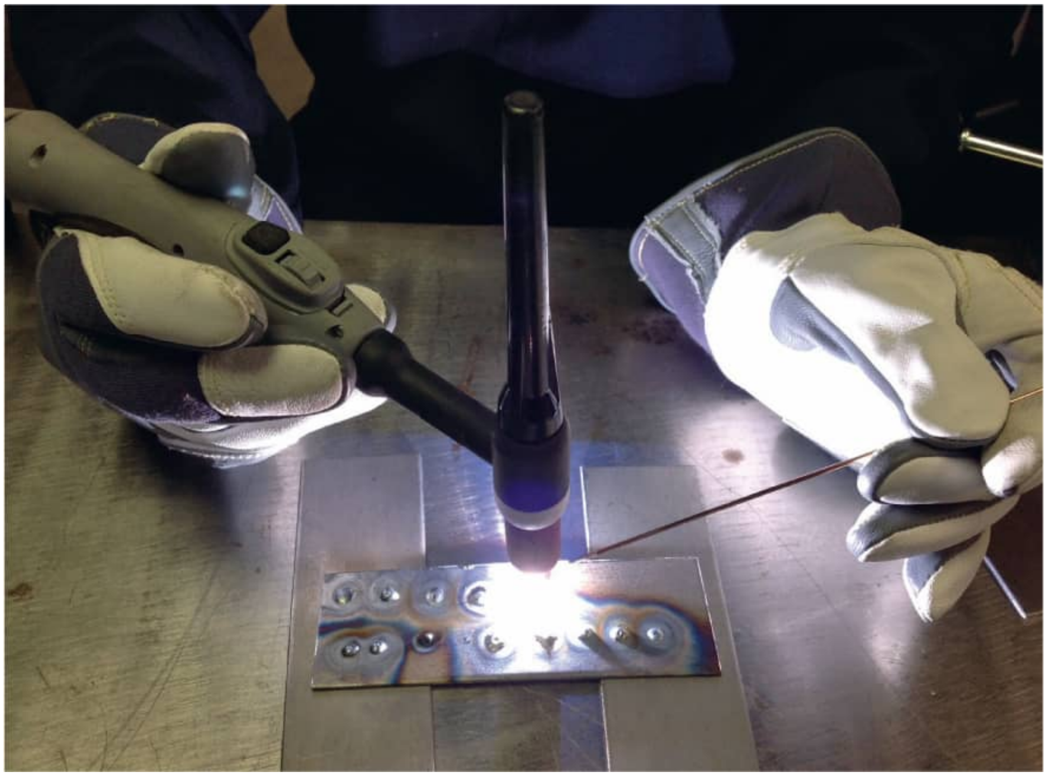
A consistent travel speed puts a uniform amount of heat into the base metal along the weld joint and is the key to creating uniform weld beads. When adding filler metal to the weld pool, dip the end of the rod into the molten puddle frequently, and at a consistent rate. When joining thinner sheet metals, move the torch in a straight line. Use a circular or zigzag motion when joining thicker metals. The amperage has a large impact on travel speed. You can travel faster when using higher amperages. This puts less heat into the base metal. Lower amperages require a slow travel speed in order to maintain the molten puddle. This heats up the base metal for a longer period of time. When learning how to weld, it may be best to reduce the amount of amperage to gain more control over the molten puddle.

Moving too fast can cause incomplete fusion, in which the weld metal has not fused together.

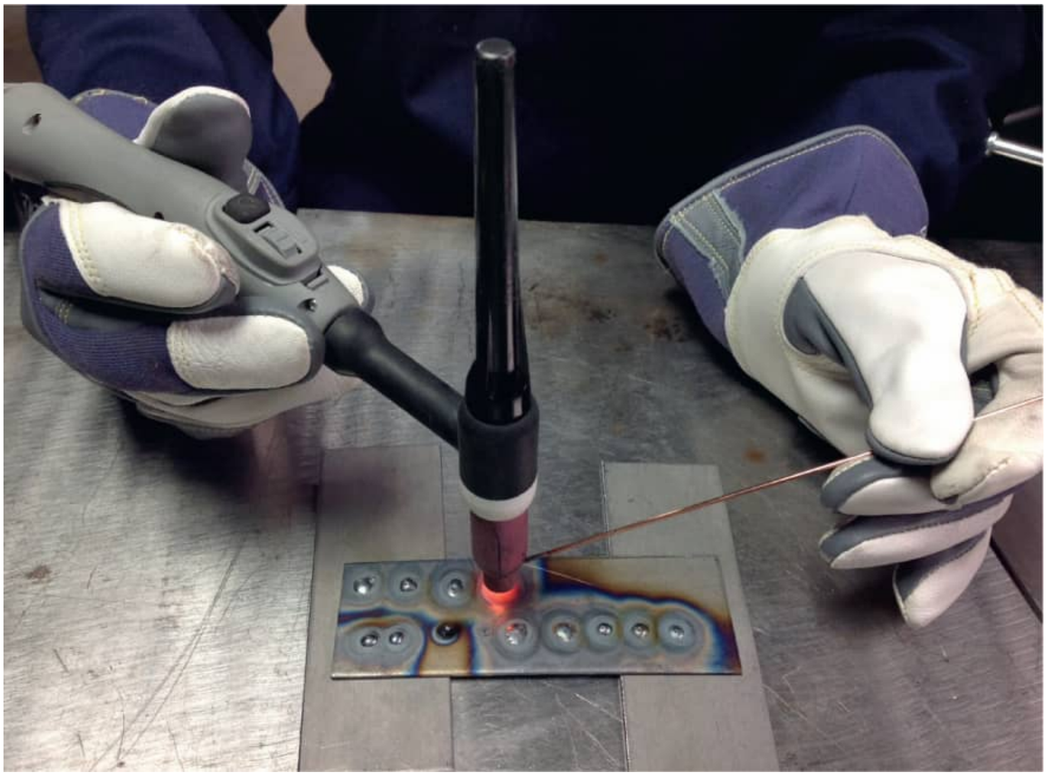
Practice TIG by welding tube to sheet. Try to get the same amount of filler metal on both pieces.

HEAT

In TIG welding, as in other processes, the amount of heat is determined by the amperage. The thickness of the base metal determines the amperage setting. Heat is also controlled by the addition of filler rod into the molten puddle. As the cooler filler metal is added, it reduces the heat in the weld pool. Frequently dipping the filler rod into the puddle helps prevent the liquid metal from spreading out or melting through the base metal. The only way to build up a consistent weld bead is to add filler metal during the entire weld.



Learn to add filler metal by heating one spot until it melts, then dipping the filler rod into the puddle to build up the weld.



Keep the torch in place for a few seconds after welding so the shielding gas can protect the weld as it solidifies.

COMMON TIG WELDING PROBLEMS

Learning TIG welding is like learning to drive a car. At first, it's difficult concentrating on pushing the gas pedal and steering the car while paying attention to the traffic on the road. With time and practice, steering becomes more automatic. Turning corners and switching lanes gets easier. The foot on the gas pedal develops a mind of its own. Instead of thinking about letting off the gas to slow down, your leg lifts automatically when traffic slows down in front of you. TIG welding, or any welding process, may feel awkward at first. Keep practicing. In time, your mind and body will be in sync, and welding will become more instinctive and less difficult. With practice, you will be able to make adjustments without thinking too much about them. Keep in mind that TIG welding with the incorrect shielding gas, polarity, type of tungsten, or filler rod is like trying to win the Daytona 500 with four flat tires. No matter how good the driver is, there is no chance of finishing the race.

Here are some problems you might encounter and how to fix them.

TUNGSTEN MELTS AWAY

- Wrong polarity—switch to DCEN
- Tungsten too small—use larger-diameter tungsten
- Wrong kind of tungsten—switch from pure (green) tungsten to ceriated (gray)

WELD HAS HOLES

- Wrong gas—use only 100 percent argon
- Incorrect gas flow—check flow and set to 15–25 cfh
- Loose connection or damaged flow meter—check gas connections
- Damaged gas hose or torch cable—check for tears and holes in hoses
- Torch too far away—stay about $^{1}/_{16}$ inch from weld pool
- Tungsten stickout too far—move end of tungsten closer to torch cup
- Windy conditions—turn off blowing fans or shut open garage doors

WELD BEAD IS CONTAMINATED

- Dirty metal—make sure metal is clean in and around weld area
- Filler rod contaminated—remove dust and oil from filler rods
- Shielding gas compromised—check for problems listed under “Weld has holes,” at left
- Incorrect filler rod—check that filler rod is the same type as the metal being welded
- Tungsten contaminated—regrind tungsten so it is clean

PROBLEMS WELDING ALUMINUM

- Metal not changing color when heated—this is normal; puddle will only look wet
- Weld puddle not forming on metal—remove oxide layer
- Weld puddle taking a long time to melt—increase positive side of AC balance
- Metal getting too hot—move faster or make shorter welds

