How To Weld

Todd Bridigum

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On the front cover: *Monte Swann*

On the back cover: A multi-pass fillet weld applied to both sides of a tee joint. *Monte Swann*

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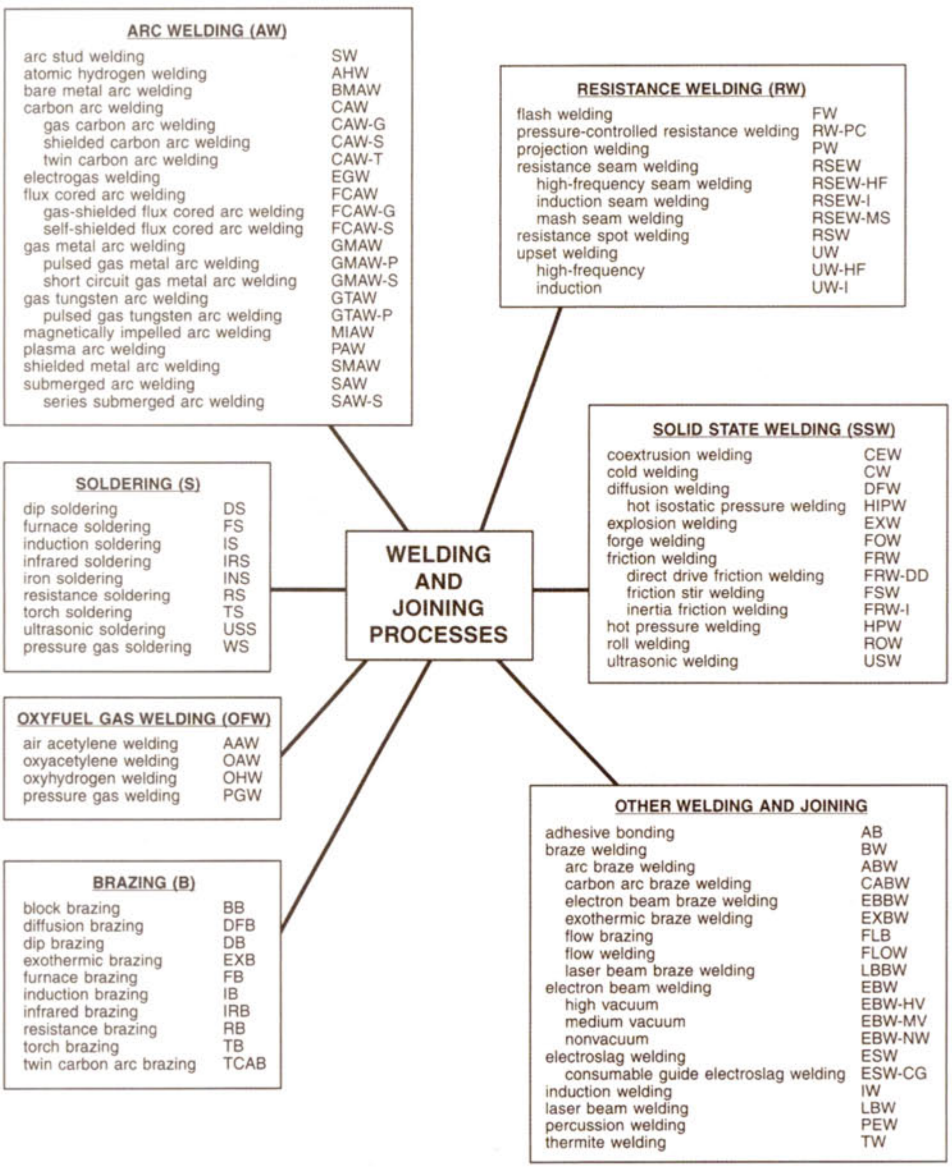
INTRODUCTION

Many books have been written about welding, so when I took up the challenge to write one, I wanted to set it apart from the others. Some of the published books have a lot of technical content, but are difficult for the non-professional to read. Others specialize in one or two welding processes, are outdated, or fall short in explaining how to weld. As a welding instructor I've taught hundreds of students how to weld with varying degrees of success. In my experience some people have a natural talent for it; for others it is more difficult to learn. Only a few just didn't get it or were too afraid of fire, but I could count them on one hand.

The next question is, can you learn how to weld from a book or do you need an instructor's help? The role I play in the classroom is that of diagnostician. In other words, after someone knows how to operate the equipment safely and has done some basic exercises then it is a matter of figuring out what they are doing wrong and making a correction.

Troubleshooting is the key to good welding. Sometimes it is something wrong with the equipment and/or materials being used, which I always look at first and is easy to fix. If it is not the materials or equipment then it is operator error—something is wrong with the student's welding technique. This is a far more difficult problem to correct because it has to do with an individual's hand/eye coordination, body position, perception of distances and angles, and old habits. Without an instructor telling you what to change, it is more difficult to learn how to weld, but not impossible.

In this book I strive to provide useful information for you to work safely and troubleshoot your own problems, yet I would strongly advise taking a class to get more welding time and access to a variety of welding and fabrication equipment. Bear in mind that not all instructors are created equal. If you can get recommendations from former welding students or people who work at your local welding supplier, you may find an instructor who can help you a great deal.



