



HOBART INSTITUTE
OF WELDING TECHNOLOGY

Shielded Metal Arc Welding

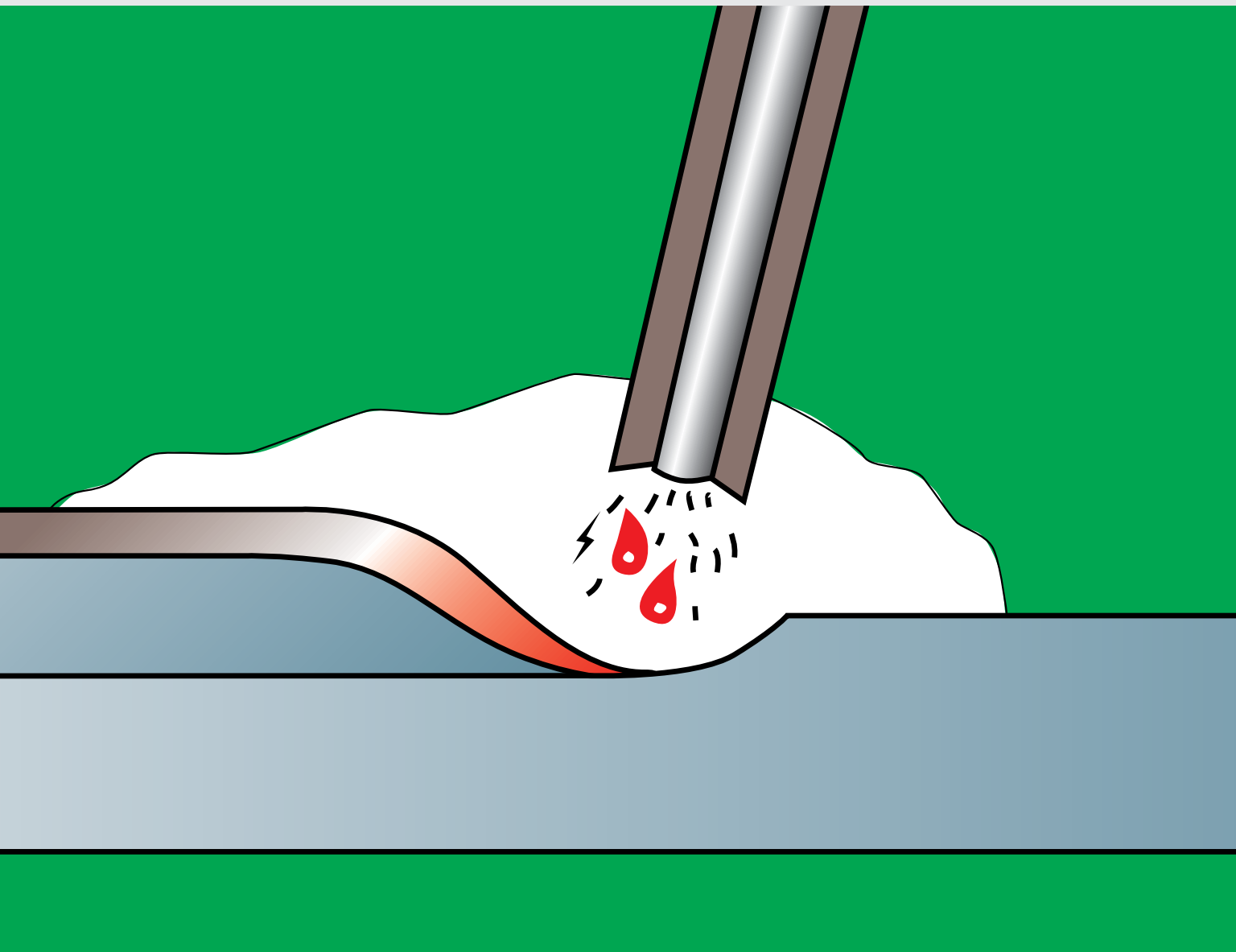


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CHAPTER 1

INTRODUCTION TO THE PROCESS

Shielded Metal Arc Welding (SMAW) is an electric arc welding process where the heat for welding is generated by an electric arc between a covered metal electrode and the work. The filler metal is deposited from the electrode and the electrode covering provides the shielding. Some slang names for this process are “stick welding” or “stick electrode welding: A diagram of this process is shown in Illustration 1-1.

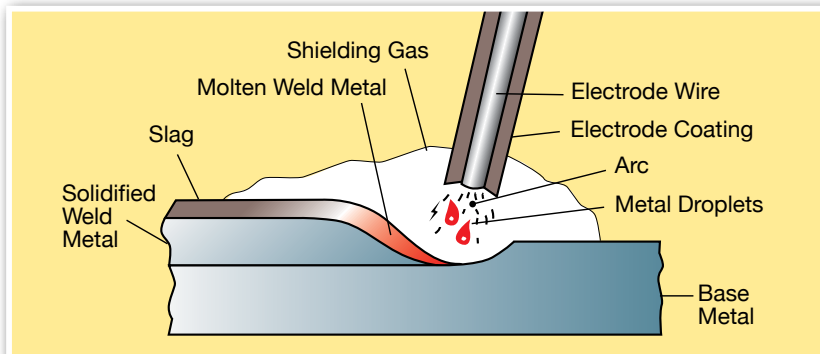


Illustration 1-1 – Shielded Metal Arc Welding

The shielded metal arc welding process is one of the most simple and versatile arc welding processes. This process can be used to weld both ferrous and nonferrous metals and it can weld thicknesses above approximately 18 gauge in all positions. The arc is under the control of the welder and is visible. The welding process leaves a slag on the surface of the weld bead which must be removed.

The most popular use for this process is for the welding of mild and low alloy steels. The equipment is extremely rugged and simple, and the process is flexible in that the welder only needs to take the electrode holder and work lead to the point of welding.

Most sources give credit for the invention of the electric arc to Sir Humphrey Davy of England, in 1801. For the most part, the electric arc remained a scientific novelty until 1881, when the carbon arc street lamp was invented and the first attempts to weld using the carbon arc process were made. The metal arc welding process came into being when the carbon electrodes were replaced by metal rods in 1889. Coverings for the bare wire electrodes were first developed in the early 1900's. The first major use occurred during World War I, especially in the shipbuilding industry. After the war, there was a period of slow growth until the early 1930's when shielded metal arc welding became a major manufacturing method and a dominant welding process. Today, the shielded metal arc welding process is a widely used welding process, even though its relative importance had been declining slowly in recent years.

METHODS OF APPLICATION

The shielded metal arc welding process is basically a manually operated process. The electrode is clamped in an electrode holder and the welder manipulates the tip of the electrode in relation to the metal being welded. The arc is struck, maintained, and stopped manually by the welder. There are several variations of this process which are done automatically. These are gravity welding, fire cracker welding, and massive electrode welding. These methods comprise only a very small percentage of welding done by the shielded metal arc welding process. They will be explained in Chapter 5.

ADVANTAGES AND LIMITATIONS

Shielded metal arc welding is widely used because of its versatility, portability, and comparatively simple and inexpensive equipment. And it does not require auxiliary gas shielding or granular flux.

The shielded metal arc welding process can be used for making welds in any position that can be reached with an electrode. Electrodes can be bent so they can be used to weld blind areas. Long leads can be used to weld in many locations at great distances from the power source. Shielded metal arc welding can be used in the field because the equipment is relatively light and portable. This process is also less sensitive to wind and draft than gas shielded arc welding processes.

Shielded metal arc welding can be used to weld a wide variety of metal thicknesses. This process is more useful than other welding processes for welding complex structural assemblies because it is easier to use in difficult locations and for multi-position welding. Shielded metal arc welding is a popular process for pipe welding. Weld joints with high quality and strength can be obtained with shielded metal arc welding.

The shielded metal arc welding process has several limitations. Operator duty cycle and overall deposition rates for covered electrodes are usually less than provided with a continuous electrode process. This is because electrodes have a fixed length and welding must be stopped after each electrode has been consumed. The portion of the electrode that is clamped into the holder must be discarded. Another limitation is that the slag must be removed from the weld after every pass. Finally, the shielded metal arc welding process cannot be used to weld some of the nonferrous metals.

CHAPTER 2

PRINCIPLES OF OPERATION

The shielded metal arc welding process uses the heat of the electric arc to melt the consumable electrode and the work being welded. The welding circuit includes a power source, welding cables, an electrode holder, a work clamp and a welding electrode. One of the welding cables connects the power source to the electrode holder and the other cable connects to the workpiece.

The welding begins when the arc is initiated by momentarily touching the electrode to the base metal which completes the electrical circuit. The welder guides the electrode manually, controlling both the travel speed and the direction of travel. The welder maintains the arc by controlling the distance between the work material and the tip of the electrode (length of the arc). Some types of electrodes can be dragged along the surface of the work so that the coating thickness controls the arc length, which controls the voltage.

The heat of the arc melts the surface of the base metal and forms a molten weld puddle. The melted electrode metal is transferred across the arc and becomes the deposited weld metal. The deposit is covered by a slag produced by components in the electrode coating. The arc is enveloped in a gas shield provided by the disintegration of some of the ingredients of the electrode coating. Most of the electrode core wire is transferred across the arc, but small particles escape from the weld area as spatter, and a very small portion leaves the welding area as smoke.

ARC SYSTEMS

The constant current type of power source is preferred for manual shielded metal arc welding. The constant current welding machines provide a nearly constant welding current for the arc.

The constant current output is obtained with a drooping volt ampere characteristic, which means that the voltage is reduced as the current increases. The changing arc length causes the arc voltage to increase or decrease slightly, which in turn changes the welding current. Within the welding range, the steeper the slope of the volt-ampere curve, the smaller the current change for a given change in the arc voltage.

Under certain conditions, there is a need for variations in the volt-ampere slope. A steep volt-ampere characteristic is de-

sirable when the welder wants to achieve maximum welding speed on some welding jobs. The steeper slope gives less current variation with changing arc length and it gives a softer arc. The types of machines that have this kind of curve are especially useful on sheet metal. Machines with this characteristic are typically used with large diameter electrodes and high amperages. On some applications, a less steep volt-ampere characteristic is more desirable, such as welding over rust, or all position pipe welding where better arc control with high penetration capability is desired. Machines with the less steep volt-ampere curve are also easier to use for depositing the root passes on joints that have varying fitup. This type of power source characteristic allows the welder to control the welding current in a specific range, by changing the arc length and producing a more driving arc. The variations in the power sources are caused by the differences in the basic power source designs. Illustration 2-1 shows volt-ampere curves for different performance characteristics. This shows several slopes, all of which can provide the same normal volt-age and current. The flatter slopes give a greater current variation for a given voltage change or arc length change. More positive starting is given by machines that have a higher short circuit current.

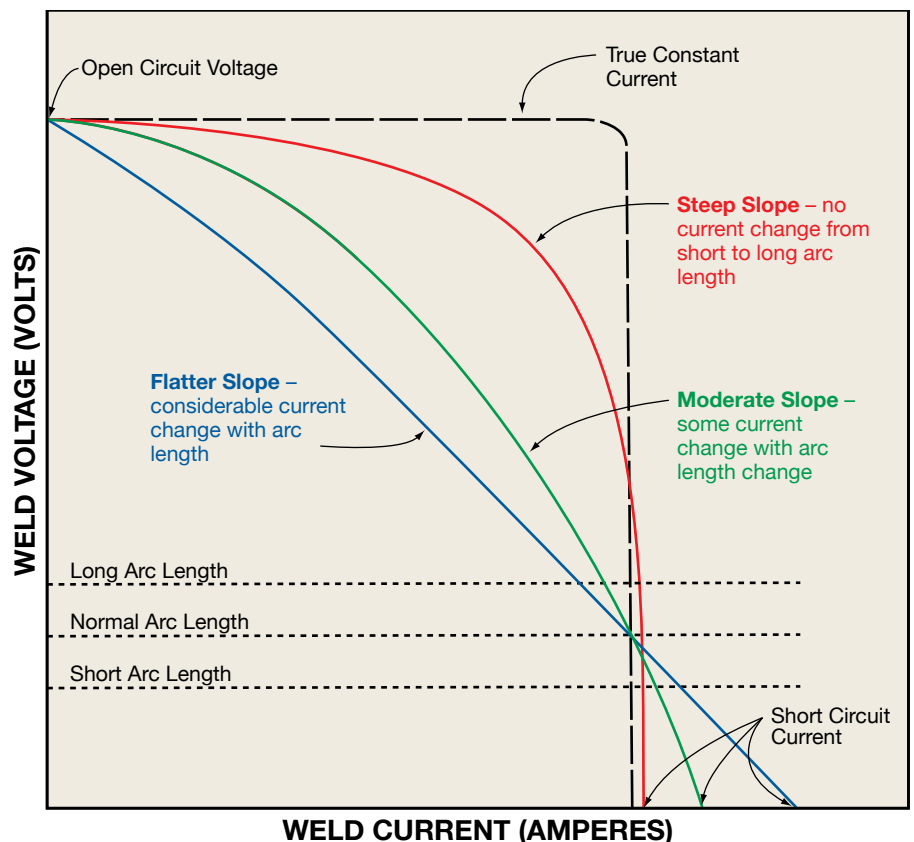


Illustration 2-1 – Typical Volt-Ampere Curves for Constant Current Types of Power Sources

METAL TRANSFER

The intense heat of the welding arc melts the tip of the electrode and melts the surface of base metal. The temperature of the arc is about 9000°F (5000°C) which causes almost instantaneous melting of the surface of the work. Globules form on the tip of the electrode and transfer through the arc to the molten weld puddle on the surface of the work. When the detaching globules are small during the transfer, this is known as spray type metal transfer. When the globules are relatively large during transfer, it is known as globular type metal transfer.

Surface tension sometimes causes a globule of metal to connect the tip of the electrode to the weld puddle. This causes an electrical short and makes the arc go out. Usually this is a momentary occurrence, but occasionally the electrode will stick to the weld puddle. When the short circuit occurs, the current builds up to a short circuit value and the increased current usually melts the connecting metal and re-establishes the arc. A welding machine with a flatter volt-ampere curve will give a higher short circuit current than a machine with a steeper volt-ampere curve. The electrode sticking problem will be slightly less with a machine that has a flatter volt-ampere curve.

A softer arc, produced by a steeper slope, will decrease the amount of weld spatter. A more driving arc produced by a flatter slope, causes a more violent transfer of metal into the weld puddle which will cause a greater splashing effect. This greater splashing effect will generate more spatter from the weld puddle.

When the welds are made in the flat or horizontal positions, the transfer of the metal is induced by the forces of gravity, magnetism, and surface tension. When the welds are made in the vertical or overhead positions, the forces of magnetism and surface tension induce the metal transfer with the force of gravity opposing metal transfer. Lower currents are used for vertical and overhead welding to allow shorter arc lengths and promote a smaller metal droplet size less affected by gravity.

CHAPTER 3

EQUIPMENT FOR WELDING

The equipment for the shielded metal arc welding process consists of a power source, welding cable, electrode holder, and work clamp or attachment. A diagram of the equipment is shown in Illustration 3-1.

POWER SOURCES

The purpose of the power source or welding machine is to provide the electric power of the proper current and voltage to maintain a welding arc. Many different sizes and types of power sources are designed for shielded metal arc welding. Most power sources operate on 230 or 460 volt input electric power. Power sources that operate on 200 or 575 volt input power are also available.

Types of Current

Shielded metal arc welding can be accomplished using either direct current (DC) or alternating current (AC). Electrode negative (straight polarity) or electrode positive (reverse polarity) can be used with direct current. Each type of current has distinct advantages, but the selection of which type of welding current is used, usually depends on the availability of equipment and the type of electrode selected. Direct current flows in one direction continuously through the welding circuit. The advantages it has over alternating current are:

1. Direct current is better at low currents and with small diameter electrodes.
2. All classes of covered electrodes can be used with satisfactory results.
3. Arc starting is generally easier with direct current.
4. Maintaining a short arc is easier.
5. Direct current is easier to use for out-of-position welding because lower currents can be used.

6. Direct current is easier to use for welding sheet metal.
7. It generally produces less weld spatter than alternating current.

Polarity or direction of current flow is important when direct current is used. Electrode negative (straight polarity) is often used when shallower penetration is required. Electrode positive (reverse polarity) is generally used where deep penetration is needed. Normally, electrode negative provides higher deposition rates than electrode positive. The polarity to be used is often governed by the type of electrode.

Alternating current is a combination of both polarities that alternates in regular cycles. In each cycle the current starts at zero, builds up to a maximum value in one direction, decays back to zero, builds up to a maximum value in the other direction, and again decays to zero. The direction of current changes 120 times with the 60 Hertz current that is used in the United States. Depth of penetration and deposition rates for alternating current are generally intermediate between those for DC electrode positive and DC electrode negative. Some of the advantages of alternating current are:

1. Arc blow is rarely a problem with alternating current.
2. Alternating current is well suited for the welding of thick sections using large diameter electrodes.

Power Source Duty Cycle

Duty cycle is defined as the ratio of arc time to total time. For a welding machine, a 10 minute time period is used. Thus for a 60 duty cycle machine the welding load would be applied continuously for 6 minutes and would be off for 4 minutes. Most industrial type constant current machines are rated at 60% duty cycle. The formula for de-

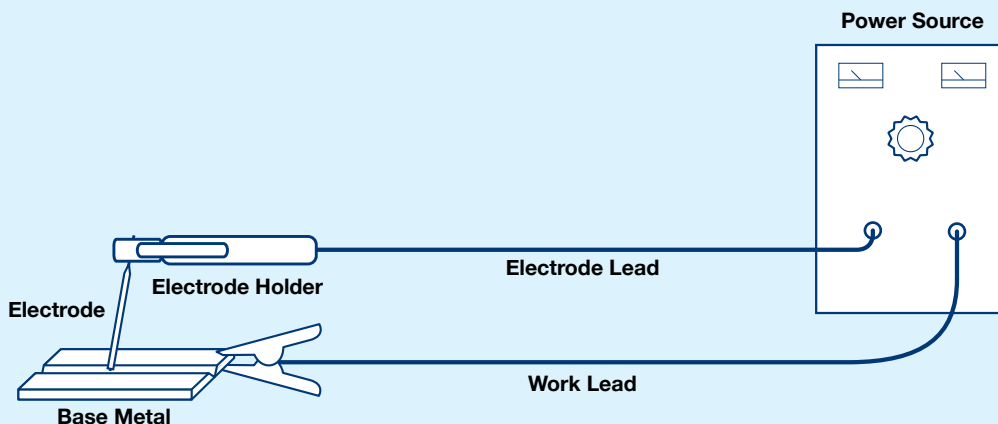


Illustration 3-1 – Equipment for Shielded Metal Arc Welding

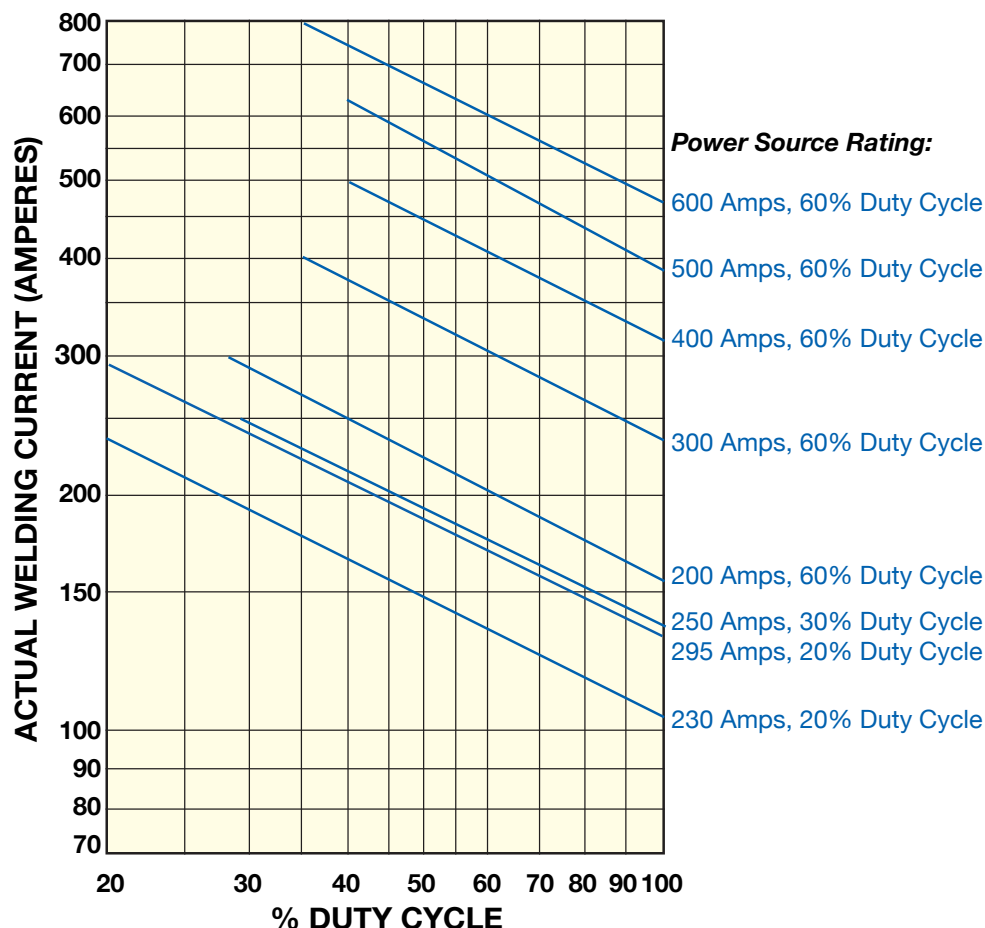


Illustration 3-2 – Duty Cycle vs Current Load

termining the duty cycle of a welding machine for a given load current is:

$$\% \text{ Duty Cycle} = \frac{\text{Rated Current}^2}{\text{Load Current}^2} \times \text{Rated Duty Cycle}$$

For example, if a welding machine is rated at a 60% duty cycle at 300 amperes, the duty cycle of the machine when operated at 350 amperes would be.

$$\% \text{ Duty Cycle} = \frac{300^2}{350^2} \times 60 = 44\%$$

Illustration 3-2 represents the ratio of the square of the rated current to the square of the load current multiplied by the rated duty cycle. Rather than work out the formula this chart can be used. A line is drawn parallel to the sloping lines through the intersection of the subject machines rated current output and rated duty cycle. For example, a question might arise whether a 400 amp 60% duty cycle machine could be used for a fully automatic requirement of 300 amps for a 10-minute welding job. It shows that the machine can be used at slightly over 300 amperes at a 100% duty cycle. Conversely, there may be a need to draw more than the rated current from a welding machine, but for a short period. This illustration can be used to compare various machines. All machines should be related to the same duty cycle for a time comparison.

Types of Power Sources

The output characteristics of the power source must be of the constant-current (CC) type. The normal current range is from 25 to 500 amps using conventional size electrodes. The arc voltage is from 15 to 35 volts.

Generator and Alternator Welding Machines

The generator can be powered by an electric motor for shop use or by an internal combustion engine (gasoline, gas, or diesel) for field use. Engine driven welders can have either water or air cooled engines and many of them provide auxiliary power for emergency lighting, power tools, etc. Generator welding machines can provide both AC or DC power.

An alternator welding machine is an electric generator that is made to produce AC power. This power source has a rotating assembly. These machines are also called rotating or revolving field machines.

On dual control machines, normally a generator, the slope of the output curve can be varied. The open circuit, or “no load”, voltage is controlled by the fine adjustment control knob. This control is also the fine welding current adjust-

ment during welding. The range switch provide coarse adjustment of the welding current. In this way, a soft or harsh arc can be obtained. With the flatter curve and its low open circuit voltage, a change in arc voltage will produce a greater change in output current. This produces a digging arc preferred for pipe welding. With steeper curve and its high open circuit voltage, the same change in arc voltage will produce less of a change of output current. This is a soft, or quiet arc, useful for sheet metal welding. In other words, the welder allows the most flexibility for the welder. This type of welding machine gives the smoothest operating arc because there is less voltage ripple produced.

Transformer Welding Machines

The transformer type welding machine is the least expensive, lightest, and smallest of any of the different types of welders. It produces alternating current for welding. The transformer welder takes power directly from the line, transforms it to the power required for welding, and by means of various magnetic circuits, inductors, etc., provides the volt-ampere characteristics proper for welding. The welding current output of a transformer welder may be adjusted in many different ways. The simplest method of adjusting output current is to use a tapped secondary coil on the transformer. This is a popular method employed by many of the limited input, small welding transformers. The leads to the electrode holder and the work are connected to plugs, which may be inserted in sockets on the front of the machine in various locations to provide the required welding current. On some machines, a tap switch is employed instead of the plug-in arrangement. In any case, exact current adjustment is not entirely possible.

On industrial types of transformer welders, a continuous output current control is usually employed. This can be obtained by mechanical means, or electrical means.



Illustration 3-3 – DC Constant Current Portable Welder/Generator.

Photo courtesy of Hobart Brothers Company.



Illustration 3-4 – Diesel Engine Driven Power Source

Photo courtesy of Miller Electric Manufacturing Co.

The mechanical method usually involves moving the core of the transformer. Any of the methods which involve mechanical movement of the transformer parts require considerable movement for full range adjustment. The more advanced method of adjusting current output is by means of electrical circuits. In this method the core of the transformer or reactor is saturated by an auxiliary electric circuit which controls the amount of current delivered to the output terminals. By merely adjusting a small knob, it is possible to provide continuous current adjustment from the minimum to the maximum of output.

Although the transformer type of welder has many desirable characteristics, it also has some limitations. The power required for a transformer welder must be supplied by a single phase system, and this may create an unbalance of the power supply lines, which is objectionable to most power companies. In addition, transformer welders have a rather low power factor unless they are equipped with power factor correcting capacitors. The addition of capacitors corrects the power factor under load and produces a reasonable power factor which is not objectionable to electric power companies.

Transformer welders have the lowest initial cost. Transformer welders require less space and are normally quiet in operation. In addition, alternating current welding power supplied by transformers reduces arc blow which can be troublesome on many welding applications. They do not, however, have as much flexibility for the operator as the dual controlled generator.

Transformer-Rectifier Welding Machines

The previously described transformer welders provide alternating current to the arc. Some types of electrodes can be operated successfully only with direct current power. A method of supplying direct current power to the arc other than the use of a rotating generator is by adding a rectifier, which is an electrical device which changes alternating current into direct current. Transformer-rectifier welding machines operate on single phase input power. These machines are used when both AC and DC current are needed. A single phase type of AC welder is connected to the rectifier which then produces DC current for the arc. By means of a switch which can change the output terminals to the transformer, or to the rectifier, the operator can select either AC or DC current for his welding requirement. The transformer-rectifier welding machines are available in different sizes. These machines are more efficient electrically than the generator welding machines and they provide quieter operation. Illustration 3-5 shows an AC/DC single phase power source.

Three Phase Rectifier Welding Machines

Three phase rectifier welding machines provide DC welding current to the arc. These machines operate on three phase input power. The three phase input helps overcome the line unbalance that occurs with the single phase transformer-rectifier welding machines. In this type of machine, the transformers feed into a rectifier bridge which then produces direct current for the arc. The three-phase rectifier unit is more efficient electrically than a generator and it provides quiet operation. This type of machine also gives the least voltage ripple and produces the smoothest arc of the static type welding machines. Illustration 3-6 shows a three phase solid state constant current power source. It automatically monitors output voltage and makes required changes to compensate for line voltage fluctuation.

Inverter Power Sources

In this type of power source, which utilizes the inverter, the power from the line is first rectified to pulsing direct current. This then goes to a high frequency oscillator or chopper, which changes the DC to high-voltage, high-frequency AC in the range 5 to 50 kHz. The output of the chopper circuit is controlled in accordance with welding procedure requirements. The high frequency AC is then transformed down to the operating welding voltage. The advantage of the inverter is the use of a small lightweight transformer, since transformers become smaller as frequency increases. The high frequency AC current is then rectified with silicon diodes to provide direct current output at normal welding current and voltage. The inverter power source has become economically feasible due to the availability of high current, high speed solid state electronic components at a reasonable cost.



**Illustration 3-5 – AC/DC
Single Phase Power Source**

Photo courtesy of Miller Electric Manufacturing Co.



**Illustration 3-6 – Three Phase
Constant Current Power Source**

Photo courtesy of Miller Electric Manufacturing Co.



Illustration 3-7 – Inverter Power Source for SMAW

Photo courtesy of Miller Electric Manufacturing Co.

Inverter power sources are about 25% the weight of a conventional rectifier of the same power capacity, and about 33% of the size. They provide higher electrical efficiency, a higher power factor, and a faster response time. There are several variations of the inverter power source available.

Selecting a Power Source

Selecting a welding machine is based on:

1. The amount of current required for the work
2. The power available to the job site
3. Convenience and economic factors

The size of the machine is based on the welding current and duty cycle required. Welding current, duty cycle and voltage are determined by considering weld joints, weld sizes, and welding procedures. The incoming power available dictates this fact. Finally, the job situation, personal preference, and economic considerations narrow the field to the final selection. The local welding equipment supplier should be consulted to help make your selection. The following data should be known when selecting a welding power source:

1. Rated load amperes (current)
2. Duty cycle
3. Voltage of power supply (incoming)
4. Frequency of power supply (incoming)
5. Number of phases of power supply (incoming)

CONTROLS

The controls are usually located on the front panel of the welding machine. These usually consist of a knob or tap switch to set the rough current range and a knob to adjust the current within the set range. On the DC welding machines there is usually a switch to change polarity, and on combination AC-DC machines, there is usually a switch to select the polarity or AC current. There is an On-Off switch that is also located on the front of the machine.

Arc Force Control

Some machines have a separate arc force control. This is a function of amperage triggered by a preset (on P.C. board) voltage. The preset trigger voltage is 18 volts. What this means is that anytime the arc voltage drops from normal welding voltage to 18 volts or less, the arc force current is triggered which gives the arc a surge of current to keep the arc from going out.

When an arc is struck, the electrode is scratched against the work. At that point, the voltage goes to -0- and the arc force current is triggered and the arc is initiated quickly. On a standard machine without arc force control, arc striking is difficult and electrode sticking may occur.

After the arc is established, a steady burn-off is desired. As the electrode burns and droplets of metal are transferred from the end of the electrode to the work piece, there is a time period when the droplet is still connected to the end of the electrode, but is also touching the work piece. When this occurs, the machine is, in effect, in a “dead-short” – the voltage drops, the arc force is triggered and the droplet is transferred. On machines without arc force, the burn-off is the same, however, without the arc forced to help, an arc outage may occur and the electrode will stick in the puddle.

When working in tight joints, such as pipe welding, the arc length is very short and with standard machines, it is difficult to maintain the arc since it wants to “short-out” against the sidewalls or bottom of the joint. The arc force control can be adjusted on this type application to prevent electrode sticking, since whenever the voltage drops, the arc force current is triggered and the sticking doesn’t happen because the current surge occurs.

In many applications, there is a need for a very forceful arc to obtain deeper penetration, or in the case of arc gouging, the forceful arc is essential in helping to force the metal out of the groove being gouged. With arc force control, this type application is made much easier than with conventional machines where arc length becomes critical and arc outages can occur. When welding with a given size electrode, there is always an optimum amperage setting. When using arc force control, the optimum amperage setting is continually working to maintain the arc, which means that although we can’t see it on the meters there is usually some added amperage to assist in rod burn-off. This in turn means we really get a slightly faster burn-off than with a conventional rectifier. When working out-of-position, a forceful arc is needed to help put metal in place. Arc forced control can be adjusted to provide just the amount needed by each individual operator. Arc force can also be of assistance when welding rusty or scaly material, since the more forceful arc will help to break up these deposits.

ELECTRODE HOLDER

The electrode holder serves as a clamping device for holding the welding electrode and transferring the welding current to the electrode. The insulated handle separates the welder’s hand from the welding circuit. Electrode holders come in various sizes and are designated by the current carrying capacity.

WELDING CABLES

The welding cables and connectors connect the power source to the electrode holder and to the work. These cables are normally made of copper or aluminum. The cable that connects the work to the power source is called the work lead. The work leads are usually connected to the work by pincher clamps or a bolt. The cable that connects the electrode holder to the power source is called the electrode lead.

The size of the welding cables used depends upon the output capacity of the welding machine and the distance between the welding machine and the work. Cable sizes range from the smallest at AWG No. 8 to AWG No. 410 with amperage ratings of 75 amperes and upward, Illustration 3-9 shows recommended cable sizes for use with different welding currents and cable lengths.

ACCESSORIES

Accessory equipment used for shielded metal arc welding consists of items used for removing slag and cleaning the weld bead. Chipping hammers are often used to remove the slag. Wire brushes or grinders are the most common methods for cleaning the weld.

Manufacturers offer various options and accessories also, depending on the type of power source and the procedure recommendations.



Illustration 3-8 – Work Clamp and Electrode Holder
Photo courtesy of Miller Electric Manufacturing Co.