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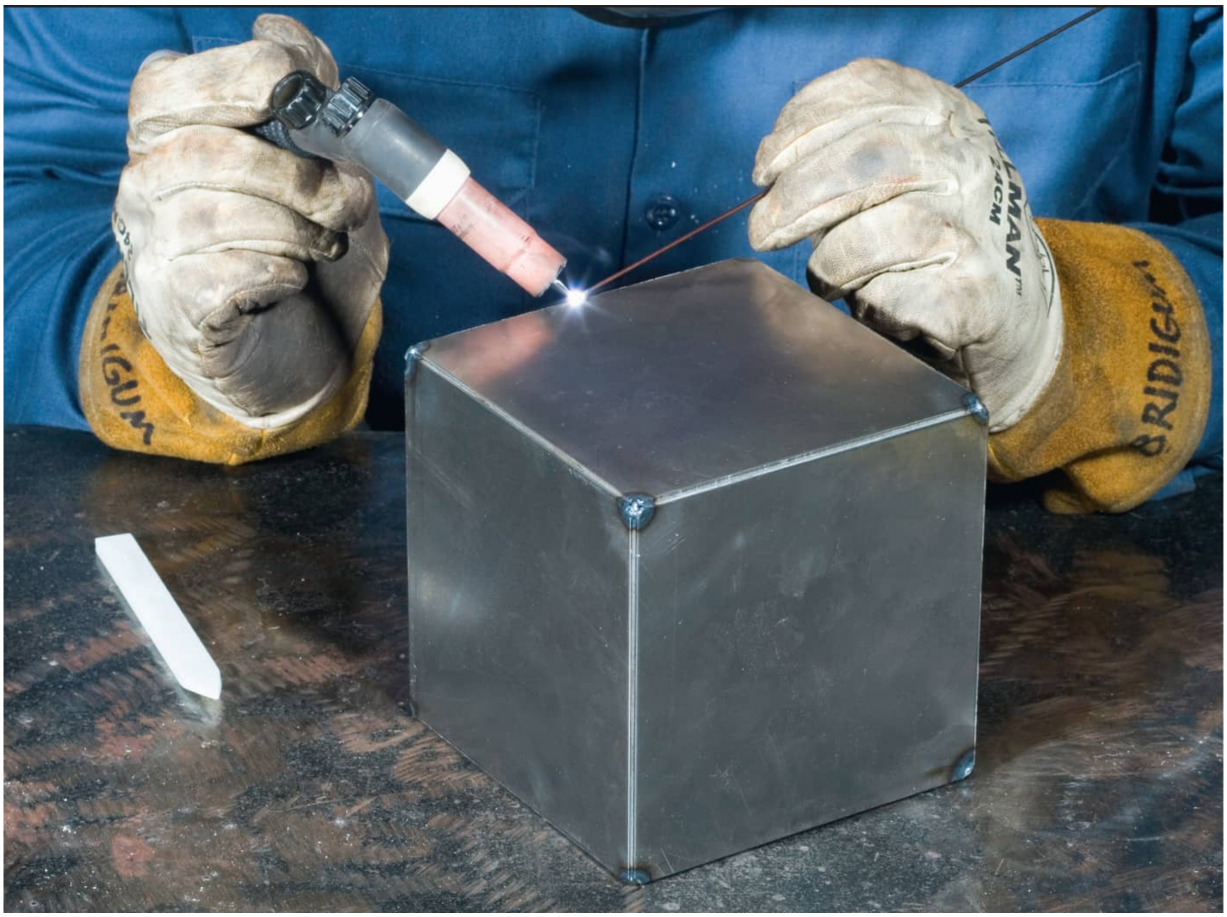
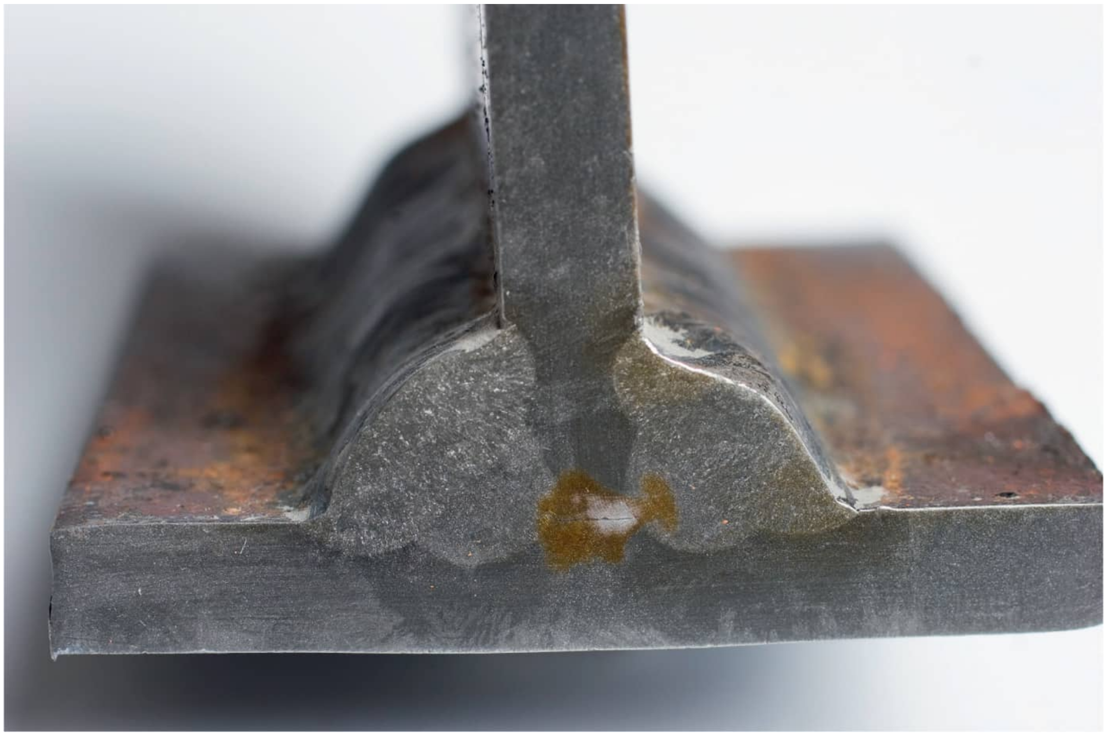
FABRICATION AND METAL DISTORTION



A metal cube is a great fabrication project for beginners. Fit the six sides together and tack the corners and edges.



A cutaway section of weld can be polished and etched to reveal the grains of the metal.

WHAT'S IN METALS

If you've ever seen photos of magnified snowflakes, you know that the beautiful crystal shapes make geometric patterns. Metal is the same: it is a crystalline substance, and the crystals of the metal are called grains. As a snowflake melts, the tiny frozen crystals holding it together turn into a liquid. When metal is melted, the same thing happens. The solid crystal patterns break down, and all the grains in the liquid mix together. When the metal cools, these grains re-form in different ways, depending upon the rate of cooling. The way the grains are arranged when the metal is heated and cooled can make a big difference in its strength. There are many different grain structures, some more favorable than others. The carbon atoms in steel move around freely when melted but can be distributed unevenly among the iron atoms as the metal solidifies. These different grain structures are known as the "ites": austenite, ferrite, pearlite, cementite, and martensite.

DIFFERENT METALS FOR DIFFERENT USES

Metals have a wide variety of properties. Think of metal properties like personalities, each one having different attributes. For example, metal that is stamped into a car door panel needs to be softer than the metal used to make a drill bit. Climate and environment are also factors—steel used to build an oil rig in the Gulf of Mexico needs different properties than metals used for pistons and engine blocks or a pipeline in northwest Canada. The heat from welding affects metals in a variety of ways and often changes its properties.

Heat was applied to this screwdriver made of hard alloy steel. Notice that a crack formed in the center when it cooled down.

CHEMICAL PROPERTIES

A metal's chemical properties are how it reacts with other elements in the environment. For example, when oxygen and water combine with the iron in steel, it forms iron oxides, more commonly known as rust. Corrosion describes the "wasting away" of a material. Salt corrodes aluminum, eating away at the metal without a new material being formed. Stainless steel is often used for projects because of its resistance to corrosion.

PHYSICAL PROPERTIES

Physical properties are unique to each kind of metal. For example, different metals liquefy at different temperatures; it takes a lot less heat to melt lead than to melt iron. The melting point for each type of metal is different, and we can use that to our advantage. Tungsten has one of the highest melting points, which is why we use it as an electrode in the TIG welding process—it can withstand the heat of the welding arc.

Metals also conduct heat and electricity at different rates. Copper is highly conductive and is used for electrical wiring because it does the job most efficiently for the cost involved. Silver and gold are better conductors, but they are rarer and more expensive. Most metals are electrically conductive, meaning electrons can easily pass through them. This allows us to use an electrical current to create an arc for welding.

Thermal conductivity is measured by the rate at which heat passes through a material. This type of conductivity can affect how fast a metal heats up and cools down. If you hold two metal bars, one aluminum and one stainless steel, and heat them, you will notice the heat travels faster through the aluminum bar and slower through the stainless steel.

MECHANICAL PROPERTIES

These properties determine the behavior of metal under an applied load, such as when a steel rack is holding heavy pipes. Tensile strength measures the force required to pull a piece of metal apart. Steel welding electrodes, such as wires and rods, have designated tensile strengths given in their AWS classification numbers. Hot and cold environments change metals' mechanical properties as well. That is why they are tested in all types of conditions, including how they are affected by earthquakes. Knowing the mechanical properties of a metal you are using in a weld is important for designing and building structures that last.

This tensile test example pulled apart under a heavy load. Notice how the metal stretched before breaking.

Filling a hole by torch welding requires the part to be heated to its melting point. Then, the filler metal and base metal can be combined.

By moving the torch in a circular motion and adding filler metal, the weld can fuse completely all the way around until the hole is filled.

HEATING AND COOLING

When metals are heated, they expand in size. The heat of a weld bead or torch causes an uneven expansion of the metal, which leads to distortion. When metals are cooled, they contract (get smaller). This is useful when two pieces of metal are stuck together and you need to separate them. Placing them in a freezer or outside on a cold day causes both parts to contract; with luck, they will come apart.

ACCOUNTING FOR DISTORTION

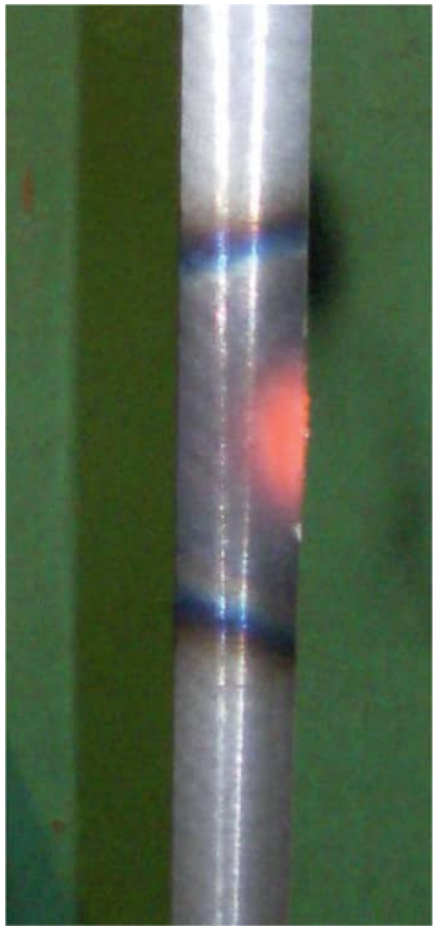
There is no getting around the fact that heat is required for welding. If a chunk of metal is heated uniformly, it expands in all directions and shrinks back to its original size. When a piece of metal is heated on one side, the hotter side will expand. Because the heated side expands more than the unheated side, stresses occur between the very hot metal and the cooler metal around it. These are called shrinkage stresses. As the metal cools, shrinkage continues to cause tension in the weld by pulling the surrounding metal toward the previously heated area. When this happens, it changes the shape of the piece, causing distortion. Although it’s impossible to completely avoid distortion, there are techniques to help minimize and control it.

MINIMIZING DISTORTION

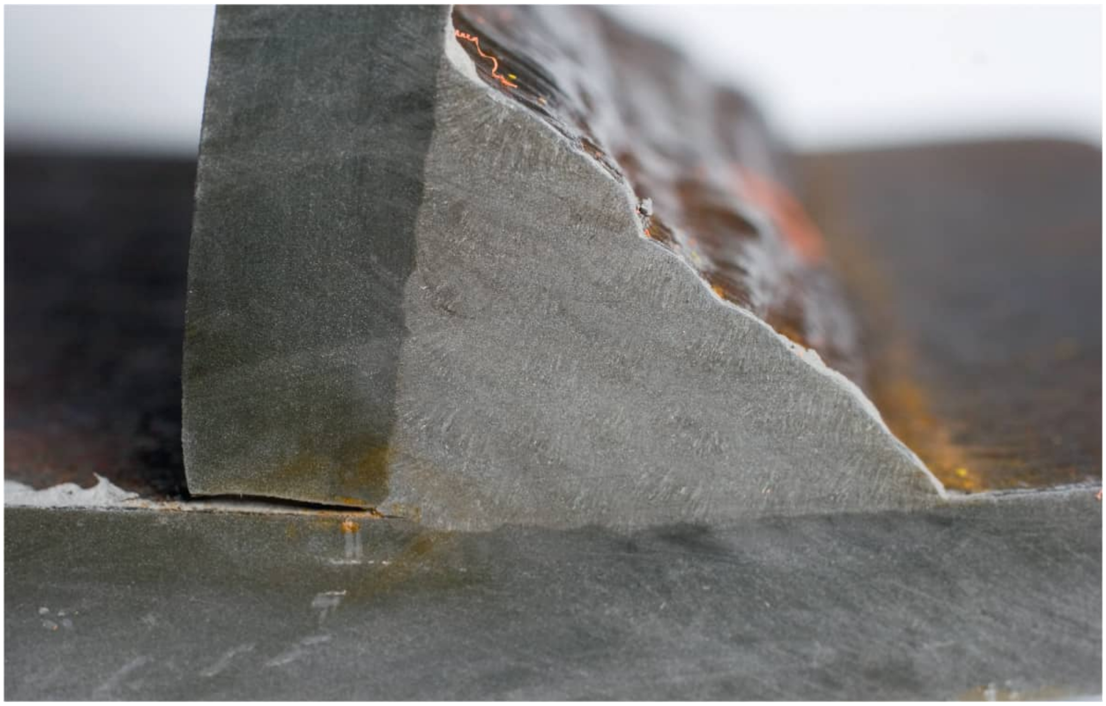
Don't overweld. Most beginners make the mistake of using too much weld metal on a project. There are some situations in which a full-length weld is required—for example, parts that need to be watertight, such as a water trough, require full-length welds. In most situations, however, full-length welds are not necessary. As a general practice, be conservative with the amount of welding you do on a project. If you weld the joints properly, you might need less weld metal than you think.