AWS A3.0:2001, Figure 54a, Reproduced with permission from the American Welding Society (AWS), Miami, FL USA

CHAPTER 1
HISTORY AND PROCESS OVERVIEW

Here is a fun way to think about how important welding and metal fabrication are to our standard of living today. What if all the welds in the world came apart at one time and welders weren't available to repair them? Society as we know it would fall apart, or at least electricity would go away. Power plants are held together by welds and maintained by pipefitters, ironworkers, boilermakers, and machinists. All of us rely on electricity and on those skilled professionals for our standard of living. What about wind and solar panels? Each of these relies on manufacturing processes and welding to be fabricated and installed.

I believe metal fabrication is the single largest influence on how the world looks today, from the cities to the country and even into space. Today we tend to think in the short term, which is understandable since our computers, cell phones, cars, and televisions seem to be outdated or obsolete every few years. If we back up and look at the larger picture in the context of welding, the technology available to work and join metals is extraordinary.

Humankind moved from the Stone Age into the Bronze Age about 5,500 years ago. Copper was the first metal to be worked because it exists in its pure form in nature, and using it didn't require separating iron from ore. About 3,200 years ago, people discovered how to separate iron from rock and the Iron Age began. Forge welding, the first metal-joining process, was developed during the Iron Age. The people able to transform rock into usable iron tools through forge welding, known to us today as blacksmiths, were thought to possess magical powers a few millennia ago. It took a lot of time, work, and skill to fabricate metal, and for thousands of years that is *all* we had.

Then, in the late 1800s and early 1900s, gas, arc, and resistance welding were discovered. These breakthroughs, combined with Bessemer's furnace (which enabled industry to make large quantities of high-quality steel) led the world through the last stages of the Industrial Revolution and into the modern age. Yet if we look at the Brooklyn Bridge and Eiffel Tower, both were constructed during the 1880s and both are riveted together, not welded. In those days, welding processes produced hard, brittle welds that were not suitable for joining large sections of iron or steel under heavy loads. The development of a flux coating on the welding rod was the key to making arc welding more usable, but that took another 50 years to perfect. By the 1930s, welding was being used to construct ships, pipelines, and skyscrapers. For better or worse, war has been the main factor in the advancement of many technologies, including metalworking. The biggest wars—World Wars I and II and the Cold War—precipitated the biggest advances in welding. Research and development of new technologies has trickled down to civilian use.

Modern equipment allows us to easily do welding jobs at home that would take a blacksmith weeks to complete. You can find high-quality steel, aluminum, and other metals in almost any structural shape and size at the local steel yard. Joining them is as easy as pulling the trigger of a wirefeed gun.

Still, welding is a skill difficult to master. Think of it like this: I can put a band-aid on someone's cut and give them an aspirin, but that doesn't make me a doctor. I can change a light fixture and its switch in my home, but that doesn't make me an electrician. Just because someone can lay a bead does not make him or her a welder.

The good news is we no longer have to dedicate our lives to the craft in order to join metals. But we should recognize the difference between what we know how to do and a professional who has spent most of his life learning and working in the trade. New ways of processing, refining, and combining metals, as well as the further development of new welding processes using lasers, electron beams, and friction, indicate that the rate of new discoveries and applications of different metal-joining processes will continue into the foreseeable future. The Internet and books are great resources to learn more about the history of welding and metalworking.

WELDING PROCESSES OVERVIEW

Welding processes can be divided into two basic categories: manual and automated. This book deals with the former, the manual processes, the ones in which the person doing the work has a direct influence on how the weld turns out. This puts the pressure on the person operating the equipment to produce a good weld.

Some of the manual processes are considered semiautomatic, in which one or several aspects of the weld is controlled by the machine. For example, in wirefeed welding the wire is automatically electrified and fed into the molten puddle by the machine. Two processes, which can be manually operated but are more commonly automated, are not covered in this book: plasma arc welding (PAW) and submerged arc welding (SAW). Both have applications in industry, but are not common in most metal fabrication shops because of lack of need or cost of equipment.

Automated is not the best term to describe the wide variety of welding processes in which there is no manual control over the welding process, but the welding does occur in an automatic manner. The only influence an operator has in these cases is to set up the equipment and materials properly.

Some examples of automated process welding are:

- Resistance welding, which includes resistance spot, seam, and projection welding
- Solid-state welding, which includes explosion and friction (stir) welding
- Laser-beam welding and cutting
- Electron-beam welding
- Electroslag welding
- Thermite welding
- Robotic systems (used for welding)

These processes are used extensively in the manufacturing and research industries. The use of robotics and automated processes has grown rapidly in the past few decades and computer numerical controlled (CNC) equipment in machining, welding, and metal forming has revolutionized industry. In today's metalworking shop, the welder may wear many hats, including operating machines that cut, fold, punch, and form metals, so it is important to learn both welding and metal fabrication. If you are working in your own shop you will need to do both out of necessity. The welding processes (and related tools and equipment) covered in this book are common manual processes used every day in metal fabrication shops large and small.