Weld Type	Weld Current	Length of Cable in Feet – Cable Size A.W.G.					
		60'	100'	150'	200'	300'	400'
Manual (Low Duty Cycle)	100	4	4	4	2	1	1/0
	150	2	2	2	1	2/0	3/0
	200	2	2	1	1/0	3/0	4/0
	250	2	2	1/0	2/0		
	300	1	1	2/0	3/0		
	350	1/0	1/0	3/0	4/0		
	400	1/0	1/0	3/0			
	450	2/0	2/0	4/0			
	500	2/0	2/0	4/0			

Note: Length of cable circuit equals total electrode and work cable

Illustration 3-9 – Suggested Copper Welding Cable Sized for Shielded Metal Arc Welding

CHAPTER 4 COVERED ELECTRODES

The covered electrode provides both the filler metal and the shielding for the shielded metal arc welding process. Covered electrodes have different compositions of core wire and a wide variety of types of flux covering. The core wire provides the filler metal and the electrode covering performs one or all of the following functions, depending upon the type of electrode:

1. Forms a slag blanket over the molten puddle and solidified weld.
2. Provides shielding gas to prevent atmospheric contamination of both the arc stream and the weld metal.
3. Provides ionizing elements for smoother arc operation.
4. Provides deoxidizers and scavengers to refine the grain structure of the weld metal.
5. Provides alloying elements such as nickel and chromium for stainless steel.
6. Provides metal such as iron powder for higher deposition rates.

The first two functions listed prevent the pickup of nitrogen and oxygen into the weld puddle and the red hot solidified weld metal. The nitrogen and oxygen form nitrides and oxides which embrittle the weld metal.

CLASSIFICATION

The classification system for covered electrodes used throughout industry in the United States was devised by the American Welding Society. In this system, designations for covered electrodes consist of the letter E (for electrode) and four (or five) digits for carbon steel and low-alloy steel covered electrodes. Sometimes a suffix appears on the end as well. These digits have specific meanings, which are:

1. The first two (or three digits) indicate the minimum tensile strength in 1,000 psi, of the weld metal deposited. Illustration 4-1 lists the different digits used.

Classification	Minimum Tensile Strength ^a psi (MPa)	Minimum Yield Strength ^b psi (MPa)
E60XX	62,000 (425)	50,000 (345)
E70XX	70,000 (485)	57,000 (460)
E80XX	80,000 (550)	67,000 (460)
E90XX	90,000 (620)	77,000 (530)
E100XX	100,000 (760)	87,000 (600)
E110XX ^b	110,000 (760)	95,000 (655)
E120XX ^b	120,000 (825)	107,000 (740)

a) Refer to appropriate specification for exact property requirements.

b) E110XX and E120XX use low hydrogen type of coating only.

Illustration 4-1 – Digits Indicating Tensile and Yield Strength for Covered Electrodes

Classification	Positions
EXX1X	Flat, Horizontal, Vertical, Overhead
EXX2X	Flat Horizontal – Fillets
EXX4X	Flat, Horizontal, Overhead, Vertical Down

Illustration 4-2 – Digits Indicating Welding Position In Which Electrode May Be Used

2. The third (or fourth) digit indicates the welding positions that the electrode can be used in. Illustration 4-2 lists the use of the different digits.
3. The fourth (or fifth) digit indicates the current characteristics and the types of electrode coating. Illustration 4-3 shows what the different digits indicate.
4. A suffix is sometimes added to the EXXX designations (it does not apply to the E60XX classification). The suffix indicates the chemical composition of the deposited weld metal. Illustration 4-4 shows the meaning of various suffixes.

Classification	Type of Current Used	Penetration	Coating
EXXX0 ^a	DCEP	Deep	Cellulose, Sodium
EXXX1	AC, DCEP	Deep	Cellulose, Potassium
EXXX2	AC, DCEN	Medium	Rutile, Sodium
EXXX3	AC, DCEP, DCEN	Light	Rutile, Potassium
EXXX4	AC, DCEP, DCEN	Medium	Rutile, Iron Powder
EXXX5	DCEP	Medium	Low Hydrogen Sodium
EXXX6	AC, DCEP	Medium	Low Hydrogen Potassium
EXXX7	AC, DCEN	Medium	Iron Powder, Iron Oxide
EXXX8	AC, DCEP	Medium	Low Hydrogen, Iron Powder
EXXX9	AC, DCEP, DCEN	Medium	Iron Oxide, Titania, Potassium (Rutile)

a) The last digit indicates the usability of the electrode. The exception is the E6020 electrode which runs on DCEN, DCEP or AC current. It gives medium penetration and has an iron oxide, sodium coating.

Illustration 4-3 – Digits Indicating Arc and Coating Characteristics

AWS Classification ^c		UNS Num-ber ^d	Weight Percent ^{a,b}									Additional Elements Type - Amount
A5.5	A5.5M		C	Mn	Si	P	S	Ni	Cr	Mo		
Carbon-Molybdenum Steel Electrodes												
E7010-A1	E4910-A1	W17010	0.12	0.60	0.40	0.03	0.03	–	–	0.40 to 0.65	–	
E7011-A1	E4911-A1	W17011	0.12	0.60	0.40	0.03	0.03	–	–	0.40 to 0.65	–	
E7015-A1	E4915-A1	W17015	0.12	0.90	0.60	0.03	0.03	–	–	0.40 to 0.65	–	
E7016-A1	E4916-A1	W17016	0.12	0.90	0.60	0.03	0.03	–	–	0.40 to 0.65	–	
E7018-A1	E4918-A1	W17018	0.12	0.90	0.80	0.03	0.03	–	–	0.40 to 0.65	–	
E7020-A1	E4920-A1	W17020	0.12	0.60	0.40	0.03	0.03	–	–	0.40 to 0.65	–	
E7027-A1	E4927-A1	W17027	0.12	1.00	0.40	0.03	0.03	–	–	0.40 to 0.65	–	
Chromium-Molybdenum Steel Electrodes												
E8016-B1	E5516-B1	W51016	0.05 to 0.12	0.90	0.60	0.03	0.03	–	0.40 to 0.65	0.40 to 0.65	–	
E8018-B1	E5518-B1	W51018	0.05 to 0.12	0.90	0.80	0.03	0.03	–	0.40 to 0.65	0.40 to 0.65	–	
E8016-B2	E5516-B2	W52016	0.05 to 0.12	0.90	0.60	0.03	0.03	–	1.00 to 1.50	0.40 to 0.65	–	
E8018-B2	E5518-B2	W52016	0.05 to 0.12	0.90	0.80	0.03	0.03	–	1.00 to 1.50	0.40 to 0.65	–	
E8015-B2L	E4915-B2L	W52115	0.05	0.90	1.00	0.03	0.03	–	1.00 to 1.50	0.40 to 0.65	–	
E8016-B2L	E4916-B2L	W52116	0.05	0.90	0.60	0.03	0.03	–	1.00 to 1.50	0.40 to 0.65	–	
E8018-B2L	E4918-B2L	W52116	0.05	0.90	0.80	0.03	0.03	–	1.00 to 1.50	0.40 to 0.65	–	
E9015-B3	E6215-B3	W53015	0.05 to 0.12	0.90	1.00	0.03	0.03	–	2.00 to 2.50	0.90 to 1.20	–	
E9016-B3	E6216-B3	W53016	0.05 to 0.12	0.90	0.60	0.03	0.03	–	2.00 to 2.50	0.90 to 1.20	–	
E9018-B3L	E6218-B3	W53018	0.05 to 0.12	0.90	0.80	0.03	0.03	–	2.00 to 2.50	0.90 to 1.20	–	
E8015-B3L	E5515-B3L	W53115	0.05	0.90	1.00	0.03	0.03	–	2.00 to 2.50	0.90 to 1.20	–	
E8018-B3L	E5518-B3L	W53118	0.05	0.90	0.80	0.03	0.03	–	2.00 to 2.50	0.90 to 1.20	–	
E8015-B4L	E5515-B4L	W53415	0.05	0.90	0.80	0.03	0.03	–	0.40 to 0.60	0.40 to 0.65	–	
E8016-B5	E5516-B5	W51316	0.07 to 0.15	0.40 to 0.70	0.30 to 0.60	0.03	0.03	–	0.40 to 0.60	1.00 to 1.25	V - 0.05	
E8015-B6 ^e	E5515-B6 ^e	W50215	0.05 to 0.10	1.0	0.90	0.03	0.03	0.40	4.0 to 6.0	0.45 to 0.65	–	
E8016-B6 ^e	E5516-B6 ^e	W50216	0.05 to 0.10	1.0	0.90	0.03	0.03	0.40	4.0 to 6.0	0.45 to 0.65	–	
E8018-B6 ^e	E5518-B6 ^e	W50218	0.05 to 0.10	1.0	0.90	0.03	0.03	0.40	4.0 to 6.0	0.45 to 0.65	–	
E8015-B6L ^e	E5515-B6L ^e	W50205	0.05	1.0	0.90	0.03	0.03	0.40	4.0 to 6.0	0.45 to 0.65	–	
E8016-B6L ^e	E5516-B6L ^e	W50206	0.05	1.0	0.90	0.03	0.03	0.40	4.0 to 6.0	0.45 to 0.65	–	
E8018-B6L ^e	E5518-B6L ^e	W50208	0.05	1.0	0.90	0.03	0.03	0.40	4.0 to 6.0	0.45 to 0.65	–	
E8015-B7 ^e	E5515-B7 ^e	W50315	0.05 to 0.10	1.0	0.90	0.03	0.03	0.40	6.0 to 6.0	0.45 to 0.65	–	
E8016-B7 ^e	E5516-B7 ^e	W50316	0.05 to 0.10	1.0	0.90	0.03	0.03	0.40	6.0 to 6.0	0.45 to 0.65	–	
E8018-B7 ^e	E5518-B7 ^e	W50318	0.05 to 0.10	1.0	0.90	0.03	0.03	0.40	6.0 to 6.0	0.45 to 0.65	–	
E8015-B7L ^e	E5515-B7L ^e	W50305	0.05	1.0	0.90	0.03	0.03	0.40	6.0 to 6.0	0.45 to 0.65	–	
E8016-B7L ^e	E5516-B7L ^e	W50306	0.05	1.0	0.90	0.03	0.03	0.40	6.0 to 6.0	0.45 to 0.65	–	
E8018-B7L ^e	E5518-B7L ^e	W50308	0.05	1.0	0.90	0.03	0.03	0.40	6.0 to 6.0	0.45 to 0.65	–	
E8015-B8 ^e	E5515-B8 ^e	W50415	0.05 to 0.10	1.0	0.90	0.03	0.03	0.40	8.0 to 10.5	0.85 to 1.20	–	
E8016-B8 ^e	E5516-B8 ^e	W50416	0.05 to 0.10	1.0	0.90	0.03	0.03	0.40	8.0 to 10.5	0.85 to 1.20	–	
E8018-B8 ^e	E5518-B8 ^e	W50418	0.05 to 0.10	1.0	0.90	0.03	0.03	0.40	8.0 to 10.5	0.85 to 1.20	–	
E8015-B8L ^e	E5515-B8L ^e	W50405	0.05	1.0	0.90	0.03	0.03	0.40	8.0 to 10.5	0.85 to 1.20	–	
E8016-B8L ^e	E5516-B8L ^e	W50406	0.05	1.0	0.90	0.03	0.03	0.40	8.0 to 10.5	0.85 to 1.20	–	
E8018-B8L ^e	E5518-B8L ^e	W50408	0.05	1.0	0.90	0.03	0.03	0.40	8.0 to 10.5	0.85 to 1.20	–	
E9015-B9 ^j	E6215-B9 ^j	W50425	0.08 to 0.13	1.20	0.30	0.01	0.01	0.80	8.0 to 10.5	0.85 to 1.20	V - 0.15 to 0.30 Cu - 0.25 Al - 0.04 Nb (Cb) - 0.02 to 0.10 N - 0.02 to 0.07	
E9016-B9 ^j	E6216-B9 ^j	W50426	0.08 to 0.13	1.20	0.30	0.01	0.01	0.80	8.0 to 10.5	0.85 to 1.20	V - 0.15 to 0.30 Cu - 0.25 Al - 0.04 Nb (Cb) - 0.02 to 0.10 N - 0.02 to 0.07	

Illustration 4-4 – Specifications for Low Alloy Steel Electrodes for Shielded Metal Arc Welding
(Source: AWS A5.5, A5.5M)

AWS Classification ^c		UNS Num-ber ^d	Weight Percent ^{a,b}									Additional Elements Type - Amount
A5.5	A5.5M		C	Mn	Si	P	S	Ni	Cr	Mo		
Nickel Steel Electrodes												
E8016-C1	E5516-C1	W22016	0.12	1 25	0.60	0.03	0.03	2.00 to 2.75	–	–	–	
E8018-C1	E5518-C1	W22018	0.12	1 25	0.80	0.03	0.03	2.00 to 2.75	–	–	–	
E7015-C1L	E4915-C1L	W22115	0.05	1 25	0.50	0.03	0.03	2.00 to 2.75	–	–	–	
E7016-C1L	E4916-C1L	W22116	0.05	1 25	0.50	0.03	0.03	2.00 to 2.75	–	–	–	
E7018-C1L	E4918-C1L	W22118	0.05	1 25	0.50	0.03	0.03	2.00 to 2.75	–	–	–	
E8016-C2	E5516-C2	W22016	0.12	1 25	0.60	0.03	0.03	2.00 to 2.75	–	–	–	
E8018-C2	E5518-C2	W22018	0.12	1 25	0.80	0.03	0.03	2.00 to 2.75	–	–	–	
E7015-C2L	E4915-C2L	W23115	0.05	1.25	0.50	0.03	0.03	3.00 to 3.75	–	–	–	
E7016-C2L	E4916-C2L	W23116	0.05	1.25	0.50	0.03	0.03	3.00 to 3.75	–	–	–	
E7018-C2L	E4918-C2L	W23118	0.05	1.25	0.50	0.03	0.03	3.00 to 3.75	–	–	–	
E8016-C3	E5516-C3	W21016	0.12	0.40 to 1.25	0.80	0.03	0.03	0.80 to 1.10	0.15	0 35	V - 0.05	
E8018-C3	E5518-C3	W21018	0.12	0.40 to 1.25	0.80	0.03	0.03	0.80 to 1.10	0.15	0 35	V - 0.05	
E8018-C3L	E5518-C3L	W20918	0.08	0.40 to 1.40	0.50	0.03	0.03	0.80 to 1.10	0.15	0 35	V - 0.05	
E8016-C4	E5516-C4	W21916	0.10	1.25	0.60	0.03	0.03	1.10 to 2.00	–	–	–	
E8018-C4	E5518-C4	W21918	0.10	1.25	0.60	0.03	0.03	1.10 to 2.00	–	–	–	
E9015-C5L	E6215-C5L	W25018	0.05	0.40 to 1.40	0.50	0.03	0.03	6.00 to 7.25	–	–	–	
Nickel-Molybdenum Steel Electrodes												
E8018-NM1	E5518-NM1	W21118	0.10	0.80 to 1.25	0.60	0.02	0.02	0.80 to 1.10	0.10	0.40 to 0.65	V - 0.02 Cu - 0.10 Al - 0.05	
Manganese-Molybdenum Steel Electrodes												
E8018-D1	E5518-D1	W18118	0.12	1.00 to 1.75	0.80	0.03	0.03	0.90	–	0.25 to 0.45	–	
E9015-D1	E6215-D1	W19015	0.12	1.00 to 1.75	0.60	0.03	0.03	0.90	–	0.25 to 0.45	–	
E9018-D1	E6218-D1	W19018	0.12	1.00 to 1.75	0.80	0.03	0.03	0.90	–	0.25 to 0.45	–	
E10015-D2	E9615-D2	W10015	0.15	1.65 to 2.00	0.60	0.03	0.03	0.90	–	0.25 to 0.45	–	
E10016-D2	E9616-D2	W10016	0.15	1.65 to 2.00	0.60	0.03	0.03	0.90	–	0.25 to 0.45	–	
E10018-D2	E9618-D2	W10018	0.15	1.65 to 2.00	0.80	0.03	0.03	0.90	–	0.25 to 0.45	–	
E8016-D3	E5516-D3	W18016	0.12	1.00 to 1.80	0.60	0.03	0.03	0.90	–	0.40 to 0.65	–	
E8018-D3	E5518-D3	W18018	0.12	1.00 to 1.80	0.80	0.03	0.03	0.90	–	0.40 to 0.65	–	
E9018-D3	E6218-D3	W19118	0.12	1.00 to 1.80	0.80	0.03	0.03	0.90	–	0.40 to 0.65	–	
General Low Alloy Steel Electrodes												
E(X)XX10-G ^f	EXX10-G ^f	–	–	1.00 min ^g	0.80 min ^g	0.03	0.03	0.50 min ^g	0.30 min ^g	0 20 min ^g	V - 0.10 min ^g Cu - 0 20 ^g	
E(X)XX11-G ^f	EXX11-G ^f	–	–	1.00 min ^g	0.80 min ^g	0.03	0.03	0.50 min ^g	0.30 min ^g	0 20 min ^g	V - 0.10 min ^g Cu - 0 20 ^g	
E(X)XX13-G ^f	EXX13-G ^f	–	–	1.00 min ^g	0.80 min ^g	0.03	0.03	0.50 min ^g	0.30 min ^g	0 20 min ^g	V - 0.10 min ^g Cu - 0 20 ^g	
E(X)XX15-G ^f	EXX15-G ^f	–	–	1.00 min ^g	0.80 min ^g	0.03	0.03	0.50 min ^g	0.30 min ^g	0 20 min ^g	V - 0.10 min ^g Cu - 0 20 ^g	
E(X)XX16-G ^f	EXX16-G ^f	–	–	1.00 min ^g	0.80 min ^g	0.03	0.03	0.50 min ^g	0.30 min ^g	0 20 min ^g	V - 0.10 min ^g Cu - 0 20 ^g	
E(X)XX18-G ^f	EXX18-G ^f	–	–	1.00 min ^g	0.80 min ^g	0.03	0.03	0.50 min ^g	0.30 min ^g	0 20 min ^g	V - 0.10 min ^g Cu - 0 20 ^g	
E(X)XX16-G ^f	EXX16-G ^f	–	–	1.00 min ^g	0.80 min ^g	0.03	0.03	0.50 min ^g	0.30 min ^g	0 20 min ^g	V - 0.10 min ^g Cu - 0 20 ^g	
E7020-G	E4920-G	–	–	1.00 min ^g	0.80 min ^g	0.03	0.03	0.50 min ^g	0.30 min ^g	0 20 min ^g	V - 0.10 min ^g Cu - 0 20 ^g	
E7027-G	E4927-G	–	–	1.00 min ^g	0.80 min ^g	0.03	0.03	0.50 min ^g	0.30 min ^g	0 20 min ^g	V - 0.10 min ^g Cu - 0 20 ^g	

Illustration 4-4 – Specifications for Low Alloy Steel Electrodes for Shielded Metal Arc Welding
(Source: AWS A5.5, A5.5M)

AWS Classification ^c		UNS Num-ber ^d	Weight Percent ^{a,b}									Additional Elements Type - Amount
A5.5	A5.5M		C	Mn	Si	P	S	Ni	Cr	Mo		
General Low Alloy Steel Electrodes												
E(X)XX10-G ^f	EXX10-G ^f	–	–	1.00 min ^g	0.80 min ^g	0.03	0.03	0.50 min ^g	0.30 min ^g	0 20 min ^g	V - 0.10 min ^g Cu - 0 20 ^g	
E(X)XX11-G ^f	EXX11-G ^f	–	–	1.00 min ^g	0.80 min ^g	0.03	0.03	0.50 min ^g	0.30 min ^g	0 20 min ^g	V - 0.10 min ^g Cu - 0 20 ^g	
E(X)XX13-G ^f	EXX13-G ^f	–	–	1.00 min ^g	0.80 min ^g	0.03	0.03	0.50 min ^g	0.30 min ^g	0 20 min ^g	V - 0.10 min ^g Cu - 0 20 ^g	
E(X)XX15-G ^f	EXX15-G ^f	–	–	1.00 min ^g	0.80 min ^g	0.03	0.03	0.50 min ^g	0.30 min ^g	0 20 min ^g	V - 0.10 min ^g Cu - 0 20 ^g	
E(X)XX16-G ^f	EXX16-G ^f	–	–	1.00 min ^g	0.80 min ^g	0.03	0.03	0.50 min ^g	0.30 min ^g	0 20 min ^g	V - 0.10 min ^g Cu - 0 20 ^g	
E(X)XX18-G ^f	EXX18-G ^f	–	–	1.00 min ^g	0.80 min ^g	0.03	0.03	0.50 min ^g	0.30 min ^g	0 20 min ^g	V - 0.10 min ^g Cu - 0 20 ^g	
E(X)XX16-G ^f	EXX16-G ^f	–	–	1.00 min ^g	0.80 min ^g	0.03	0.03	0.50 min ^g	0.30 min ^g	0 20 min ^g	V - 0.10 min ^g Cu - 0 20 ^g	
E7020-G	E4920-G	–	–	1.00 min ^g	0.80 min ^g	0.03	0.03	0.50 min ^g	0.30 min ^g	0 20 min ^g	V - 0.10 min ^g Cu - 0 20 ^g	
E7027-G	E4927-G	–	–	1.00 min ^g	0.80 min ^g	0.03	0.03	0.50 min ^g	0.30 min ^g	0 20 min ^g	V - 0.10 min ^g Cu - 0 20 ^g	
Military-Similar Electrodes												
E9018M ^h	E6218M ^h	W21218	0.10	0.60 to 1.25	0.80	0.030	0.030	1.40 to 1.80	0.15	0.35	V - 0.05	
E10018M ^h	E6918M ^h	W21318	0.10	0.75 to 1.70	0.60	0.030	0.030	1.40 to 2.10	0.35	0.25 to 0.50	V - 0.05	
E11018M ^h	E7618M ^h	W21318	0.10	1.30 to 1.80	0.60	0.030	0.030	1 25 to 2.50	0.40	0.25 to 0.50	V - 0.05	
E12018M ^h	E8318M ^h	W22218	0.10	1.30 to 2.25	0.60	0.030	0.030	1 75 to 2.50	0.30 to 1.50	0.30 to 0.55	V - 0.05	
E12018M1 ^h	E8318M1 ^h	W23218	0.10	0.80 to 21.6	0.65	0.015	0.012	3.00 to 3.80	.065	0.20 to 0.30	V - 0.05	
Pipeline Electrodes												
E7010-P1	E4910-P1	W17110	0.20	1 20	0.60	0.03	0.03	1.00	0.30	0.50	V - 0.10	
E8010-P1	E5510-P1	W18110	0.20	1 20	0.60	0.03	0.03	1.00	0.30	0 50	V - 0.10	
E9010-P1	E6210-P1	W19110	0.20	1 20	0.60	0.03	0.03	1.00	0.30	0 50	V - 0.10	
E8018-P2	E5518-P2	W18218	0.12	0.90 to 1.70	0.80	0.03	0.03	1.00	0.20	0 50	V - 0.10	
E9010-P2	E6218-P2	W19218	0.20	1 20	0.80	0.03	0.03	1.00	0.20	0 50	V - 0.10	
E8045-P2	E5545-P2	W18245	0.20	1 20	0.80	0.03	0.03	1.00	0.20	0 50	V - 0.10	
E9045-P2	E6245-P2	W19245	0.20	1.20	0.60	0.03	0.03	1.00	0.20	0 50	V - 0.10	
E10045-P2	E6945-P2	W10245	0.20	1.20	0.60	0.03	0.03	1.00	0.20	0 50	V - 0.10	
Weathering Steel Electrodes												
E7018-W ⁱ	E4918-W1 ⁱ	W20018	0.12	0.40 to 0.70	0.40 to 0.70	0.025	0.025	0 20 to 0.40	0.15 to 0.30	–	V - 0.05 Cu - 0.30 to 0.60	
E8018-W ⁱ	E5518-W2 ⁱ	W20118	0.12	0.50 to 1.30	0 35 to 0.80	0.03	0.03	0.40 to 0.80	0.45 to 0.70	–	Cu - 0.30 to 0.75	

a) Single values are maximum, except where specified otherwise.

b) Weld metal shall be analyzed for those elements for which specific values are shown. Other elements listed without specified values shall be reported, if intentionally added.

The total of these latter unspecified elements and all other elements not intentionally added shall not exceed 0.05%.

c) The suffixes A1, B3, C3, etc., designate the chemical composition of the electrode classification.

d) SAE HS-1086 / ASTM DS-56, *Metals & Metal Alloys in the Unified Numbering System*.

e) The E8015-B6 (E5515-B6) and E8015-B6L (E5515-B6L) electrodes were formerly classified as E502-15 in AWS A5.4-92, *Specifications for Stainless Steel Electrodes for Shielded Metal Arc Welding*. The E8016-B6 (E5516-B6) and E8016-B6L (E5516-B6L) were formerly classified as E502-16 in A5.4-92. The 8018-B6 (E5518-B6) and E8018-B6L (E5518-B6L) were not formerly classified, but were produced to the E502 composition ranges in A5.4-92 and with the EXXX18 covering of this specification. Similarly, the E80XX-B7(L) (E55XX-B7(L) classifications were formerly classified as E7Cr-XX in A4.5-92; and the E80XX-B8(L) (E55XX-B8(L)) classifications were formerly classified as E505-XX in A5.4-92.

f) The letters "XX" used in the classification designations for all electrodes in this table stand for the various tensile strength levels (70, 80, 90, 100, 110, and 120 ksi (49, 55, 62, 69, 76, and 83 MPa x 10)).

g) In order to meet the alloy requirements of the "G" group, the undiluted weld metal shall have the minimum of at least one of the elements listed in the table. Additional chemical requirements may be agreed to between supplier and purchaser.

h) These classifications are intended to be similar to types of electrodes covered by MIL-E-22200/1 and MIL-E-22200/10.

i) In AWS A5.5-81, E7018-W1 (E4918-W1) was designated E7018W and E8018-W2 (E5518-W2) was designated E8018-W.

j) Mn + Ni shall be 1.50% max.

Illustration 4-4 – Specifications for Low Alloy Steel Electrodes for Shielded Metal Arc Welding (Source: AWS A5.5, A5.5M)

For example, the E8018-81 designation indicates that electrode deposits metal with a minimum tensile strength of 80,000 psi (550 MPa), can be used in all welding positions, has a low hydrogen iron powder coating that can be run on AC or DCEP power, and has chemical composition in the weld deposit of .12 C, .90 Mn, .03 P, .04 S, .80 Si, .40-.65 Cr and .40-.65 Mo. Other types of electrodes are classified in different ways. Illustration 4-5 lists the American Welding Society (AWS) specifications covering filler metals for shielded metal arc welding. For example, stainless steel electrodes are classified according to the chemical analysis of the weld metal and the type of welding current that can be used. An example of this is the E308-15 designation. The E stands for Electrode. The 308 indicates the chemical composition of the weld metal. The different classifications are shown in Illustration 4-6.

The suffix indicates the positions and the type of welding current that can be used. A suffix of 15 means direct current electrode positive is used and a 16 means that alternating current or direct current electrode positive may be used. All stainless steel electrode classifications that are now used have a one in the suffix that indicates that they are all position electrodes.

SIZING

The size of the electrode is designated by the diameter of the core wire and the length of the electrode. Standard electrode diameters are 1/16 in. (1.6 mm) to 5/16 in. (7.9 mm). Lengths of the electrodes are from 9 in. (229mm) to 18 in. (457mm), although electrodes for special applications are made up to 36 in. (914mm) long. The most common electrode length is 14 in. (346mm). The bare uncoated end of the electrode, which is needed to make electrical contact with the electrode holder, is standardized at lengths ranging from 3/4 in. (19mm) to 1-1/2 in. (38mm).

SELECTION OF ELECTRODE CLASS

The deposited weld metal should equal or exceed the mechanical properties of the base metal and have approximately the same composition and physical properties. Identification of the base metal is absolutely required to

AWS Specification	Specification Title / Metal
A5.1	Carbon Steel Electrodes for SMAW
A5.3	Aluminum and Aluminum Alloy Electrodes for SMAW
A5.4	Stainless Steel Electrodes for SMAW
A5.5	Low Alloy Steel Covered Arc Welding Electrodes
A5.6	Copper and Copper Alloy Arc Welding Electrodes
A5.11	Nickel and Nickel Alloy Welding Electrodes for SMAW
A5.13	Surfacing Electrodes for SMAW
A5.15	Welding Electrodes and Rods for Cast Iron
A5.21	Bare Electrodes and Rods for Surfacing

Illustration 4-5 – AWS Filler Metals Specifications for Shielded Metal Arc Welding

properly select the correct electrode. If the identification is not known, tests must be made based on appearance, magnetic check, chisel test, flame test, fracture test, spark test, or chemistry test. The selection of welding electrodes for specific job applications is quite involved, but can be based on the following eight factors:

- 1. Base Metal Strength Properties** – Identification of the base metal is required. In the cases of mild and low alloy steels, the electrodes are chosen to at least match the tensile strength of the base metal.
- 2. Base Metal Composition** – The chemical composition of the base metal must be known. Matching the chemical composition is not as important for mild steels as it is for stainless steels, low alloy steels, and nonferrous metals. For these metals, matching the chemical composition of the filler metal to the base metal is required.
- 3. Welding Position** – Electrodes are designed to be used in specific positions. The electrodes should be chosen to match the positions of the welding to be encountered.
- 4. Welding Current** – Covered electrodes are designed to operate on specific currents and polarity. The type of electrode used might depend on the type of welding current available. Electrodes should be operated on their recommended current type.
- 5. Joint Design and Fit-Up** – The electrodes should be chosen according to their penetration characteristic. For joints with no beveling or tight fit-up, an electrode with a digging arc would be the best. For welding on thin material, a light penetrating electrode would be the best.
- 6. Thickness and Shape of Base Metal** – Weldments may include thick sections or complex shapes which may require maximum ductility to avoid weld cracking. Electrodes that give the best ductility should be used.