Avoid oversized welds. Welds with proper fusion need only be as large as the metal thickness being welded. A really big weld does not make something stronger. In fact, it's the opposite: large welds increase distortion and weaken the metal being welded. When this happens, the metal tends to crack apart right next to the weld bead.

Skip around. Don't weld a project in a straight line from one end to the other. Make smaller welds, moving around from area to area. Certain projects, such as the boom arm of a crane, may have a specific welding sequence to keep them straight. Backstepping and intermittent welding can spread out the heat. This minimizes distortion because the heat never builds up too intensely in one area.



One side of a bar is heated to about 1,800°F. When it cools, the bar will be distorted, bending toward the heated side.



A large amount of weld metal caused these plates to bend. Make smaller welds to minimize the amount of distortion.

CONTROLLING DISTORTION

Prebending metal pieces is a way of compensating for distortion. Before welding, parts are slightly bent and held in place with braces or clamps. Joints can also be preset at certain angles. When welding is complete, the shrinkage stresses in the weld pull the pieces into alignment. Try tacking a T joint together with the pieces about 5 degrees off the usual 90-degree angle. If the parts are not clamped, the shrinkage on fillet welds pulls the base metal about $^{1}/_{32}$ inch per weld pass.

You can also use clamps for holding parts in place while they are being welded. Clamping parts to a tabletop or large structural shape, such as an I beam or piece of channel, will provide the needed support. Securing the pieces through a heating and cooling cycle will reduce the amount of distortion.

Clamps and crossbars hold pieces in place, acting as a counterforce to the distortion that occurs when welding.

Finally, preheating an entire part before welding—not just the part you are welding—will reduce the temperature difference between the base metal and the weld area. If the preheat is uniform throughout the weld area, the rate of expansion and contraction is reduced. After welding, allow the part to cool slowly. Some metals need to be stress relieved after welding. Postweld heating is one of the most common methods of stress relief. This type of stress relief is done in an oven, with heating coils, or by using a torch.

FIXING DISTORTION

If your part becomes somewhat distorted from welding, there are a couple of ways to correct the problem:

- You can use a hydraulic jack, clamps, pry bars, and levers to move parts back into alignment. You may need to slightly overbend the pieces because they tend to spring back a little when the pressure is released.
- You can also heat small areas with a torch to create intentional distortion in a way that brings the parts into realignment (more on this below). Heat can also be applied by running weld beads on the convex surface to pull the piece back into alignment; the beads can be ground off later for a smooth finish.

Localized heating can be applied in a spot, line, V shape, or block pattern on sheet and structural shapes. Keep in mind that thin-gauge metals are most affected by the heat and are more likely to warp. Start by using a small amount of heat on sheet metals.

You can use localized heating to bend parts. Metals are softer when they are hot, making it easier to change their shape.

1. Mark the area to be heated with soapstone.
2. Keep temperatures below a red heat. Localized heating temperatures should not exceed 1,200°F (650°C).
3. Heat one spot to a specific temperature and begin moving in a pattern or straight line. The metal will pull toward the side that you are heating.
4. Do not reheat areas already heated.
5. Spray the heated area with a fine mist of water to increase the shrinkage stresses and further distort the base metal. With localized heating, the distortion is used to pull the pieces into alignment.

FABRICATION STEP BY STEP

When building a project, it is typical to spend 90 percent of your time cutting materials to size, fitting them together, cleaning the joints to be welded, and tacking up the pieces. The last 10 percent is spent welding the joints.

It is helpful to think of fabricating and welding as two different skill sets. It is possible to spend most of your time fabricating a beautiful project only to mess it up with bad welds. A poorly fabricated project with misaligned joints, large gaps, and poor fit-up will be difficult to tackle for even the most skilled welder. Start with the basics. Learn how to weld before diving into a major project. Observe the behavior of the weld and base metal while practicing your technique. Once you see the effects of heat and welding, you will become a much better fabricator.

Simple projects can be useful—such as this TIG torch holder and Vise-Grip table clamp for holding small parts when welding, brazing, or soldering.

PLANNING

Have a plan. Take some time to make a few simple drawings. Think about the size of the project and how parts will fit together. Experienced welders do a lot of fabricating in their head. They can imagine how the project will turn out when it is put together in different ways.

Decide on the structural shapes and what sheet or plate to use. Make a list of materials you need before going to the steelyard. Consider buying extra material so you can make changes during the project if your initial design does not work out.

Select the best welding process for the job. If the machine or process you are using is not powerful enough, avoid doing the work. Match the filler metal to the base metal. If you are not sure which one to use, do some research to find the answer.

CUTTING

Take the time to cut the pieces accurately. Measure twice; cut once. Cutting a piece too large is easier to fix than cutting it too small. Joints should have good fit-up for easier welding and less distortion. There are several tools you can use for cutting metal to size. Cutting parts with an oxy/acetylene torch or plasma cutter will require some grinding to remove the dross and smooth out the cut.

CLEANING

Clean your metal. The joints and surrounding area should be free of paint, rust, dirt, oil, and mill scale. There are several household products that remove rust. Solvents do a good job of removing oil and grease. Remember: a clean weld is a strong weld.

BEVELING

Groove welds on thicker metal pieces should be beveled for adequate joint penetration. This is especially important when the weld bead will be ground flush with the base metal.

Cardboard or plywood templates work well for plasma cutting odd shapes.

Cardboard templates can be folded or rolled into shapes for practice before bending the sheet-metal pieces.

FIT-UP AND ALIGNMENT

The way you put two pieces of metal together can make the welding easy or difficult. Joints with poor fit-up are difficult to weld. Large gaps require large amounts of weld metal to fill them; the more filler metal you add to a joint, the greater the shrinkage stresses that occur. The more shrinkage stress, the more distortion in the final piece. Do a good job fitting the pieces together, keeping the edges straight and square. If necessary, build up metal on one piece before welding it to another.

CLAMPING

When using a welding table, use clamps to secure the pieces to the flat surface. Having a large number of Vise-Grips and other clamps available comes in handy. Spacer bars and temporary metal supports can be held in place with clamps. Use a small piece of metal clamped to the end of a tube to keep parts flush with each other.

TACKING

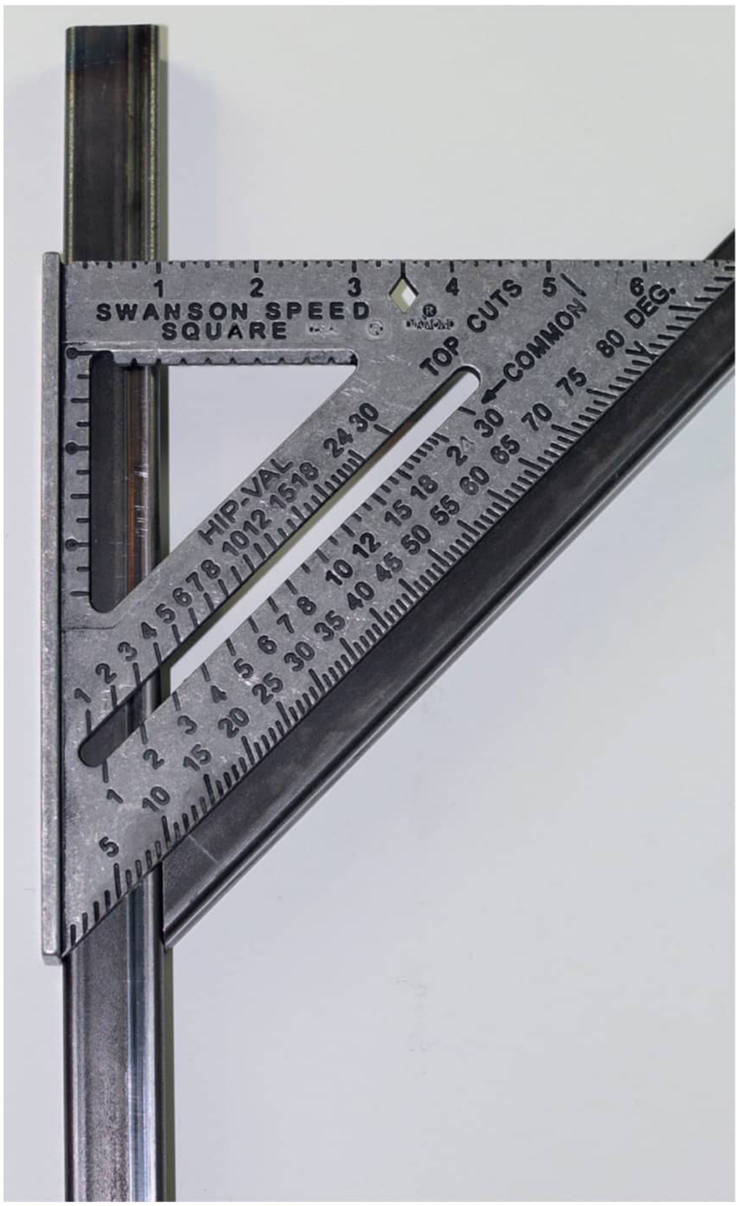
Tack all the parts together before you start welding. It is easy to cut a tack—you can do so with a cutoff wheel, leaving the rest of the joint intact. It is much more difficult to cut a weld.

The size of a tack should be in proportion to the thickness of metal and size of the part. A tack on sheet metal can be small, while plates 1 inch thick may require tacks 2 inches long. Three tacks in a triangular orientation will hold pieces in place. If you only use one or two tacks, the joints could move out of alignment when welded.

Instead of thinking about your project as a single unit, break it down into smaller pieces—these are called subassemblies. For example, if the project is a table, it may be useful to tack together each side first. Then, bring the two halves together with the crosspieces in between. On other projects, separate pieces can be completely welded before being joined to the whole project.

MEASURING

Measure your project carefully to be sure everything is correct. The time to make adjustments is *before* welding. Since tacks are small, you can move parts into alignment with clamps. As noted, tacks are also easy to cut apart, or they may break on their own as pieces are shifted into place. Remove unwanted tack welds by sanding them down before retacking.



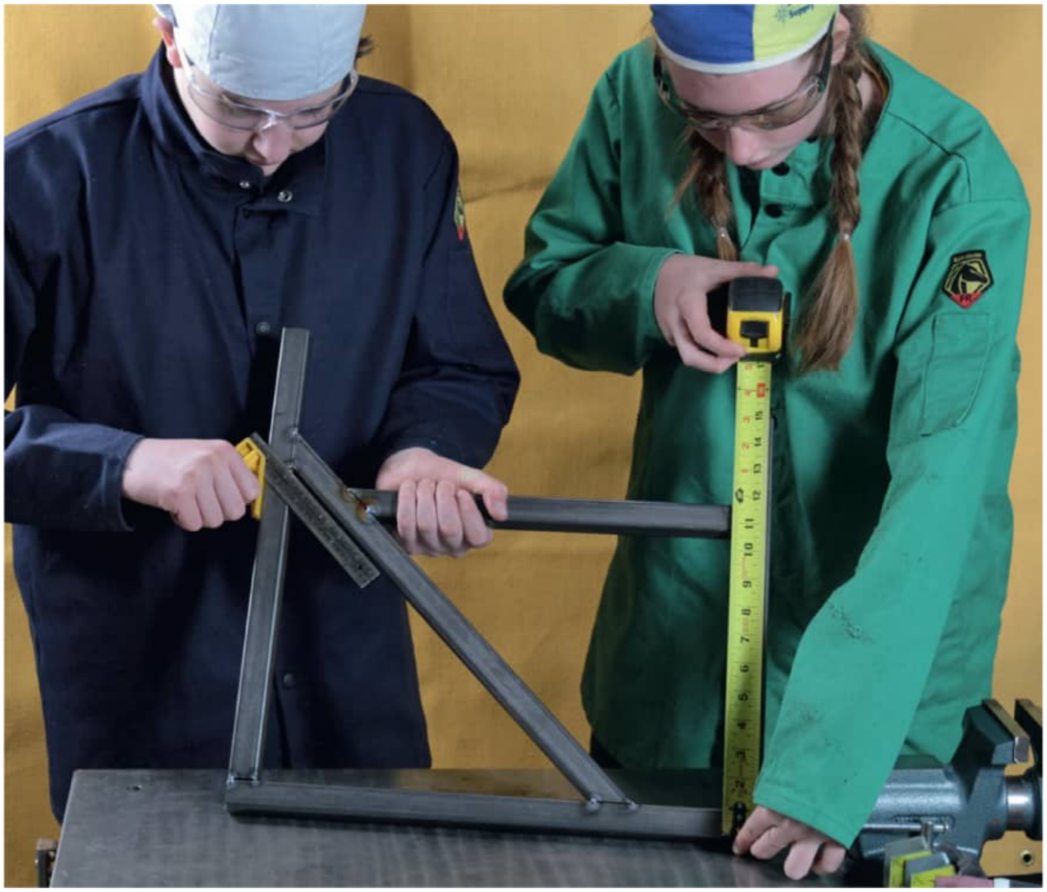
Speed squares are typically used by carpenters, but they also work for checking angles and alignment on metal projects.