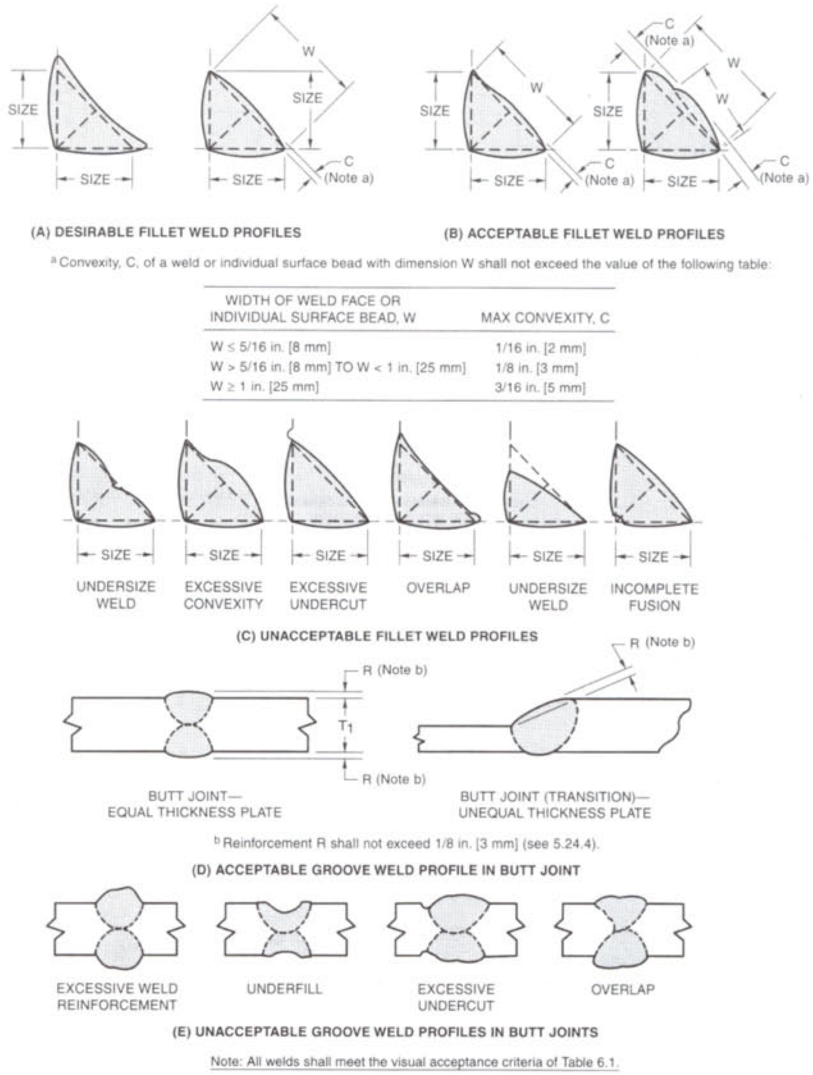
WELD CERTIFICATION

What is a certified welder? There is no simple answer, as many different organizations offer certifications for a wide variety of processes. A certification in welding is different than most other fields due to the variety of possibilities and lack of one central welding union or authority. There are organizations dedicated to the study and advancement of welding, such as the American Welding Society (AWS), which has welding codes and standards used by many organizations to qualify their employees, but there is no one welding test that everyone uses. So, a certified welder is someone who has taken a welder qualification test using guidelines put forth by a company or organization, and performed the test correctly. The welding code or standards also outline how the weld will be tested using destructive, non-destructive, and visual inspection methods and evaluated for pass or fail. Organizations that outline welder qualification requirements include ASME International Boiler and Pressure Vessel Code, Department of Defense Naval Ship Division Code, American Petroleum Institute TD 650 Welded Steel Tanks for Oil Storage, and AWS D1.1 Structural Steel Code, just to name a few.

The code to be used for any one weld certification test will depend upon: the structure or part to be welded (skyscraper, railcar, etc.), the type of material used, the type of filler metal to be used to join the base metals, the material thickness, type of joint design, and in what position the welding is to be done. As each one of these variables changes, so can the test. The possibilities are endless. Typically, even if a welder holds certification papers, the potential employer will qualify him again using the same or different standards to prove that the welder can do the job correctly. For example, a union pipefitter may hold a certification, but will need to take and pass the same test again before going to work retro-fitting a privately held power plant.

Fully automated welding systems, like this robot, are most useful when large quantities of the same part are required. The person programming or running the robot should have a background in welding. Welding education includes information on selecting welding processes, proper machine settings for the material thickness, joint designs, position of welding, and the evaluation of finished welds. A robot still cannot do these on its own. *Monte Swann*

These are plate and pipe welds used in certification. The groove weld on the left has been cut into strips with an oxy/acetylene torch in preparation for a bend test. The pipe on the right is marked with the weld position and welder identification number. The two horseshoe-shaped pieces of metal in the center are the sample pieces from the bend tests. The top is a face bend and the bottom is a side bend sample. *Monte Swann*



WIDTH OF WELD FACE OR INDIVIDUAL SURFACE BEAD, W	MAX CONVEXITY, C
W ≤ 5/16 in. [8 mm]	1/16 in. [2 mm]
W > 5/16 in. [8 mm] TO W < 1 in. [25 mm]	1/8 in. [3 mm]
W ≥ 1 in. [25 mm]	3/16 in. [5 mm]

Figure 5.4—Acceptable and Unacceptable Weld Profiles (see 5.24)

This is a page for the AWS structural steel welding code book. If you take a welded joint and cut it in half, you will be able to see the weld profile. The shape of this profile, which is essentially the shape of the weld bead, is important to the integrity of the joint and the structure. As you can see, certain profiles are unacceptable and are more likely to lead to the weld failing to stay together. *AWS D1.1/D1.1M 2006, Figure 5.4, Reproduced with permission from the American Welding Society (AWS), Miami, FL USA*

Certifications are legal documents attesting to the ability of a person to perform the weld adequately. It can also indicate to potential employers that a welder is familiar with the process and testing procedures. However, just because someone says he is a certified welder doesn't guarantee that he has a wide range of knowledge, or can even weld that well using different types and thicknesses of metals, joint designs, positions, and processes.