F-1	High Deposition Group (EXX20, EXX24, EXX27, EXX28)
F-2	Mild Penetration Group (EXX12, EXX13, EXX14)
F-3	Deep Penetration Group ((EXX10, EXX11)
F-4	Low Hydrogen Group (EXX15, EXX16, EXX18)

AWS ^d Classification	UNS Number ^f	Weight Percent ^{b,c}											
		C	Cr	Ni	Mo	Nb (Cb) Plus Ta	Mn	Si ^e	P	S	N	Cu	Other
E209-XX	W32210	0.06	20.5 to 24.0	9.5 to 12.0	1.5 to 3.0	–	4.0 to 7.0	1.00	0.04	0.03	0.10 to 0.30	0.75	V - 0.10 to 0.30
E219-XX	W32310	0.06	19.0 to 21.5	5.5 to 7.0	0.75	–	8.0 to 10.0	1.00	0.04	0.03	0.10 to 0.30	0.75	V - 0.10 to 0.30
E240-XX	W32410	0.06	17.0 to 19.0	4.0 to 6.0	0.75	–	10.5 to 13.5	1.00	0.04	0.03	0.10 to 0.30	0.75	
E307-XX	W30710	0.04 to 0.14	18.0 to 21.5	9.0 to 10.7	0.05 to 1.5	–	3.30 to 4.75	1.00	0.04	0.03	–	0.75	
E308-XX	W30810	0.08	18.0 to 21.0	9.0 to 11.0	.075	–	0.5 to 2.5	1.00	0.04	0.03	–	0.75	
E308H-XX	W30810	0.04 to 0.14	18.0 to 21.0	9.0 to 11.0	.075	–	0.5 to 2.5	1.00	0.04	0.03	–	0.75	
E308L-XX	W30813	0.04	18.0 to 21.0	9.0 to 11.0	.075	–	0.5 to 2.5	1.00	0.04	0.03	–	0.75	
E308Mo-XX	W30820	0.08	18.0 to 21.0	9.0 to 12.0	2.0 to 3.0	–	0.5 to 2.5	1.00	0.04	0.03	–	0.75	
E308LMo-XX	W30823	0.04	18.0 to 21.0	9.0 to 12.0	2.0 to 3.0	–	0.5 to 2.5	1.00	0.04	0.03	–	0.75	
E309-XX	W30910	0.15	22.0 to 25.0	12.0 to 14.0	.075	–	0.5 to 2.5	1.00	0.04	0.03	–	0.75	
E309H-XX	W30913	0.04 to 0.15	22.0 to 25.0	12.0 to 14.0	.075	–	0.5 to 2.5	1.00	0.04	0.03	–	0.75	
ER309L-XX	W30917	0.04	22.0 to 25.0	12.0 to 14.0	.075	–	0.5 to 2.5	1.00	0.04	0.03	–	0.75	
E309Nb-XX	W30917	0.12	22.0 to 25.0	12.0 to 14.0	.075	0.70 to 1.00	0.5 to 2.5	1.00	0.04	0.03	–	0.75	
E309Mo-XX	W30920	0.12	22.0 to 25.0	12.0 to 14.0	2.0 to 3.0	–	0.5 to 2.5	1.00	0.04	0.03	–	0.75	
E309LMo-XX	W30923	0.04	25.0 to 28.0	12.0 to 14.0	2.0 to 3.0	–	0.5 to 2.5	1.00	0.04	0.03	–	0.75	
E310-XX	W31010	0.08 to 0.20	25.0 to 28.0	20.0 to 22.5	.075	–	1.0 to 2.5	1.00	0.04	0.03	–	0.75	
E310H-XX	W31015	0.35 to 0.45	25.0 to 28.0	20.0 to 22.5	.075	–	1.0 to 2.5	0.75	0.04	0.03	–	0.75	
E310Nb-XX	W31017	0.12	25.0 to 28.0	20.0 to 22.0	.075	0.70 to 1.00	1.0 to 2.5	0.75	0.04	0.03	–	0.75	
E310Mo-XX	W31020	0.12	25.0 to 28.0	20.0 to 22.0	2.0 to 3.0	–	1.0 to 2.5	0.75	0.04	0.03	–	0.75	
E312-XX	W31310	0.15	28.0 to 32.0	8.0 to 10.5	.075	–	0.5 to 2.5	1.00	0.04	0.03	–	0.75	
E316-XX	W31610	0.08	17.0 to 20.0	11.0 to 14.0	2.0 to 3.0	–	0.5 to 2.5	1.00	0.04	0.03	–	0.75	
E316H-XX	W31610	0.04 to 0.08	17.0 to 20.0	11.0 to 14.0	2.0 to 3.0	–	0.5 to 2.5	1.00	0.04	0.03	–	0.75	
E316L-XX	W31613	0.04	17.0 to 20.0	11.0 to 14.0	2.0 to 3.0	–	0.5 to 2.5	1.00	0.04	0.03	–	0.75	
E316LMn-XX	W31622	0.04	18.0 to 21.0	15.0 to 18.0	2.5 to 3.5	–	5.0 to 8.0	0.90	0.04	0.03	0.10 to 0.25	0.75	
E317-XX	W31710	0.08	18.0 to 21.0	12.0 to 14.0	3.0 to 4.0	–	0.5 to 2.5	1.00	0.04	0.03	–	0.75	
E317L-XX	W31713	0.04	18.0 to 21.0	12.0 to 14.0	3.0 to 4.0	–	0.5 to 2.5	1.00	0.04	0.03	–	0.75	

Illustration 4-6 – Specifications for Stainless Steel Electrodes for Shielded Metal Arc Welding
(Source: AWS A5.4, A5.4M)

AWS ^d Classification	UNS Number ^f	Weight Percent ^{b,c}											
		C	Cr	Ni	Mo	Nb (Cb) Plus Ta	Mn	Si ^e	P	S	N	Cu	Other
E318-XX	W31910	0.08	17.0 to 20.0	11.0 to 14.0	2.0 to 3.0	6xC, min to 1.00 max	0.5 to 2.5	1.00	0.04	0.03	–	0.75	
E320-XX	W88021	0.07	19.0 to 21.0	32.0 to 36.0	2.0 to 3.0	8xC, min to 1.00 max	0.5 to 2.5	0.60	0.04	0.03	–	3.0 to 4.0	
E320LR-XX	W88022	0.03	19.0 to 21.0	32.0 to 36.0	2.0 to 3.0	8xC, min to 0.40 max	1.50 to 3.50	.030	0.020	0.015	–	3.0 to 4.0	
E330-XX	W88331	0.18 to 0.25	18.0 to 21.0	14.0 to 17.0	.075	–	1.0 to 2.5	1.00	0.04	0.03	–	0.75	
E330H-XX	W88335	0.18 to 0.25	18.0 to 21.0	14.0 to 17.0	.075	–	1.0 to 2.5	1.00	0.04	0.03	–	0.75	
E347-XX	W34710	0.08	18.0 to 21.0	18.0 to 21.0	.075	8xC, min to 1.00 max	0.5 to 2.5	1.00	0.04	0.03	–	0.75	
E349-XX	W34910	.013	18.0 to 21.0	18.0 to 21.0	0.35 to 0.65	0.75 to 1.20	0.5 to 2.5	1.00	0.04	0.03	–	0.75	V - 0.10 to 0.30 Ti - 0.15 max W - 1.25 to 1.75
E383-XX	W88028	0.03	22.0 to 25.0	26.5 to 29.0	3.2 to 4.2	–	0.5 to 2.5	.90	0.02	0.02	–	0.6 to 1.5	
E385-XX	W88904	0.03	22.0 to 25.0	19.5 to 121.5	4.2 to 5.2	–	1.0 to 2.5	.90	0.03	0.02	–	1.2 to 2.0	
ER409Nb-XX	W40910	0.12	22.0 to 25.0	11.0 to 14.0	.075	0.50 to 1.50	1.0	1.00	0.04	0.03	–	0.75	
E410-XX	W41010	0.12	22.0 to 25.0	11.0 to 13.5	.075	–	1.0	.90	0.04	0.03	–	0.75	
E410NiMo-XX	W41016	0.06	22.0 to 25.0	11.0 to 12.5	0.40 to 0.70	–	1.0	.90	0.04	0.03	–	0.75	
E430-XX	W43010	0.10	25.0 to 28.0	15.0 to 18.0	.075	–	1.0	.90	0.04	0.03	–	0.75	
E430Nb-XX	W43011	0.10	25.0 to 28.0	15.0 to 18.0	.075	0.50 to 1.50	1.0	1.00	0.04	0.03	–	0.75	
E630-XX	W37410	0.05	25.0 to 28.0	16.0 to 16.5	.075	0.15 to 0.30	0.25 to 0.75	0.75	0.04	0.03	–	3.25 to 4.00	
E16-8-2-XX	W36810	0.10	25.0 to 28.0	14.5 to 16.5	1.0 to 2.0	–	0.5 to 2.5	0.60	0.03	0.03	–	0.75	
E2209-XX	W39209	0.04	25.0 to 28.0	21.5 to 23.5	2.5 to 3.5	–	0.5 to 2.0	1.00	0.04	0.03	0.08 to 0.20	0.75	
E2553-XX	W39553	0.06	28.0 to 32.0	24.0 to 27.0	2.9 to 3.9	–	0.5 to 1.5	1.00	0.04	0.03	0.10 to 0.25	1.5 to 2.5	
E2593-XX	W39593	0.04	17.0 to 20.0	24.0 to 27.0	3.5 to 4.5	–	0.5 to 1.5	1.00	0.04	0.03	0.08 to 0.25	1.5 to 3.0	
E2594-XX	W39594	0.04	17.0 to 20.0	24.0 to 27.0	2.5 to 3.0	–	0.5 to 2.0	1.00	0.04	0.03	0.20 to 0.30	0.75	
E2595-XX	W39595	0.04	17.0 to 20.0	24.0 to 27.0	2.0 to 4.5	–	2.5	1.2	0.03	0.025	0.20 to 0.30	0.4 to 1.5	W - 0.4 to 1.00
E3155-XX	W73155	0.10	18.0 to 21.0	20.0 to 22.5	2.5 to 3.5	0.75 to 1.25	1.0 to 2.5	1.00	0.04	0.03	–	0.75	Co - 18.5 to 21.0 W - 2.0 to 3.0
E33-31-XX	W3310	0.03	18.0 to 21.0	31.0 to 35.0	1.0 to 2.0	–	2.5 to 4.0	0.9	0.02	0.01	0.3 to 0.5	0.4 to 0.8	

a) Analysis shall be made for the elements for which specific values are shown in the table. If, however, the presence of other elements is indicated in the course of analysis, further analysis shall be made to determine that the total of these other elements, except iron, is not present in excess of 0.05%.

b) Single values are maximum percentages.

c) Classification suffix -XX may be -15, -16, -17, or -26. Please refer to AWS A5.4 Clause A8 of Annex A for explanation.

d) SAE HS-1086 / ASTM DS-56, *Metals & Metal Alloys in the Unified Numbering System*.

e) E308LMo-XX and E309LMo-XX were formerly named E308MoL-XX and E309MoL-XX, respectively.

f) E309Nb-XX and E310Nb-XX were formerly named E309Cb-XX and E310Cb-XX. The change was made to conform to the worldwide designation of the element niobium.

Illustration 4-6 – Specifications for Stainless Steel Electrodes for Shielded Metal Arc Welding (Source: AWS A5.4, A5.4M)

7. Service Conditions and/or Specifications – For weldments subject to severe service conditions such as low temperature, high temperature, or shock loading, the electrode that matches the base metal composition, ductility, and impact resistance properties should be used. This usually indicates selecting low hydrogen types of electrodes.

8. Production Efficiency and Job Condition – Some electrodes are designed for high deposition rates, but may be used under specific position requirements. If they can be used, the high deposition electrodes would be the best.

According to Section IX of the ASME Boiler and Pressure Vessel Code and the AWS Structural Welding Code, the covered electrodes for welding mild and low-alloy steel can be placed into four categories. The electrode within each of these categories generally operate and run the same way.

The high deposition types of electrodes have additions of iron powder in their coatings. These additions of iron powder usually range from 40-55% of the weight of the coating. During welding, the large amounts of iron powder in the electrode coating go into the weld puddle which increase the deposition rates. These electrodes are usually selected when high deposition welding is desired.

The mild penetration types of electrodes are generally used for welding sheet metal, partial penetration welds when strength is not the governing factor, and other less critical applications. These electrodes have rutile as a main component in their coatings. The EXX14 electrodes have an addition of 25-40% iron powder in the coatings to give these electrodes a higher deposition rate than the EXX12 and EXX13 types.

The deep penetration types of electrodes are the EXX10 and the EXX11 electrodes. The electrodes are used on applications where the deep penetrating characteristics of the weld are needed and for full penetration welding. These electrodes have cellulose as the major component in their coatings. The cellulose is the material that gives these electrodes their deep penetrating characteristic.

The low hydrogen electrodes are those electrodes which have a very low moisture content in their coatings. These electrodes are used for welding steels when hydrogen cracking can be a problem, such as in many of the low alloy steels. Much of the hydrogen in the weld metal comes from the electrode coating. The cellulose types of electrodes require higher moisture contents in their coatings to operate properly. Illustration 4-7 shows the general characteristics of different types of electrodes on penetration, surface contour, and deposition rates.

SELECTION OF ELECTRODE SIZE

The correct choice of electrode size involves consideration of a variety of factors such as:

1. Type, position, and preparation of the joint.
2. Ability of the electrode to carry high current values without weakening the weld metal or losing deposition efficiency.
3. Mass of the work metal and its ability to maintain its original properties after welding.
4. Characteristics of the assembly with reference to the effect of stresses set up by heat application.
5. Practicability of heat treatment before and/or after welding.
6. Specific requirements as to welding quality.
7. Cost of achieving the desired results.

Most of the classes of electrodes are designed to be used for multiple pass welding. Each diameter electrode has its own specific limits on the current carrying capacity. The large diameter electrodes are also used to give the highest welding speed possible. When welding in the vertical and overhead positions, smaller diameter electrodes are preferred because gravity will affect a smaller weld puddle less than a larger one. The weld puddle created by small diameter electrodes is easier for the welder to control. The type of weld joint also has a limiting effect on the size of the electrodes. Small diameter electrodes may have to be used to reach the root of the joint where larger electrodes would not fit. For example, in V-groove joints, smaller diameter electrodes may have to be used to put in the root pass, and possibly several more of the initial passes. The experience of the welder will also influence the size of the electrode used depending on the welders manipulative skill with the electrode. The largest possible electrode size should be used to obtain the fastest welding speeds, providing that this does not cause overwelding. Overwelding can be harmful and wasteful. The proper electrode diameter to be used is the one that, when used with the proper welding conditions, will result in a weld of the required quality and size at the greatest productivity.

CONFORMANCES AND APPROVALS

Covered electrodes must conform to the specifications or be approved by code making organizations for many applications of shielded metal arc welding. Some of the code making organizations that issue specifications or approvals are the American Welding Society (AWS), American Society of Mechanical Engineers (ASME), American Bureau of Shipping (ABS), Federal Bureau of Roads, U.S. Coast Guard, Canadian Welding Bureau, and the Military. The American Welding Society (AWS) provides specifications for covered electrodes. The elec-

AWS Classification		Penetration	% Cellulose in Coating	Deposition Rate	% Iron Powder in Coating	Typical Bead Surface of Fillet Weld
A5.1	A5.21M					
E6010	E4310	Deep	25 to 40	Lower	0 to 10	Slightly concave to flat
E6011	E4311	Deep	25 to 40	Lower	0 to 10	Slightly convex
E6012	E4312	Moderate	2 to 12	Lower	0 to 10	Convex
E6013	E4313	Light to Moderate	2 to 12	Lower	0 to 10	Convex
E6027	E4327	Moderate	0 to 15	Higher	40 to 55	Flat to slightly concave
E7014	E4914	Light to Moderate	2 to 6	Moderate	25 to 40	Slightly concave to flat
E7016	E4916	Moderate	–	Lower	–	Flat to slightly convex
E7018	E4918	Moderate	–	Moderate	25 to 40	Slightly convex
E7024	E4924	Light to Moderate	1 to 5	Higher	40 to 55	Flat to slightly concave
E7028	E4928	Moderate	–	Higher	40 to 55	Flat to slightly concave

Illustration 4-7 – Relative Comparison of Different Characteristics for Several Mild Steel Electrodes

AWS Classification ^b		Tension Strength		Yield Strength at 0.2% Offset		Elongation Percentage in 4x Diameter Length
A5.1	A5.21M	A5.1 (ksi)	A5.21M (MPa)	A5.1 (ksi)	A5.21M (MPa)	
E6010	E4310	60	430	48	330	22
E6011	E4311	60	430	48	330	22
E6012	E4312	60	430	48	330	17
E6013	E4313	60	430	48	330	17
E6018	E4318	60	430	48	330	22
E6019	E4319	60	430	48	330	22
E6020	E4320	60	430	48	330	22
E6022 ^d	E4322	60	430	48	330	Not Specified
E6027	E4327	60	430	48	330	22
E7014	E4914	70	490	58	400	17
E7015	E4915	70	490	58	400	22
E7016	E4916	70	490	58	400	22
E7018	E4918	70	490	58	400	22
E7024	E4924	70	490	58	400	179 ^c
E7027	E4927	70	490	58	400	22
E7028	E4928	70	490	58	400	22
E7048	E4948	70	490	58	400	22
E7017M	E4918M	f	f	53-72 ^g	400	24

a) See Table 4 for sizes to be tested.

b) Requirements are in the as-welded condition with aging as specified in 12.2..

c) Single values are minimum.

d) A transverse tension test, as specified in 12.5 and a longitudinal guided bend test, as specified in Section 13 are required.

e) Weld metal from the electrode identified as E7024-1 (E4924-1) shall have elongation of 22% minimum.

f) Tensile strength of this weld metal is a nominal 70 ksi (530 MPa).

Illustration 4-8 – Tension Test Requirements^{a, b, c}
(Source: AWS A5.1 and AWS A5.1M)

trodes manufactured must meet specific requirements in order to conform to a specific electrode classification. Most code making organizations such as the American Society of Mechanical Engineers (ASME) and the American Petroleum Institute (API) recognize and use the AWS Specifications. Some of the code making organizations such as the American Bureau of Shipping (ABS) and the Military, must directly approve the electrodes before they can be used for welding on a project that is covered by that code. These organizations send inspectors to witness welding and testing and approve the classification of covered electrodes.

To conform to the AWS specifications for mild steel electrodes, the covered electrode must be able to produce a weld deposit that meets specified mechanical properties. The requirements vary depending on the class of electrode. Illustration 4-8 gives a list of mechanical properties required by different mild steel covered electrodes.

CHAPTER 5

WELDING APPLICATIONS

Shielded metal arc welding is a widely used welding process because of its overall versatility. Welding can be performed at a distance from the power source which makes it popular for welding in the field. The equipment for this process is relatively simple to operate, portable, and inexpensive. Shielded metal arc welding is a major process used for maintenance and repair work. It is popular in small production shops where limited capital is available and where the amount of welding done is minor compared to the other manufacturing operations. Shielded metal arc welding is often used for tacking parts together which are to be welded by another process.

INDUSTRIES

Field Welded Storage Tanks

Field welded storage tanks differ from pressure vessels because they are used to store petroleum, water or other liquids at atmospheric pressure. Shielded metal arc welding is widely used in the fabrication and erection of field welded storage tanks. These tanks are generally constructed of low-carbon and structural steels. Nickel steels are employed when higher toughness is required. This process is used to weld longitudinal and circumferential seams on the tanks as well as the structural support members.

Pressure Vessels

Pressure vessels and boilers are also welded using this process. Shielded metal arc welding is primarily used for welding attachments to the vessel. All sizes of electrodes are commonly used. For applications where the vessels

will be operating at low temperatures, smaller electrodes are used on multiple pass welds. This will produce smaller weld beads that build up the weld in relatively thin layers. The smaller weld beads give a stronger, tougher weld. Illustration 5-1 shows a shielded metal arc welding application.

Industrial Piping

Shielded metal arc welding is widely used in the industrial piping industry which includes many types of pressure piping. The types of electrodes most often used are the E6010 and E7018 electrodes for welding low carbon steel pipe. A common practice is the use of E6010 electrodes to weld in the root passes and the E7018 electrodes are used to weld in the fill and cover passes. Welding on industrial piping is generally done from the bottom to the top, except on small diameter pipe where it is done both ways. The reason that welding from bottom to top is most often done is because slag is often trapped when welding in the opposite direction. For welding low carbon steel pipe with a 70,000 psi (485MPa) tensile strength, E7010 and E7018 electrodes are used. Illustration 5-2 shows shielded metal arc welding to put the cover pass on piping.

Shielded metal arc welding is often used for welding on other types of industrial piping. EXX15, EXX16, and EXX18 electrodes are used for welding chromium-molybdenum alloy pipe. When welding stainless steel pipe, gas tungsten arc welding is often used to put in the root pass and shielded metal arc welding is used to weld in the fill and cover passes. Medium and high carbon steel pipe are also welded by this process. For these, smaller diameter electrodes are used than on low carbon steels to lessen the heat affect on the pipe.

Transmission Pipelines

The shielded metal arc welding process is used for welding on transmission or cross-country pipelines. Welding is done in the field and it is usually done from the outside of the pipe. When possible, welding should be done from both sides of the pipe. E6010 and E7018 electrodes are used for welding transmission pipelines. There are several common procedures in use for welding transmission pipelines. One of these is to put in the root pass with E6010 electrodes and put in the fill and cover passes with E7018 electrodes. Another is to use E7018's to weld in all passes, and a third is to weld in the root pass with the gas metal arc welding process and put in the rest of the passes with E7018 electrodes.



Illustration 5-1 – Shielded Metal Arc Welding Application

Nuclear Power Plants

The nuclear power industry employs this process for many applications. It is often used in the shop fabrication of low carbon and low alloy steel heavy walled pressure vessel, for welding longitudinal and circumferential weld seams. Shielded metal arc welding is the best method for welding nozzles and attachments to the vessels. A major application of this process is welding pressure piping for use in the nuclear power facilities. Nuclear power system pressure piping requires stronger quality control than normal pressure piping.

Structures

The construction industry is a major application for shielded metal arc welding. Most of the welding done on buildings and bridges is done in the field at long distances from the power sources, which makes this process popular for these applications. Most types of covered electrodes are used in structural work because of the wide variety in the tensile strengths of the steels used. Illustration 5-3 shows welding the base of a support column using shielded metal arc welding.

Ships

Shielded metal arc welding is still the major process used in shipbuilding. It is used for many different applications including welding in areas where the other processes

cannot reach. Most types of low carbon steel covered electrodes are used except the EXX12, EXX13, and EXX14 types. These three types of electrodes are not approved for use on the main structural members in the ship because of the relatively low ductility obtained from the weld deposits of these electrodes. The electrodes with large amounts of iron powder in their coatings are popular for many shipbuilding applications because of the high deposition rates obtained. These types of electrodes are especially used on the many fillet welds that are made in a ship structure. Backing tape is often used for backing the weld metal when one side welding is



Illustration 5-2 – E7018 Electrode being used to Weld the Cover Pass on a Joint in Industrial Piping

Photo courtesy of Miller Electric Manufacturing Co.



**Illustration 5-3
– Welding the Base of a Support Column with the Shielded Metal Arc Welding Process**

Photo courtesy of Miller Electric Manufacturing Co.

done. Illustration 5-4 shows shielded metal arc welding for shipbuilding.

Transportation

Another industry where this welding process is widely used is in the railroad industry. E60XX and E70XX electrodes are used to weld many parts of the underframe, cab, and engine of the locomotive. The underframe fabrication consists of mostly fillet welds. The frames and brackets for the diesel engines are also welded with these electrodes. Railroad cars are commonly welded together by the shielded metal arc process. Underframes are often welded with E6020, E7016, and E7018 electrodes. The sills for the underframes are welded using E7024 electrodes because high deposition rates are desired for this application. This process is used to a lesser extent in the automotive industry. It is mainly used for welding low production components or on items where there are frequent model changes. This is done because the fixturing and equipment for this process are less expensive.

Industrial Machinery

The frames of many types of heavy industrial machinery are welded together using this process. It is the major process used for welding piping associated with this machinery. Shielded metal arc welding is used for welding areas where the other processes cannot reach.

Heavy Equipment

Another major application of this process is in the heavy equipment industry such as mining, agricultural, and earthmoving equipment. In these industries, shielded

metal arc is used for welding structural steels, which are used for the frames, beams, and many other items in the assembly. Most types of covered electrodes are used depending on the type of steel being welded. Stainless steel and nonferrous metals are also used for some parts.

Miscellaneous

This welding process is commonly used in many general fabrication or small job shops on a wide variety of applications. There are many other applications possible in this area because of the overall versatility of this process, but these are too numerous to mention.

Maintenance and Repair

One industry where shielded metal arc welding is the major welding process and will probably always remain so, is in the maintenance and repair industry. This is especially true in small shops or in general plant maintenance, where relatively inexpensive equipment, portability, and versatility are important considerations. This process is the major one used for repair welding on railroad engines and cars as well as for cast iron engine blocks and heads on automobiles. Nickel electrodes are commonly employed for the repairing of cast iron parts. Resurfacing worn parts and putting a hard surface on parts are two other applications. There are special surfacing and build-up electrodes which are used for these purposes. Illustrations 5-5 and 5-6 show maintenance and repair applications using shielded metal arc welding.

VARIATIONS OF THE PROCESS

Gravity welding, which is seldom used today, was an automatic variation of the shielded metal arc welding process. Gravity welding was popular because one operator could operate several gravity feeders at the same time which increased the production rate. The welder installed the electrode in the feeder and the electrode fed as it burned off, which gave a high quality horizontal fillet weld. Usually 28 in. (710mm) long electrodes of the drag type (E6027, E7024, E7028) were used. These were used in diameters of 7/32 in. (5.6mm) and in 114 in. (6.4mm). This was possible in some shipbuilding work since the welds were often close together, which made it possible for the welding operator to quickly move from one holder to another to reload them, start them, and allow them to operate unattended.



Illustration 5-4 – Shielded Metal Arc Welding used in Ship Construction

Photo courtesy of Huntington Ingalls Shipbuilding



Illustration 5-5
Shielded Metal Arc
Welding is widely used for
Maintenance and Repair

Firecracker welding is a method of automatically making welds using a long electrode with an electrically non-conductive heavy coating. This method has been used very little in North America because of the popularity of semi-automatic processes. This method can be used for square groove butt welds and full fillet lap welds. To make a firecracker fillet weld, the work is positioned flat. The welding electrode is placed in the joint and a retaining bar is placed over it. The arc is started by shorting the end of the electrode to the work. The arc length depends on the thickness of the coating. As the arc travels along the electrode, the electrode melts and makes a deposit on the metal immediately underneath it. Once the arc is started, the process automatically proceeds to completion.

Another variation of shielded metal arc welding is the use of massive electrodes which have extremely large diameters and long lengths. These electrodes are so heavy that they require a manipulator to hold and feed them. Massive electrode welding is primarily used for repairing very large castings.



Illustration 5-6 – Shielded Metal Arc Welding
in a Shop Setting

CHAPTER 6

COST OF SHIELDED METAL ARC WELDING

The cost of welding for a specific application is one of the most important factors for determining whether or not shielded metal arc welding should be used. The calculation methods used in this chapter can also be used to compare the costs of this welding process with other welding processes. Shielded metal arc welding is a very low initial investment cost, however, its moderate deposition rates and low operator factors may be outweighed by other considerations. The cost of this welding process consists of three major items. These are:

- 1) Labor and overhead cost
- 2) Electrode cost
- 3) Electric power cost

LABOR COST

The labor and overhead costs are usually combined in cost calculations, which is common practice in many metal working industries. The hourly rate and the overhead rate vary from plant to plant and the actual hourly rates for each plant should be used for this calculation. The operator factor is the percentage of time that the welder is actually welding. Since a large amount of time goes into set-up, preheating, slag removal, and changing electrodes, the operator factor for this process is relatively low. It can range from as low as 10% to as high as 50%, but it is usually in the area of 20-40%. The operator factor varies from plant to plant and for different types of weldments. The deposition rates of the electrodes affect the labor and overhead costs because the rate at which the electrode is deposited affects productivity. The travel speeds for the shielded metal arc welding process are often fairly low. The equation for determining the labor and overhead cost per foot of weld is:

$$\text{Labor Cost} = \frac{\text{Labor + Overhead Cost/hr} \times \text{Pounds of Weld Deposit/Weld}}{\text{Deposition Rate} \times \text{Operator Factor}}$$

ELECTRODE COST

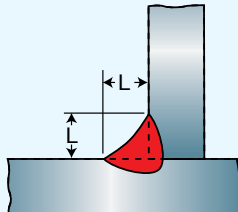
The cost of the electrode per foot of weld is determined by several factors. The first is the weight of electrodes deposited per foot of weld. This is dependent on the size of the weld to be made. The second is the cost per pound of the electrode. The third is the deposition efficiency of the electrode. The deposition efficiency is the percentage of the total weight of the electrode that is actually deposited in the weld. This varies from electrode to electrode and for the calculations used in this chapter, a 2 in. (51mm) stub loss is assumed. Some of the weight is lost to spatter, slag and some of the electrode becoming gas. Illustration 6-1 shows the electrode consumption for different sizes and types of welds. The equation for the cost of the electrode per foot of weld is:

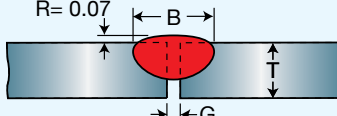
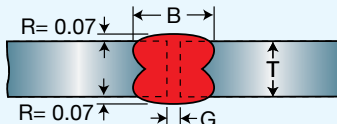
$$\text{Electrode Cost} = \frac{\text{Weight of Deposit} \times \text{Electrode Cost Per Lb.}}{\text{Deposition Efficiency}}$$

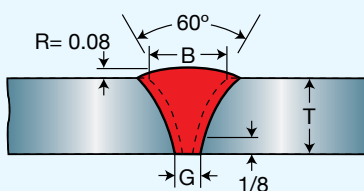
ELECTRIC POWER COST

The cost of the electric power is a relatively minor cost factor, but it can become important when large amounts of welding are required on a certain job. The cost of electric power used is dependent on the amount of welding current, welding voltage, the efficiency of the power source, welding time, and the cost per kilowatt-hour. The power source efficiency will be assumed for the calculations in this chapter. The equation for estimating the electric power cost is:

$$\text{Electric Power Cost} = \frac{\text{Welding Current} \times \text{Welding Voltage}}{\text{Power Source Efficiency}} \times \text{Arc Time} \times \frac{\text{Power Cost per kW-hr}}{1000}$$

HORIZONTAL FILLET	Size of Fillet L (inches)		Pounds of Electrodes required per linear foot of weld* (Approximate)		Pounds of steel deposited per linear foot of weld	
	1/8		0.048		0.027	
	3/16		0.113		0.063	
	1/4		0.189		0.106	
	5/16		0.296		0.166	
	3/8		0.427		0.239	
	1/2		0.760		0.425	
	5/8		1.185		0.663	
	3/4		1.705		0.955	
	1		3.030		1.698	

SQUARE GROOVE BUTT JOINTS	Joint Dimensions (inches)			Pounds of Electrodes required per linear foot of weld* (Approximate)		Pounds of steel deposited per linear foot of weld	
	Matl. Thick T	Bead Width B	Root Open O	Without Reinforce- ment	With Reinforce- ment	Without Reinforce- ment	With Reinforce- ment
...Welded one side 	3/16	3/8	0	–	0.16	–	0.088
			1/16	0.04	0.20	0.020	0.109
...Welded both sides If root of top weld is chipped or flame gouged and welded, add 0.07 lb. to steel deposited (equivalent to approx. 0.13 lb. of electrodes.) 	1/4	7/16	1/16	0.05	0.23	0.027	0.129
			3/32	0.07	0.26	0.039	0.143
	5/16	1/2	1/16	0.06	0.27	0.033	0.153
3/32			0.09	0.30	0.050	0.170	
	1/8	1/4	0	–	0.21	–	0.119
1/32			0.03	0.24	0.013	0.132	
	3/16	3/8	1/32	0.04	0.36	0.020	0.199
1/16			0.07	0.39	0.040	0.218	
	1/4	7/16	1/16	0.10	0.47	0.053	0.261
3/32			0.14	0.53	0.080	0.288	

V-GROOVE BUTT JOINT	Joint Dimensions (inches)			Pounds of Electrodes required per linear foot of weld* (Approximate)		Pounds of steel deposited per linear foot of weld	
	Matl. Thick T	Bead Width B	Root Open O	Without Reinforce- ment	With Reinforce- ment	Without Reinforce- ment	With Reinforce- ment
	1/4	0.207	1/16	0.15	0.25	0.085	0.143
	5/16	0.311	3/32	0.31	0.46	0.173	0.258
	3/8	0.414	1/8	0.50	0.70	0.282	0.394
	1/2	0.558	1/8	0.87	1.15	0.489	0.641
	3/4	0.702	1/8	1.35	1.68	0.753	0.942
	3/4	0.847	1/8	1.94	2.35	1.088	1.320
	0.81	1.138	1/8	13.45	4.00	1.930	2.240

* Includes scrap end and spatter loss.

** R = height of reinforcement.

Illustration 6-1 – Calculation of Electrode Consumption

Table 6-1 will help you estimate electrode quantity and cost for a variety of joints. The bases for the tabulations are explained below. Should you encounter a variation in conditions or joint preparation that is not shown in the tables, substitute appropriate figures in the electrode requirements formula and calculate it.

Electrode requirements have been calculated as follows:

$$Wt = \frac{D}{1-L}$$

Where W = Weight of electrodes required

D = Weight of steel deposited

L = Total electrode losses

To arrive at the weight of steel deposited, it is necessary to calculate first the volume of deposited metal (area of the groove multiplied by the length). Then this volumetric value is converted to weight by the factor 0.283 pounds per cubic inch for steel. Where weld reinforcement is involved, it is added to the requirements for net, unreinforced welds.

	ELECTRODE TYPE				
	E6011	E6013	E7014	E7018	E7024
Electrode Diameter (in.)	3/16"	3/16"	3/16"	3/16"	3/16"
Deposition Rate (lbs/hr)	4.5	4.2	5.3	4.8	9.5
Welding Current (amps)	180	220	240	250	280
Welding Voltage (volts)	26	22	26	25	33
Operator Factor (%)	35	35	35	35	35
Labor + Overhead Costs (\$/hr)	30.00	30.00	30.00	30.00	30.00
Arc Time (hr/ft)	.068	.073	.058	.063	.032
Weight of Deposit (lbs)	.106	.106	.106	.106	.106
Deposition Efficiency (%)	69	63	66	72	67
Electrode Cost (\$/Lb)	5	5	5	5	5
Electric Power Cost (\$/kW-hr)	.06	.06	.06	.06	.06
Power Source Efficiency (%)	50	50	50	50	50
Labor Cost (\$/ft)	2.019	2.163	1.714	1.893	1.116
Electrode Cost (\$/Ft)	.768	.841	.803	.736	.791
Electric Power Cost (\$/Ft)	.038	.042	.043	.047	.035
Total Cost (\$/Ft)	2.825	3.046	2.560	2.676	1.942

Illustration 6-2 – Cost Comparison of Different 3/16" Diameter Electrodes used for making a 1/4" Fillet Weld.

EXAMPLE

The following are sample calculations using values taken from Illustration 6-2 for E6011, 3/16" electrode, 1/4" fillet weld.

Labor Cost =	$\frac{\text{Labor + Overhead Cost/hr} \times \text{Pounds of Weld Deposit/Weld}}{\text{Deposition Rate} \times \text{Operator Factor}} = \frac{30 \text{ $/hr} \times .106 \text{ lbs/ft}}{4.5 \text{ lbs} \times 35 \%} = \text{\$2.019}$
Electrode Cost =	$\frac{\text{Weight of Deposit} \times \text{Electrode Cost Per Lb.}}{\text{Deposition Efficiency}} = \frac{.106 \text{ lbs/ft} \times 5.00 \text{ $/lb}}{69 \%} = \text{\$.768}$
Electric Power Cost =	$\frac{\text{Welding Current} \times \text{Welding Voltage}}{\text{Power Source Efficiency}} \times \text{Arc Time} \times \frac{\text{Power Cost per kW-hr}}{1000} = \frac{180 \text{ amps} \times 26 \text{ volts}}{50 \%} \times .068 \text{ hr/ft} \times \frac{.06 \text{ $/kW-hr}}{1000} = \text{\$.038}$

TOTAL WELD COST PER FOOT = \\$2.825

CHAPTER 7 WELDING METALLURGY

PROPERTIES OF THE WELD

The properties of the weld are items such as the chemical composition, the mechanical strength and ductility, and the microstructure. These items will determine the quality of the weld. The chemical properties are affected by the types of materials used. The mechanical properties and microstructure of the weld are determined by the heat input of welding as well as the chemical composition of the materials.