A combination square is often used by welders for layout work and "squaring up" parts (making them 90 degrees).

Whenever possible, tack parts together while flat on a table. This helps to keep the pieces in alignment.

You can use almost any objects to keep parts in place when tacking as long as they can withstand high temperatures. These fire bricks are made to be safe around high heat.

Making signs from round rod or square bar is a great way to practice planning, cutting, fitting, tacking, and welding.



Knowing how to use squares and read tape measures is important. Carefully check your project's dimensions after tacking it together.

WELDING

A common mistake made by beginners is to overweld their projects. Avoid making welds larger than they need to be. When a weld fails, new welders tend to add more weld in an attempt to fix the problem so that the parts will hold. It may surprise you how little weld is necessary for parts to hold if the work is done correctly the first time.

Make practice welds first. Use scrap metal that is the same thickness as your project, and take the time to dial in the machine settings. Try to use the same joint designs you will be using in the final weld. The heat setting on a T joint may be too hot for a butt joint with a gap in between the pieces.

Don't weld in just one area—skip around. Use backstepping and intermittent welds to reduce the amount of distortion. Wrap your welds around corners, where stresses are concentrated. To reduce the chances of a weld cracking, avoid ending a weld bead on a corner. If a joint should be welded all the way around, don't leave any gaps or lack of fusion where the beads connect with each other.

If things are not working, stop welding and troubleshoot any problems. You may be using incorrect equipment, machine settings, shielding gas, or electrodes. The problem could also be caused by improper welding technique. If the problem is lack of experience, you are in luck: a little more practice is all it takes to improve your welding skills.

Weld is missing from the end of this triangular gusset. Wrap welds around corners to reduce the chances of cracking or tearing.

Use a marking tool to indicate the location of tacks, welds, and features such as drilled holes.

Numbers were put on this cube project to keep track of the weld sequence. Distortion is reduced by skipping around to different areas.

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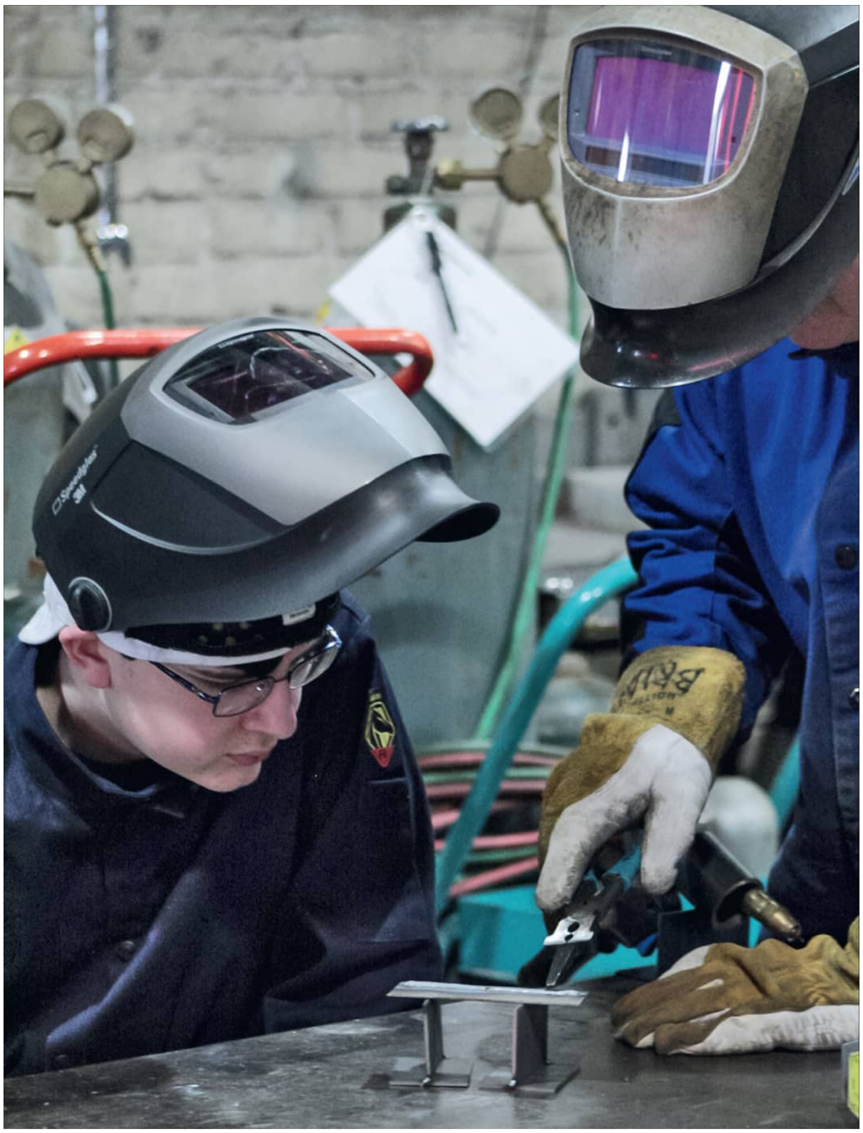
WELDING EXERCISES



You will develop welding skills with time under the helmet. Once learned, these skills can last a lifetime.

WHEN TWO PIECES OF METAL COME TOGETHER

You never know what kind of metals you might need to join when fabricating a part or making repairs. Sheet to plate, angle to tubing, flat bar to pipe—the combinations are endless. Welders learn by practice. Cut small pieces of metal 2 inches wide and 4 to 6 inches long out of sheet or plate. These are called coupons, and they are an economical way to practice a lot of welds on different types of joints. You can make many types of joints from two metal coupons. T, lap, butt, and corner are the most common. Practicing welding on these joints better prepares you for whatever welding situations come your way. The part you are repairing may not look exactly like a T, lap, butt, or corner, but it will probably resemble one of them.

Practice welding on pipe and tubing. Welding around a pipe or welding around corners is one of the more challenging welding skills to master. If you are a new welder or have a new welding machine, it will take some time to get the feel for how the arc looks and sounds. Time under the helmet is necessary to learn what the molten metal looks like as it fuses into the workpiece. The best way to do this is by making many weld beads on whatever scrap metal is laying around. Metals such as steel can be welded over and over until the surface is covered with weld beads. Turn the heat up and down on the welding machine. Watch to see whether the weld bead is fusing into the metal or just sitting on top of it. Knowing what proper fusion looks like is an important part of welding. A properly fused weld bead looks as if the bead is sitting in the welded metal with a smooth transition between the two. The thickness of your practice metal is critical to understanding how much heat is needed to make the weld. Try making practice beads on thinner and thicker sheet, tubing, angle, and plate. You can also practice on cast steel components and old equipment that is no longer useful. Remember that as you weld, the metal will get hotter and hotter. Be sure to cool down your practice metal occasionally by submerging it in water or air cooling for 10 to 15 minutes.

Short pieces of tube and angle can be cut, notched, and welded for practice to simulate the joint on an actual project.

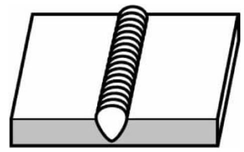
Weld tests on pipe and plate are cut into strips and bent to test the strength of the welds.

JOINT DESIGNS

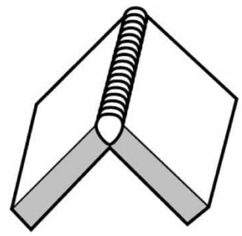
Each weld joint is shown in four different positions: flat, horizontal, vertical, and overhead.

FLAT

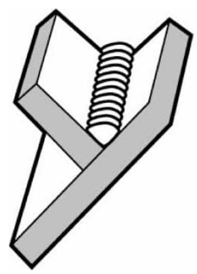
BUTT JOINT



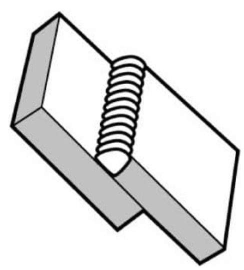
CORNER JOINT



T-JOINT

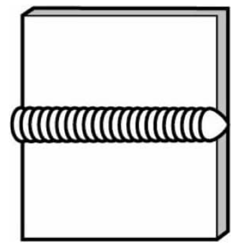


LAP JOINT

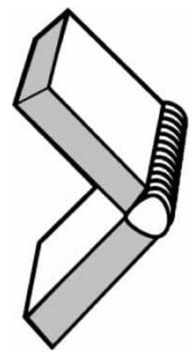


HORIZONTAL

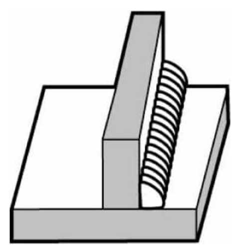
BUTT JOINT



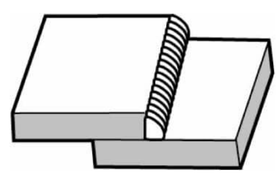
CORNER JOINT



T-JOINT

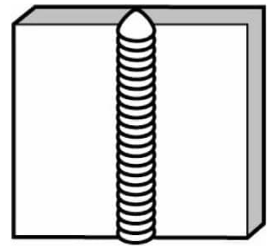


LAP JOINT

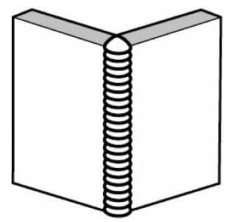


VERTICAL

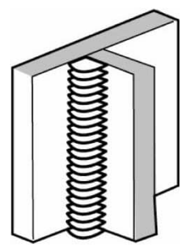
BUTT JOINT



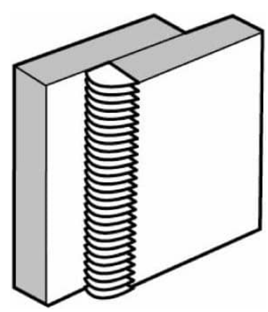
CORNER JOINT



T-JOINT

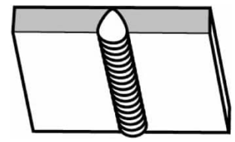


LAP JOINT

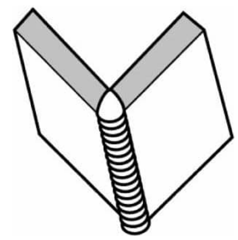


OVERHEAD

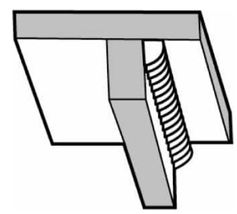
BUTT JOINT



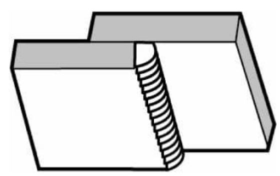
CORNER JOINT



T-JOINT



LAP JOINT



T

Joints in which the pieces come together at a right angle (90 degrees) are called T joints. In this type of joint, the welding surface area is in the corner where the two pieces come together. Because of this arrangement, the metal surfaces being melted are close together and there is more area for the heat to dissipate. This is why T joints require more heat for proper fusion and good welding than other joints. Turn up your heat when welding into the corner of a T joint.