You can get certified by joining a union, working in industry, or taking a certification test. Your local AWS chapter or a weld-testing company may provide testing services. The place to start would be a welding program at your local technical college. The welding instructor should be able to answer your questions regarding weld certifications and what the school has to offer. Be aware: taking a certification test usually requires a strong knowledge of welding basics and time practicing and perfecting your skills, with some cost involved.

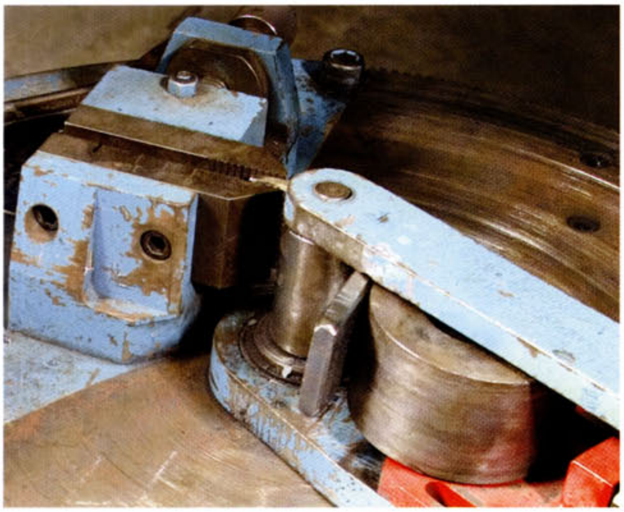
In this picture, one of the groove weld strips is placed in the vise and the backing plate is marked with soapstone. *Monte Swann*

Next, a fiber cutoff wheel is used to cut most of the way through the backing plate. *Monte Swann*

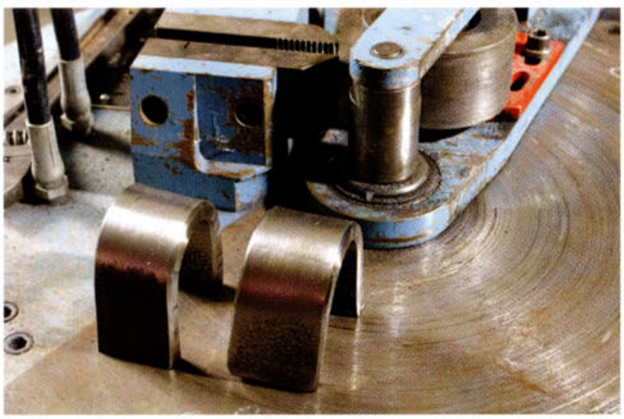
The backing plate is then removed with a hammer and chisel. *Monte Swann*

The rest of the extra weld metal is ground down and the test strip is carefully sanded flush. *Monte Swann*

The sample strip is clamped in a motorized wrap-around-bend test jig. *Monte Swann*



The test strip is wrapped around a 1½-inch diameter mandrel. *Monte Swann*



Once the machine has made a complete cycle, the bent test piece is removed and visually inspected to the criteria of the welding code being used. Two pieces are bend-tested; one is a face bend (top of the weld) and the other a root bend (bottom of the weld). *Monte Swann*

WELDING VS. BRAZING AND SOLDERING

The term "welding" is applied in many ways. Solid-state welding processes produce coalescence, or mixing, of metals at temperatures below the melting point of the base metals, and without the addition of a filler metal. For example, explosion welding, in which the surfaces of two metals become interlocked together in what looks like a series of microscopic waves, is a result of friction caused by the directed force of the explosion. In forge welding, the base metal is heated to white hot, which makes it soft (plasticized) without reaching the melting point, remaining in a solid state as the force of hammering causes the surface molecules to fuse together. There is even a method called cold welding that doesn't require heat, just smooth surfaces and enough pressure to form a bond between them.

Resistance welding is similar to solid-state welding in that time and pressure are key factors; only an electric current is used to generate the heat required for joining the materials. Spot fusion is a common form of resistance welding used to weld ductwork and automobile frames.

In gas and arc welding, the base metals to be joined are heated to their melting point, mixed with a compatible filler metal, then allowed to cool and solidify into one piece. In this kind of welding, coalescence and fusion take place within the joint (not just on the surface) and two separate pieces of metal become one. The depth of penetration is far greater in this case, meaning that the weld zone is much further into the metal's thickness. When the weld has penetrated all the way through the weld joint, this is called 100 percent penetration or complete joint penetration (CJP). Typically the filler metal used when gas and arc welding is similar in content to the base metal. Think of melting ice into water, then mixing in some motor oil and attempting to refreeze the combination. Water and oil don't mix and will not bond. If you did the same experiment with water and orange juice, the water would dilute the juice and the combination would freeze together well. In order for fusion to take place, the materials being welded together must be compatible.

Brazing and soldering are not welding processes at all. These two processes use less heat, far below the base metal's melting point, and a filler metal alloy that is dissimilar to the base metal. The bronze or solder adheres to the surface of the base metal and travels through the joint via capillary action. This method can be a very effective way of joining metals and should be used in certain situations. Refer to the section on brazing and soldering for further information.

THE MOST COMMON WELDING/CUTTING PROCESSES AND THEIR RELATED NAMES

In the welding world there are many names for the same thing. This can be confusing when talking to other people about the subject. Chart 1-1 shows a list of common names used for similar processes. There is a section of the book for each one of these processes.