Chemical Properties

The chemical composition of the base metal is a major factor in determining the choice of the electrodes to be used for welding. The chemical composition of the base metal influences the need for preheating and postheating, because preheating and postheating are used to prevent the weld area from becoming brittle and weak,

When welding steels, the carbon and other alloy content influences the hardness and hardenability of the weld metal, which in turn influences the amount of preheat and postheat needed. The two terms hardness and hardenability are not the same. The maximum hardness of the steel is primarily a function of the amount of carbon in the steel. Hardenability is a measure of how easily a martensite structure is formed when the steel is quenched. Martensite is the phase or metallurgical structure in steel

where the maximum hardness of the steel can be obtained. Steels with low hardenability have to have very high cooling rates to form martensite, where steels with high hardenability will form martensite even when they are slow cooled in air. The hardenability will determine to what extent a steel will harden during welding. The carbon equivalent formula is one of the best methods of determining the weldability of steels. This value is determined by the amounts of some of the alloying elements used. There are several different formulas used, one of these is as follows:

$$\text{Carbon Equivalent} = \%C + \frac{\%Cr}{10} + \frac{\%Mn}{6} + \frac{\%Mo}{10} + \frac{\%Ni}{20} + \frac{\%Cu}{40}$$

Steels with lower carbon equivalents generally are more readily weldable and require fewer precautions such as the use of preheat and postheat.

Steels with higher carbon equivalents are generally more difficult to weld. When welding many of the steels, matching the chemical properties of the filler metal is not as important as matching the mechanical properties. Often filler metal with a lower carbon content than the base metal is used because the weld metal absorbs carbon from the base metal during solidification.

The amount of preheat needed depends on the type of metal being welded, the metal thickness, and the amount of joint restraint. Preheating helps reduce the cooling rate

Type of Metal		Preheat
Low Carbon Steel		Room Temperature or up to 200°F (93°C)
Medium Carbon Steel		400-500°F (205-260°C)
High Carbon Steel		500-600°F (260-315°C)
Low Alloy Nickel Steel	Less than 1/4" (6.4mm) thick	Room Temperature
	More than 1/4" (6.4mm) thick	500°F (260°C)
Low Alloy Nickel Chrome Steel	Carbon less than .20%	200-300°F (93-150°C)
	Carbon .20%-.35%	600-800°F (315-425°C)
	Carbon above .35%	900-1100°F (480-595°C)
Low Alloy Manganese Steel		400-500°F (205-260°C)
Low Alloy Chrome Steel		Up to 750°F (400°C)
Low Alloy Molybdenum Steel	Carbon less than .15%	Room Temperature
	Carbon more than .15%	400-650°F (205-345°C)
Low Alloy High Tensile Steel		150-300°F (66-150°C)
Austenitic Stainless Steel		Room Temperature
Ferritic Stainless Steels		300-350°F (150-260°C)
Martensitic Stainless Steels		400-600°F (205-315°C)
Cast Irons		700-900°F (370-480°C)
Copper		500-800°F (260-425°C)
Nickel		200-300°F (93-150°C)
Aluminum		Room Temperature or up to 300°F (150°C)

Illustration 7-1 – Preheats for Various Metals

of the part being welded. This is important on many steels because a slower cooling rate will not allow as much of the hard and brittle martensite structure to form in the metal. Since martensite formation is the carbon equivalent, steels with high carbon equivalents will generally require higher preheat temperatures than those with low carbon equivalent values. Illustration 7-1 shows typical preheat values for different steels and cast iron. Another major factor that also determines the amount of preheat needed is the base metal thickness. Thicker base metals usually need higher preheat temperatures than thinner base metals because of the larger heat sinks that the thicker metals provide. Thick metals draw the heat away from the welding zone quicker because there is a larger mass of metal. This would increase the cooling rate of the weld if the same preheat temperature is used as with thinner base metals. The third major factor determining preheat is the amount of joint restraint. Joint restraint is the resistance of a joint configuration to moving during the heating and cooling of the weld zone. When there is high resistance to moving or high joint restraint, large amounts of internal stresses build up. Higher preheat temperatures are needed as the amount of joint restraint increases. Slower cooling rates reduce the amount of internal stresses that build up as the weld cools.

For the welding of nickel-base metals, copper-base metals, and stainless steels, the chemical properties of the weld metal are often the most important properties of the weld. The chemical composition of the weld metal must closely match the chemical composition of the base metal to give the weldment good corrosion resistance and creep resistance. Creep resistance of a metal is the resistance to softening at high temperatures which can cause deformation if there is a load on the metal.

Mechanical Properties

The mechanical properties that are most important in the weld are the tensile strength, yield strength, elongation,

reduction of area, and impact strength. The first two are measures of the strength of the material, the next two are a measure of the ductility, and the last is a measure of the impact toughness. These properties are important in shielded metal arc welding.

The yield strength, ultimate tensile strength, elongation, and reduction of area are all measured from a .505 in. (12.8mm) diameter machined testing bar. The metal is tested by pulling it in a tensile testing machine. Illustration 7-2 shows a tensile bar before and a tensile bar after testing. The yield strength of the metal is the stress at which the material is pulled beyond the point where it will return to its original length. The tensile strength is the maximum load that can be carried by the metal. This is also measured in psi (MPa). Elongation is a measure of ductility that is also measured on the tensile bar. Two points are marked on the bar 2 in. (51 mm) apart before testing. After testing, the distance between the two points is measured again and the percent of change in the distance between them, or percent elongation is measured. Reduction of area is another method of measuring ductility. The original area of the cross section of the testing bar is 505 sq. in (104 sq. mm).

During the testing the diameter of the bar reduces as it elongates. When the bar finally breaks, the diameter of the bar at the breaking point is measured, which is then used to determine the area. The percent reduction of this cross sectional area is called the reduction of area. Impact tests are used to measure the toughness of a metal. The toughness of a metal is the ability of a metal to absorb mechanical energy by deforming before breaking. The Charpy V-notch test is the most commonly used method of making impact toughness tests. Illustration 7-3 shows a typical Charpy V-notch test bar. Bars with V-notches are put in a machine where they are struck by a hammer attached to the end of a pendulum. The energy that it takes to break these bars is known as the impact strength and it is measured in foot-pounds (Newton-meters) .



Illustration 7-2 – Tensile Strength Testing Bar



Illustration 7-3 – Charpy V-Notch Bar

Microstructure

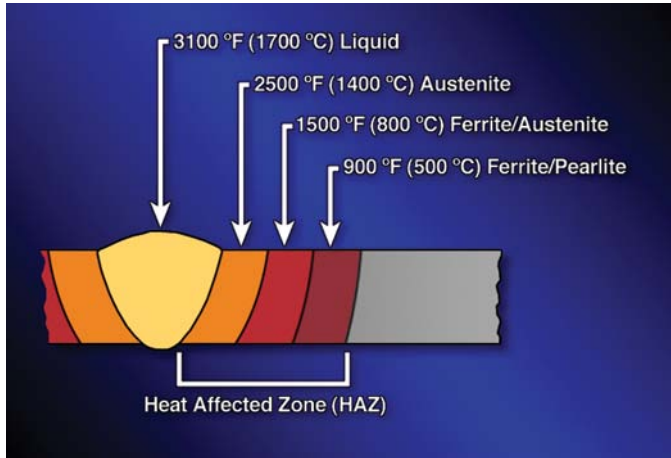


Illustration 7-4 – Cross-Section of a Weld showing the Different Zones and Lines in the Weld Area

Illustration 7-4 shows a cross section of a weld bead showing the weld metal zone, the heat affected zone, and the base metal zone. The weld metal zone is where the metal was molten during welding. The heat affected zone is the area where the heat from welding has an effect on the microstructure of the base metal. The base metal zone is the area that was not affected by the welding. The extent of change of the microstructure is dependent on four factors:

The extent of change of the microstructure is dependent on four factors:

- 1) The maximum temperature that the weld metal
- 2) The time that the weld spent at that temperature.
- 3) The chemical composition of the base metal.
- 4) The cooling rate of the weld.

The weld metal zone, which is the area heated above about 2800°F (1540°C) and melted, generally has the coarsest grain structure of the three areas. For the most part, when welding with the shielded metal arc process, a fairly fine grain size is produced on cooling in steels so a large grain size in the weld zone is not much of a problem when this process is used. Large grain size is undesirable because it gives the weld poor toughness and cracking resistance. The solidification of the weld metal starts at the edge of the weld puddle next to the base metal. The grains that form at the edge are called dendrites and they grow toward the center of the weld into the area that is still molten. This gives the weld metal its characteristic columnar grain structure. The grains that form in the weld zone are similar to the grains that form in castings. The grain size in the weld zone can be affected by the electrode covering as well as the factors mentioned before. One of the functions of the electrode coverings is to provide deoxidizers and scavengers to reduce the grain size

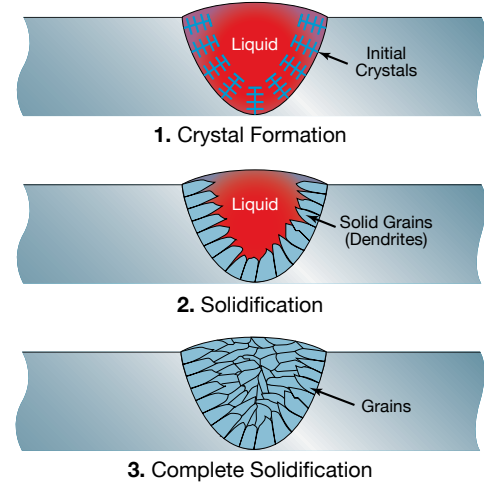


Illustration 7-5 – The Solidification Pattern of the Weld Area

of the metal. The greater the heat input to the weld and the longer it is held at high temperatures, the larger the grain size will be. A fast cooling rate will produce a smaller grain size than a slower cooling rate. Preheating will give larger grain sizes, but it is often necessary to prevent the formation of the hard and brittle martensite structure. The heat affected zone is the area around the metal zone which has been affected by the heat of welding but did not become molten. For example, in mild steels, the area that reaches a temperature of 2200-2800°F (1220-1550°C) goes through a grain coarsening. The area of the heat affected zone that reaches 1700-2200°F (950-1220°C) will go through grain refinement. The area that is heated from 1400-1700°F (780-950°C) is annealed and made considerably softer. The base metal zone is the area that is heated to 1300°F (720°C) or less and is basically unchanged.

METALS WELDABLE

Shielded metal arc welding may be used to weld a wide variety of base metals. The metals that are the most easily welded by the shielded metal arc welding process are the mild steels, low alloy steels, stainless steels and chromium-molybdenum steels. Cast irons, medium and high carbon steels, and hardenable types of steel may also be welded using this process but special precautions must be taken. The selection and care of the electrodes is more critical when welding hardenable steels. Copper alloys and nickel are often welded by this process, but gas metal arc welding and gas tungsten arc welding are more widely preferred and used for the welding of these metals. Zinc, lead, and tin cannot be welded by shielded metal arc welding because of their low melting points. Aluminum can be welded by this process, but it is not very popular. Magnesium is not welded with the shielded metal arc welding process.

Steels

In general steels are classified according to the carbon content such as low carbon, medium carbon, or high carbon steels. In addition, steels are also classified according to the types of alloy used such as chrome-moly, nickel-manganese, etc. For the purposes of the discussion in this chapter, the different steels will be classified according to their welding characteristics.

Mild Steels

Mild steels are generally those steels that have low carbon contents and are the most readily weldable. These steels are the most widely used type of metal for industrial fabrication. Included in this group are the low carbon steels and the high strength structural steels.

Low carbon steels have carbon contents ranging up to .30%. Mild steel electrodes of the EG0XX series classification may be used for welding these steels, but E70XX series electrodes are used when higher strengths are required. The E70XX series electrodes are used especially when the carbon content of the steels approach .30%. Preheating is often used, especially on thicker sections, highly restrained joints, or where codes require preheating. Other precautions such as controlled interpass temperature and postheating are often required. These heat controls help reduce the cooling rate of the weld metal and prevent large amounts of martensite from forming. On thicker sections, cracking may occur in the weld deposit or the heat affected zone if preheating, interpass temperature control, and postheating are not used. The use of these heat controls will help to prevent the reduction of weld toughness, strength, and ductility.

The high strength structural steels are steels whose yield strength falls between 45,000 psi (310 MPa) and 70,000 psi (485 MPa) and their carbon content is generally below .25%. These steels have relatively small amounts of alloying elements. Some common examples of these steels are the ASTM designations of A242, A441, A572, A588, A553 and A537. Preheating is generally not required when low hydrogen electrodes are used except on thick sections or highly restrained joints where preheating is required. Preheating is required when the higher hydrogen types of electrode are used.

Low Alloy Steels

The low alloy steels discussed here will be those steels that are low carbon and have alloy additions less than 5%. This includes the quenched and tempered steels, heat treated low alloy steels and the low nickel alloy steels. Elements such as nickel, chromium, manganese, and molybdenum are the main, alloying elements used. These steels have a higher hardenability than mild steels and it is this factor that is the principal complication in

welding. This higher hardenability permits martensite to form at lower cooling rates. As the alloy content and the carbon content increases, the hardenability also increases. In general, the weldability of the steel decreases as the hardenability increases. One of the best methods for determining the weldability of a low alloy steel is the use of a carbon equivalent formula. Steels that have carbon equivalents below about .40% usually do not require the use of preheating and postheating in the welding procedure and generally have the best weldability. Steels with carbon equivalents higher than .40% require more precautions for welding. Generally the higher the carbon equivalent, the more difficult the steel is to weld. Low alloy steels are fairly weldable but not as easily weldable as the mild steels. The selection of electrodes for the welding of these steels is usually based on the strength and mechanical properties desired of the weld rather than matching chemical compositions except in the case of the low nickel alloys.

The quenched and tempered heat treated steels have yield strengths ranging from 50,000 psi (345 MPa) to very high yield strengths and have carbon contents ranging to .25%. Some common examples of these types of steel are the ASTM designations A533 Grade B, A537 Grade B, A51 4, A51 7, A543, and A553. The .25% carbon limit is used to provide fairly good weldability. These steels provide high tensile and yield strength along with good ductility, notch toughness, corrosion resistance, fatigue strength and weldability. The presence of hydrogen is always bad in steel but it is even more critical in these types of steels compared to mild steels. Low hydrogen electrodes should be used when welding these steels. Preheat is generally not used on thinner sections but it is used on thicker or highly restrained sections. Postweld heat treatment is generally not used because the shielded metal arc welds made in these have good toughness. The steels are generally used in the welded or stress relieved conditions.

The nickel alloy steels included in these low alloy steel groups are those with less than 5% nickel contents. The 2-1/4% and 3-1/2% nickel steels are usually welded with covered electrodes that have the same general chemical composition as the base metal. Preheating is required with highly restrained joints.

Heat Treatable Steels

The heat treatable steels are the medium and high carbon steels and medium carbon steels that have been alloyed. This group includes quenched and tempered steels after welding, normalized or annealed steels, and medium and high carbon steels. These steels are more difficult to weld than the other types of steels already mentioned in this chapter. The most important factor for selecting the type of covered electrode to be used is matching the chemical compositions of the base metal and the filler metal.

Medium carbon steels are those that have carbon contents ranging from .30% to .60% and high carbon steels have carbon contents ranging from .6% to about 1.0%. When medium and high carbon steels are welded, precautions should be included in the welding procedure because of the hardness that can occur in the weld joint. As the carbon content increases up to .60%, the hardness of the fully hardened structure (or martensite) increases to a maximum value. When the carbon content is above .60%, the hardness of the fully hardened structure does not increase so these steels can be welded using about the same welding procedures as the medium carbon steels. Martensite, which is the phase that steel is in at its fullest hardness, is harder and more brittle in a high carbon steel than it is in low carbon steel. A high carbon martensitic structure can have a tendency to crack in the weld metal and the heat affected zone during cooling. Welding procedures that lower the hardness of the heat affected zone and the weld metal reduce the cracking tendency. This can be done by using a procedure that reduces the carbon content in the filler metal, and by slowing the cooling rate. The procedure would include the use of low hydrogen electrodes, a preheat, interpass temperature control, and a postheat. The procedures used for welding medium carbon steels can be simpler than the one just mentioned, but that depends on the specific application. Medium carbon steels can be welded with the low hydrogen electrodes of the E70XX, E80XX, or E90XX classifications. High carbon steels should be welded with the low hydrogen electrodes of the E80XX to the E120XX classes using the electrode of the proper tensile strength to match the tensile strength of the base metal. Generally, high carbon steels are not used in welded production work. These steels are usually only welded in repair work. Mild steel electrodes may also be used, but the deposited weld metal absorbs carbon from the base metal and thus loses a considerable amount of ductility. Stainless steel electrodes of the austenitic type are sometimes used, but the fusion zone may still be hard and brittle. A preheat and/or postheat will help eliminate the brittle structure.

The quenched and tempered steels after welding have carbon contents ranging from about .25% to .45% which distinguishes them from the steels that are quenched and tempered before welding. These steels also have small additions of alloying elements. Some common examples of these steels are the AISI designations 4130, 4140 and 4340. Because of the higher carbon contents, the steels in this group can be heat treated to extremely high levels of strength and hardness. Some of these steels have enough alloy content to give them high hardenability. Because of this combination of carbon and alloy content, the steels must be preheated before welding. The weldability of these steels is also influenced by the purity of the steels. High amounts of sulfur and phosphorous in the steel increase the sensitivity to cracking and reduce the ductility. The shielded metal arc welding process is often

used for welding steels that are quenched and tempered after welding. The selection of the proper electrode to be used is based on the chemical composition, strength required, and thickness of the base metal. The composition of the weld metal is usually similar to that of the base metal. Low hydrogen electrodes are the most commonly used for the welding of these steels.

Chromium-Molybdenum Steels

The chromium-molybdenum steels in this section are those with alloy contents of about 6% or less. These steels are in the low carbon range, generally up to .15%, and are readily weldable. The chromium and molybdenum alloying elements provide these steels with good oxidation resistance and high temperature strength. The chromium is mainly responsible for the oxidation resistance and the molybdenum is mainly responsible for the high temperature strength. All of the electrodes manufactured for welding stainless steels, recognized by the AWS, are of the low hydrogen type. Stainless steel electrodes of the EXXX-15 type have a lime based coating and the EXXX-16 type have a titania based coating. The type EXXX-15 electrodes give greater penetration where the EXXX-16 type give a smoother surface finish. The shielded metal arc welding process is one of the most common methods of welding the chromium-molybdenum steels. The stainless steel low hydrogen electrodes (EXXX-15, EXXX-16 and EXXX-18) are used for welding except on the 1/2% Cr-1/2% Mo steels where the mild steel EXX10, EXX11, and EXX13 may be used. The cellulose coated electrodes for welding the other chromium-molybdenum steels are not used because they can cause underbead cracking. The use of the low hydrogen electrodes greatly reduces the amount of hydrogen present during welding.

Stainless & Higher Chromium-Molybdenum Steels

The steels included in this group are the higher chrome-moly steels, martensitic stainless steels, ferritic stainless steels and the austenitic stainless steels. The major element that sets these steels apart from other steels is the high chromium content. Stainless steels have more than about 11% chromium. The addition of chromium gives the steels a very high resistance to oxidation and it increases the hardenability up to a point. If a steel contains too much chromium, it cannot be hardened at all. Stainless steels containing chromium above about 16% are generally non-hardenable. Chromium levels above about 25% give the stainless steel very good oxidation resistance at high temperatures. In general, when welding stainless steel, the chemical composition of the filler metal and the base metal is matched.

The higher chrome-moly steels contain about 6-10% chromium and .5-1% molybdenum. These steels are limited to a maximum carbon content of about .10% to limit the hardness because these steels are very sen-

sitive to air hardening. For the welding of these steels, preheating, interpass temperature control, slow cooling, and postweld heat treatment are required to make a weld with good mechanical properties.

The martensitic hardenable stainless steels generally have chromium contents between 11 and 13%. Some typical examples of these kinds of steels are the AISI designations 403, 405, 410, 420, and 440. The most easily weldable are the steels with the lowest carbon contents. For applications requiring high hardness, such as cutlery, higher carbon contents are desired such as those that types 420 and 440 contain. Types such as 420 and 440 are rarely welded. Electrodes with the same chemical compositions as the base metal are usually required for welding martensitic stainless steels. Sometimes, austenitic stainless steel or inconel types of covered electrodes are used to weld martensitic stainless steel to avoid the use of preheat, but they give weld metal with lower strength than the base metal. When using martensitic stainless steel covered electrodes, preheating and postheating are required so that the weld metal will not be weaker than the base metal.

The ferritic nonhardenable stainless steels have chromium contents greater than 13%. As mentioned before, the higher chromium content makes these steels nonhardenable. Some typical examples of these types of stainless steels are the AISI designations 430, 436, 442 and 446. These stainless steels require preheating and postheating. Type 446 steel, which has 25% chromium, is very susceptible to rapid grain growth in the weld heat affected zone. Cast Irons Large grain sizes reduce the toughness and make the weld area more susceptible to cracking. Preheating and postheating are used to minimize this grain growth. Austenitic stainless steel electrodes are often used, but this does not help reduce the grain size of the heat affected zone.

The austenitic nonhardenable stainless steels have at least 11 or 12% chromium and ranging up to about 26% chromium with additions of nickel ranging from about 3.5 to 22%. Nickel is a strong austenite former and it helps keep these kinds of steels in the austenitic phase at all temperatures which also makes these steels nonhardenable. Austenitic stainless steels have very good oxidation resistance and high temperature strength. The austenitic stainless steels are designated by the AISI as the 200 and 300 series. In the 200 series of steels, manganese is used to replace some of the nickel. Some common examples of these steels are the Types 302, 304, 308, 310, 316, 321, 347, 201, and 202. Austenitic stainless steels have good toughness and ductility and the most readily weldable of the stainless steels. When shielded metal arc welding is used to weld austenitic stainless steel, the filler metal composition is generally chosen to match the base metal.

The weld metal that is deposited by austenitic stainless steel electrodes generally has higher chromium and nickel contents than the base metal. Distortion is often a problem when welding these steels because they have a coefficient of expansion that is about 50% higher than for carbon steels, which creates residual stresses. Preheating and postheating are usually not required, but preheating may be used to remove the chill.

Free Machining Steels

Free machining steels are steels that have additions of sulfur, phosphorous, or lead in them to make these steels easier to machine. Except for the lead, phosphorous, and sulfur contents, these steels often have chemical compositions of mild, low-alloy, and stainless steels. This addition of these elements makes these steels unweldable. The reason for this is because the elements lead, phosphorous and sulfur have melting points that are much lower than the melting point of steel. As the weld solidifies, these elements remain liquid much longer than the steel so that they coat the grain boundaries which causes hot cracking in the weld. Hot cracking is cracking that occurs before the weld has had a chance to cool. Because of this hot cracking problem, free machining steels cannot be welded successfully.

Cast Irons

Many types of cast irons may be welded using shielded metal arc welding. Cast irons have a carbon content that is higher than the carbon content of steel. Carbon is present in cast irons in two forms, as free carbon (graphite) and as combined carbon (as in steels). There are several types of cast irons which are the white, gray, malleable, modular, and austenitic. All of these are weldable except white cast iron which is considered unweldable.

Gray Cast Iron

In gray cast irons the graphite has a flake appearance. These flakes produce sharp notches and discontinuities which make gray cast iron brittle. The tensile strength of gray cast irons is usually between 30,000 psi (210 MPa) and 40,000 psi (280 MPa). The success of using shielded metal arc welding is usually dependent on the specific tensile strength, the form and distribution of graphite, the amount of sulfur and phosphorous, and the amount of joint restraint. Nickel base welding electrodes are widely used for the welding of gray cast iron. Preheating and interpass temperature control are required for the welding of gray cast irons, except on minor repair jobs.

Nodular and Malleable Cast Irons

In malleable cast irons, the graphite has a nearly spheroidal appearance and in nodular iron the graphite has a spheroidal appearance. The malleable and nodular cast

irons do not have the brittleness that the gray cast irons have because of the shape of the graphite. Nickel-base covered electrodes are also used for the welding of malleable and nodular cast irons. After these cast irons have been welded, they should be annealed to obtain optimum ductility.

Copper and Copper Alloys

Shielded metal arc welding is mainly used for minor repair jobs, difficult to reach fillets, or dissimilar metals when it is used to weld copper and copper alloys. Shielded metal arc welding does not do as good a job as the gas metal arc welding or the gas tungsten arc welding process. The filler metal that is used for the welding of the copper and copper alloys contains deoxidizers. Shielded metal arc welding of these metals is generally restricted to the flat position. Out of position welding can only be performed satisfactorily on phosphor bronzes and copper nickels. Shielded metal arc welding is usually not recommended for the welding of many of the copper alloys because it produces poor mechanical properties and many unsound welds. The coppers and brasses are generally not welded using this process.

Nickel and Nickel Alloys

The shielded metal arc welding process can be used to weld nickel and nickel alloys in thicknesses ranging down to about .050" (1.3mm). The covered electrodes used have chemical compositions similar to the base metals being welded. Elements such as manganese, columbium and titanium are contained by the electrodes and act as deoxidizers and prevent weld metal cracking. Direct current electrode positive welding current is used when welding nickel and nickel alloys. Flat position welding is used whenever possible because it produces a better quality weld. Molten nickel alloy weld metal does not flow as well as molten steel weld metal so the nickel alloy weld metal must be deposited where it is needed. Oscillating or weaving techniques are usually needed because of this. The heat of the welding arc usually does not have a bad effect on the nickel-base metals. Preheat is usually not required for welding these metals but the base metal should be warmed to at least 70°F (21°C) to avoid the condensation of moisture which could produce porosity in the weld metal.

CHAPTER 8

WELD AND JOINT DESIGN

The weld joint design used for shielded metal arc welding is determined by the design of the workpiece, metallurgical considerations, and by codes or specifications. Joints are designed for accessibility and economy during construction. Good accessibility during construction also helps reduce the cost and generally raises the quality of the weld joint. A weld joint consists of a type of weld made in a type of joint. There are five basic types of joints, but these can be used in combinations. A joint is defined as being the junction of members which are to be joined or have been joined. Illustration 8-1 shows the five basic joint classifications. Each of the different types of joints can be joined by many different types of welds. Illustration 8-2 shows the most common types of welds made. The type of weld made is governed by the joint configuration. Illustration 8-3 shows the weld nomenclature used for groove and fillet welds.

STRENGTH

The strength required of the weld joint is a major consideration when determining the design of a welded joint. Weld joints are either full penetration or partial penetration, depending on the strength required for the weld joint.

Full penetration weld joints are those that have weld metal through the full cross section of the joint where partial penetration weld joints are those that have an unfused area in the joint. Welded joints that are subject to static, cyclic, or impact loads usually require full penetration when full strength is required. These factors are even more important when the weld joints are used for low temperature service. Partial penetration welds may be adequate for joints that are statically loaded. These types of joints are easier to prepare and require less filler metal than full penetration joints.

POSITION

The shielded metal arc welding process can be used in all welding positions. The position that the welding is to be done in, affects the design of the joint. Some examples of this are shown in the illustrations at the end of the chapter. A diagram of the welding position capabilities of shielded metal arc welding is shown in Illustration 8-4. Welding in the horizontal, vertical, and overhead positions depends on the skill of the welder and the type of electrode being used. The high deposition class of electrodes can normally only be used in the flat and horizontal positions.

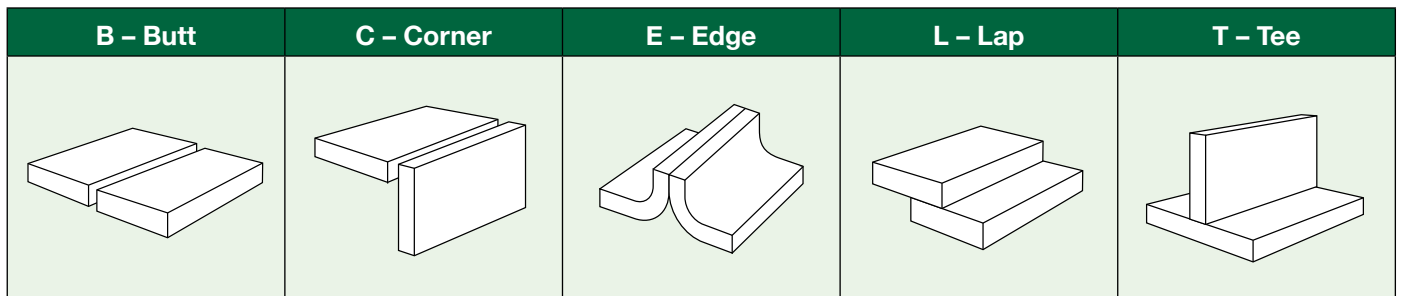


Illustration 8-1 – There are only five basic joints. They can, however, be used in combinations.

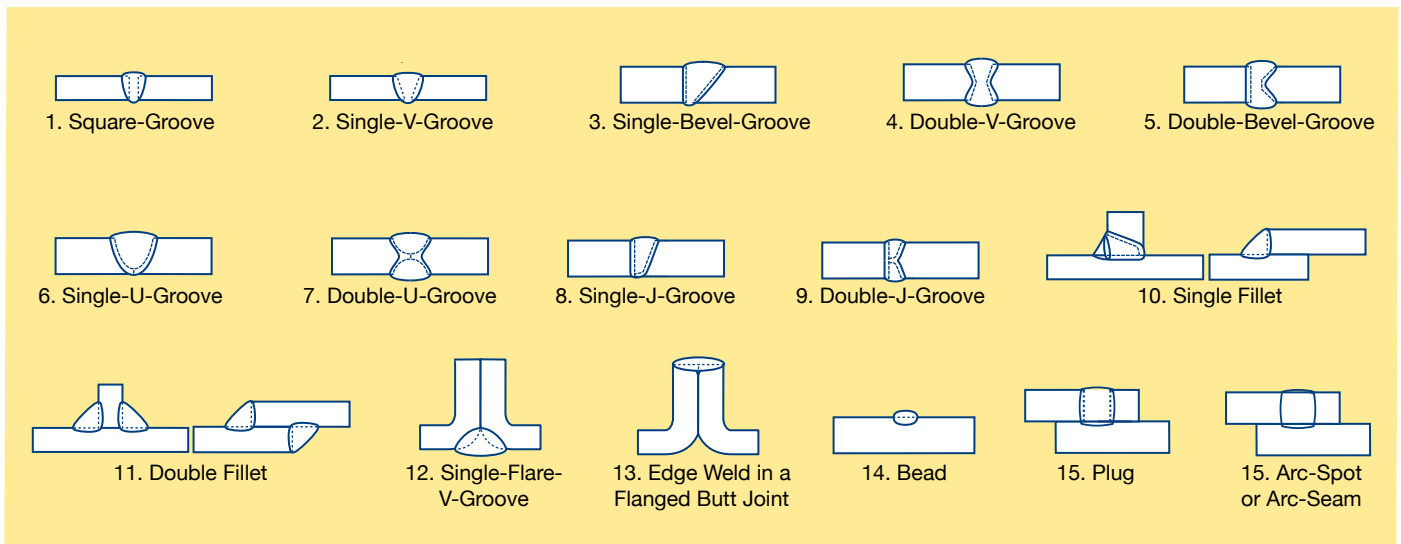


Illustration 8-2 – Common Types of Welds (Many other variations of welds are possible)

because of the large weld puddles produced by these electrodes. Welding positions are classified by a set of numbers and letters. The four basic welding positions are designated by the numbers 1 for flat, 2 for horizontal, 3 for vertical, and 4 for overhead. F designations are used for fillet welds and G designations are used for groove welds. The 5G and 6G positions are test positions used in pipe welding. Illustration 8-4 also shows the number and letter designations for both plate and pipe.

THICKNESS

The thickness of the metal that can be welded by the shielded metal arc welding process depends on welder skill, joint position, type of joint, fit-up, type of electrode, welding speed, arc length, welding current, and arc characteristics. The minimum thickness of metal that can be welded is dependent on the skill of the welder. A skilled welder can weld steel as thin as 1/16 in. (1.6mm). Steel as thick as 1/44 in. (6.4 mm) can be welded without groove preparation if the width of the root opening is adequate to achieve full penetration welds. Partial penetration welds can be made in 1/2 in. (12.7mm) thick metal without beveling. Thicker materials than those mentioned require joint preparation and multiple passes. Common beveled joint configurations for groove welds are the U-, V-, J-, bevel-,

and combination grooves. These configurations make it possible to get full penetration welds on thicker material. The thicker the material, the more passes it takes to fill the joint for a given joint design. Single-bevel and V-groove are the types of edge preparation used most often.

U-grooves are the most commonly used because they are the easiest to prepare. The bevels on the sides of the groove can be prepared by flame cutting, where the joint faces of the J- and U-grooves are prepared by machining. Flame cutting is quicker than machining, so flame cutting reduces the preparation time.