MIG welding was used to join this sheet-metal T joint. The top and bottom pieces have nearly the same amount of weld.

LAP

The key to welding a lap joint is to have enough heat to get good fusion into the base plate. If an equal amount of heat is directed at the base plate and the upper plate edge, the edge will always melt away before the base plate gets hot enough to liquefy. When welding lap joints, direct most of the heat toward the base plate and let the puddle wash up on the edge. A lap joint requires more heat than a butt joint or corner joint but less heat than a T joint.

A lap joint cross-section shows two fillet welds. The welder used multiple passes to make “full-sized” welds.

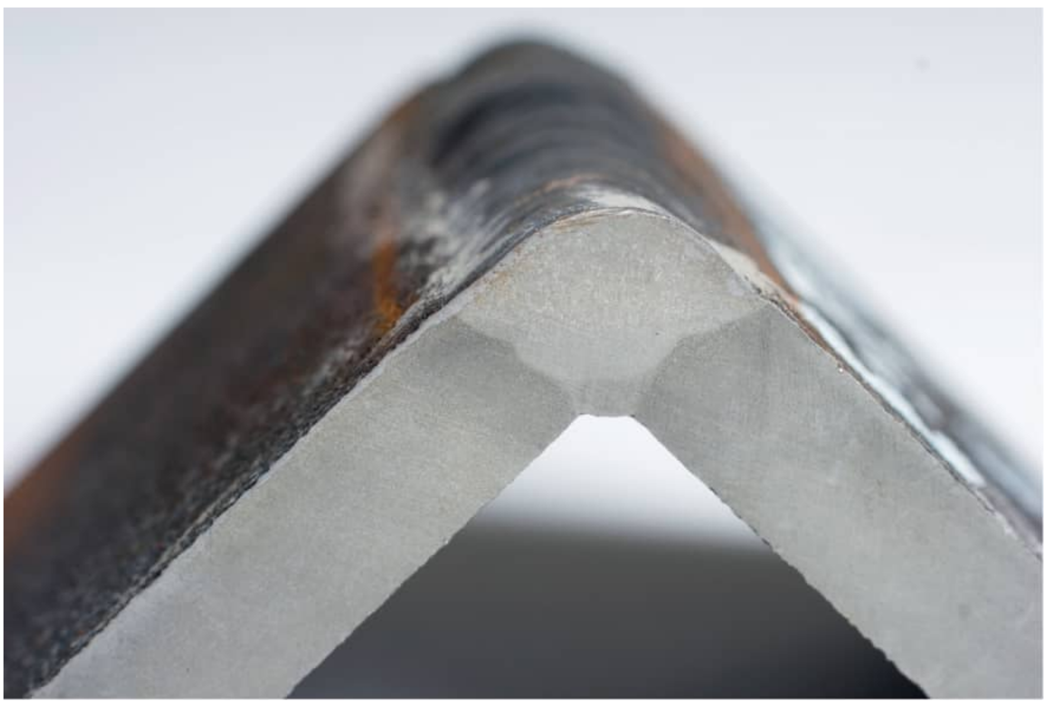
BUTT

Butt joints are a little more complicated than other types because of how they are put together. A butt joint may or may not be beveled. A bevel is a small, angled groove cut into the metal's edge. A gap called a root opening can be left between the two pieces or they can be placed directly next to each other. Whether you bevel the metal pieces or use a root opening between the plates will depend upon the metal thickness and whether the joint can be welded on both sides or just one. The idea with a butt joint is to put the weld metal as close to the center of the joint as possible. This is usually referred to as penetration into the joint. If the weld is only on top of the joint, it will not be as strong. On thicker metals (⅛ inch or more), beveling the pieces and having a root opening allows the weld bead to flow into the center of the joint. On butt joints, too much heat will cause burn-through, creating a hole in the metal. If this happens, use less heat, faster travel speed, and a smaller gap between plates. Be careful not to overcompensate and underweld your work or put the bead too far away from the center of the joint. An equal amount of heat should be directed at each edge of a butt joint unless the pieces are not the same thickness. In that case, more heat should be directed at the thicker of the two.

Thick plate butt joints often have beveled edges and a root opening to achieve better penetration. A backup bar bridges the gap between pieces.

CORNER

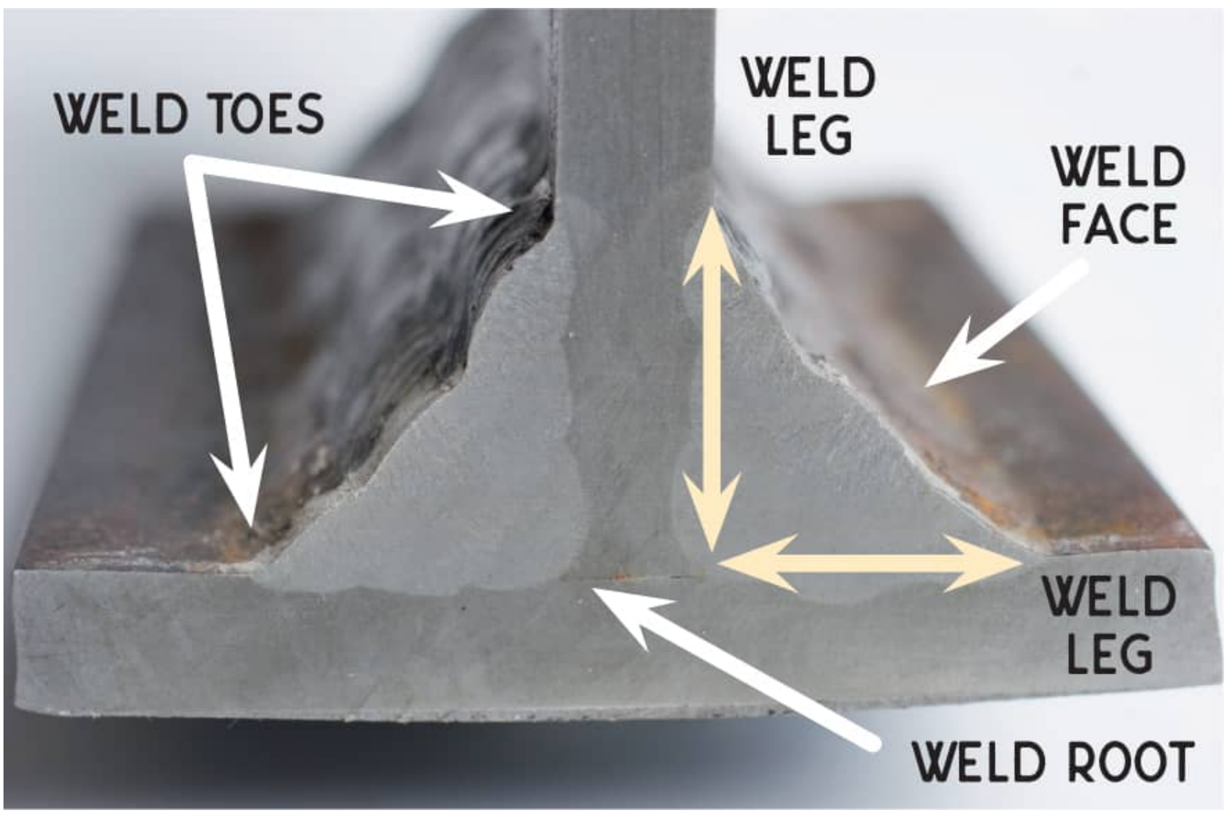
There are three types of corner joints. In open corner joints, the two pieces of metal meet corner to corner at the edges without overlapping. In a half-open corner, one of the edges overlaps the other about half the thickness of the metal. In a closed corner joint, one edge fully overlaps the full thickness of the other piece, creating an L shape. An open corner joint gives the final weld a rounded appearance. A closed corner joint has a square edge but may require beveling one piece to achieve adequate penetration. Welding the outside of a corner joint requires less heat than other types of joints.



This cross-section of an open corner joint shows that the weld size is equal to the thickness of the plate.

FILLET WELDS

Fillet welds are the most common type of weld. T and lap joints usually have fillet welds holding them together. A good example is one tube fitting into the other in a copper water pipe or car exhaust. The two pieces overlap, and where the edge of the larger-diameter tube meets the outside wall of the smaller-diameter tube is a lap joint where a fillet weld can be made. Think of a fillet weld as a triangular shape sitting on top of two surfaces 90 degrees from each other. It is not designed to penetrate a joint. Good fusion must take place between the weld and the base metal, especially at the root of the joint, which is the inside corner. If a weld bead wanders away from the corner, this means it has not been placed in the joint correctly. Fillet welds need to be in the corner as much as possible. Welds sitting on top of the corner or next to the corner of a joint are much weaker and may not hold up. Try to make your fillet weld the same size as the metal thickness being welded.



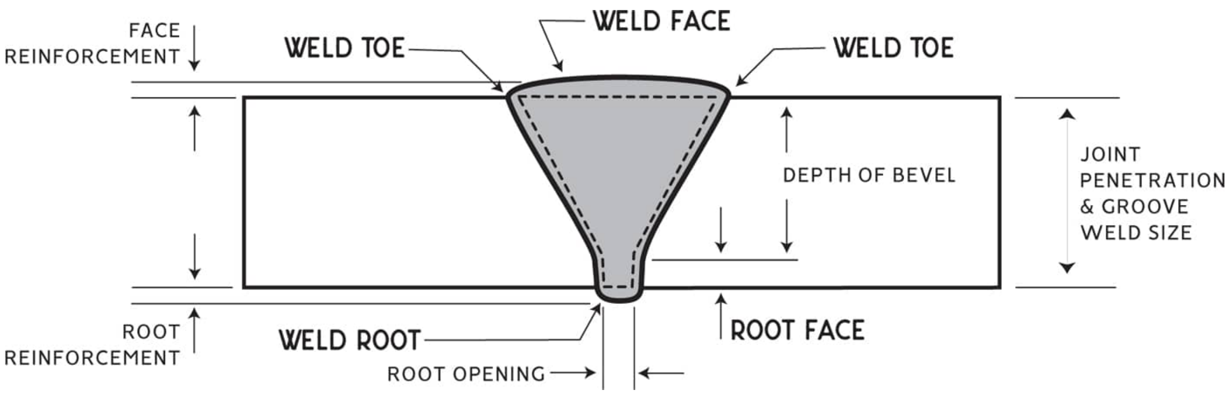
The parts of a fillet weld.