Communicating with people about welding can be challenging, and few people will like being corrected on

Refer To	Proper Term	Also Known As
Chapter 7	OAW – Oxygen Acetylene Welding	Oxy/Acetylene Gas Welding Oxy/Fuel Welding
Chapter 8	TB - Torch Brazing	Braze Welding Brazing
Chapter 13	OFC – Oxygen Fuel Cutting	Oxy/Acetylene Cutting Torch Cutting
Chapter 10	SMAW – Shielded Metal Arc Welding	Stick Welding Arc Welding (Carbon Arc Cutting)
Chapter 11	GMAW – Gas Metal Arc Welding	Wirefeed Welding (solid wires) MIG – Metal Inert Gas MAG – Metal Arc Gas Short Arc Spray Transfer Welding Pulse Spray Transfer Welding
Chapter 11	FCAW – Flux Core Arc Welding	Wirefeed Welding (tubular wires) FCAW-S (Self Shielded) Inner Shield FCAW-G (Gas Shielded) Dual Shield
Chapter 12	GTAW – Gas Tungsten Arc Welding	TIG – Tungsten Inert Gas Heliarc WIG – Wolfram Inert Gas
Chapter 13	PAC – Plasma Arc Cutting	Plasma Cutting

Chart 1-1
*Colors indicate related gas and arc welding and cutting processes.

their terminology. Be patient and ask questions so you and the steel-yard jockey, welding sales representative, or welding professional are on the same page.

ABOUT THE WELDING EXERCISES

Mild carbon steel is used in all the practice exercises (except one). When you learn how to weld, use this type of material. The steel is relatively cheap compared to stainless steel or aluminum. Mild steel is easiest to weld and is a good choice for practicing your basic welding technique before moving on to the more exotic and expensive materials. Take some time to study the joint designs, types of welds, and welding positions and be prepared by knowing the advantages and limitations of the equipment you are using.

All of the metal I use is cut into 2 × 6-inch pieces. The only exception is Exercise 2 in Chapter 10 (Shielded Metal Arc Welding [SMAW]). When learning to weld, make your beads at least 6 inches long as it's more difficult to maintain good technique on longer beads. These welding exercises are the same ones I use in the classroom and they are meant to be done in the order presented, since the skills learned in each exercise build off those learned in the previous ones. If you are having trouble with difficult projects, don't be afraid to go back to the earlier exercises and redo them to perfect your technique. The first exercise—running a bead on a plate—is not only about welding properly, but having the machine controls or torch settings right. Make certain your equipment is functioning properly and the correct torch tips, electrodes, filler rods, and shielding gases are used. Having everything running smoothly will allow you to concentrate on improving your welding technique and reduce frustration.

Challenge yourself by making up additional exercises not covered in this book. In my welding classes I typically have students begin by welding all the various joint designs in the flat position. Then we move to horizontal, vertical, and overhead positions. Each new welding position is more difficult than the previous one, and all the combinations of joint designs and welding positions have unique challenges.

The welds in the exercises are to be made over the full length of the material. Remember, these welds are for *practice only.* Later, depending on the project in which you use your welding skills, you may not need to, or want to, make full-length welds.

CHAPTER 2
SAFETY

Safety is a primary concern since there are many ways to get injured or killed when welding. I once asked one of my coworkers to teach me how to use the table saw. Before we started, he asked me, "Are you afraid of it?" The saw wasn't even turned on and I said yes. He said "Good, because as soon as you aren't afraid of it you will lose a finger." That made sense to me. As soon as you lose respect for something dangerous it is liable to bite you.

The owner's manual that comes with your welding/cutting and fabricating equipment is full of good and useful information. Read through it; know how your equipment works and the specific hazards related to its use.

Take one minute to consider the consequences of your actions. This is especially true when cutting. Steel is strong and supports heavy weight very well, but can be cut easily with a torch. A drum, cylinder, or container can also be cut with a torch, but without knowing exactly what is inside it you could be in for a lot of trouble. Leaning into a belt sander or pushing metal through a vertical band saw requires only one slip before disaster. Spinning pulleys, flywheels, and drill chucks are hazards. If your hair or clothing get wrapped around a motorized turning part or caught in a pinch point where moving and non-moving parts come together, it will pull you in. And in the case of someone's hair, the machine can actually scalp you.

Whenever you start any machine, ensure that you are not in the path of any shrapnel should something come apart. Stand to the side of any machine, like a mounted bench grinder. Or for example, after installing a new hard wheel, hold a 4½-inch angle grinder at arms length with the spindle in a horizontal position pointing away from you. Think about what direction things are moving, or could move in, and avoid that area. Don't forget: something doesn't have to be moving in order to inflict severe injury. You can run into sharp metal or machinery. Running and horseplay in a metal shop is asking for a laceration or to be impaled on anything laying around. Alcohol and drugs are also a bad idea in a metal fabrication shop. If you shouldn't be driving, you shouldn't be welding.

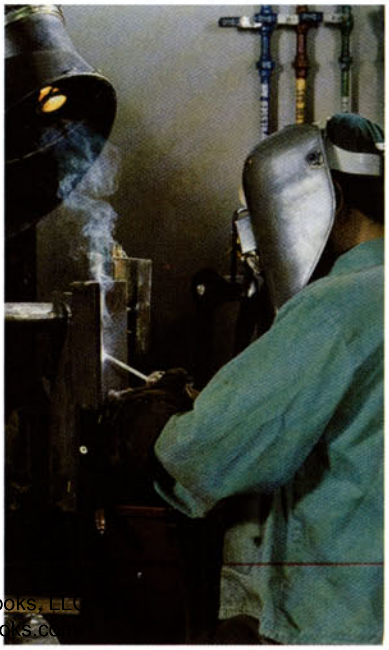
SHOP SAFETY PRACTICES

Setting up shop

Before you begin to buy equipment, the first thing to consider is the location of your shop. Welding and cutting in a basement is not a good idea since welding smoke is lighter than air and will travel to the floors above. A detached garage or other building is ideal.