U-grooves generally require less filler metal than V-grooves, but spacer strips may be used in V-grooves to provide easier access to the root. Larger electrodes may be used for the first pass when welding U-grooves, than may be used for the first pass when welding V-grooves. This is because of the rounded bottom that the U-grooves have.

Single bevel and J-grooves are often used for corner and T-joints. Single-V, single-U, and single-bevel grooves are the most common types of edge preparation for butt joints that are 3/16 in. (4.8mm) or 1/4 in. (6.5mm) thick to about 3/4 in. (19.1mm) thick.

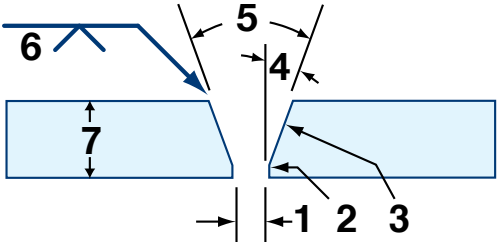
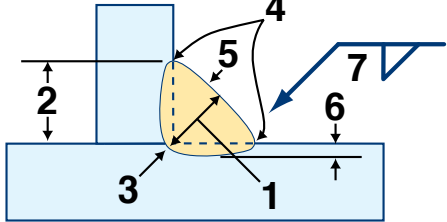
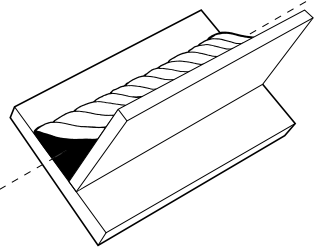
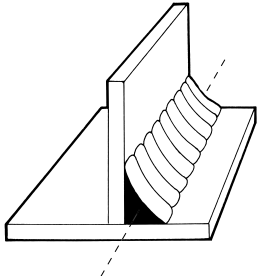
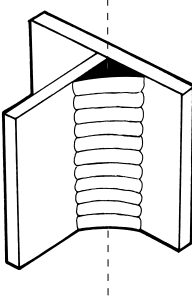
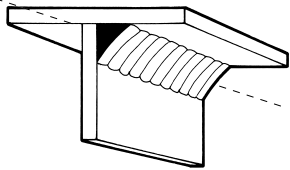
Groove Weld	Fillet Weld
	
1. ROOT OPENING (RO): the separation between the members to be joined at the root of the joint. 2. ROOT FACE (RF): Groove face adjacent to the root of the joint. 3. GROOVE FACE: The surface of a member included in the groove. 4. BEVEL ANGLE (A): the angle formed between the prepared edge of a member and a plane perpendicular to the surface of the member. 5. GROOVE ANGLE (A): the total included angle of the groove between parts to be joined by a groove weld. 6. SIZE OF WELD (S): the joint penetration (depth of bevel plus the root penetration when specified). The size of a groove weld and its effective throat are one in the same. 7. PLATE THICKNESS (T): Thickness of plate welded.	1. ACTUAL THROAT OF A FILLET WELD: The shortest distance from the root of the fillet weld to its face. 2. LEG OF A FILLET WELD: The distance from the root of the joint to the toe of the fillet weld. 3. ROOT OF A WELD: The points at which the back of the weld intersects the base metal surfaces. 4. TOE OF A WELD: The junction between the face of the weld and the base metal. 5. FACE OF WELD: The exposed surface of a weld on the side from which the welding was done. 6. DEPTH OF FUSION: The distance that fusion extends into the base metal or previous pass from the surface melted during welding. 7. SIZE OF WELD (S): Leg length of the fillet.

Illustration 8-3 – Weld Nomenclature

Fillet Welds			
FLAT POSITION 1F	HORIZONTAL POSITION 2F	VERTICAL POSITION 3F	OVERHEAD POSITION 4F
			
Axis of Weld Horizontal	Axis of Weld Horizontal	Axis of Weld Vertical	Axis of Weld Horizontal

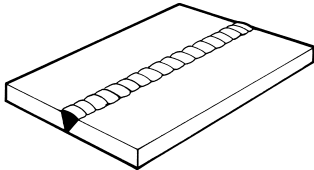
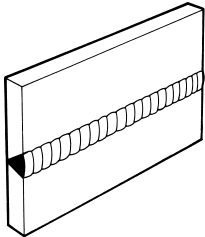
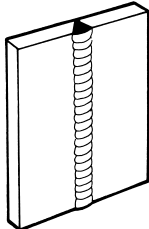
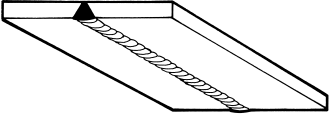
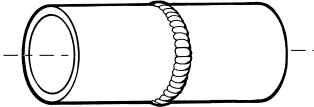
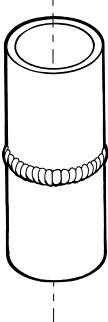
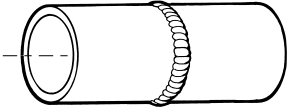
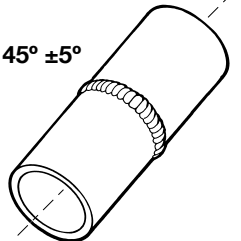
Groove Welds			
FLAT POSITION 1G	HORIZONTAL POSITION 2G	VERTICAL POSITION 3G	OVERHEAD POSITION 4G
			
Plates, Axis of Weld Horizontal	Plates vertical, Axis of Weld Horizontal	Plates vertical, Axis of Weld Vertical	Plates Overhead, Axis of Weld Horizontal
FLAT 1G	HORIZONTAL 2G	HORIZONTAL FIXED 5G	45° FIXED 6G
			
Pipe shall be turned or rolled while welding axis of pipe horizontal	Axis of Pipe Vertical	"Bell Hole" Pipe shall not be turned or rolled while welding axis of pipe horizontal	"Arkansas Bell Hole" 45° ±5° Pipe stationary with axis approximately 45°

Illustration 8-4 – Welding Test Positions

When the base metal is 3/4 in. (19.1mm) or more, double-V, double-U, double-bevel, and double-J-grooves are usually recommended if welding from both sides is possible. Joints welded with these grooves, produce less distortion and reduce the amount of filler metal required than for grooves that must be welded from one side. Groove angles of 45° to 60° are used for thinner base metals needing grooves, but are too large for use in thicker base metals. Smaller groove angles are used for the larger metal thicknesses because less welding time is required than to fill a 45° or 60° groove angle.

There are many variations of the basic joint designs. One design that is often used for the welding of thick walled pipe and thick plate over 3/4 in. (19.1mm) thick is the variation of the single V-groove joint, shown in Illustration 8-5. This is used when the joint is accessible from one side. It uses a steeper slope toward the top of the joint where the bevel angle has been reduced. The advantage of this type of joint design over a normal V-groove design is that it is less expensive to weld because less filler metal is required to fill the joint. The wider V-groove toward the bottom gives good accessibility to the root of the joint. A disadvantage of this joint design is that it is more difficult to prepare the two different bevel angles.

ACCESSIBILITY

Accessibility is another important factor in determining the joint design for shielded metal arc welding. Welds can be made from either one side or both sides of the base metal. On thicker metals, when both sides of the joint are accessible, double bevels are usually made. The advantage of this is that the double bevels have less area to fill than single bevels and require less filler material. The roots of the welds are usually near the center of the base metal when double bevels are used. When the joints are only accessible from one side, U- and J-groove preparations are often used so that the root is more easily accessible, and on thick sections less filler metal is required to fill the joint than with a standard V-groove preparation. However, U- and J-grooves are harder and more expensive to prepare. The weld joint designs in the rest of the chapter are those commonly used for shielded metal arc welding. Illustration 8-6 shows the minimum effective throat thicknesses used for partial penetration welds, according to the AWS Structural Welding Code (AWS D1.1). The effective throat thickness is the minimum distance between the root of the weld and the surface less the reinforcement. Illustration 8-7 shows the American Welding Society “Standard Welding Symbols” some of which have been used in the weld joint designs.

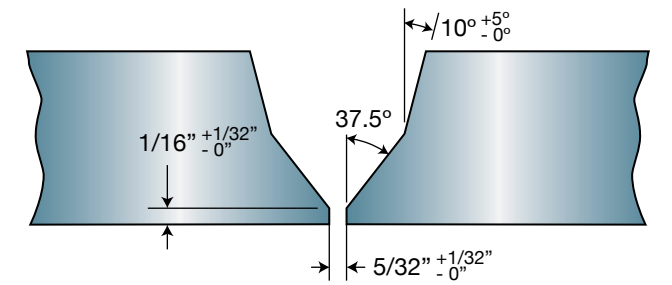


Illustration 8-5 – Variation of Single-V-Groove Joint Design for Unlimited Thickness Base Metal

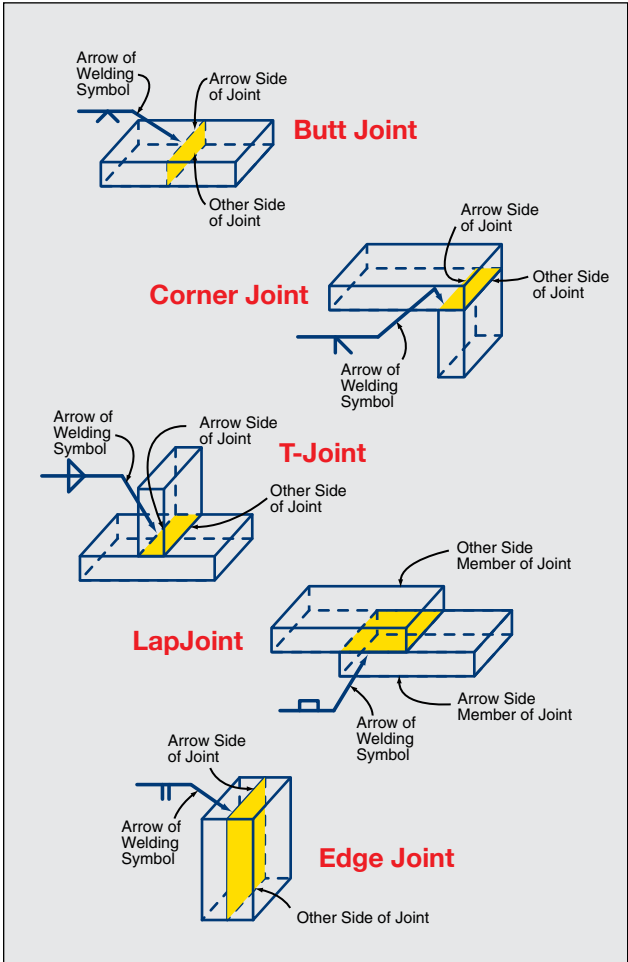
Base Metal Thickness of Thicker Part Joined	Minimum Weld Size
To 1/4" (6.5mm) inclusive	1/8" (3mm)
Over 1/4" to 1/2" (6.4-12.7mm) inclusive	3/16" (5mm)
Over 1/2" to 3/4" (12.7-19.0mm) inclusive	1/4" (6mm)
Over 3/4" to 1-1/2" (19.0-38.1mm) inclusive	5/16" (8mm)
Over 1-1/2" to 2-1/4" (38.1-57.1mm) inclusive	3/8" (10mm)
Over 2-1/4" to 6" (57.1-152mm) inclusive	1/2" (13mm)
Over 6" (152mm) inclusive	5/8" (16mm)

Illustration 8-6 – Minimum Weld Size for Partial Joint Penetration Groove Welds

Basic Welding Symbols and their Location Significance

Type of Weld		Arrow Side	Other Side	Both Sides	No Arrow Side or Other Side Significance
Fillet					not used
Plug or Slot				not used	not used
Spot or Projection				not used	
Stud			not used	not used	not used
Seam				not used	
Back or Backing				not used	not used
Surfacing			not used	not used	not used
Edge					not used
GROOVES	Square				
	V				not used
	Bevel				not used
	U				not used
	J				not used
	Flare-V				not used
	Flare Bevel				not used
Scarf for Brazed Joint					not used

Basic Joints Identification of Arrow Side and Other Side Joint



Supplementary Symbols

Weld Around	Field Weld	Melt-thru	Consumable Insert	Backing Spacer

Contour		
Flush or Flat	Convex	Concave

Process abbreviations
Where process abbreviations are to be included in the tail of the welding symbol, reference is made to table 1, Designation of Welding and Allied Processes by Letters of ANSI/AWS A2.4:2007
American Welding Society
550 N.W. LeJeune Road, Miami, Florida 33126

Location of Elements of a Welding Symbol

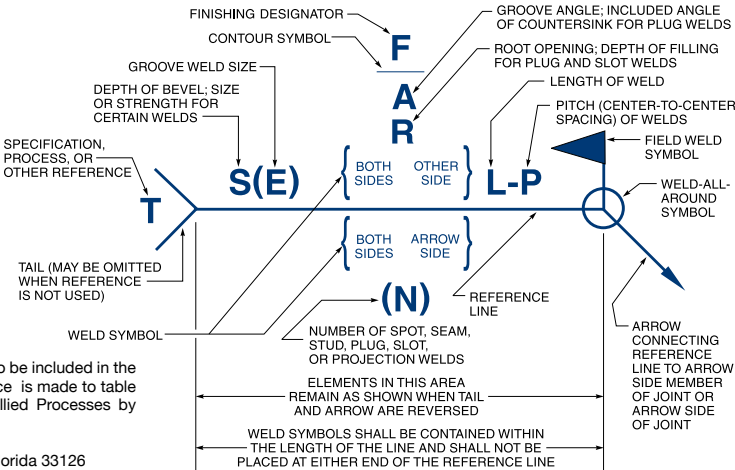


Illustration 8-7 – Welding Symbols

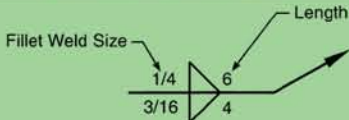
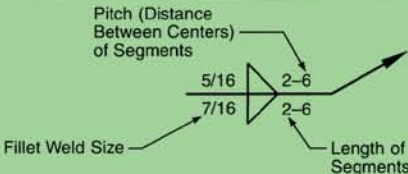
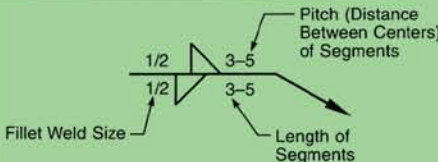
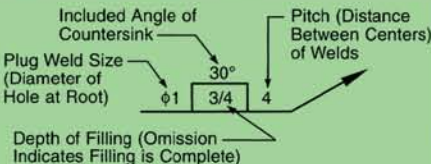
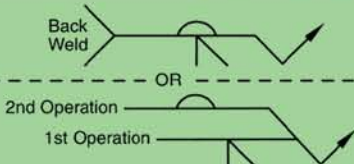
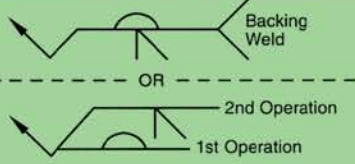
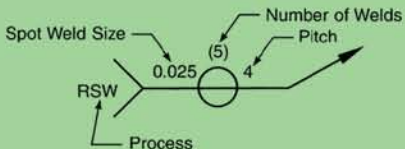
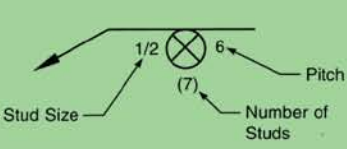
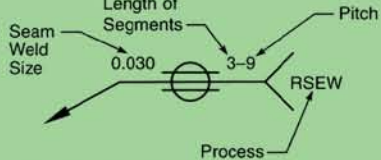
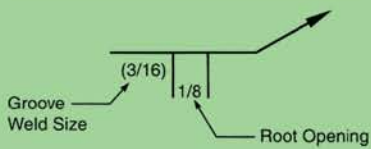
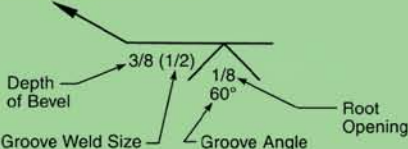
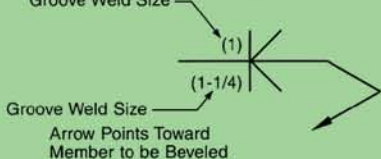
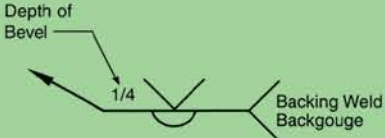
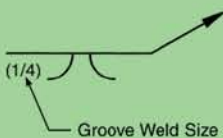
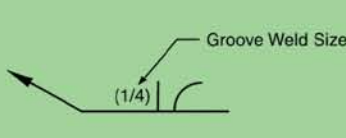
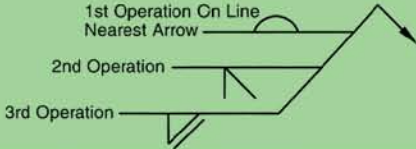
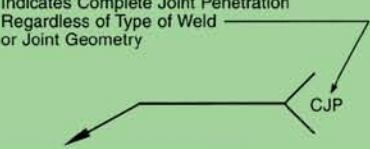
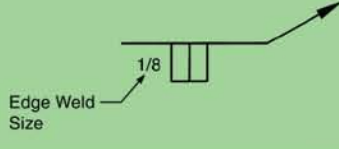
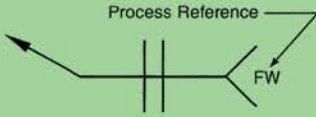
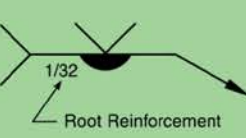
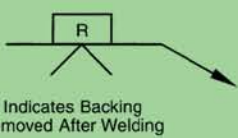
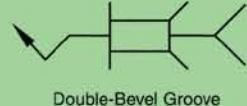
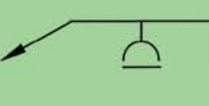
Typical Welding Symbols				
Double-Fillet Welding Symbol		Chain Intermittent Fillet Welding Symbol		Staggered Intermittent Fillet Welding Symbol
 Fillet Weld Size $\frac{1}{4}$ Length 6 Pitch (Distance Between Centers) of Segments $\frac{3}{16}$ Omission of Length Indicates that Weld Extends Between Abrupt Changes in Direction or as Dimensioned		 Pitch (Distance Between Centers) of Segments $\frac{5}{16}$ Length of Segments 2-6 Fillet Weld Size $\frac{7}{16}$		 Pitch (Distance Between Centers) of Segments $\frac{1}{2}$ Length of Segments 3-5 Fillet Weld Size $\frac{1}{2}$
Plug Welding Symbol		Back Welding Symbol		Backing Welding Symbol
 Included Angle of Countersink 30° Pitch (Distance Between Centers) of Welds 4 Plug Weld Size (Diameter of Hole at Root) $\frac{3}{4}$ Depth of Filling (Omission Indicates Filling is Complete)		 Back Weld OR 2nd Operation 1st Operation		 Backing Weld OR 2nd Operation 1st Operation
Spot Welding Symbol		Stud Welding Symbol		Seam Welding Symbol
 Spot Weld Size 0.025 Number of Welds (5) Pitch 4 Process RSW		 Stud Size $\frac{1}{2}$ Pitch 6 Number of Studs (7)		 Seam Weld Size 0.030 Length of Segments 3-9 Pitch 3-9 Process RSEW
Square-Groove Welding Symbol		V-Groove Welding Symbol		Double-Bevel-Groove Welding Symbol
 Groove Weld Size (3/16) Root Opening $\frac{1}{8}$		 Depth of Bevel $\frac{3}{8}$ Groove Weld Size (1/2) Groove Angle 60° Root Opening $\frac{1}{8}$		 Groove Weld Size (1) Root Opening (1-1/4) Arrow Points Toward Member to be Beveled
Symbol with Backgouging		Flare-V-Groove Welding Symbol		Flare-Bevel-Groove Welding Symbol
 Depth of Bevel $\frac{1}{4}$ Backgouging		 Groove Weld Size (1/4)		 Groove Weld Size (1/4)
Multiple Reference Lines		Complete Joint Penetration		Edge Welding Symbol
 1st Operation On Line Nearest Arrow 2nd Operation 3rd Operation		 Indicates Complete Joint Penetration Regardless of Type of Weld or Joint Geometry CJP		 Edge Weld Size $\frac{1}{8}$
Flash or Upset Welding Symbol		Melt-Thru Symbol		Joint with Backing
 Process Reference FW		 Root Reinforcement $\frac{1}{32}$		 R Indicates Backing Removed After Welding
Joint with Spacer		Contour Symbols		
With Modified Groove Weld Symbol		Flush	Flat	Convex
 Double-Bevel Groove			 Flat	
				Concave
				

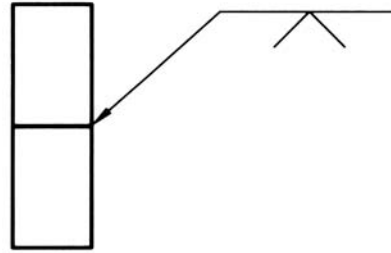
Illustration 8-7 – Welding Symbols (continued)

Application of Arrow and Other Side Convention

(A) Arrow side V-groove weld symbol



Weld Cross Section

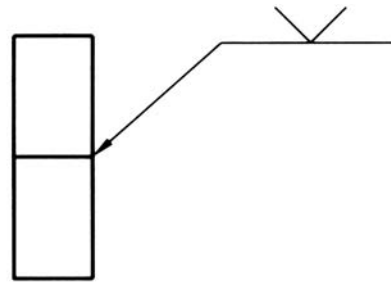


Symbol

(B) Other side V-groove weld symbol



Weld Cross Section

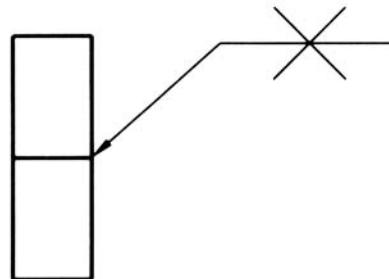


Symbol

(C) Both sides V-groove weld symbol



Weld Cross Section



Symbol

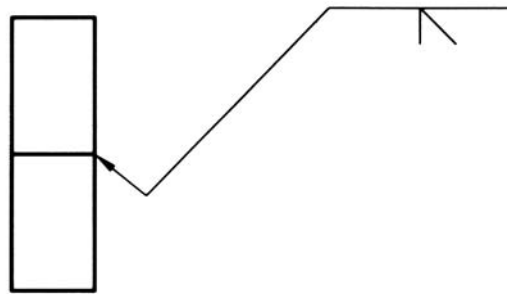
Illustration 8-8 – Weld Joint Designs

Application of Break in Arrow of Welding Symbol

(A) Arrow side



Weld Cross Section

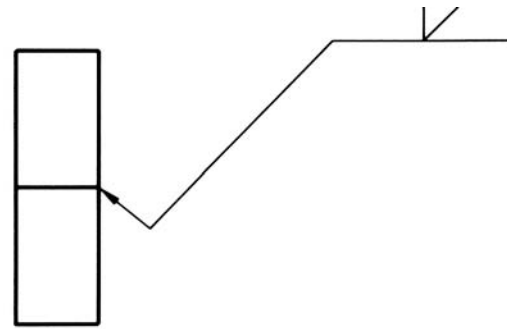


Symbol

(B) Other side



Weld Cross Section

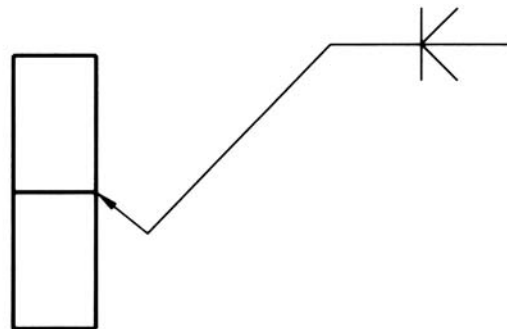


Symbol

(C) Both sides



Weld Cross Section

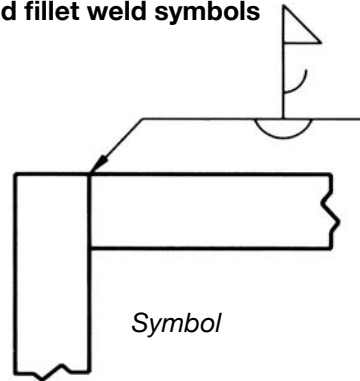
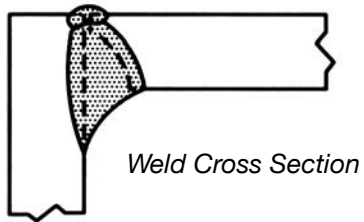


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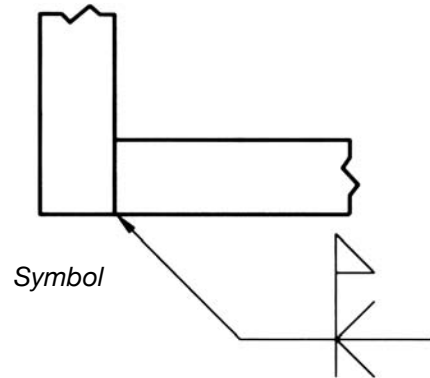
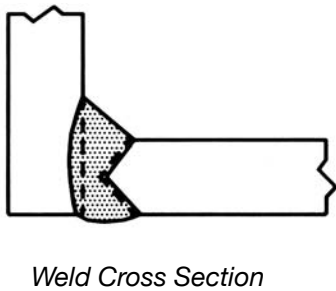
Illustration 8-8 – Weld Joint Designs (continued)

Combinations of Weld Symbols

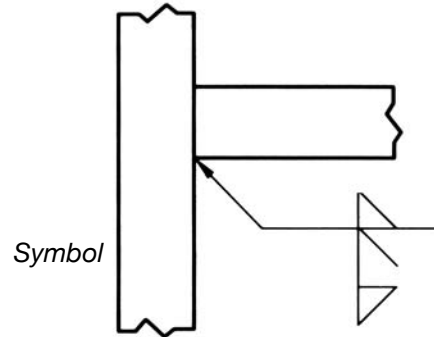
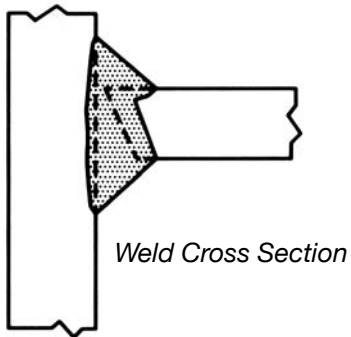
(A) Back or backing, single J-groove and fillet weld symbols



(B) Double-bevel-groove and fillet weld symbols



(C) Single-bevel-groove and double fillet weld symbols



(D) Double-square-groove and double fillet weld symbols

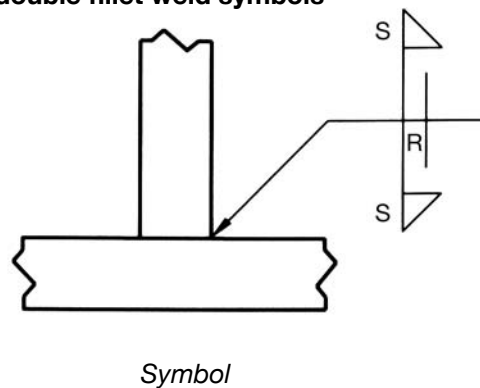
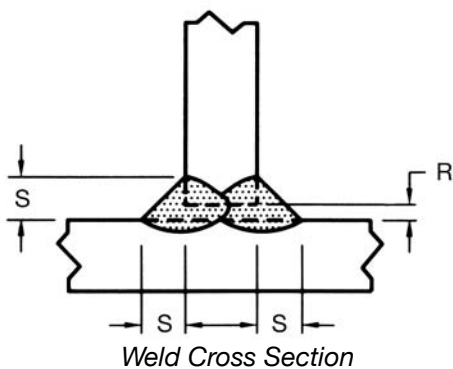
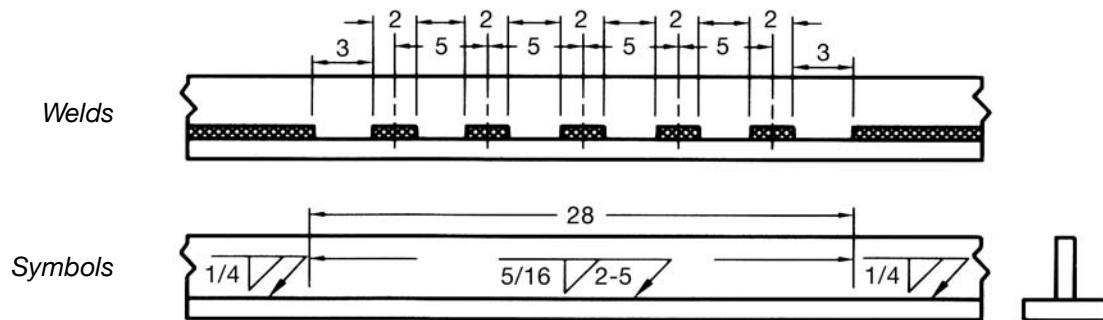


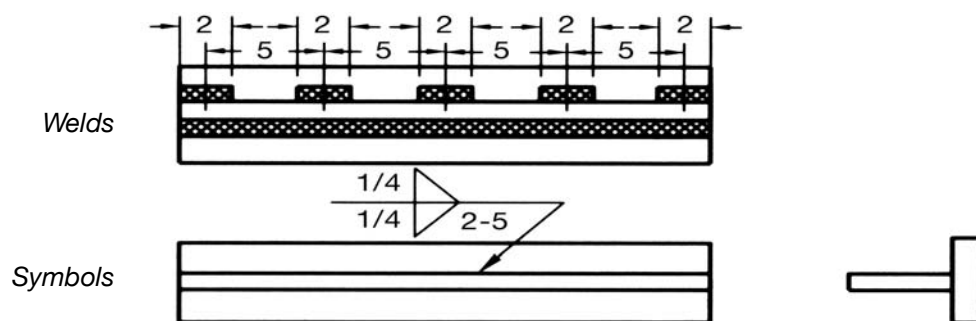
Illustration 8-8 – Weld Joint Designs (continued)

Specification of Location and Extent of Fillet Welds

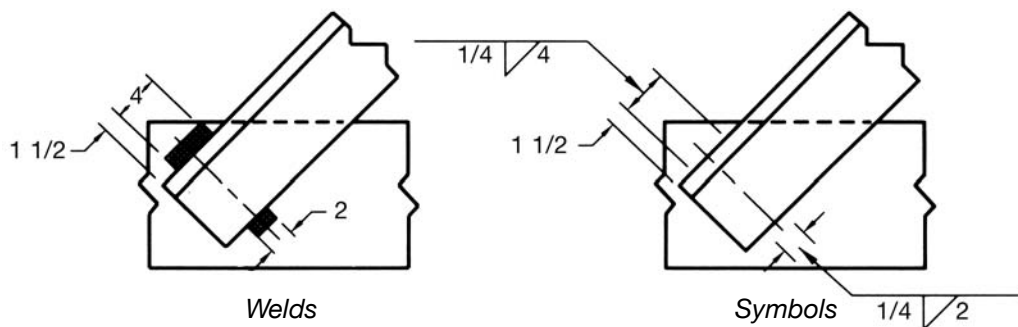
(A) Combined intermittent and continuous welds (one side of joint)



(B) Combined intermittent and continuous welds (both sides of joint)



(C) Welds definitely located



(D) Welds approximately located

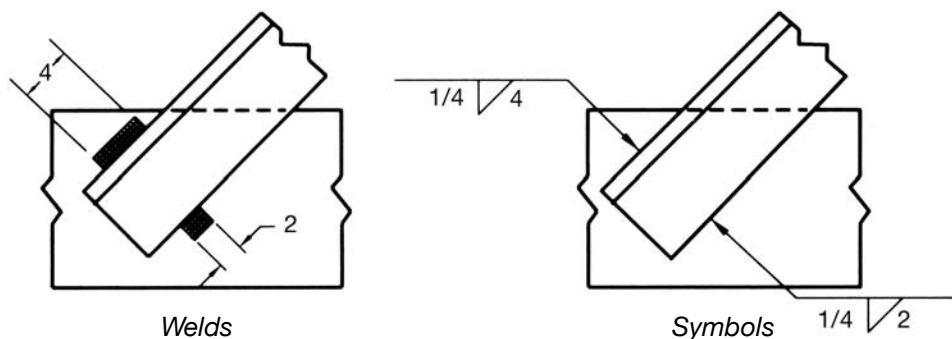
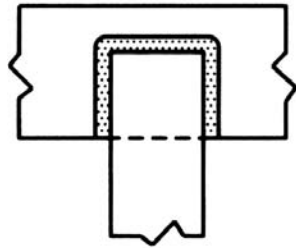


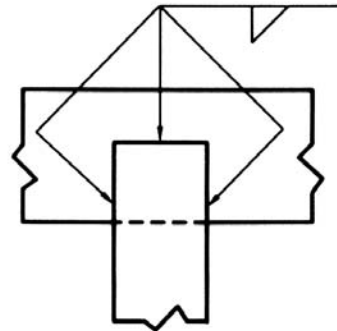
Illustration 8-8 – Weld Joint Designs (continued)

Specification of Extent of Welding

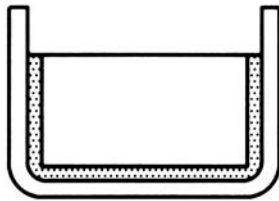
(A) Welds with abrupt changes in direction