GROOVE WELDS

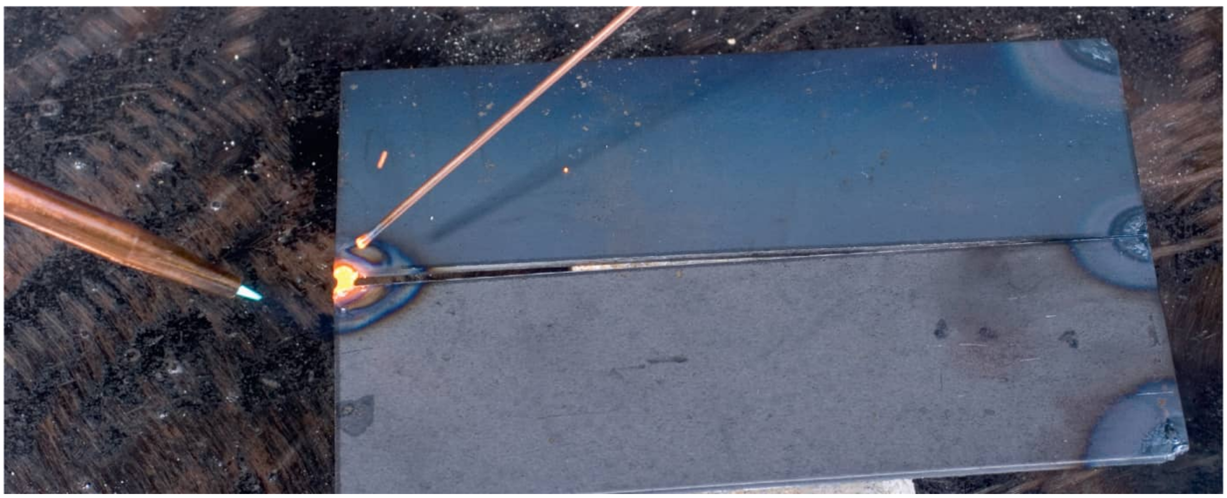
Groove welds are applied to butt joints because the weld penetrates into the joint. You can make groove welds on sheet metal, on plate, or when connecting the two ends of pipe or tubing. You can also apply them to the other types of joints, especially if complete joint penetration (CJP) is required. The size of a groove weld is determined by the thickness of the base metal. A full-size groove weld on ⅛-inch sheet metal is ⅛ inch. A groove weld can be smaller than the thickness of the base metal, but never larger. It may be applied on a T joint for full penetration. Afterward, a fillet weld may be applied to the same side as the groove weld and/or the other side of the same joint to increase its strength.

Metals ⅛ inch thick or more are typically beveled before welding. This increases the weld penetration. You can accomplish beveling with a grinder on metals up to ¼ inch thick. Pieces ⅜ inch and thicker are typically beveled with a torch, cut with a horizontal band saw, or milled. The more penetration a groove weld has into a joint, the stronger it will be. The depth of a bevel will depend upon whether you need a full-penetration weld, whether the joint is to be beveled on both sides (double bevel or double V), and whether you need extra metal at the root of the weld to carry the heat required for full penetration.

The root opening is a gap left between the pieces of metal. Root openings are typically used in butt joints to achieve adequate penetration and can be used in T joints for the same purpose. On metals thinner than ⅛ inch, the proper root opening will make the joint easier to weld. However, on pieces $^{1}/_{32}$ inch or less in thickness, you may not need any root opening to achieve full penetration. Typically, the smaller the gap, the shallower the penetration is in the joint. The larger the gap, the more difficult it can be to weld, sometimes requiring one or both edges to be built up with surface welds before you can do the final welding.



The parts of a groove weld.



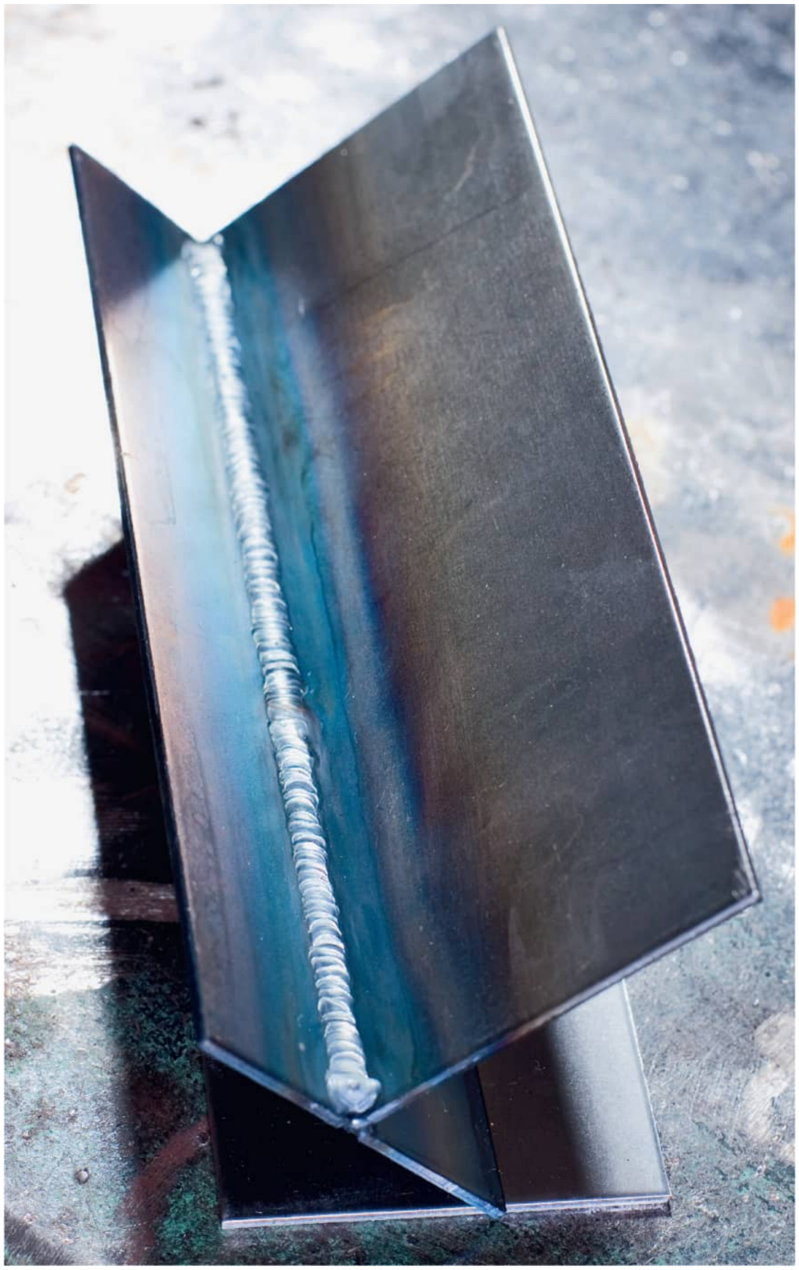
Tacking two pieces together with a gap between them allows penetration into the center of the joint.

WELDING IN POSITION

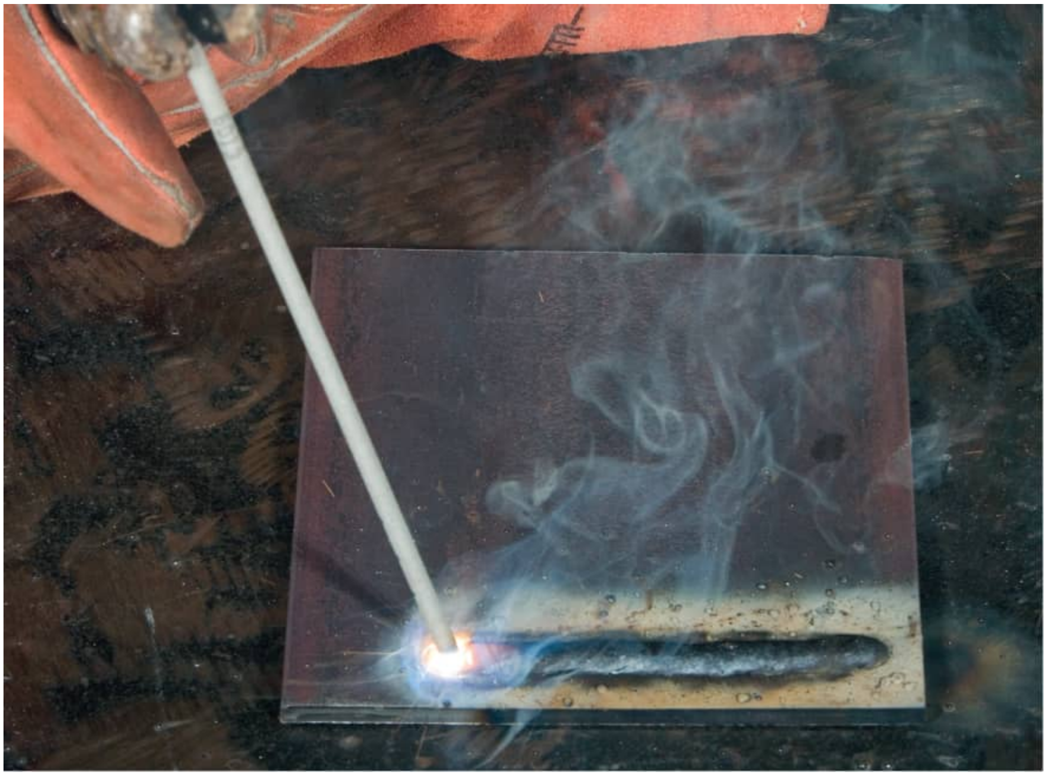
When you are learning to weld, welding a new kind of material, or using a new welding process, start by welding in the flat position. This is the easiest position to weld in, and you can get comfortable and steady. There is one odd thing to consider about fillet welds made in the flat position, however: if a T joint is placed flat on the table, it will actually be in the horizontal position. When tipped at a 45-degree angle, that same T joint is in the flat position. Think of capping the ends of that T joint and filling it with water. The T joint creates a trough, and if held at a 45-degree angle, the water stays in. When the T joint is flat on the table, the water spills out of that trough. Instead of water, think of liquid metal in the molten pool of your weld. The same principles of gravity apply.

When welding joints in the horizontal position, gravity becomes a factor. Good welding technique and proper welding angles will help compensate for the effects of gravity on the molten pool. Horizontal welds are more difficult than flat-position welds, but they generally keep your back straight (meaning less fatigue) and keep the smoke and fumes out of your breathing zone.

Practice welding both flat and horizontally before attempting vertical and overhead welds, known as welding out of position.



A T joint in the flat position looks like a trough in which the liquid weld pool is not affected by gravity.



Make many weld beads in the flat position before trying to weld horizontally, vertically, or overhead.

Horizontal welds tend to droop because of gravity. Angle the torch, gun, or electrode upward to help support the bead.

WELDING OUT OF POSITION

The characteristics of welding vertical joints can change drastically depending on which direction you travel. Downward welding is easier because the weld pool is following the pull of gravity. Problems can occur when you add too much filler material, overflowing the top of the molten pool and only sitting on the surface of the metal. You can avoid this overlapping of the filler metal over the base metal by closely watching the molten pool for proper fusion. Downward welding provides less penetration into the base metal, which is useful for welding materials ⅛ inch or less in thickness because you would likely burn through them welding upward. But on thicker pieces, over ⅛ inch, upward welding is required for adequate penetration. Upward welding is more difficult because you are working against gravity, traveling in the opposite direction of its pull.

Vertical welds are more sensitive to the amount of heat input. If you allow the molten pool to grow too big or too fluid, the liquid metal will spill out of the puddle and run down the face of the joint. To successfully weld in the vertical position, use good welding technique and a little less heat than you would for the same type of project in another position. Reducing the amount of heat is important because there is less room for error than welding flat and horizontal.

Since the metal is liquefied in the manual welding processes, you might think welding overhead would be impossible. However, liquid metal has a fair amount of surface tension, which means it will stay together in the molten puddle as long as it doesn’t become too big and form into a droplet. The amount of heat required to weld overhead is similar to the amount required in the flat position. Set the welding machine controls and make your test welds in the flat position. This will help you know what amount of heat is needed to weld overhead.

For sheet metals, travel vertical upward with TIG or oxy/acetylene and downward with MIG. For plate, always travel vertical upward with stick, flux-core, or MIG.

When working overhead, try to get underneath the bead for the best view of the weld as you are making it.