The area where welding and cutting is taking place should be well ventilated. Most people solve this problem by opening the garage door or working outside. This is a good solution if you are using welding processes that don't require use of a shielding gas such as SMAW, FCAW-S, and oxy/acetylene. The processes that do use a shielding gas, such as GMAW, FCAW-G, and GTAW, are wind sensitive. Even the air movement generated by a fan can blow away the shielding gas, contaminating your weld and ruining it. Of these wind sensitive processes, some generate more fumes than others. For example, GTAW generates the least amount of fumes, GMAW next, and FCAW-G generates the most.

Your decision to install an exhaust system or use a respirator will depend upon which welding and cutting processes you are performing and with what type of materials you will be working. Also consider that when you heat certain materials to their melting point, you send very small particles into the atmosphere. Breathing in enough of these particles will make you sick in the short term and increase your risk of long-term health problems. See the section on respirators in this chapter for more information. Some simple ductwork and an exhaust fan can go a long way in reducing the amount of exposure to toxic fumes, but may not be the most practical or useful solution. If you decide to install ventilation, go to the OSHA website (www.osha.gov) and search for OSHA standard 1910.252(c)(3)(i). The standard gives you duct diameters and minimum airflow rates in relation to the distance the vent is from the weld zone. Your vent system



Notice the welding fumes, which are lighter than air, float up from the weld and get sucked into a vent positioned above the weld joint. Welding in the vertical position as shown will keep your head out of the smoke plume. When welding in the flat and horizontal positions, be aware of keeping your head out of the plume. *Monte Swann*

Along with an ABC fire extinguisher and first aid kit, a fire blanket can be used to snuff out fires. In addition, hot pieces of metal can be wrapped in the blanket to slow the cooling rate of certain metals after welding. Because it is located at a public school, this fire extinguisher is tagged with dates of inspection. The directions on this fire extinguisher explain its proper use. When you need to use an extinguisher, remember PASS: Pull the pin, Aim for the base of the fire, Squeeze the handle, and Sweep back and forth. *Monte Swann*

can be ambient capture, meaning an overhead hood or down-draft table, or source capture, consisting of a moveable arm. A moveable arm provides the most versatility, because it can be moved closer to the source of any smoke and fumes.

Keep safety in mind

Working with electric arcs, flames, and molten metal greatly increases the risk of starting a fire. Before you start welding or cutting, be certain to check the work area for any flammable materials, like rags and cardboard, and remove them. Flammable liquids—such as oil-based paint, finishes, solvents, and gasoline—even if in a metal container, should also be removed from the area or stored in a flammable materials cabinet. Batteries pose an explosion hazard; never weld near batteries. Buy a couple of ABC fire extinguishers and have them handy. The very small extinguishers will not last long when it counts the most. I recommend purchasing a 6-7-pound extinguisher, at a minimum. Don't be afraid to buy a larger one.

A metal bucket full of water is good to have around for cooling metal after practice welding. Never use water to extinguish a fire around molten metal, because water will react violently with the molten metal. A bucket of sand helps put out any flames. Different sizes of scrap sheet metal come in very handy as a barrier between your welding or cutting and something hazardous. For example, if sparks gather in openings between and underneath walls or come in contact with wood floors, they can smolder and possibly catch on fire. Concrete floors and regular bricks have moisture trapped inside. When a hot flame from a torch comes close enough, it will turn the water into steam, which will expand rapidly causing an explosion, sending concrete fragments in all directions at a high rate of speed. Automotive work is especially hazardous due to fuel lines, fuel tanks, and flammable upholstery. Use sheet-metal barriers to deflect heat and sparks away from dangerous areas.

A bottle of eyewash solution is handy for flushing unwanted fragments or liquids out of your eyes, and could help in an emergency. Let someone know where you are and what you are doing if you are working solo. Have a well-stocked first aid kit with tweezers, burn cream, disinfectant, bandages, and tape to take care of the minor injuries you will face in the shop. Finally, make it a policy to hang around the shop for one-half hour after all welding and cutting is finished. It will give you peace of mind to know that your shop is not on fire after you leave.

Keeping a (relatively) clean and well-organized work area will help in everything you do. It is a lot easier to trip and fall over debris, tangled welding hoses, or cables in a messy shop, and anything you fall into will likely go right through your clothing and skin. Cables and cords usually need to be on the floor, so have out only what you need to do the current job. Keep the rest wrapped up and be careful walking around. Sweep after you finish working since steel dust is slippery on some floor surfaces.

BUYING WELDING EQUIPMENT

Deciding what type of welding machine and equipment to buy can be difficult. There are some basic questions you need to answer before purchasing anything. What type of materials will you be working with? Steel only, aluminum and/or stainless steel, as well? Some welding processes, such as GTAW, are well suited to welding a variety of materials. Others, such as SMAW, would be a bad choice for welding aluminum. There is more information on the advantages and disadvantages of each process later in the book.

The next thing to consider is the thickness of the metals to be welded and, more importantly, the maximum material thickness you want to weld. The capacity your machine has is directly related to how much heat it can generate. You need more heat to weld thicker sections and less to weld sheet metal. The capacity or amperage of a machine is also directly related to cost. With some processes, such as SMAW, you can weld thicker sections for a lower cost than if you were using GMAW. Processes like GMAW will be significantly more expensive to weld 3/8-inch material and over, but require less skill. This will be discussed later in the book.