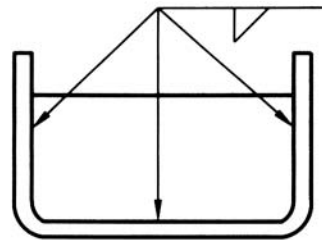
Welds



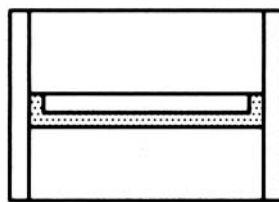
Symbols



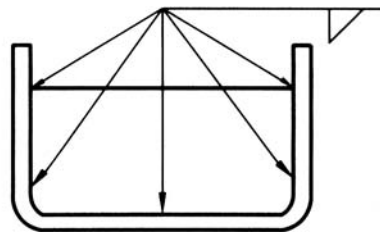
Welds



Symbols



Welds

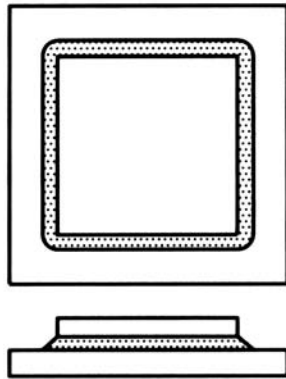


Symbols

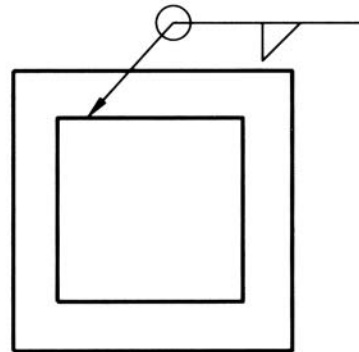
Illustration 8-8 – Weld Joint Designs (continued)

Specification of Extent of Welding

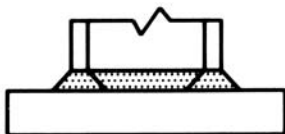
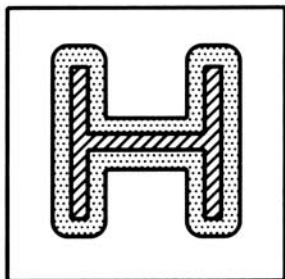
(B) Application of weld-all-around symbol



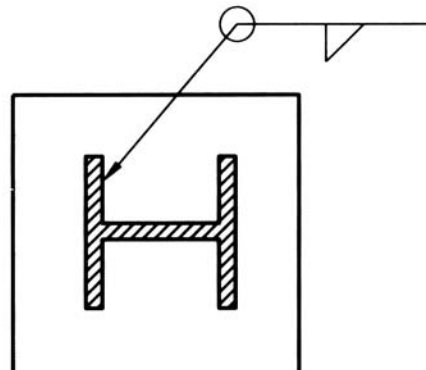
Welds



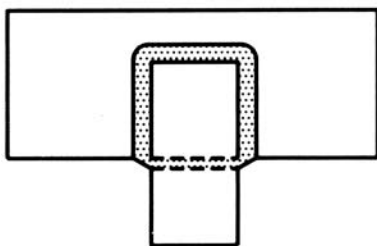
Symbol



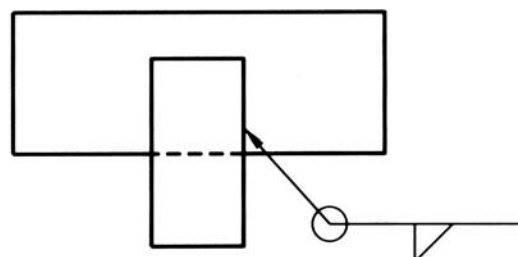
Welds



Symbol



Welds

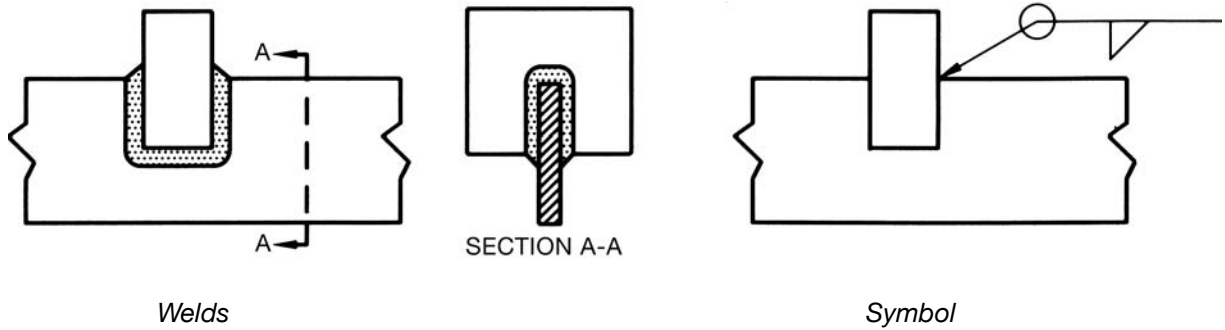


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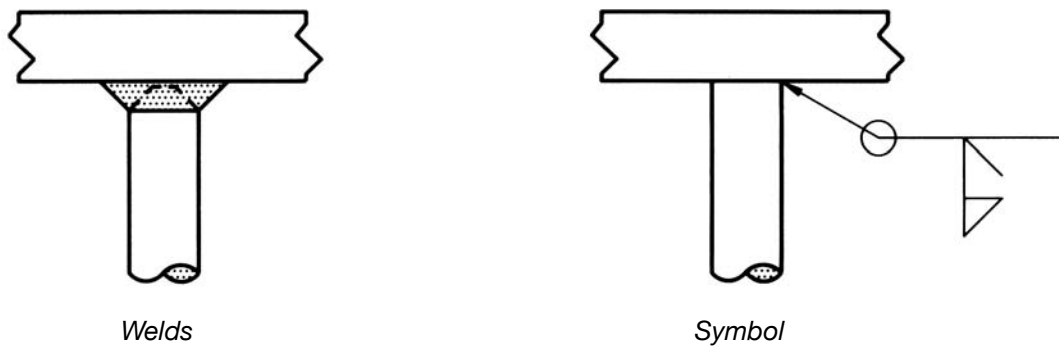
Illustration 8-8 – Weld Joint Designs (continued)

Specification of Extent of Welding

(C) Weld in several planes



(D) Weld around a shaft



(E) Seal weld

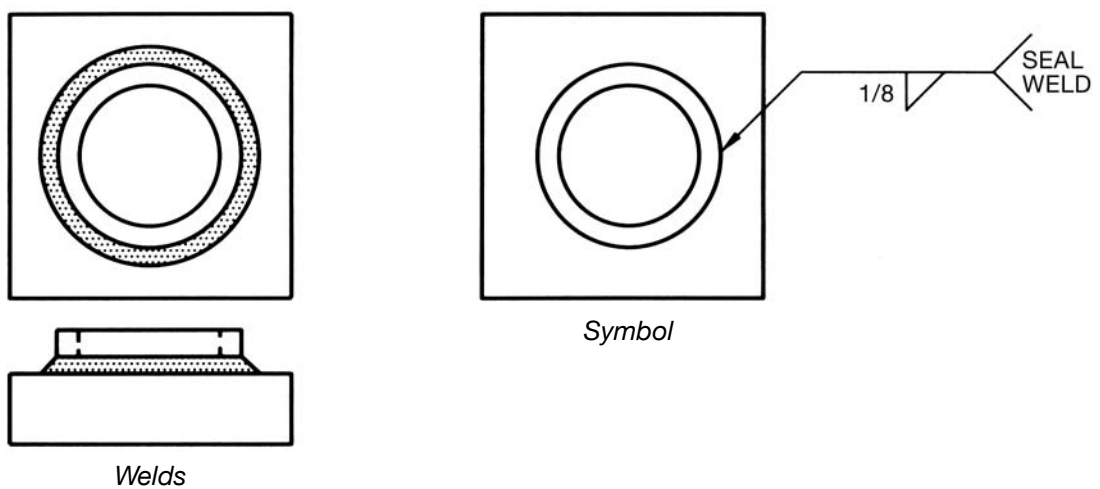


Illustration 8-8 – Weld Joint Designs (continued)

Applications of Typical Weld Symbols

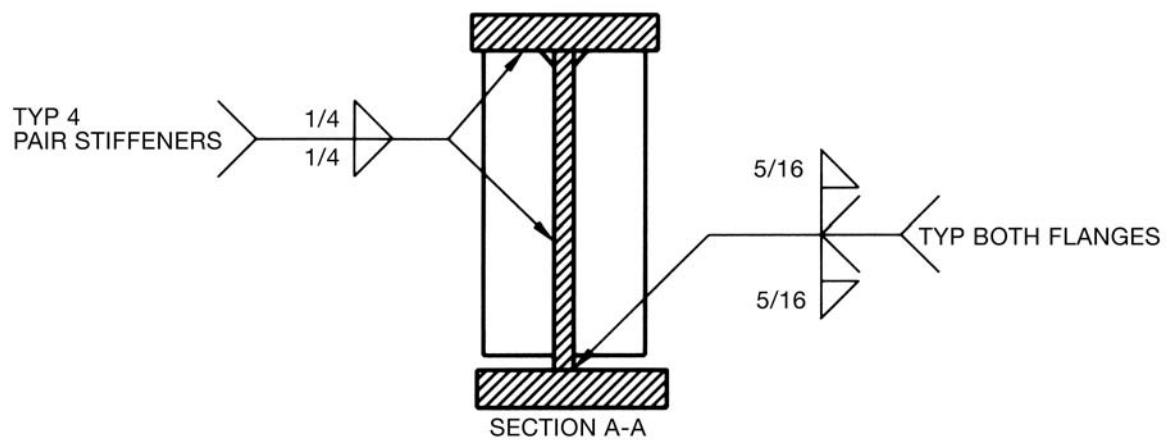
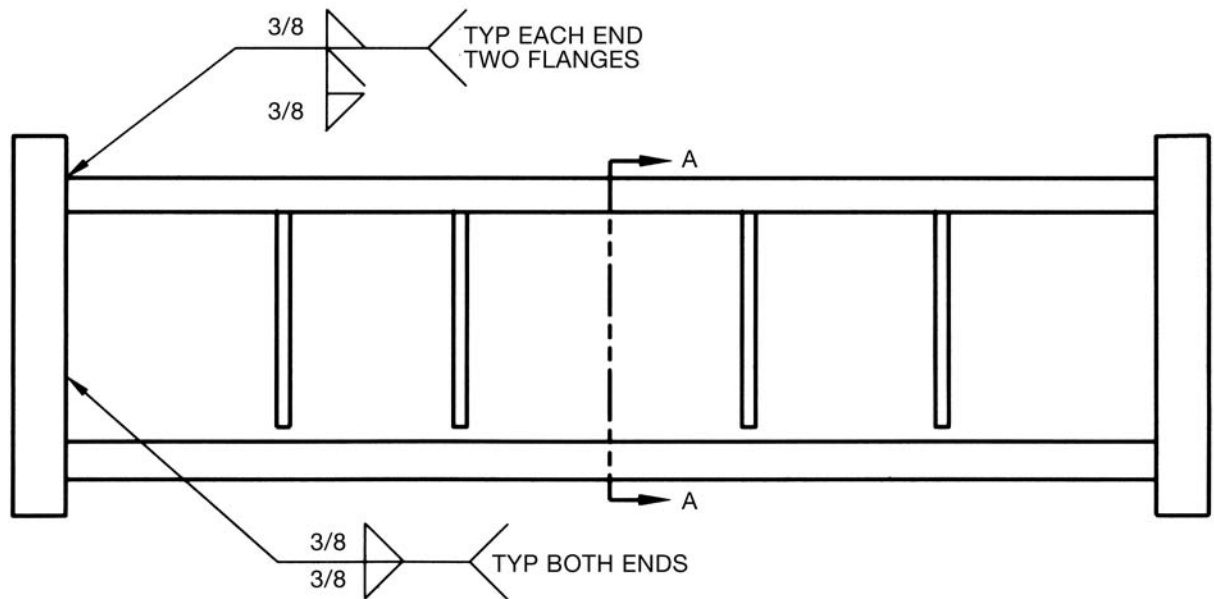


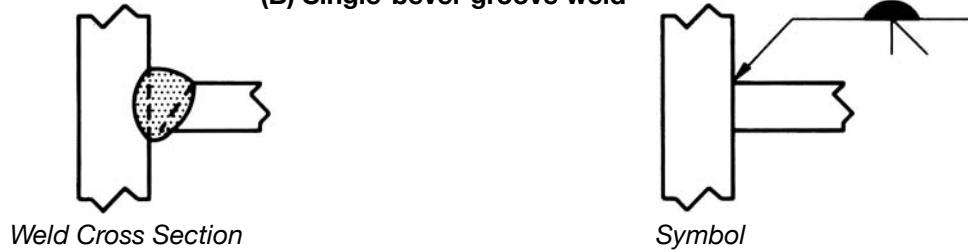
Illustration 8-8 – Weld Joint Designs (continued)

Applications of Typical Weld Symbols

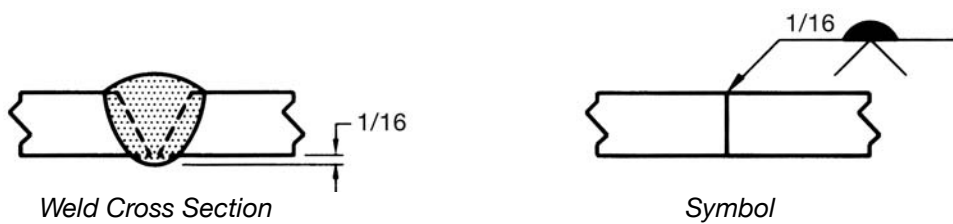
(A) Square-groove weld



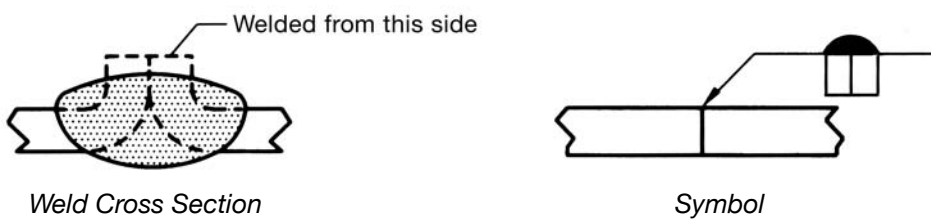
(B) Single-bevel-groove weld



(C) Single-V-groove weld



(D) Edge weld



(B) Corner-flange weld

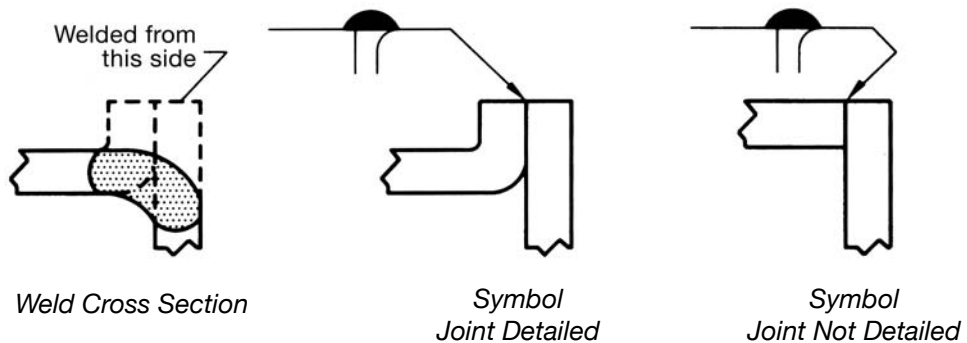


Illustration 8-8 – Weld Joint Designs (continued)

CHAPTER 9

WELDING PROCEDURE VARIABLES

The welding procedure variables are those that control the welding process and the quality of the welds that are produced. There are three major types of welding variables used for welding. These are the fixed or preselected, primary adjustable, and the secondary adjustable variables.

The fixed or preselected welding variables are those that are set before the actual welding takes. These are items such as electrode type, electrode size, and type of current. These variables cannot be changed after welding starts.

The primary adjustable variables are the major variables used to control the welding process once the fixed variables have been selected. The primary variables control the formation of the weld bead by affecting the bead width, bead height, penetration, arc stability, and weld soundness. The primary welding variables are welding current, arc voltage, and travel speed. These can be easily adjusted and measured so they can be used effectively to control the welding process.

The secondary adjustable variables are the minor adjustable variables that are used to control the welding process. These variables are usually more difficult to measure. Secondary adjustable variables are the work angle and the travel angle of the electrode.

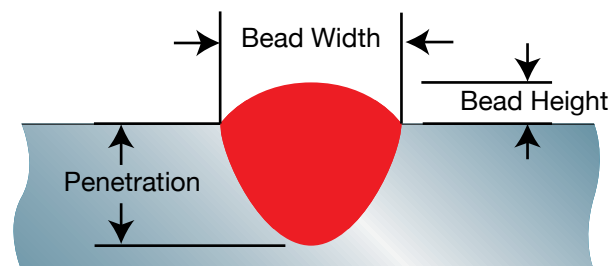


Illustration 9-1 – Bead Height, Width and Penetration

The penetration of the weld is defined as the greatest depth below the surface of the base metal that the weld metal reaches. The bead height or reinforcement is the height of the weld metal above the surface of the base metal. The deposition rate is the weight of the metal that is deposited per unit of time. The definitions of bead height, bead width, and penetration are shown in Illustration 9-1.

The welding variables are discussed with particular attention to the three major characteristics of penetration, deposition rate, and bead shape. Illustration 9-2 is a chart showing the effects of welding variables on the three major characteristics.

Desired Characteristic		WELDING VARIABLE / CHANGE REQUIRED				
		Arc Length	Welding Current	Travel Speed	Travel Angle	Electrode Diameter
Deeper penetration		–	Increase	–	Drag	Smaller
Shallower Penetration		–	Decrease	–	Push	Larger
Bead Height and Width	Larger Bead	–	Increase	Decrease	–	–
	Smaller Bead	–	Decrease	Increase	–	–
	Higher, Narrower	Decrease	–	Increase	Drag	–
	Flatter, Wider	Increase	–	Decrease	Push	–
Faster Deposition Rate		–	Increase	–	–	Smaller
Slower Deposition Rate		–	Decrease	–	–	Larger

NOTE: These are the effects of changing only one variable at a time.

Illustration 9-2 – Effects of Welding Variables on the Penetration, the Bead Size and Shape, and the Deposition Rate

FIXED VARIABLES

Electrode

The type of electrode used has an effect on the penetration, deposition rate, and shape of the weld bead. The type of electrode used usually depends upon the specific application. Some types of electrodes have a digging arc and produce welds with deep penetration. The deep penetrating effect of these electrodes is because of the high amount of cellulose in their coatings. Some types of electrodes produce moderate penetration while others produce light penetration. The deposition rate of the electrode is also greatly influenced by the type of electrode used. Iron powder is the main influence on deposition rate. Electrodes with high amounts of iron powder in their coatings can operate at higher welding currents than other types of electrodes. The iron powder goes into the weld metal and helps give the electrodes that have iron powder in their coatings, the highest deposition rates of any of the mild steel electrodes. The electrodes with the thinnest electrode coatings generally have the lowest deposition rates. The bead size and shape is also influenced by the type of electrode used. The iron powder electrodes generally produce wider and flatter beads. The characteristics of the different electrodes were discussed in Chapter 4.

Electrode Size

Larger diameter electrodes use higher welding currents so the deposition rates and penetration depths increase as the electrode wire diameter is increased. Lower deposition rates and penetration depths are obtained with smaller electrode wire diameters because lower welding currents are used. Illustration 9-3 shows typical deposition rates for different sizes of E6010, E7018, and E7024 electrodes.



Current Type

The melting rate in the arc zone is directly related to the electrical energy in the welding arc. Part of the energy is used to melt the electrode and coating, some is lost to the atmosphere, and the rest goes to melt the base metal. The energy balance is determined by the electrical polarity and the constituents of the electrode covering.

The different types of current affect the deposition rate and the depth of penetration. Direct current electrode positive gives the most penetration at a given welding current setting, followed by alternating current, with direct current electrode negative giving the least penetration. However, for a given welding current setting, direct current electrode negative gives the highest deposition rates for covered electrodes followed by alternating current, with direct current electrode positive giving the lowest deposition rates.

PRIMARY VARIABLES

Welding Current

The welding current is the most important factor in determining the characteristics of the weld. The welding current is controlled by a knob or handle on the welding machine. The amount of current used is determined by the type of electrode, size of electrode, position and joint design. The welding current is the best variable to be used



Core Wire Diameter		E6010			E7018			E7024		
Inches	(mm)	Lbs/hr	(Kg/hr)	Amps	Lbs/hr	(Kg/hr)	Amps	Lbs/hr	(Kg/hr)	Amps
3/32	(2.4)	1.3	(.6)	60	1.7	(.8)	90	–	–	–
1/8	(3.2)	2.1	(.9)	100	3.1	(1.4)	150	5.3	(2.4)	150
5/32	(4.0)	3.1	(1.4)	130	4.7	(2.1)	230	6.9	(3.1)	225
3/16	(4.8)	4.0	(1.8)	160	6.5	(3.0)	300	9.5	(4.3)	280
7/32	(5.4)	–	–	–	9.5	(4.3)	350	9.8	(4.5)	320
1/4	(6.4)	–	–	–	9.6	(4.4)	400	12.2	(5.5)	360

Illustration 9-3 – Typical Deposition Rates of Different Sizes of E6011, E7018, and E7024 Electrodes

for controlling the depth of penetration and the volume of the weld metal. As the welding current is increased and the other factors remain constant, the penetration and the deposition rate increases. The size of the weld bead also increases. Excessive weld current can produce large amounts of spatter, undercutting, and an irregular weld deposit. Lowering the welding current while the other factors remain constant will reduce the deposition rate, the amount of penetration, and the size of the weld bead. An extremely low weld current can produce excessive piling up of weld metal and lack of fusion with the base metal. The manufacturers recommend the current ranges that should be used for each type and size of electrode. The effects of the welding current are shown in Illustration 9-4.

Travel Speed



The travel speed is another important factor to consider for controlling the weld characteristics. The travel speed is determined by the welder, who manually controls the rate that the arc travels along the work. Increasing the travel speed while the other variables remain constant, reduces the width of the weld bead and increases the penetration. There is an optimum travel speed where the penetration is maximum. Increasing the travel speed beyond this point will decrease the penetration. Excessive travel speed will produce a weld bead that is too small with an irregular contour. This can produce welds that have too small a cross-section. A very slow travel speed can result in excessive piling up of weld metal and lack of fusion at the edges of the weld. The effects of travel speed are also shown in Illustration 9-4.

Welding Voltage (Arc Length)

The welding voltage is another important variable in shielded metal arc welding. The arc voltage is determined by the arc length between the end of the electrode and the base metal. The arc voltage is controlled manually by the welder who can move the tip of the electrode close to, or away from, the surface of the base metal. As the arc length is increased, the arc voltage increases, whereas decreasing the arc length decreases the arc voltage. The welding voltage



primarily affects the shape of weld bead cross-section and the general appearance of the weld. Increasing the welding voltage produces a wider and flatter weld bead and increases the susceptibility to arc blow. When the arc length is too long, which makes the welding voltage too high, the weld bead can look irregular with poor penetration and spatter. Also, the weld metal may be not properly shielded by the gas from the decomposition of the electrode coating, and much of the heat may be lost to the atmosphere. Decreasing the arc length will produce a stiffer and more easily controlled arc. A very short arc length can cause electrode sticking to the base metal. The effects of too long an arc length are also shown in Illustration 9-4.

SECONDARY VARIABLES

Electrode Angles

The angular position of the electrode in relation to the work, may have an effect on the quality of the weld deposit. The position of the electrode determines the ease at which the filler metal is deposited, freedom from undercutting and slag inclusions, and the uniformity of the bead.

The electrode angles are called the travel angle and the work angle. The travel angle of the electrode is the angle between the joint and the electrode in the longitudinal plane. The work angle is the angle between the electrode and the perpendicular plane to the direction of travel. These are shown in Illustration 9-5. Increasing the travel angle in the direction of welding generally builds up the bead height. A work angle that is too large may result in undercutting. Especially with the low-hydrogen types of electrodes, the electrode angles are important in maintaining weld quality.

GOOD Proper Current Voltage & Speed	BAD Welding Current Too Low	BAD Welding Current Too High	BAD Arc Too Long (Voltage Too High)	BAD Travel Speed Too Fast	BAD Travel Speed Too Slow
					
<i>Cross section Weld Bead</i>	<i>Cross-section Weld Bead</i>	<i>Cross section Weld Bead</i>	<i>Cross section Weld Bead</i>	<i>Cross section Weld Bead</i>	<i>Cross section Weld Bead</i>
					
<i>Face Weld Bead</i>	<i>Face Weld Bead</i>	<i>Face Weld Bead</i>	<i>Face Weld Bead</i>	<i>Face Weld Bead</i>	<i>Face Weld Bead</i>
A smooth, regular, well formed bead. No undercutting, overlapping or piling up. Uniform in cross section. Excellent weld at minimal material and labor cost.	Excessive piling up of weld metal. Overlapping bead has poor penetration. Slow up progress. Wasted electrodes and productive time.	Excessive spatter to be cleaned off. Undercutting along edges weakens joint. Irregular deposit. Wasted electrodes and productive time.	Bead very irregular with poor penetration. Weld metal not properly shielded. An inefficient weld. Wasted electrodes and productive time.	Bead too small, with contour irregular. Not enough weld metal in cross section. Weld not strong enough. Wasted electrodes and productive time.	Excessive piling up of weld metal. Overlapping without penetration at edges. Too much time consumed. Wasted electrodes and productive time.

Illustration 9-4 – Effects of the Welding Variables on the Weld Bead

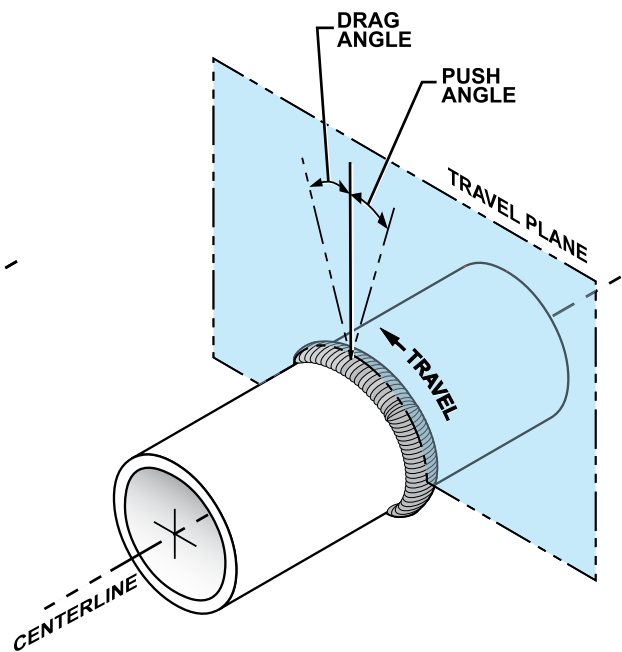
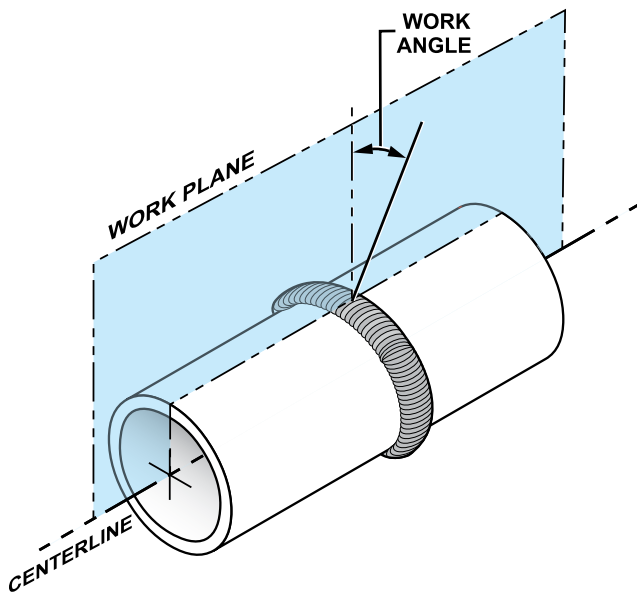
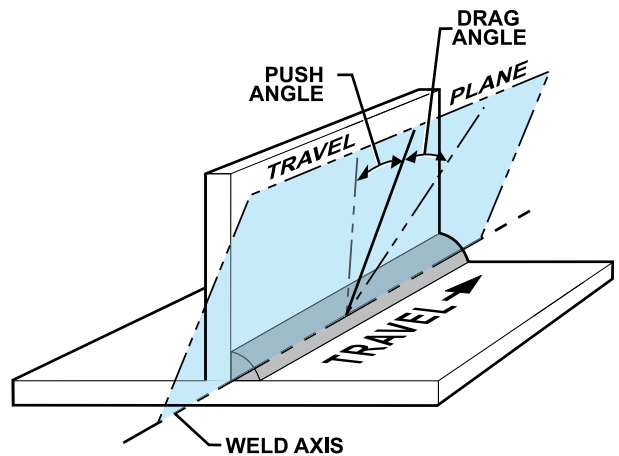
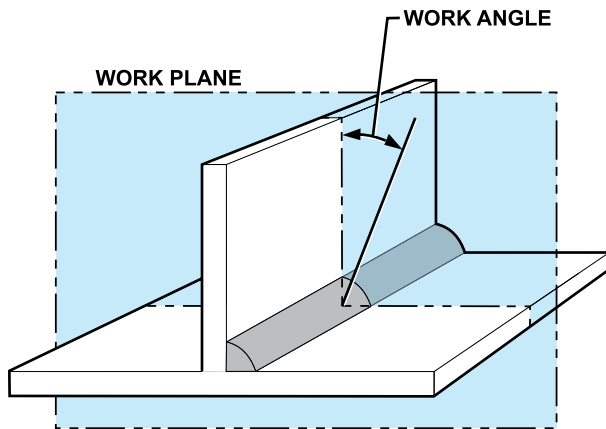
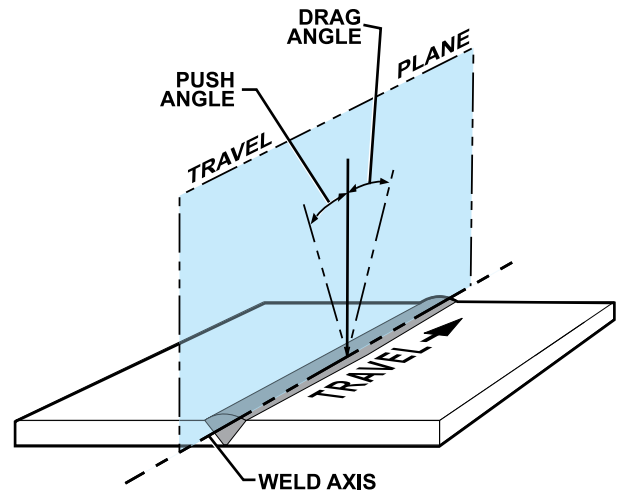
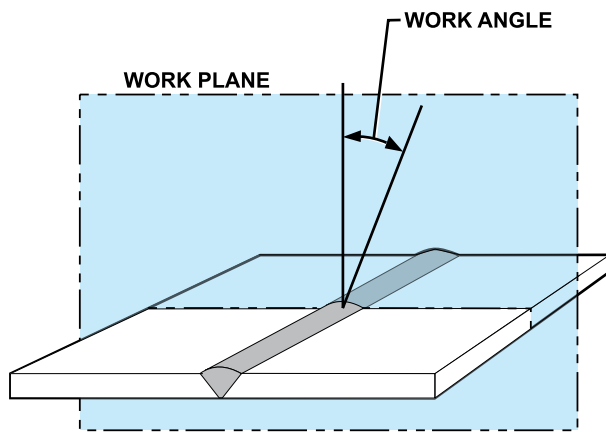


Illustration 9-5 – Travel Angle and Work Angle

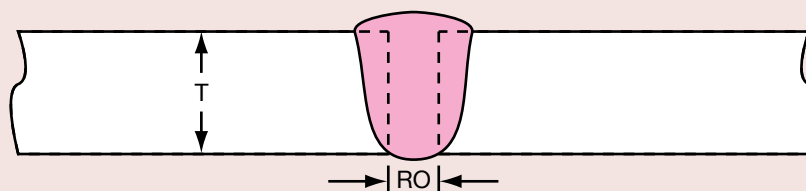
CHAPTER 10

WELDING PROCEDURE SCHEDULES

The welding procedure schedules in this chapter give typical welding conditions that can be used to obtain high quality welds under normal welding conditions. These welding procedure schedules provide only a few examples of the many different welding procedures that can be used. These tables are not the only conditions that can be used because factors such as weld appearances, operator skill and the specific application often require variations from the schedules. As the particular requirements of the application become better known, the settings may be adjusted to obtain the optimum welding conditions. Qualifying tests or trials should be made prior to actual production. The following schedules are based on welding low carbon mild steels with recommended types of mild steel covered electrodes under normal welding conditions.