WELDS FOR PRACTICE

BEADS

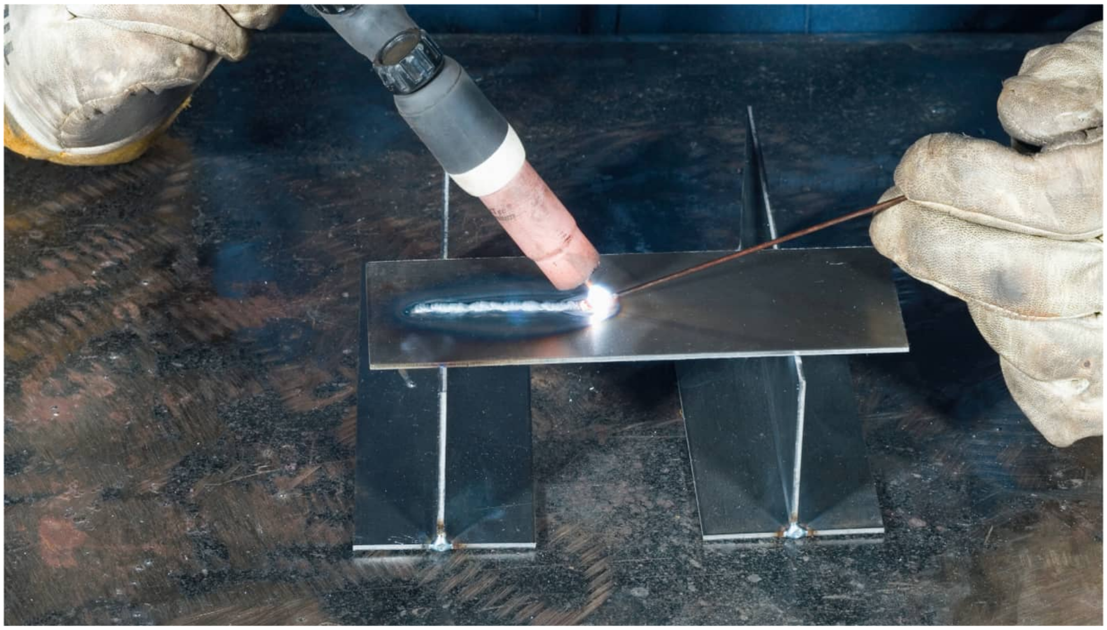
Run many practice beads to figure out how welding works. Make your practice beads about 6 inches long. The position of your hands, arms, and body can make a big difference in how comfortable you are. A comfortable welder has a better chance of staying steady while welding. Having control of the torch, gun, or electrode holder is key to maintaining the proper distance and guiding the weld down the joint. Once you are comfortable, make several weld beads. Experiment with speed—weld fast and slow. Experiment with heat—turn the machine setting up and down, making a new bead with each change. Look at the bead after each weld. A good bead will be nearly the same width from beginning to end. It will be fused into the base metal, meaning it is mostly flat with a slight convexity, and the toes of the weld will blend smoothly with the base metal. If it looks like the weld has skipped over an area or is very narrow in one spot, it is most likely because your speed was not consistent. Try to get more comfortable so you can move the weld bead along at the same speed over the whole length. If the bead stands up on the plate with a big hump in the middle and a sharp corner at the toe, it could mean the heat was too low or you added too much filler metal. Try turning up the heat and adding less filler metal or turning down the wire feed speed. Keep in mind you may have to travel faster with higher heat. Running lots of beads allows you to experiment with these variables without using a lot of metal. Once you have consistently good results, try welding different joints.

Start with one bead, chip away any slag, and make another weld next to the first. Continue making welds, cleaning after each pass.

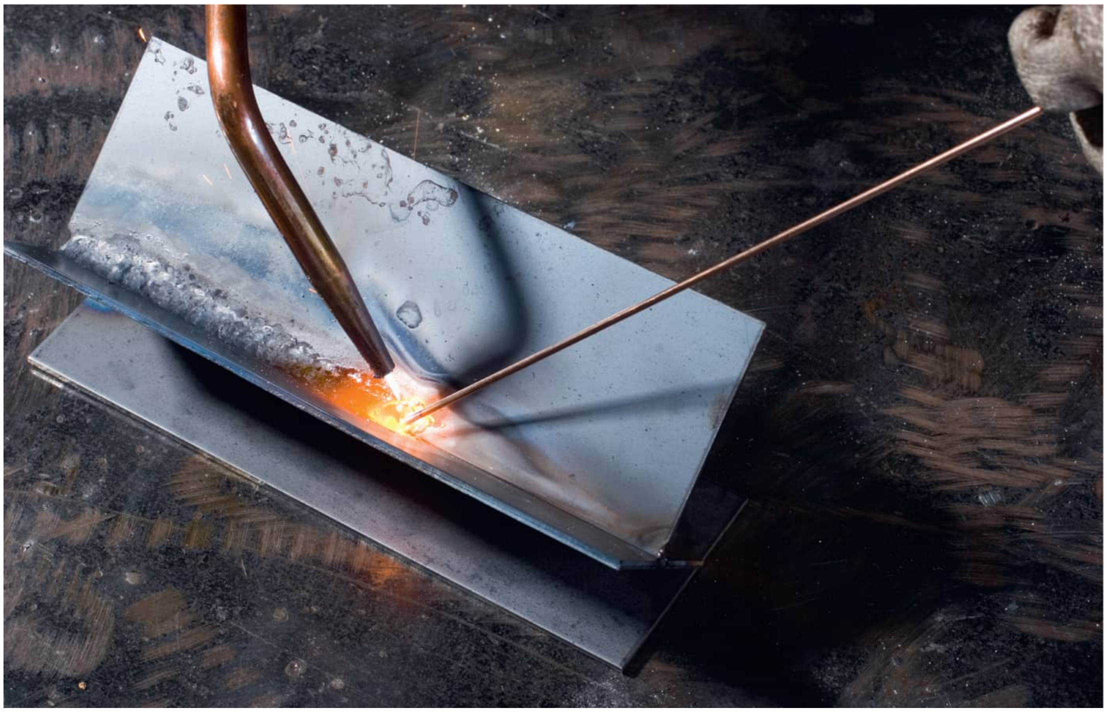
Beads can be deposited in overlapping layers. Point the electrode at the toe of the previous pass to tie them together.

After building up many layers, cut the welds in sections and sand them smooth. Look for unwanted pits, gaps, or slag inclusions.

Build up weld bead by adding filler metal into the liquid pool as you move it down the plate under the torch's flame.



TIG and oxy/acetylene torches work in similar ways. Use a push technique and add filler metal by dipping it in the puddle.



When welding any T joint, be sure to melt both pieces of metal before adding filler rod so that each side has proper fusion.

T JOINTS

Welding into the corner of a T joint requires you to hold the torch, gun, or electrode holder at an angle that allows the heat to melt metal on both sides at the same time. To do this, keep your torch about the same distance away from each side. A T joint forms a 90-degree angle, so this means the welding torch should be 45 degrees relative to each side of the joint. At the same time, you need to place the heat directly in the bottom of the corner, also known as the root of the joint. It is easy to get off track and wander up one side or the other. This will put a nice bead on that side of the plate but will not connect the two pieces. Pay attention to both the angle and the position of your torch flame or welding arc for the entire length of the joint. It is even more important to see the weld happening in the joint and be able to guide it along where it needs to go.

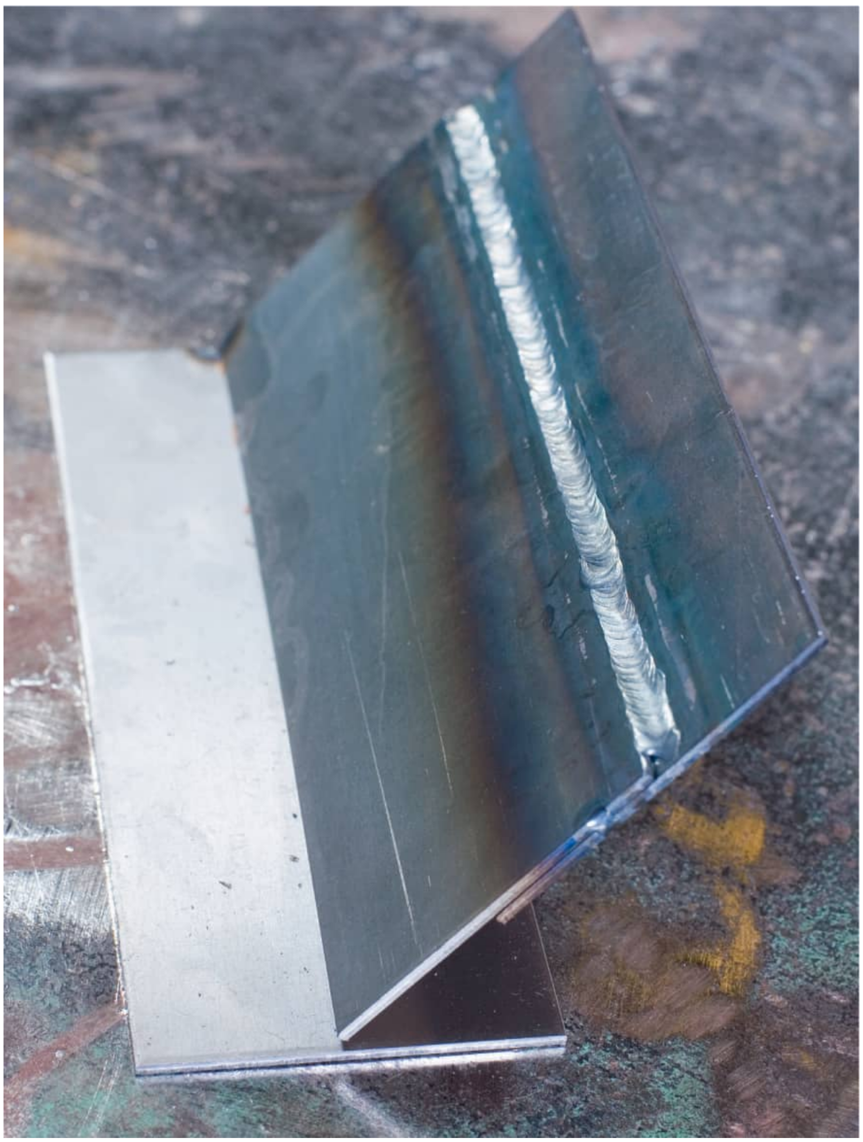
Angle the torch, gun, or electrode 45 degrees relative to each side of a T joint to heat both sides evenly.

This MIG gun is angled 35 degrees from the bottom plate to help support the weld pool. Otherwise, the weld may droop, becoming uneven.

This lap joint on a ¼-inch steel plate was successfully welded in one pass using a ⅛-inch-diameter electrode. Additional passes are not necessary.

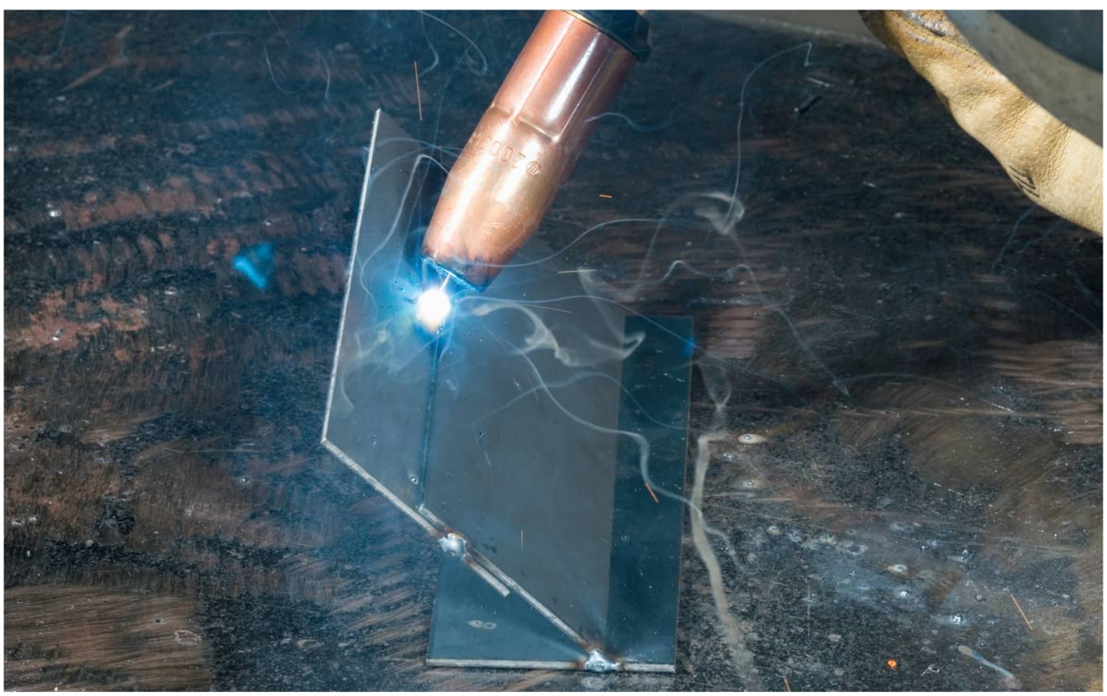
LAP JOINTS

Welding a lap joint is a little like running a bead on a plate. The difference is that the edge of the top plate needs to be fused into the weld along the joint. Point your torch, wire, or stick electrode toward the base plate. Avoid directing the flame or arc toward the edge because it will probably melt away from the heat. Make a weld and watch the edge as you go. Make little circles if needed to bring the weld bead up onto the edge. The edge of the lap should fully fuse into the bead on the bottom plate.