Where will you be welding? Indoors, outdoors, in a garage with the doors open? As we discussed earlier, this is an important consideration because some processes are wind sensitive. Whatever machine or torch setup you decide to buy, I strongly suggest going to your local welding supplier. You can find one near you in the phone book and it will be well worth the effort to visit one or two. It will help if you read up on welding a little and have some ideas going in, but the people working there will be much more knowledgeable about the subject than employees of big chain hardware or home stores. Stores that have the welding machines next to table saws and drywall have a limited variety of equipment to choose from and often carry machines that will not ultimately suit your needs. A good welding supplier will take the time to answer questions, as well as point you in the direction of some other useful accessories. Decide on a budget, but don't go cheap. How much you pay for a welding machine will depend upon what process you will be using. But a broad range of prices for a good welding machine range between $600 and $3500. Buying a machine up-front that will do the jobs you want to do should offset the cost of buying a cheap machine first, using it for a couple of years and then buying another, better machine. See Chapter 9 (Introduction to Arc Welding) for more information on welding machines.

When you buy your machine, be certain to stock up on all the consumables you will need. Parts of a wirefeed gun, for example, are considered consumables, and some are replaced less frequently than others. But having extra contact tips and nozzles will be helpful during a fabrication project. Having extra sanding/grinding wheels, filler rods, tips, torch, and gun parts on hand can be the difference between finishing a project and waiting. If you are lucky enough to inherit welding equipment from a family member or friend, find out exactly what you are getting into. What will the equipment do and not do? Is it old and in need of a tune-up? This is where a welding supplier can come in handy, setting you up with new welding cables, a new torch or wirefeed gun, gas lines, bench-testing regulators, and tuning up your machine. The cost to do these things is reasonable and could save you a lot of trouble down the road. Used equipment can be great, but could cause a lot of frustration if it's acting funny or be a pain if a regulator blows or there is a fire or you get shocked due to an electrical problem.

No matter what size space you will be working in, portable equipment is wonderful. I put as many things on wheels as possible. Welding machines, tables, and material racks can all be made mobile by welding up a simple frame out of angle iron or steel tubing, and then welding or bolting casters to the bottom. I had a student who modified a two-wheeled cart to fit his smaller GTAW machine and shielding gas cylinder. He mounted the machine vertically with the controls facing up, and the back of the machine was mounted away from the floor to accommodate the cooling fan. The other side had the cylinder chained in the normal position. With today's lightweight machines, there are many more possibilities. Putting things on wheels gives you greater versatility and access in your shop. It's a lifesaver if you need room in the garage for your car, too. Once you have some welding equipment, materials, and skill you can fabricate all kinds of brackets, shelving, and storage, as well as modify any store-bought items. Custom make what will work best for you. Have a home for tools so the next time they can be found easily. And always keep safety in mind.

PERSONAL PROTECTIVE EQUIPMENT (PPE)

Personal protective equipment is just a fancy way of saying what you should wear in the shop. What you'll need depends on the particular job you are doing. During my first semester of welding school we used track torches to cut bevels on thick steel plates, which is a gas cutting-torch on a motorized track. As I was in the middle of watching the track torch do its work with my dark cutting goggles on, one of the instructors walked behind me and said casually, "Your shoe is on fire," and kept on walking. I took off the goggles and looked down to see my canvas shoe in flames. After I put the fire out, I went to my locker and pulled out the leather work boots I had chosen not to wear. I was not dressed properly for the job at hand and got lucky not to be severely burned. Working with the hazards of welding requires proper dress, and even then your clothing can catch on fire. Keep in mind, the risk of being burned increases depending on the welding process, amount of heat and sparks, and how well you are protected by what you are wearing. Wearing the proper protective equipment for the job will greatly reduce the risk of personal injury, especially if the work involves cutting, grinding, and welding out of position (vertical and overhead).

What you should not wear

Nylon and polyester clothing should not be worn. Heat from welding or cutting can cause the material to melt to your skin. The unfortunate people who have had this happen need skin grafts to replace the damaged area on their bodies. Wrist-watches, rings, and jewelry should be removed because they heat up quickly and can get caught on materials, shelves, and moving parts. Long hair should be tied back. Sandals and open-toed footwear are a bad idea.

Upper and lower body

A good pair of jeans is all I've ever worn in the shop, at least between my ankles and waist. The jeans you wear should be the correct length and not be cuffed at the bottom. A cuff on your jeans or shirt, or even a shirt pocket without a cover flap, is a spark collector. Sparks like to be with other sparks and if enough of them end up in your cuffs, there will be a fire. Your jeans should be in good condition without any frays. At a minimum, put some tape over the frayed area, but only as a temporary measure. What you wear on top depends on what kind of work you are doing.