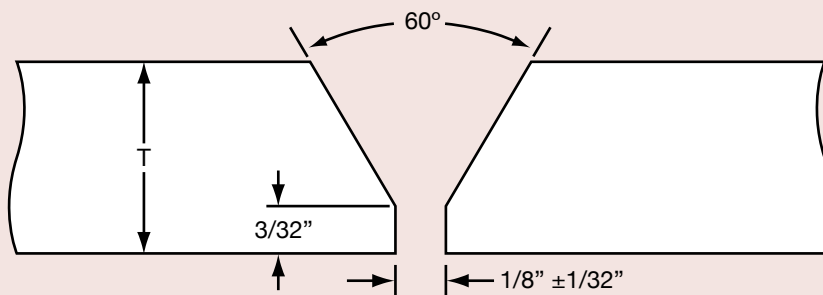
When adjusting or changing the variables for welding, the effect of one variable on the others must be considered. One variable cannot usually be changed very much without adjusting or changing the other variables in order to maintain a stable arc and good overall welding conditions.

The tables are based on the type of weld, base metal thickness, welding position, number of passes, welding current, travel speed, electrode size, and type of covered electrode used. The arc voltage is not included because it depends on the arc length held by the welder, it is not constant and it will vary from welder to welder.



Thickness of Base Metal in. (mm)	Position	Root Opening in. (mm)	Electrode Type	Electrode Diameter in. (mm)	Welding Current	Travel Speed in./min. (mm/s)
1/8 (3.2)	Flat Horizontal	.0 (0)	E6010	3/32 (2.4)	60-80	8-10 (3.4-4.2)
	Vertical Overhead					7-8 (3.0-3.4)
3/16 (4.8)	Flat Horizontal	0-1/16 (0-1.6)	E6010	1/8 (3.2)	110-120	8-10 (3.4-4.2)
	Vertical Overhead					7-8 (3.0-3.4)
1/4 (1.6)	Flat Horizontal	1/16-3/32 (.9)	E6010	5/32 (4.0)	120-140	8-10 (3.4-4.2)
	Vertical Overhead				130-140	7-8 (3.0-3.4)

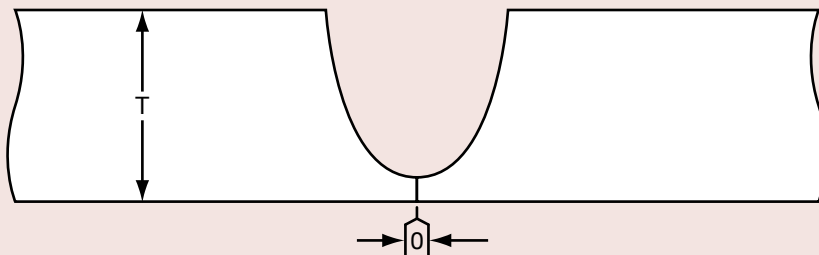
Illustration 10-1 – Square-Groove Welds on Plate from 1/8-1/4 inch (3.2-6.4mm) Thick



First pass put in from back side and its root is gouged or chipped out.

Thickness of Base Metal in. (mm)	Position	Number of Passes	Electrode Type	Electrode Diameter in. (mm)	Welding Current	Travel Speed in./min. (mm/s)
3/8 (9.5)	Flat	3	E6010	3/16 (4.8)	160-175	9-11 (3.8-4.7)
	Horizontal	4	E6010	3/16 (4.8)	160-175	9-11 (3.8-4.7)
			E7018	5/32 (4.0)	170-190	9-11 (3.8-4.7)
	Vertical Up	3	E6010	3/16 (4.8)	150-165	6-7 (2.5-3)
	Overhead	4	E7018	5/32 (4.0)	130-150	7-9 (3.0-3.8)
1/2 (12.7)	Flat	4	E6010	3/16 (4.8)	160-175	9-11 (3.8-4.7)
	Horizontal	6	E6010	3/16 (4.8)	160-175	9-11 (3.8-4.7)
			E7018	5/32 (4.0)	170-190	9-11 (3.8-4.7)
	Vertical Up	3	E6010	3/16 (4.8)	150-165	6-7 (2.5-3)
	Overhead	7	E7018	5/32 (4.0)	130-150	7-9 (3.0-3.8)
5/8 (15.9)	Flat	5	E6010	3/16 (4.8)	160-175	9-11 (3.8-4.7)
	Horizontal	7	E6010	3/16 (4.8)	160-175	9-11 (3.8-4.7)
			E7018	5/32 (4.0)	170-190	9-11 (3.8-4.7)
	Vertical Up	4	E6010	3/16 (4.8)	150-165	6-7 (2.5-3)
	Overhead	10	E7018	5/32 (4.0)	130-150	7-9 (3.0-3.8)

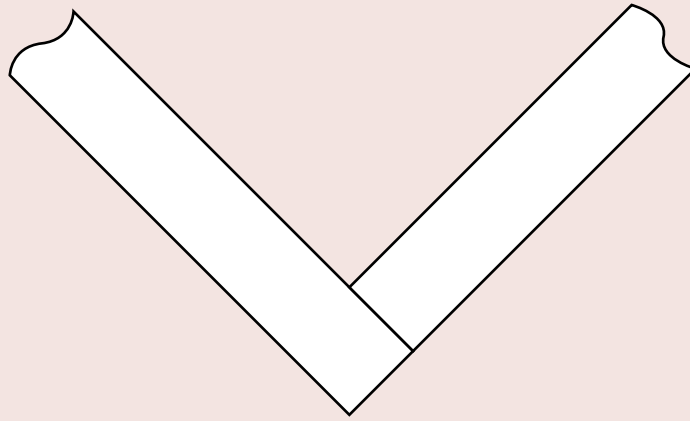
Illustration 10-1 – V-Groove Welds on Plate from 3/8-5/8 inch (3.2-6.4mm) Thick



First pass put in from back side and its root is gouged or chipped out.

Thickness of Base Metal in. (mm)	Position	Number of Passes	Electrode Type	Electrode Diameter in. (mm)	Welding Current	Travel Speed in./min. (mm/s)
1 (25.4)	Flat	9	E7018	1/4 (6.4)	320-350	8-9 (3.4-3.8)
	Horizontal	13	E7018	5/32 (4.0)	160-180	10-12 (4.2-5.1)
	Vertical	11	E6010	3/16 (4.8)	150-165	6-7 (2.5-3)
			E7018	5/32 (4.0)	130-150	6-9 (2.5-3.8)
	Overhead	13	E7018	5/32 (4.0)	130-150	6-9 (2.5-3.8)
2 (51) and over	Flat	25+	E7018	1/4 (6.4)	320-350	8-9 (3.4-3.8)
	Horizontal	35+	E7018	5/32 (4.0)	160-180	10-12 (4.2-5.1)
	Vertical	30+	E6010	3/16 (4.8)	150-165	6-7 (2.5-3)
			E7018	5/32 (4.0)	130-150	6-9 (2.5-3.8)
	Overhead	35+	E7018	5/32 (4.0)	130-150	6-9 (2.5-3.8)

Illustration 10-3 – U-Groove Welds on Plate Greater than 1 inch (25.4mm) Thick



Thickness of Base Metal in. (mm)	Position	Number of Passes	Electrode Type	Electrode Diameter in. (mm)	Welding Current	Travel Speed in./min. (mm/s)
1/4 (6.4)	Flat	1	E7024	5/32 (4.0)	215-225	10-12 (4.2-5.1)
	Horizontal	1	E7024	5/32 (4.0)	215-225	10-12 (4.2-5.1)
	Vertical	1	E7018	5/32 (4.0)	160-180	4-6 (1.7-2.5)
	Overhead	3	E6010	3/16 (4.8)	150-165	6-7 (2.5-3)
			E7018	5/32 (4.0)	130-150	4-6 (1.7-2.5)
1/2 (12.7)	Flat	2	E7024	1/4 (6.4)	370-400	10-12 (4.2-5.1)
	Horizontal	3	E7024	1/4 (6.4)	370-400	10-12 (4.2-5.1)
	Vertical	2	E7018	5/32 (4.0)	160-180	4-6 (1.7-2.5)
	Overhead	4	E6010	3/16 (4.8)	150-165	6-7 (2.5-3)
			E7018	5/32 (4.0)	130-150	4-6 (1.7-2.5)
3/4 (19.1)	Flat	4	E7024	1/4 (6.4)	370-400	10-12 (4.2-5.1)
	Horizontal	6	E7024	1/4 (6.4)	370-400	10-12 (4.2-5.1)
	Vertical	5	E7018	5/32 (4.0)	160-180	4-6 (1.7-2.5)
	Overhead	7	E6010	3/16 (4.8)	150-165	6-7 (2.5-3)
			E7018	5/32 (4.0)	130-150	4-6 (1.7-2.5)

Illustration 10-4 – Fillet Welds

CHAPTER 11

PREWELD PREPARATIONS

Several operations may be required before making a weld. These include: preparing the weld joint, setting up or fixturing the weldment, setting the variables, and in some cases preheating. The amount of preweld preparation depends upon the size of the weld, the material to be welded, the ease of fit-up, the quality requirements, the governing code or specification, and the welder.

PREPARING THE WELD JOINT

There are different ways of preparing the edge of the joint for welding. Joints for fillet or square groove welds are prepared simply by squaring of the edges of the members to be welded, if the as-received edge is not suitable. Common types of machined bevels are V-, U-, J-, bevel-, and combination-grooves. The more complex the type of bevel, the longer the edge preparation takes and the more expensive it becomes. The methods that are the most often used for edge preparation are oxygen fuel gas cutting, shearing, machining, air carbon-arc gouging, grinding, chipping, and plasma arc cutting. Plasma arc cutting is widely used for the cutting and beveling of stainless steels and nonferrous metals.

V-groove and single-bevel-grooves are the types of grooves most often used because they can easily be prepared by oxygen fuel cutting. If correctly done, this process leaves a smooth surface with a scale that can be easily removed. The edges of U-grooves can be done by using special types and techniques, or by machining which will produce a more uniform groove.

To produce good quality welds, the surfaces of the weld joint should be clean of rust, scale, dirt, oil and grease. Grinding is useful for removing rust and scale including the scale left by oxyacetylene cutting and other related processes. Grease and oil must be removed from the joint surfaces by wiping or by the use of degreasers. Scale, rust, dirt, oil, and grease can contaminate the weld metal and cause defects in the weld.

FIXTURING AND POSITIONING

Fixtures and jigs are devices that are used to hold the parts to be welded in proper relation to each other. This alignment is called fit-up. Good fit-up is required for obtaining high quality welds. Poor fit-up increases the welding time and is the cause of many poor quality welds. The size of the root opening has an effect on the speed at which the welding of the root pass can be accomplished. Root openings are used so that full penetration welds can be made. Root passes in joints with a proper root opening can be welded much faster than joints that have ex-

cessive root opening. Fixtures and jigs are used for three major purposes which are:

- 1) To minimize distortion that is caused by welding heat
- 2) To minimize fit-up problems
- 3) To increase the welding efficiency of the welder

When a welding fixture or a jig is employed, the components of a weldment can be assembled and securely held in place while the weldment is positioned and welded. The use of those devices is dependent on the specific application. These devices are more often used when large numbers of same parts are produced. When fixtures and jigs can be used, the production time for the weldments can be greatly reduced.

Positioners are used to move the workpiece into a position so that welding can be done more conveniently. Positioning is sometimes needed simply to make the weld joint accessible. The main objective of positioning is to put the joint in the flat or other more favorable position which increases the efficiency of the welder because higher welding speeds can be used. Flat position welding usually increases the quality of the weld because it makes the welding easier.

PREHEATING

The use of preheat is sometimes needed, depending on the type of metal being welded, the base metal thickness, and the amount of joint restraint. These factors were discussed in Chapter 7. The specific amount of preheat needed for a given application is often obtained from the welding procedure.

The preheat temperature of the base metal is often carefully controlled. Several good methods of doing this are: furnace heating, electric induction coils, and electric resistance heating blankets. On thin metals, hot air blasts or radiant lamps may be used. With these methods temperature indicators are connected to parts being preheated. Another method of preheating is using torches. These give more localized heating than the previously mentioned methods, and when using torches for preheating it is important to avoid localized overheating and deposits of incomplete combustion products from collecting on the surface of the parts to be welded. Colored chalks and pellets are often used to measure the temperature of the preheat. These melt at a specific predetermined temperature. Another method of measuring the temperature is by using a hand held temperature indicator. These can give meter readings, digital readings or recorder readings depending on the type of temperature indicator.

CHAPTER 12

WELDING DISCONTINUITIES AND DEFECTS

Shielded metal arc welding, like other welding processes, has welding procedure problems that may develop which can cause defects in the weld. Some defects are caused by problems with the materials. Other welding problems may not be foreseeable and may require immediate corrective action. A poor welding technique and improper choice of welding parameters can cause weld defects. Defects that can occur when using the shielded metal arc welding process are slag inclusions, wagon tracks, porosity, piping porosity, undercutting, lack of fusion, overlapping, burn through, arc strikes, craters, and excessive weld spatter. Many of these welding technique problems weaken the weld and can cause cracking. Other problems that can occur which can reduce the quality of the weld are arc blow, fingernailing, and improper electrode coating moisture contents.

DEFECTS CAUSED BY WELDING TECHNIQUE

Slag Inclusions

Slag inclusions occur when slag particles are trapped inside the weld metal which produces a weaker weld. These can be caused by:

- 1) Erratic travel speed
- 2) Too wide a weaving motion
- 3) Slag left on the previous weld pass
- 4) Too large an electrode being used
- 5) Letting slag run ahead of the arc

This defect can be prevented by:

- 1) A uniform travel speed
- 2) A tighter weaving motion
- 3) Complete slag removal before welding
- 4) Using a smaller electrode
- 5) Keeping the slag behind the arc, which is done by shortening the arc, increasing the travel speed, or changing the electrode angle



Illustration 12-1
Slag Inclusion



Illustration 12-2
Wagon Tracks

Wagon Tracks

Wagon tracks are linear slag inclusions that run the longitudinal axis of the weld. They result from allowing slag to run ahead of the weld puddle and by slag left on the previous weld pass. These occur at the toe lines of the previous weld bead.

Porosity

Porosity is gas pockets in the weld metal that may be scattered in small clusters or along the entire length of the weld. Porosity weakens the weld in approximately the same way that slag inclusions do. Porosity may be caused by:

- 1) Excessive welding current
- 2) Rust, grease, oil or dirt on the surface of the base metal
- 3) Excessive moisture in the electrode coatings
- 4) Impurities in the base metal, such as sulfur and base metal phosphorous
- 5) Too short an arc length except when using low-hydrogen or stainless steel electrodes
- 6) Travel speed too high which causes freezing of the weld puddle before gases can escape

This problem can be prevented by:

- 1) Lowering the welding current
- 2) Cleaning the surface of the base metal
- 3) Redrying electrodes
- 4) Changing to a different base metal with a different composition
- 5) Using a slightly longer arc length
- 6) Lowering the travel speed to let the gases escape
- 7) Preheating the base metal, using a different type of electrode, or both



Illustration 12-3
Piping Porosity

Piping Porosity

Piping porosity is the name given to elongated gas pockets and is usually caused by sulfur or moisture trapped in the weld joint. The best method of preventing this is to lower the travel speed to permit gases to escape before the weld metal freezes.



Illustration 12-4
Undercutting

Undercutting

Undercutting is a groove melted in the base metal next to the toe or root of a weld that is not filled by the weld metal. Undercutting causes a weaker joint and it can cause cracking. This defect is caused by:

- 1) Excessive welding current
- 2) Too long an arc length
- 3) Excessive weaving speed
- 4) Excessive travel speed

On vertical and horizontal welds, it can also be caused by too large an electrode size and incorrect electrode angles. This defect can be prevented by:

- 1) Choosing the proper welding current for the type and size of electrode and the welding position
- 2) Holding the arc as short as possible
- 3) Pausing at each side of the weld bead when a weaving technique is used
- 4) Using a travel speed slow enough so that the weld metal can completely fill all of the melted out areas of the base metal

Incomplete Fusion



Illustration 12-5 – Incomplete Fusion

Incomplete fusion is when the weld metal is not fused to the base metal. This can occur between the weld metal and the base metal or between passes in a multiple pass weld. Causes of this defect can be:

- 1) Excessive travel speed
- 2) Electrode size too large
- 3) Welding current too low
- 4) Poor joint preparation
- 5) Letting the weld metal get ahead of the arc

Incomplete fusion can usually be prevented by:

- 1) Reducing the travel speed
- 2) Using a smaller diameter electrode
- 3) Increasing the welding current
- 4) Better joint preparation
- 5) Using a proper electrode angle



Illustration 12-6
Overlapping

Overlapping

Overlapping is the protrusion of the weld metal over the edge or toe of the weld bead. This defect can cause an area of lack of fusion and create a notch which can lead to crack initiation. Overlapping is often produced by:

- 1) Too slow a travel speed which permits the weld puddle to get ahead of the electrode

- 2) An incorrect electrode angle that allows the force of the arc to push the molten weld metal over unfused sections of the base metal
- 3) Welding away from the ground connection with large electrodes like the E6020, E6027, E7024, and E7028 which have very fluid weld puddles.

Overlapping can be prevented by or corrected by:

- 1) A higher travel speed
- 2) The electrode angle should be such that the force of the arc does not push the molten metal out of the weld puddle and over the cold base metal
- 3) Grinding off excess weld metal

Melt-Through

Melt-through is when the arc melts through the bottom of the weld. This can be caused by:

- 1) Excessive welding current
- 2) Too slow a travel speed
- 3) Too wide of a root gap

This can be prevented by:

- 1) Reducing the welding current
- 2) Increasing the travel speed
- 3) Reducing the size of the root gap

Arc Strikes

Many codes prohibit striking the arc on the surface of the work-piece. Striking the arc on the base metal outside of the weld joint can produce a hard spot on the base metal surface. Failures can then occur due to the notch effect. The arc strikes might create a small notch on the surface of the metal which can act as an initiating point for cracks.



Illustration 12-7
Arc Strikes

Craters

Weld craters are a depression on the weld surface at the point where the arc was broken. These are caused by the solidification of the metal after the arc has been broken. The weld crater often cracks and can serve as an origin for linear cracking back into the weld metal or into the base metal. These craters can usually be removed by chipping or grinding and the depression can be filled in with a small deposit of filler metal. The best way of preventing weld craters is to reverse the travel of the electrode a little way back into the weld bead from the end of the weld bead before breaking the arc.

Excessive Spatter

Excessive spatter gives the weld a poor appearance, wastes electrodes, gives difficult slag removal and can lead to lack of fusion in the case of multiple pass welds. If the spatter is coarse, it is usually produced by an arc length that is too long. If the spatter is fine, it is usually caused by too high a welding current. Spatter can be removed by grinding or prevented by using a shorter arc length and lower welding currents.



Illustration 12-8
Excessive
Spatter

Distortion and Warpage

Distortion and warpage are caused by the nonuniform expansion and contraction of weld and base metal during the heating and cooling process of welding. If warpage changes the required dimensions of the total weldment, the weldment may not be acceptable. Methods to reduce distortion and warpage are:



Illustration 12-9
Distortion

- 1) Deposit only the required amount of weld metal.
- 2) Alternate sides or sequence welds.
- 3) Preset parts to compensate for distortion.

Inadequate Joint Penetration

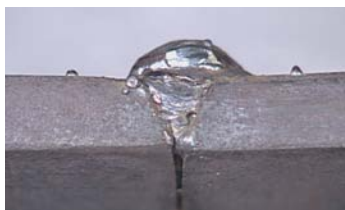


Illustration 12-10
Inadequate Joint Penetration

Inadequate joint penetration is commonly located at the root of the weld and is caused by an insufficient heat input while welding. Insufficient heat input can be caused by too low amperage, too much electrode stickout,

or too fast a travel speed. Inadequate joint penetration can also be caused by improper joint design or incorrect preparation of the joint edges. A tight root opening or a small groove angle restricts the weld metal causing lack of penetration at the root. To prevent this problem, insure that enough heat is being used on a properly designed joint and that the welder or operator has the skill necessary to produce the desired weld.

CRACKING

Cracking may be caused by an improper welding procedure, welder technique, or materials. All types of cracking can be classified as either hot cracking or cold cracking and these cracks can be oriented transversely or longitudinally to the weld.

Transverse cracks are perpendicular to the axis of the weld where longitudinal cracks are parallel to the axis of the weld. Transverse cracks are often the result of longitudinal shrinkage strains acting on excessively hard and brittle weld metal. Longitudinal cracks are often caused by high joint restraint and high cooling rates.

Hot cracking is a defect that occurs at higher temperatures and generally happens just after the weld metal starts to solidify. This type of cracking is often caused by excessive sulfur, phosphorous, and lead contents in the base metal. It can also occur because of an improper method of breaking the arc or in a root pass, when the cross sectional area of the weld bead is small compared to the mass of the base metal.

Hot cracking often occurs in deep penetrating welds and it can continue through successive layers if it is not repaired. Hot cracking may be prevented or minimized by:

- 1) Preheating
- 2) Using low-hydrogen electrodes
- 3) Increasing the cross sectional area of the weld bead
- 4) Changing the contour of the weld bead
- 5) Using base metal with very low sulfur, phosphorous, and lead contents

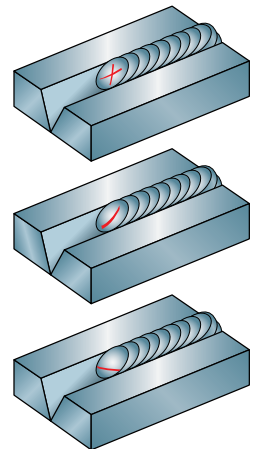


Illustration 12-11
Crater Cracks

Crater cracks are shallow hot cracks that are caused by improperly breaking the arc. Several types of these are shown in Illustration 12-11.

Crater cracks may be prevented the same way that craters are by reversing the travel of the electrode a little way back into the weld from the end of the weld before breaking the arc.

Cold cracking occurs after the weld metal solidification is complete. Cold cracking may occur several days after welding and is generally caused by hydrogen embrittlement, excessive joint restraint, and rapid cooling. Preheating and the use of low-low-hydrogen electrodes help reduce this problem.

Centerline cracks are cold cracks that often occur in single pass concave fillet welds. A longitudinal crack is a centerline crack that runs down the center of the weld as shown in Illustration 12-12.



Illustration 12-12
Longitudinal
Crack

This problem may be caused by:

- 1) Too small a weld bead for the thickness of the base metal
- 2) Poor fit-up
- 3) High joint restraint
- 4) Extension of a crater crack

The major methods of preventing centerline cracks are:

- 1) Increasing the bead size
- 2) Decreasing the gap width
- 3) Positioning the joint slightly uphill
- 4) Preventing weld craters

Base metal and underbead cracks are cold cracks that form in the heat affected zone of the base metal. Underbead cracks occur underneath the weld bead as shown in Illustration 12-13.

Base metal cracks are those cracks that originate in the heat affected zone of the weld. These types of cracking are caused by excessive joint restraint, hydrogen, and a brittle microstructure. A brittle microstructure is caused by rapid cooling or excessive heat input. Underbead and base metal cracking can be reduced or eliminated by using preheat and low-hydrogen electrodes.

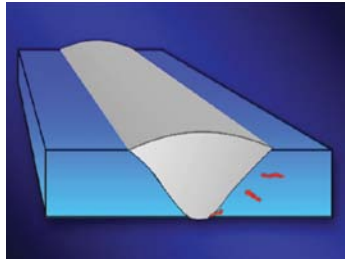


Illustration 12-13
Underbead Cracks

OTHER PROBLEMS

Arc Blow

The electric current that flows through the electrode, workpiece, and ground cable sets up magnetic fields in a circular path that is perpendicular to the direction of the current. When the magnetic fields around the arc are unbalanced, it tends to bend away from the greatest concentration of the field. This deflection of the arc is called arc blow. Deflection is usually in the direction of travel or opposite it, but it sometimes occurs to the side. Arc blow can result in excessive weld spatter and lack of fusion.

Direct current is highly susceptible to arc blow especially when welding is being done in corners and near the end of joints. Arc blow also occurs when welding complex structures and on massive structures with high currents and poor fit-up. Arc blow occurs with direct current because the induced magnetic field is in one direction. Alternating current rarely is subject to arc blow because the magnetic field is building and collapsing all the time due to the reversing current. Forward arc blow is encountered when welding away from the ground connection or at the beginning of the weld joint. Backward arc blow occurs toward the ground connection, into a corner, or toward the end of a weld joint. There are several corrective methods that can be used to correct the arc blow problem which are:

- 1) Changing to alternating current
- 2) Welding towards an existing weld or a heavy tack weld
- 3) Placing the work connection as far as possible from the weld, at the end of the weld or at the start of the weld and weld toward a heavy tack weld
- 4) Reducing the welding current and making the arc length as short as possible
- 5) Wrapping the work lead around the workpiece so that the magnetic field caused by the current in the ground cable will neutralize the magnetic field causing the arc blow

AWS Classification		Electrode Designation		Limit of Moisture Content, % by Wt, Max	
A5.1	A5.1M	A5.1	A5.1M	As-Received or Conditioned ^a	As-Exposed ^b
E6018	E4318	E6018	E4318	0.6%	Not Specified
E7015	E4915	E7015	E4915		
E7016	E4916	E7016	E4916		
		E7016-1	E4916-1		
E7018	E4918	E7018	E4918		
		E7018-1	E4918-1		
E7028	E4928	E7028	E4928		
E7048	E4948	E7048	E4948		
E6018	E4318	E6018R	E4318R	.0.3%	0.4
E7015	E4915	E7015R	E4915R		
E7016	E4916	E7016R	E4916R		
		E7016-1R	E4916-1R		
E7018	E4918	E7018R	E4918R		
		E7018-1R	E4918-1R		
E7028	E4928	E7028R	E4928R		
E7048	E4948	E7048R	E4948R		
E7018M	E4918M	E7018M	E4918M	0.1	0.4

a) As-received or conditioned electrode coverings shall be tested as specified in AWS A5.1/A5.1M, Section 16, Moisture Test.

b) As-exposed electrode coverings shall have been exposed to a moist environment as specified in AWS A5.1/A5.1M, Section 17 before being tested as specified in Section 16.

Illustration 12-14 – Moisture Content Limits in Electrode Coverings

Improper Moisture Content

The coatings of all covered electrodes contain a certain amount of moisture. An incorrect moisture content in an electrode coating can cause operating problems with the electrode. Some typical coating moisture contents of various mild steel electrode coatings are shown in Illustration 12-14.

The E6010 and E6011 electrodes have a relatively high moisture content in their coverings. These electrodes can operate fairly well when the moisture content is above the maximum limit, but an excessive amount of moisture in these electrode coatings can cause blistering of the coatings and poor arc operation. A low moisture content will cause the electrodes to give excessive amounts of spatter and possibly porosity. Too much moisture in the coatings of the other types of electrodes can cause blistering of the coating, poor arc operation, and underbead cracking.

The E7015R, E7016R, E7018R, E7028R, and E7048R have a relatively low moisture content in their coverings. Covered electrodes should always be stored in dry places. A high moisture content in low hydrogen electrode coatings will damage the quality of the weld deposit. Re-drying is often done after a long storage period except on the cellulose electrodes where it is generally not recommended.

Fingernailing

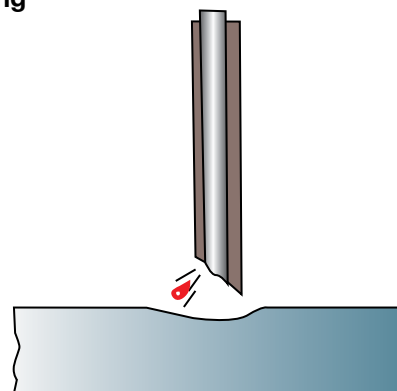


Illustration 12-15 – Fingernailing

Fingernailing is the name given to the burning off of an electrode faster on one side than on the other. This condition can be aggravated if the coating is not concentric with the core wire. Fingernailing is shown in Illustration 12-15. Arc blow is a more frequent cause of fingernailing than off-center electrodes. When welding with lower than normal current, fingernailing will appear because there is insufficient arc force to overcome minor arc blow.

CHAPTER 13 POSTWELD PROCEDURE

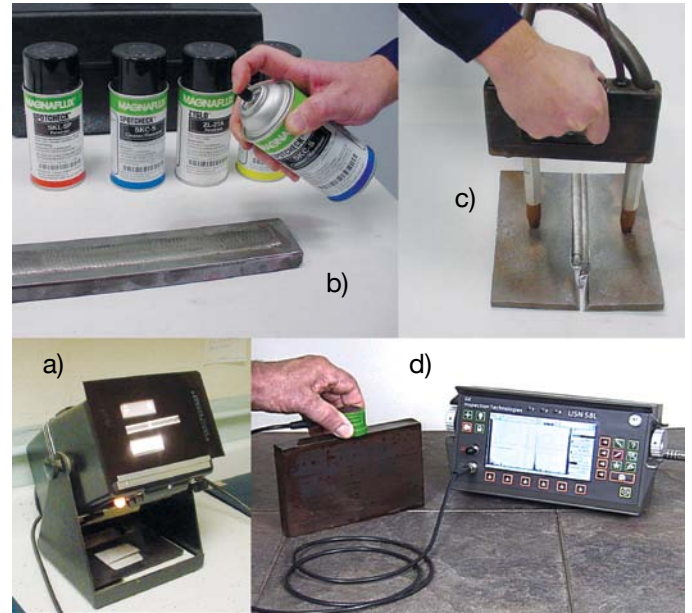
There are several operations that may be done after the weld such as cleaning, inspection, repairing of welds, straightening, and postheating. These are items which may or may not be done after welding, depending on the specific application of the welding. The first postweld procedure will be to clean the slag off the weld bead. Other postweld procedures might call for cleaning, inspecting the weld for defects, straightening and postheating.

CLEANING

After the weld bead has been deposited and the arc broken, the clean up process begins. The slag covering is removed either by chipping or some other form of slag removal. This is particularly important when making multiple-pass welds. Complete removal of the slag for multiple pass welds prevents slag inclusions, porosity and lack of fusion in the weld. After the slag has been removed, a grinder is often used to grind the surface of the weld to give a more uniform surface. A wire brush is often used also to clean up the surface of the weld.

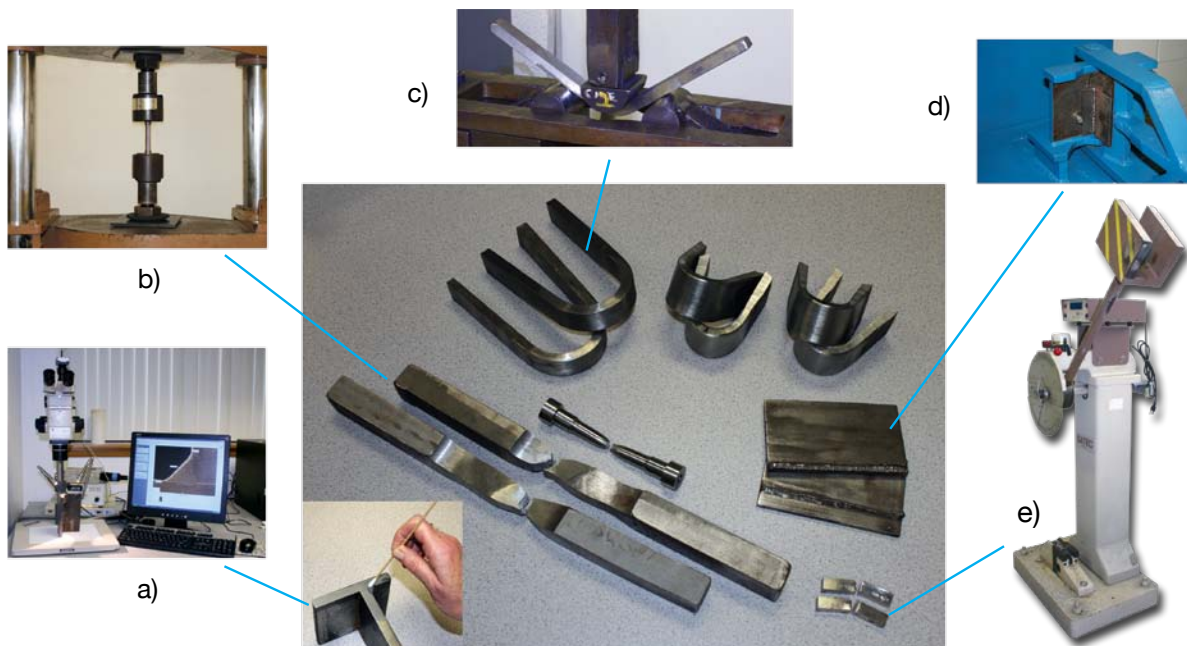
INSPECTION AND TESTING

Inspection and testing of the weld is done after cleaning to determine the quality of the weld joint. There are many different methods of inspection and testing which will not be covered in detail in this book. The use of these methods will often depend on the code or specification that covered the welding. Testing of a weldment may be done nondestructively or destructively.