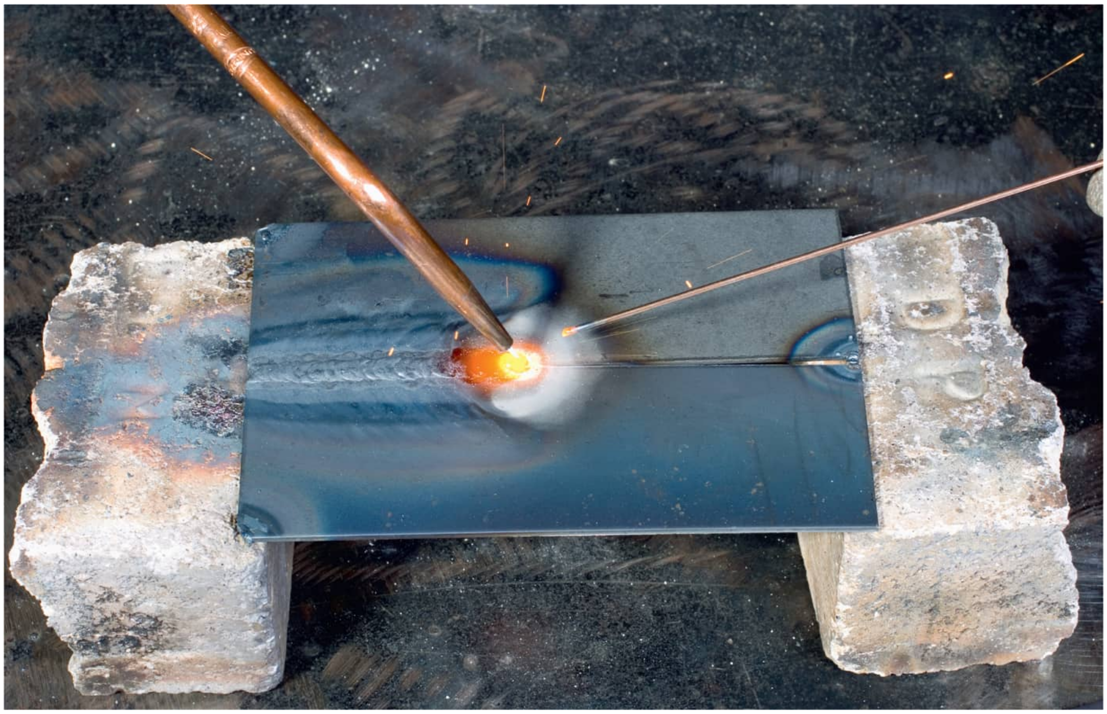


Most of this fillet weld has smooth transitions where it connects the pieces together. Avoid having too much weld buildup at the toes.

Look for a C-shaped puddle at the end of the electrode. This indicates the weld is connecting both pieces of metal.



Point the MIG gun mostly at the back plate and make small circles or zigzag motions to wash the weld metal up against the edge.

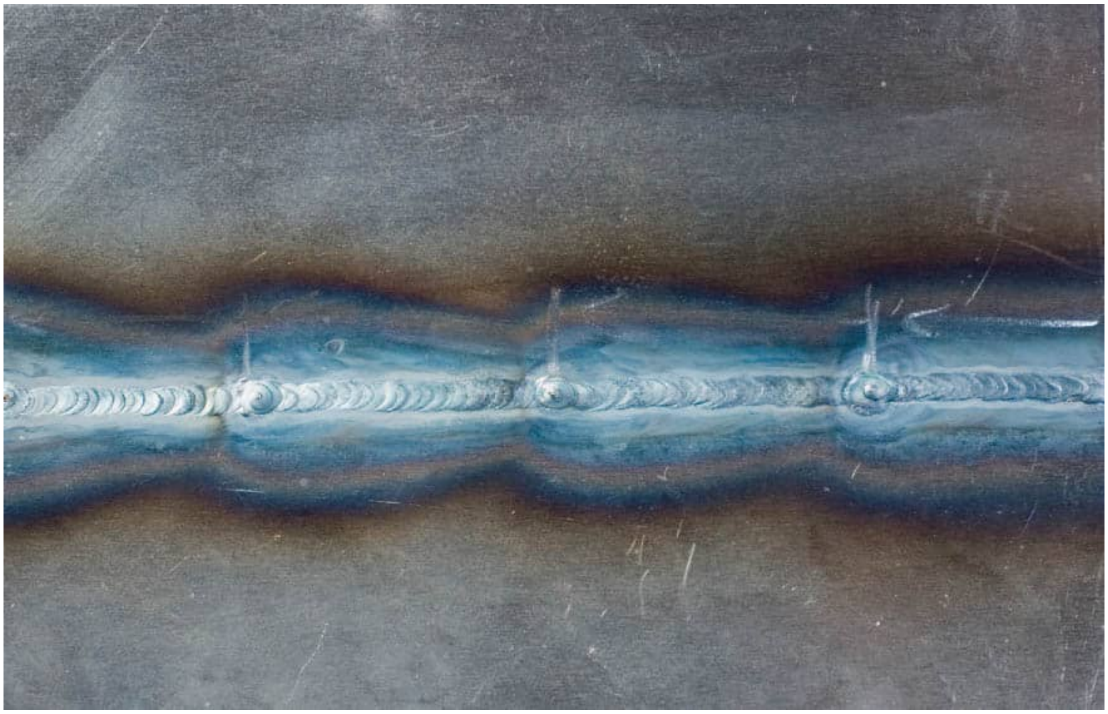


Point the torch directly at the root opening so that both edges melt, then add filler metal to close the gap.

BUTT JOINTS

Unless the metal is very thin, it is usually a good idea to have a gap between the two plates being welded. On thicker metals, the root opening can have a backing bar made of steel or copper to help keep the liquid weld metal in place while it cools down into a solid piece. Thinner metals often have an opening with no backing. You must control your heat and welding speed so that you do not burn through the opening. When the heat and speed are right, the surface tension of the liquid metal is strong enough to hold it in place while it cools. You may also bevel butt joints to allow you to make the weld closer to the center of the joint. Bevels and root openings give the welder a visual cue to follow. Direct the same amount of heat to both pieces. Keep the torch flame or welding arc directed to the center of the joint where the two pieces come together. Just like on the T, it is easy to wander away from the butt joint. Watch closely as you make the weld for the molten bead to connect both pieces in the center of the groove.

Drag the gun when MIG welding downward. Stay ahead of the molten pool that forms above the welding wire for proper fusion.



A technique called backstepping was used to TIG weld this sheet metal The heat marks show the welder made four short welds.

Push a MIG gun when welding horizontally on thin sheet metal to reduce the chances of burning through.

CORNER JOINTS

Running a weld bead on the outside edge of a corner is a balancing act. Each side of the joint "drops off" so that the joint is pointed toward the welder and is the obvious place for the weld metal to go. If the weld wanders off course, the bead runs down the side of the plate and into thin air. Corner joints need less heat than other joints. On an open corner joint, a fast travel speed and a slight side-to-side torch movement on sheet metal help to give the weld a rounded appearance. A corner on thicker plate may take many passes to fill. Let the metal cool down a little between passes—otherwise, the outside corner may get too hot and the last few welds may drip down out of the joint.

Closed corners with a bevel have a groove for the welder to follow. Be sure to place the weld into the groove, not on top of it. You can place a weld on the inside of a corner joint for extra strength.

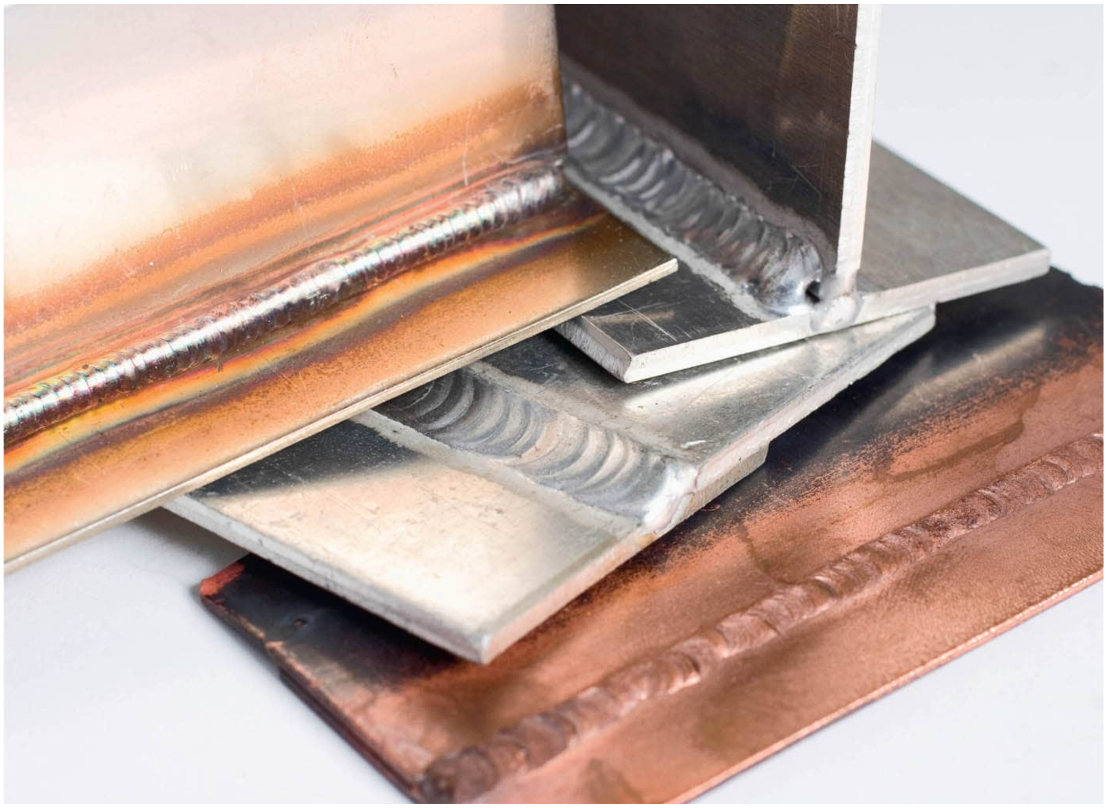
It is possible to successfully stick weld sheet metals. A small-diameter 6013 electrode was used with DCEN polarity to weld this corner joint.

Open and half-open corner joints are easily welded using a TIG torch without adding filler metal.

Leave a gap between plates so the filler metal can penetrate through on the first weld pass. Look for weld bead on the back side.

Open corner joints have welds that are evenly rounded on the face with a smooth transition to the sides.

You may need to make several weld passes to fill a joint. To prevent inclusions (small nonmetal bits trapped in the weld), be sure to remove all slag between passes.



Once you learn the fundamentals of welding, the wide world of joining metals is yours to explore.

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