Heavy-cotton, long-sleeve work shirt made of denim (not a fuzzy nap, like a sweat shirt)

- Gas welding and brazing in all positions, TIG (GTAW) welding in all positions
- Light grinding, torch cutting, and plasma cutting

Welding jacket made from green (typically) fire-retardant material

- Light wirefeed welding (GMAW/FCAW wires) in all positions

- Medium wirefeed welding (GMAW/FCAW wires) in the flat and horizontal positions
- Light to medium stick-welding (SMAW) in the flat and horizontal positions
- Medium torch and plasma cutting and heavy grinding

Welding leathers or leather jacket

- Medium to heavy wirefeed welding (GMAW/FCAW) in all positions
- Medium to heavy stick-welding (SMAW) in all positions
- Heavy torch and plasma cutting

This is an all-cotton welding jacket. The material has been treated to be fire-retardant. These jackets are inexpensive. You can also buy welding sleeves made out of the same material to be worn over your bare arms or shirt. *Monte Swann*

This welding jacket is known as a hybrid. The arms are made of leather and the body of the jacket is fire-retardant cotton material. Since your arms are closest to the sparks and liquid metal, they need a high level of protection offered by the leather. *Monte Swann*

This is a pair of welding leathers with an apron snapped onto the front. An all-leather welding jacket is also available for welding with high levels of heat and sparks and/or welding vertical and overhead joints. *Monte Swann*

Light, medium, and heavy are terms used above to describe the amount of heat, sparks, and intensity of arc light generated by the welding or cutting process and the direction it's traveling. For example, in overhead welding you will likely be under the weld where sparks, molten metal, and hot slag can drop down—a much more hazardous position than having the weld on a table in front of you. It is not a bad idea to have each level of protective clothing available, so if you do get burned you can suit up better for the job. I avoid wearing leather aprons because they can get caught in moving machinery, but having a piece of leather available can be a great way to protect you from heat and sparks in certain situations. For example, a piece of leather may be placed in your lap if you are welding while sitting on the floor.

Gloves

Another reason to visit a welding supply store is the wide variety of proper gloves. Welding gloves are all leather with a full leather gauntlet that covers the end of your sleeve. They range in heat protection from oven-mitts to almost paper thin. The sacrifice you make with wearing heavy gloves is a great reduction in manual dexterity. One wrong move with thinner gloves and they are easily burned up. Again, it depends on what kind of welding you are doing. I wear a pair of Tillman No. 30 TIG gloves for gas and TIG welding. I also wear a heavy cotton shirt. The more heat protection required up top, the thicker the gloves should be. I suggest buying one pair for lower heat and one for high heat. Your welding supplier will have a wide variety of welding gloves for all welding applications and can help you find the ones right for your job. Tillman and Revco are two good brands to look for. Revco also makes a women's line of welding gear. Keep your welding gloves dry and in good condition. Never pick up hot metal with them or they will shrivel up and be ruined quickly. Always use pliers when picking up hot metal. Keep a pair of old gloves for material handling. Oftentimes, steel you get from a yard has oil, grime, and dirt on it. Oily gloves and welding equipment are a bad combination.

It's handy (no pun intended) to have different welding gloves available for use in the shop. Watch out for holes developing in the gloves during extended use. Gloves with holes can be patched with duct tape and are good for handling materials with sharp edges. *Monte Swann*

The red-framed safety glasses have a standard, clear polycarbonate lens. The darker-framed glasses have shaded lenses for working outdoors on sunny days. The goggles at the top of the picture can fit over regular prescription glasses and protect your eyes from flying particles. *Monte Swann*

Shoes

All-leather, steel-toe, high-top boots offer the most protection. Leather shoes also work well, but it takes only one heavy object falling on your foot to convince you steel toes are a good thing. Steel toes have another advantage when it comes to moving materials around or kicking something hard. Often I find myself using the end of my steel toes as a brace or extra hand. Keep in mind, a very heavy plate of steel or fork lift will crush the steel in your shoe, but this is an unusual occurrence, even in an industrial shop. Unless you wear steel-toe slip-on boots, extra shoelaces come in handy in case the pair on your shoes gets burned up.

Safety glasses

I ask my students at the beginning of the term, "If you had to choose between losing a finger or losing an eye, which would you choose?' Always, they choose the finger. Then I up the ante and ask, how about two fingers? Sometimes we get to the whole hand before someone thinks twice. No one wants to lose an eye. Always wear your safety glasses in a shop. They are one of the least expensive things to buy and protect one of the most important parts of your body. Buy a clear comfortable pair that resists fogging. Keep them in good condition; scratches and pits can obstruct your view of the molten weld pool, making it more difficult to see what is happening. If you already wear glasses, they might be okay. The lenses should be made of polycarbonate and large enough to cover your eye socket. They should also have side shields. Specialty safety glasses referred to as flash goggles are a No. 2 or 3 shade. The shade reduces the brightness and annoyance of other welding arcs.

Contact lenses are okay to wear while welding, and no matter what you have heard, they will not melt to your eyeball. The only concern is that they can dry out quickly, so keep them moisturized. Seeing the weld is very important. Many times people learning to weld have a hard time simply because they cannot see clearly. Bifocals under your welding helmet can help, and the magnification can be placed on the lower or upper edge of the lens, or both. Instead of bifocals, you can ask your welding supplier to show you their selection of cheater lenses. These are magnifiers that fit into your welding helmet and come in a variety of strengths. In any case, you should be able to read small print up close, about 6 inches from your nose, as well as at arms length.

Ear protection

Metal fabrication can be a very loud business. Grinding, cutting, and hammering will put an extreme amount of stress on your ears. Protect your hearing by having a box of ear plugs and wearing them when the noise level gets uncomfortable. I like to use ones with a cord attached between the plugs making them easy to insert and remove. Hearing loss is compounded over time, followed by a constant ringing in your ears. Like losing an eye, the effects will last the rest of your life.

Face shields are available with a clear lens or a No. 5 shade. The same headgear can be used for both. *Monte Swann*

A clear face shield and gloves are a good choice when using grinders. Notice the sparks from a grinder come off the wheel in one direction. Be sure to keep your spark stream away from flammable materials, compressed gas cylinders, welding equipment, and other people. *Monte Swann*