**Illustration 13-2 – Nondestructive Testing Methods –
a) Radiographic, b) Penetrant, c) Magnetic Particle,
and d) Ultrasonic Testing**

Nondestructive testing is used to locate defects in the weld and base metal. There are many different nondestructive testing methods. Some of the most widely used methods are visual, magnetic particle, liquid penetrant, ultrasonic, and radiographic. Visual, magnetic particle, and liquid penetrant inspection are used to locate surface defects where ultrasonic and radiographic inspection are used to locate internal defects.



**Illustration 13-1 – Destructive Testing Methods –
a) Etched Cross-Section, b) Tensile Strength, c) Guided Bend, d) Fillet Weld Break, and e) Impact Testing**

Destructive testing is used to determine the mechanical properties of the weld such as the strength, ductility, and toughness. Destructive testing is also done by several methods, depending on the mechanical properties being tested for. Some of the most common types of destructive testing are tensile bar tests, impact tests, and bend tests.

REPAIRING OF WELDS

Repair of the weld metal is sometimes necessary when defects are found. The defects may be discovered by visual inspection and by other nondestructive testing methods. Where a defect is found, it is usually ground out or gouged out. Using a grinder is usually better for surface defects and for defects fairly near the surface of the weld metal. For deeper lying defects, an air carbon-arc gouging torch or some other similar gouging method is often used for removal. Once the defects have been removed, the low areas created by the grinding and gouging can be filled in using the shielded metal arc process. The parts are then reinspected to make sure that the defects have been properly repaired.

POSTHEATING

Postheating is the heat treatment applied to the metal after welding. Postheating is often required after the weld has been completed, but this depends upon the type of metal being welded, the specific application, and the governing codes or specifications. There are various types of postheating which are used to obtain specific properties. Some of these postheats are annealing, stress relieving, normalizing, and quenching and tempering. Postheating is done with many of the same methods that are used for preheating such as furnace heating, induction coils, and electric resistance heating blankets. One method that is used for stress relieving that does not involve heating, is called vibratory stress relief. This method does not use heating because the part being stress relieved is vibrated mechanically to relieve the residual stresses.

Annealing is a process involving heating and cooling that is usually applied to induce softening. There are different kinds of annealing, but when it is applied to ferrous alloys, it is called full annealing. Full annealing is a softening process in which a ferrous alloy is heated to a temperature above the transformation range and slowly cooled to a temperature below the transformation range. This is usually done in a furnace.

Stress relieving is the uniform heating of a structure to a high enough temperature, below the critical range, to relieve most of the residual stresses due to welding. This is followed by uniform cooling. The terms normalizing and annealing are often misnomers for this application.

Normalizing is a process where a ferrous alloy is heated to a temperature above the transformation range and is then cooled in still air to a temperature below the transformation range.

Quenching and tempering is another postweld heat treatment commonly used. The metal is heated and then quenched to provide a very hard and brittle metallurgical structure. The part is then tempered by reheating to a particular temperature dependent upon the degree of ductility, tensile strength, yield strength, and hardness required.

After welding with the shielded metal arc process, postheating is often required. For many applications, heat treating of low-carbon steels after welding is unnecessary. The medium-carbon steels usually use postheating from 1100 to 1200°F (590 to 650°C) to remove the brittle microstructure that may have been caused by too rapid cooling. High-carbon steels are often stress relieved at 1200°F (650°C) to relieve internal stresses. The various low alloy steels often require stress relieving from 1100-1250°F (590-680°C). Stainless steels are often post-weld heat treated to reduce the grain size and preserve good corrosion resistance. Annealing is used to reduce the grain size which gives better ductility. The temperatures used depend on the specific stainless steel.



Illustration 13-3 – Annealing



Illustration 13-4 – Stress Relieving

CHAPTER 14

WELDER TRAINING AND QUALIFICATION

WELDER TRAINING

Shielded metal arc welding generally requires a high degree of welder skill to produce good quality welds. As a result, many training programs emphasize this process in their training schedule. A welder that is skilled in this process generally has much less trouble learning to weld with the other arc welding processes.

The exact content of a training program will vary depending on the specific application of the process. The training program should be flexible enough so that it can be adapted to changing needs and applications. Emphasis may be placed on certain areas of the training schedule because of this. The complexity of the parts to be welded and the governing codes or specifications involved also dictate the length of such a training program.

The United States Department of Labor published a book entitled "Dictionary of Occupational Titles" that describes the duties of the different job titles for welders. The training programs used to develop the entry level skills for these job titles may vary depending on the amount of skill required. For instance, a pipe welder would need more skill than a tack welder, so the length of a training program for a pipe welder would be greater than the length of a training program for a tack welder.

The job title of arc welder (DOT 810.384-014) describes a person who has the duty of welding together components of many products made of metal. This job includes setting up the machine and part to be welded, striking the arc and guiding it along the joint, and performing duties such as chipping, grinding, and slag removal. The welder should be able to weld in all positions, be able to pass employer performance tests, and meet certification standards of governmental agencies or professional and technical associations.

A tack welder (DOT 810.684-010) makes short beads at specified points to hold the parts in place for final welding. The tack welder also performs the duties of fitter helper.

A production line welder (DOT 819.684-010) welds previously set up parts on a production line. The production line welder may also perform tack welding.

A combination welder (DOT 819.384-010) welds metal parts together to fabricate or repair the assembly. The combination welder uses both gas welding and any combination of arc welding processes. Other duties include set up of parts, cutting, grinding, and other related tasks. A combination welder may be required to pass employer performance tests to meet certification standards of governmental agencies or professional and technical associations.



Illustration 14-1 – Basic Shielded Metal Arc Welding

The welder portion of pipefitter (DOT 862.381-018) is a person who welds the pipe together after it has been located and tacked in place.

Basic Shielded Metal Arc Welding

The basic shielded metal arc welding training program is used to teach the student the basic entry level skills required for the job titles of arc welder, tack welder, production line welder, and the arc welder portion of combination welder. This course provides training on how to strike an arc, run weld beads, make good quality fillet welds, and an introduction to making groove welds. The training obtained by the student should give him enough skill to get a job as a tack welder, production line welder, and for many of the simple arc welding jobs. This course should also provide the background skill required to take an advanced shielded metal arc welding course. The following is an outline for an approximately 140 hour course:

- 1) Shielded Metal Arc Welding Basic, Course Overview
- 2) Introduction to Shielded Metal Arc Welding
- 3) Safety and Health of Welders
- 4) The Five Essentials
- 5) Striking & Controlling the Arc
- 6) Pad of Beads, Flat Position & Crater Filling
- 7) Fillet Weld, Lap Joint, Horizontal Position
- 8) Pad of Beads, Flat Position (E6010)
- 9) The Welder's Role in Quality Control
- 10) Three-Bead Fillet Weld, T-joint, Horizontal Position

- 11) Fillet Weld, T-joint, Horizontal Position, Destructive Test
- 12) Pad of Beads, Horizontal Position (E6010)
- 13) Square-Groove Weld, Butt Joint, Horizontal Position
- 14) Square-Groove Weld, Butt Joint, Horizontal Position, Destructive Test
- 15) Electrode Selection
- 16) Fillet Weld, Lap Joint, Vertical Position, Up
- 17) Fillet Weld, T-joint, Vertical Position, Up
- 18) Three-Bead Fillet Weld, T-joint, Vertical Position Up, with 2 Weave Beads
- 19) Square-Groove Weld, Butt Joint, Vertical Position, Up
- 20) Square-Groove Weld, Butt Joint, Vertical Position, Up, Destructive Test
- 21) Power Sources
- 22) Fillet Weld, Lap Joint, Overhead Position
- 23) Three-Bead Fillet Weld, T-joint, Overhead Position
- 24) Fillet Weld, T-joint, Overhead Position, Destructive Test
- 25) Square-Groove Weld, Butt Joint, Overhead Position
- 26) Distortion Control
- 27) Fillet Weld, Lap & T-joints, Horizontal & Vertical Positions
- 28) Stringer Beads, Flat, Horizontal & Vertical Positions
- 29) Fillet Weld, Lap Joint, Vertical Position, Down
- 30) Square-Groove Weld, Butt Joint, Flat Position; Fillet Welds Lap & T-joints, Horizontal Position (E7024)
- 31) The Low Hydrogen Electrode and Its Uses
- 32) Multi-Pass Fillet Weld, T-joint, Vertical Position, Up (E7018)
- 33) Multi-Pass Fillet Weld, T-joint, Horizontal Position (E7018)
- 34) Multi-Pass Fillet Weld, T-joint, Flat, Horizontal, Vertical & Overhead Positions (E7018)
- 35) Multi-Pass Fillet Weld, Lap Joint, Horizontal Position, (E7018 & E7024)
- 36) AWS QC10 2G Qualification Test
- 37) AWS QC10 3G Qualification Test
- 38) AWS QC10 Destructive Test

Advanced Shielded Metal Arc Welding

The prerequisites for the advanced shielded metal arc welding course should be successful completion of the basic shielded metal arc welding course or equivalent welding training or experience. The purpose of this course is to develop the entry level skills for arc welder, production line welder, tack welder and the arc welding portion of combination welder. This course provides the skill training required for the student to make good quality fillet and multiple pass groove welds. This includes learning to use the proper weld bead sequence and welding grooved joints in all positions. A student who successfully completes this course should be able to do more complicated arc welding jobs on plate material. The following is approximately a 140 hour course outline for advanced shielded metal arc welding:

- 1) Lecture/Discussion, "Introduction"
- 2) Lecture/Discussion, "Safety and Health of Welders"
- 3) Fillet Weld, Lap Joint, Horizontal Position
- 4) Lecture/Discussion, "Air Arc Cutting and Gouging"
- 5) Fillet Weld, Lap Joint, Overhead Position
- 6) Lecture/Discussion, "Procedure and Welder Qualification"
- 7) Fillet Weld, Lap Joint, Vertical Position, Up Hill Travel
- 8) Lecture/Discussion, "Destructive Testing"
- 9) Fillet Weld, Lap Joint, Cross Section Etch Test
- 10) Lecture/Discussion, "Nondestructive Testing"
- 11) Single V-Groove Weld, Butt Joint, Horizontal Position
- 12) Single V-Groove Weld, Butt Joint, Overhead Position
- 13) Single V-Groove Weld, Butt Joint, Overhead Position, Guided Bend Test
- 14) Lecture/Discussion, "Metals Identification for Welding"
- 15) Single V-Groove Weld, Butt Joint, Vertical Position
- 16) Single V-Groove Weld, Butt Joint, Vertical Position, Guided Bend Test
- 17) Lecture/Discussion, "Welding of Cast Iron and Surfacing of Steel"
- 18) Single V-Groove Weld, Butt Joint, Flat Position
- 19) Fillet Weld, Lap Joint, All Positions

Shielded Metal Arc Pipe Welding



Illustration 14-2 – Shielded Metal Arc Welding Pipe

The prerequisites for the shielded metal arc pipe welding should be to have successfully completed the basic and advanced shielded metal arc welding courses or have equivalent welding training or experience. The pipe welding is divided into two categories which are uphill and downhill pipe welding. The purpose of these courses is to develop the entry level skills required for the welder portion of pipefitter. Since pipe welding is more difficult than plate welding, the student should be proficient in welding groove joints in plate in all positions before starting pipe welding. Shielded metal arc pipe welding, uphill method is used on power plant, refinery, and chemical installation construction. This course covers pipe welding in the 2G, 5G, and 6G positions on mild steel pipe. An outline for approximately a 210 hour course is as follows:

- 1) Lecture/Discussion, "Introduction to Up Hill Pipe Welding"
- 2) Lecture/Discussion, "Safety and Health of Welders"
- 3) Prerequisite Skill Test, Single Groove Weld, Butt Joint, Vertical and Overhead Positions
- 4) Lecture/Discussion, "How to Read and Apply Pipe Welding Procedures"
- 5) Preparation and Assembly of a Pipe Joint
- 6) Lecture/Discussion, "Weld Quality: Reading the Puddle"
- 7) Single Groove Weld, Butt Joint, Horizontal Fixed Position (5G)
- 8) Single V-Groove Weld, Butt Joint, Horizontal Fixed Position (5G), Visual Inspection

- 9) Single V-Groove Weld, Butt Joint, Vertical Fixed Position (2G)
- 10) Single V-Groove Weld, Butt Joint, Vertical Fixed Position (2G), Visual Inspection
- 11) Lecture/Discussion, "Preheat and Interpass"
- 12) Single V-Groove Weld, Butt Joint, 45° Fixed Position (6G)
- 13) Single V-Groove Weld, Butt Joint, 45° Fixed Position (6G), Guided Bend Test

In addition to the basic course outline, topics covering the welding of stainless steel pipe and the use of backing rings may be covered. Both of these are specialty items that are commonly welded by the uphill pipe welding method and are covered for use on special applications. Each of these items consists of approximately 70 hours additional training time.

The downhill pipe welding method is primarily used on cross country transmission pipelines. This course covers welding downhill in the 5G and 6G positions on mild steel pipe. The following is an outline for approximately a 140 hour course:

- 1) Lecture/Discussion, "Introduction to Downhill Pipe Welding"
- 2) Lecture/Discussion, "The Safety and Health of Welders"
- 3) Prerequisite Skill Test, Single V-Groove Weld, Butt Joint, Vertical and Overhead Positions
- 4) Lecture/Discussion, "How to Read and Apply Pipe Welding Procedures"
- 5) Preparation and Assembly of a Pipe Joint
- 6) Lecture/Discussion, "Weld Quality-Reading the Puddle"
- 7) Single V-Groove Weld, Butt Joint, Horizontal Fixed Position (5G), Downhill
- 8) Single V-Groove Weld, Butt Joint Horizontal Fixed Position (5G), Visual Inspection
- 9) Lecture/Discussion, "Pipe Welding Fixtures and Line-up Clamps"
- 10) Single V-Groove Weld, Butt Joint, 45° Fixed Position (6G), Downhill
- 11) Single V-Groove Weld, Butt Joint, 45° Fixed Position, Guided Bend Test

WELDER QUALIFICATION

Before a welder can begin work on any job covered by a welding code or specification he must become certified under the code that applies. Many different codes are in use today, and it is exceedingly important that the specific code is referred to when taking qualification tests. In general the following type of work is covered by codes: pressure vessels and pressure piping, highway and railway bridges, public building, tanks and containers that will hold flammable or explosive materials, cross country pipe line, aircraft, ordnance material, ships and boats, and nuclear power plants.

Certification is obtained differently under the various codes. Certification under one code will not necessarily qualify a welder to weld under a different code. In most cases certification for one employer will not allow the welder to work for another employer. Also, if the welder uses a different process or if the welding procedure is altered drastically, recertification is required. In most codes if the welder is continually employed, welding recertification is not required providing the work performed meets the quality requirement. An exception is the military aircraft code which requires requalification every six months.

Qualification tests may be given by responsible manufacturers or contractors. On pressure vessel work the welding procedure must also be qualified and this must be done before the welders can be qualified. Under other codes this is not necessary. To become qualified, the welder must make specified welds using the required process, base metal, thickness, electrode type, position and joint design. Test specimens must be made according to standardized sizes and under the observation of a qualified person. In most government specifications, a government inspector must witness the making of welding specimens. Specimens must be properly identified and prepared for testing. The most common test is the



Illustration 14-3 – Typical Qualification Standards

guided bend test. However, in some cases X-ray examinations, fracture tests or other tests are employed. Satisfactory completion of test specimens and providing that they meet acceptability standards, will qualify the welder for specific types of welding. The welding that will be allowed again depends on the particular code. In general, however, the code indicates the range of thicknesses which may be welded, the positions which may be employed and the alloys which may be welded.

Qualification of welders is a highly technical subject and cannot be covered fully here. It is recommended that the actual code be obtained and studied prior to taking any test. Some often used codes are:

- “Structural Welding Code”, AWS D1.1
- “ASME Boiler and Pressure Vessel Code”, Section IX, Welding Qualifications
- “Standard For Welding Pipelines and Related Facilities”, API 1104

CHAPTER 15 WELDING SAFETY

Safety is an extremely important consideration when welding.

Material Safety Data Sheets (MSDSs)

OSHA requires that employers must have a comprehensive hazard communication program to inform employees about hazardous substances that might be used in the workplace. The purpose of the MSDS is to explain the hazards involved in handling/using products such as welding consumables and the precautionary measures which must be put in place for safe welding. The employer must maintain continuous training concerning such materials, and safety in general. Provisions to safeguard employees are included in Material Safety Data Sheets (MSDSs) as prescribed by the Hazard Communications Standard of the U.S. Department of Labor. Information must be provided for all substances taken into the workplace except food, drugs, cosmetics or tobacco products used for personal consumption. The use of these data sheets in all manufacturing workplaces has been mandated since 1985. Employees must be trained on the information in Material Safety Data Sheets and labels.

AWS/ANSI Z49.1

A set of safety rules which should be followed is presented in the American National Standard Institute Z49.1, "Safety in Welding and Cutting", published by the American Welding Society. There are a number of hazards associated with shielded metal arc welding. These do not necessarily result in serious injuries. They can also be of a minor nature which can cause discomforts that irritate and reduce the efficiency of the welders. These hazards are:

- 1) Electrical shock
- 2) Arc radiation
- 3) Air contamination
- 4) Fire and explosion
- 5) Weld cleaning and other hazards

ELECTRICAL SHOCK

There are several precautions that should be taken to prevent an electrical shock hazard. The first item that should be done before welding is to make sure the arc welding equipment is installed properly, grounded, and in good working condition. The electrical equipment should be maintained and installed in accordance with the National Electrical Code and any state and local codes that apply. Power supplies should be connected to an adequate electrical ground such as an approved building ground, cold water pipe, or ground rod. Power supplies are connected to the ground through the cable that connects the power supply to the electrical system ground. Cables with

frayed or cracked insulation and faulty or badly worn connections can cause electrical short circuits and shocks. If it is necessary to splice lengths of welding cable together, the electrical connections should be tight and insulated. The proper size of welding cables should also be used because constant overloading of a welding cable that is too small can destroy the insulation and create bare spots in the insulation. This occurs because of the excessive heat that is built up in the cable and destroys the insulation. An improperly insulated welding cable is both an electrical shock hazard and a fire hazard.

The welding area should be dry and free of any standing water which could cause electrical shock. When it is necessary to weld in a damp or wet area, the welder should wear rubber boots and stand on a dry insulated platform.

ARC RADIATION

The welding arc of shielded metal arc welding emits large amounts of invisible ultraviolet and infrared rays. Skin that is exposed to the arc for a short time can suffer serious ultraviolet and infrared burns which are essentially the same as sunburn, but the burn caused by welding can take place in a much shorter time and can be very painful. Because of this, the welder should always wear protective clothing suitable for the welding to be done. These clothes should be fairly heavy and not easily burned. Leather is often used to make jackets, capes and bibs, or other similar arrangements to shield the arms, shoulders, chest, and stomach from the arc radiation and arc spatter. Leather is also used to make gloves for the welder.

The eyes should also be protected from the radiation emitted by the welding arc. Arc-burn can result if the eyes are not protected. Arc-burn of the eye is similar to sunburn of the skin and it is extremely painful for about 24 to 48 hours. Usually arc-burn does not permanently injure the eyes, but it can cause intense pain. There are several commercial solutions that are available to soothe the skin



Illustration 15-1 – Welding Helmets
Photos courtesy of Miller Electric Manufacturing Co.

Electrode Diameter Inch (mm)	Lens Shade Number
1/16 (1.6)	10
3/32 (2.4)	
1/8 (3.2)	
5/32 (4.0)	
3/16 (4.8)	12
7/32 (5.6)	
1/4 (6.4)	
5/16 (7.9)	
3/8 (9.5)	14

**Illustration 15-2 – Recommended Filter Lens Shades
Used in Shielded Metal Arc Welding (ANSI/AWS Z49.1)**

and eyes during the period of suffering. Infrared arc rays can cause fatigue of the retina of the eye. The effects of infrared rays are not nearly as noticeable or immediate as the effects of ultraviolet rays. Infrared rays are probably more dangerous in that their effects can be longer lasting and result in impaired vision. The best protection for the eyes and face is provided by a headshield that has a window set in it with a filter lens in the window. Headshields are generally made of fiberglass or a pressed fibre material so that they will be lightweight. The filter lens is made of a dark glass that is capable of absorbing infrared rays, ultraviolet rays and most visible light coming from the arc. The type of lens used varies for different welders but it should be dark enough so that the arc can be viewed without discomfort and not so dark that the welder cannot see what he is doing. Illustration 15-2 shows the different lenses commonly recommended for use in shielded metal arc welding. The higher the lens number the darker the lens. A clear glass should be put on the outside of the welding lens to protect it from spatter and breakage.

AIR CONTAMINATION

Welding smoke and fumes are generated by the arc and the decomposition of the electrode coating during welding. Because of this, the following warning is printed on the containers that covered electrodes are packaged in: "Welding may produce fumes and gases hazardous to health. Avoid breathing these fumes and gases. Use adequate ventilation. See American National Standard 49.1, Safety in Welding and Cutting, published by the American Welding Society." The welding area should be adequately ventilated because fumes and gases such as ozone are produced, which is a hazardous gas for the welder to be breathing. When welding is done in confined areas, an external air supply is required. This is furnished by the use of a gas mask on a special helmet. A second person should stand just outside the confined area to lend assistance to the welder if necessary. A mechanical exhaust should be used when welding metals with toxic coatings such as lead, copper, cadmium, and zinc.



Illustration 15-3 – A Well-Dressed Welder

FIRES AND EXPLOSIONS

Fires and explosions are hazards that can exist in a welding area if the proper precautions are not taken. The shielded metal arc welding process produces sparks and spatter which can start a fire or explosion in the welding area, if not kept free of flammable, volatile, or explosive materials. Welding should never be done near degreasing and other similar operations. Leather clothing is worn by the welder to also protect him from burns, because the leather is fire-proof. Fires can also be started by an electrical short or by overheated worn cables. In case of a fire that is started by a flammable liquid or an electrical fire, a CO₂ or dry chemical type of fire extinguisher is used. Fire extinguishers should be kept at handy spots around the shop and the welders should make a mental note of where they are located. Other precautions that have to do with explosions are also important. A welder should not weld on containers that have held combustibles unless it is absolutely certain that there are no fumes or residue left. Welding should not be done on sealed containers without providing vents and taking special precautions. The welding arc should never be struck on a compressed

gas cylinder. When the electrode holder is set down or not in use it should never be allowed to touch a compressed gas cylinder.

WELD CLEANING AND OTHER HAZARDS

Hazards can also be encountered during the weld cleaning process. Precautions must be taken to protect the skin and eyes from hot slag particles. The welding helmet, gloves, and heavy clothing protect the skin from slag chipping and grinding of the weld metal. Safety glasses should also be worn underneath the welding helmet to protect the eyes from particles that could get inside the welding helmet. The discarded stubs of the electrodes can also be a safety hazard. If these are dropped on the floor during electrode changes they can become a hazard because they roll or slide easily. If a welder steps on these he could fall and possibly be injured, so it is necessary to keep the floor of the welding area clear of electrode stubs.

SUMMARY OF SAFETY PRECAUTIONS

- 1) Make sure your arc welding equipment is installed properly and grounded and is in good working condition. This will help prevent fatal electric shocks.
- 2) Always wear protective clothing suitable for the welding to be done. This will help prevent injuries and burns.
- 3) Always wear proper eye protection, when welding, cutting or grinding. Do not look at the arc without proper eye protection. This will prevent eye injuries and “arc flash.”
- 4) Avoid breathing the air in the fume plume directly above the arc. This will prevent illness due to over-exposure to hazardous materials in the fume plume.
- 5) Keep your work area clean and free of hazards. Make sure that no flammable, volatile or explosive materials are in or near the work area. Good house-keeping will help prevent accidents.
- 6) Handle all compressed gas cylinders with extreme care. Keep caps on when not in use. Damaged cylinders can rupture with explosive violence.
- 7) Make sure that compressed gas cylinders are secured to the wall or to other structural supports. The impact of a fall can cause cylinder rupture or valve failure.
- 8) When compressed gas cylinders are empty, close the valve and mark the cylinder “empty”. This will prevent contamination from entering the cylinder.
- 9) Do not weld in a confined space without extra special precautions. Poor ventilation can lead to asphyxiation. Accumulation of flammable gases can explode. Always practice “confined space” safety.
- 10) Do not weld on containers that have held combustibles without taking extra special precaution. The heat of welding can ignite residual gases and cause an explosion. The heat can cause the release of hazardous fumes. Always assure a container is clean and safe for welding.
- 11) Do not weld on sealed containers or compartments without providing vents and taking special precautions. The heat of welding can cause gases to expand. The increased pressure can lead to an explosion.
- 12) Use mechanical exhaust at the point of welding when welding lead, cadmium, chromium, manganese, brass, bronze, zinc or galvanized steel, and when welding in a confined space. These “low allowable-limit materials” can cause serious injury. Ventilation will prevent overexposure.
- 13) When it is necessary to weld in a damp or wet area, wear rubber boots and stand on a dry insulated platform. This will minimize the chance of electrical shocks.
- 14) Do not use cables with frayed, cracked or bare spots in the insulation. This will prevent stray arcs between the bare cable and the ground. It will prevent electric shocks.
- 15) When the electrode holder is not in use, hang it on brackets provided. Never let it touch a compressed gas cylinder. This will prevent damage to the holder. An energized holder can arc to a grounded cylinder and cause an explosion.
- 16) Dispose of electrode stubs in a proper container since stubs on the floor are a safety hazard. Hot stubs can ignite fires or can cause trips and falls.
- 17) Shield others from the light rays produced by your welding arc. Ultraviolet arc rays can cause “arc flash” to the eyes of nearby people.
- 18) Do not weld near degreasing operations. Arc rays can interact with fumes of some cleaning agents and can produce hazardous gases. Some of these gases can kill.
- 19) When working above ground make sure that scaffold, ladder or work surface is solid. Falls from elevated positions can cause injury or even death.
- 20) When welding in high places without railings, use safety belt or lifeline. Falls from high places are more likely to cause serious injury or death.

REFERENCES FOR WELDING SAFETY

The primary reference for this book is Modern Welding Technology, by Howard B. Cary and Scott C. Helzer, published by Pearson Prentice Hall, Upper Saddle River, NJ. Other references cited include:

1. "Report on a Danish Investigation into the Health and Working Environment of Arc Welders", *Welding in the World*, Vol. 10, Nos. 3 and 4, 1972.
2. "Occupational Safety and Health Standards" Code of Federal Regulations Title 29 - Part 1910, U.S. Dept. of Labor. Available from the Superintendent of Documents, U.S. Printing Office, Washington, DC.
3. "Safety in Welding, Cutting, and Allied Processes," ANSI Z49.1 American Welding Society, Miami, FL.
4. "Effects of Welding on Health," EWH series, American Welding Society, Miami, FL.
5. "Hazard Communication Standard," 29 CFR 1910.1200, U.S. Department of Labor, Washington, DC.
6. "Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices," American Conference of Governmental Industrial Hygienists, Cincinnati, OH.
7. "Welding Workplace Safety," by Hallock Campbell. Data Sheet No. 79A, Sept., 1986, *Welding Journal*.
8. "Safety Signs and Colors," standards series ANSI Z535 America National Standards Institute, New York, NY.
9. "Electric Arc Welding Power Sources", EW-1, National Electrical Manufacturers Association, Rosslyn, VA.
10. "Arc Welding Equipment," E-60974 Series, Canadian Standards Association.
11. "Safety Standards for Arc Welding Equipment," series 60974, Underwriters Laboratories, Northbrook, IL.
12. "National Electric Code", NFPA 70, National Fire Protection Association, Quincy, MA.
13. "Thoriated Tungsten Electrodes," Safety and Health Fact Sheet No. 27, American Welding Society, Miami, FL.
14. "Lens Shade Selector," F2.2. American Welding Society, Miami, FL.
15. "Transparent Welding Curtains" by Sliney, Moss, Miller & Stephens, May 1982, *Welding Journal*, Miami, FL.
16. "The Welding Environment," American Welding Society Miami, FL.
17. "Fumes and Gases in the Welding Environment", American Welding Society, Miami, FL.
18. "Characterization of Arc Welding Fume", CAWF, American Welding Society, Miami, FL.
19. "Method for Sampling Airborne Particles Generated by Welding and Allied Processes," F1.1, American Welding Society, Miami, FL.
20. "Industrial Ventilation - A Manual of Recommended Practice", American Conference of Governmental Industrial Hygienists, Cincinnati, OH.
21. "A Sampling Strategy Guide for Evaluating Contaminants in the Welding Environment," F1.3, American Welding Society, Miami, FL.
22. "Laboratory Method for Measuring Fume Generation Rates and Total Fume Emission of Welding and Allied Processes," F1.2, American Welding Society, Miami, FL.
23. "Handling Acetylene Cylinders in Fire Situations", Safety Bulletin No. SB-4, Compressed Gas Association, York, NY.
24. Hot Work Permits (Flame or Sparks) Data Sheet 522, National Safety Council, Chicago, Illinois.
25. "Standard for Fire Prevention During Welding, Cutting and Other Hotwork," NFPA 51B, National Fire Protection Association, Quincy, MA.
26. "Safe Practices for the Preparation of Containers and Piping for Welding and Cutting." F4.1, American Welding Society, Miami, FL.
27. "Safe Hot Tapping Practices in the Petroleum and Petrochemical Industries," RP 2201, American Petroleum Institute, Washington, DC.
28. "Cylinders: Safe Storage, Handling, and Use," Safety and Health Fact Sheet No. 30. American Welding Society, Miami, FL.
29. "Arc Welding and Cutting Noise," AWN, American Welding Society, Miami, FL.
30. "Safety and Health Fact Sheets," SHF, American Welding Society, Miami, FL.

31. "Using Transparent Welding Curtains" by Dean R. Wilson, *Welding Journal*, September 2005, American Welding Society, Miami, FL.
 32. "Methods for Sampling and Analyzing Gases from Welding and Allied Processes," F1.5, American Welding Society, Miami, FL.
 33. "Guide for Estimating Welding Emissions for EPA and Ventilation Permit Reporting," F1.6, American Welding Society, Miami, FL.
 34. "Lens Shade Selector," F2.2, American Welding Society, Miami, FL.
 35. "Specification for Use and Performance of Transparent Welding Curtains and Screens," F2.3, American Welding Society, Miami, FL.
 36. "Ventilation Guide for Weld Fume," F3.2, American Welding Society, Miami, FL.
 37. "Lockout/Tagout," Safety and Health Fact Sheet No. 18, American Welding Society, Miami, FL.
 38. "Underwater Cutting and Welding," NAVSEA S0300-BB-MAN-010, U.S. Dept. of the Navy, Naval Sea Systems Command, Washington, DC.
 39. "Occupational and Educational Personal Eye and Face Protection Devices," ANSI Z87.1 American National Standards Institute, New York, NY.
 40. "Chromium, Nickel, and Welding," International Agency for Research on Cancer (IARC), Volume 49, 1990.
 41. "Specification for Underwater Welding," D3.6M, American Welding Society, Miami, FL.
 42. "Specification for Robotic Arc Welding Safety," D16.1, American Welding Society, Miami, FL.
 43. "Risk Assessment Guide for Robotic Arc Welding," D16.3, American Welding Society, Miami, FL.
 44. "Brazing Safely" BRS, American Welding Society, Miami, FL.
 45. "Brazing Handbook," BRH, American Welding Society, Miami, FL.
 46. "Soldering Handbook," SHB, American Welding Society, Miami, FL.
 47. "Resistance Welding Manual," RWM, American Welding Society, Miami, FL.
 48. "Recommended Practices for Resistance Welding," C1.1, American Welding Society, Miami, FL.
 49. "Recommended Practices for Air Carbon Arc Gouging and Cutting," C5.3, American Welding Society, Miami, FL.
 50. "Recommended Practices for Plasma Arc Cutting and Gouging," C5.2, American Welding Society, Miami, FL.
 51. "Recommended Practices for Electron Beam Welding," C7.1, American Welding Society, Miami, FL.
 52. "Thermal Spray Manual," TSM, American Welding Society, Miami, FL.
 53. "Thermal Spraying Practice, Theory and Application," TSS, American Welding Society, Miami, FL.
 54. "Recommended Practices for Laser Beam Welding, Cutting, and Drilling," C7.2, American Welding Society, Miami, FL.
-
- ### Web Sites
1. American Welding Society, <http://www.aws.org>
 2. Occupational Safety and Health Administration, <http://www.osha.gov>
 3. National Institute for Occupational Safety and Health, <http://www.cdc.gov/niosh>
 4. National Fire Protection Association, <http://www.nfpa.org>
 5. U.S. Government Printing Office, <http://www.gpo.gov>
 6. American Conference of Governmental Industrial Hygienists, <http://www.acgi.org>
 7. Canadian Standards Association, <http://www.csa.ca>
 8. American National Standards Association, <http://www.ansi.org>
 9. Compressed Gas Association, <http://www.cganet.com>
 10. American Petroleum Institute, <http://www.api.org>
 11. Underwriters Laboratories, <http://www.ul.com>
 12. National Electrical Manufacturers Association, <http://www.nema.org>
 13. Global Engineering Documents, <http://www.global.ihs.com>
 14. World Engineering Xchange, Ltd., <http://pubs.aws.org>

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