General Service Information
SERVICE WELDING GUIDE
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SENR05120001

Introduction

The service Welding Guide was developed by the Service Department and East Peoria Weld Engineering of Caterpillar Inc. The guide was developed to assist the serviceman in selecting the proper welding techniques to be employed. This fundamental information can be combined with the serviceman's welding abilities to utilize the optimum combination of factors affecting weld quality. These factors include welding process selection, recommended equipment, repair methods, types of joints and weld defects. The evaluation and application of these factors constitutes the proper service welding techniques that will produce welds in all joint positions on all types of steels.

The appendix of this booklet contains a list of reference books that have been proven to be useful to service welders. Further reading in these sources is suggested in ares of particular interest. The appendix also contains a glossary of welding terms used in this booklet.

Safety and Recommended Equipment

Safety Precautions

* Keep equipment and work area clean, dry and neat. Put tools away when you are through using them.
* Be sure work area has adequate ventilation.
* Always wear protective gloves and aprons, safety shoes and heavy cotton clothing. Keep collars and shirt cuffs buttoned. Turn trouser cuffs down. Be sure trouser legs extend below shoe tops.
* Wear a welding helmet or eye shield with proper filter plates when welding or cutting. Use a No. 4 or No. 5 filter for torch brazing, flame cutting and gas welding. Use a No. 10 or No. 12 filter for arc welding.
* Keep a CO_2 or dry powder fire extinguisher within reach-especially when flame cutting or welding on or near tractors, engines, etc.
* Remove all flammable materials, volatile liquids and explosive gases from the welding area or shield them adequately.
* Do not weld or cut on containers such as drums, barrels and tanks until you know there is no danger of fire or explosion from their contents.
* Always drill a relief hole in a closed compartment, such as a front idler or track roller frame box section, before welding or cutting on it. If this is not done, any moisture inside the compartment can vaporize, causing an extremely high pressure inside the compartment which may lead to an explosion.
* Never strike an arc on a cylinder of compressed gas or on any part of a track adjusting mechanism.
* Be sure welding cables, electrode holders and clamps are in good repair and properly insulated.
* Support large machine components such as scraper bowls and aprons, bulldozer blade, etc. solidly before working under them.
* Fasten oxygen an acetylene hoses cylinders securely in the vertical position before using. Observe all safety rules for handling compressed gas cylinders.
* Keep oxygen and acetylene hoses from being cut or burned. Inspect oxygen and acetylene hoses periodically for leaks and worn places. Check all connections for leaks before igniting flame. Do not use oil on oxygen fittings.
* Provide mechanical air movement over coated or painted surfaces being welded to dispel any toxic fumes that may be produced.

Other Recommended Equipment

Pneumatic Vibrator for slag removal

* Either chisel or needle type

Grinder, pneumatic or electric

* 7 inch or 4 inch diameter - 36 grit and/or 24 grit
* Both cup grinder and disc grinder
* Cat part #9U-6241 Electric
* Cat part #1U-5946 Pneumatic

Electric Rod Oven for electrode storage if using shielded metal arc

* A practical approach is to use an airtight container with at least a 100 watt light bulb permanently turned on.
* An old refrigerator with sealing door is perfect
* Refer to Publications section for purchasing information.

Liquid penetrant kit for surface crack detection on ferrous and non-ferrous metals

* Cat part #4C-4763 aerosol
* Cat part #9U-6335 non aerosol

Arc-Air for removing defective welds

* 3/8 inch and/or 1/4 inch carbon round or semi-round electrodes
* Use dry air supply, no lubrication present

Oxyacetylene outfit with cutting and heating heads

* Cat part #1U-6469 heavy duty Oxy-acetylene

Tempilstick crayons for determining temperature of metal

* Refer to publications section for purchasing information

Leather weld clothing for operator

* Cat part #1U-6583 Leather Gloves
* Cat part #1U-6579-80 Leather Coat
* Apron or chaps

Ceramic Weld Backing Material

* Cat part #1U-7767 Grooved
* Cat part #1U-7768 Round
* Cat part #1U-7769 Triangle

Power Supplies and Electrodes

If Stick Electrode (SMAW) Shielded Metal Arc Welding

* 400 to 600 Amp DC power source is recommended
* E7018 electrode

If Semi-Automatic (FCAW) Flux Cored Arc Welding

* 400 to 450 amp power source is recommended
* Shielding gas 75% argon 25% CO_2
* E71T-1 flux cored wire Cat part #9U-6652

If Semi-Automatic (GMAW) Gas Metal Arc Welding

* 400 to 450 amp power source is recommended
* Shielding gas 75% argon 25% CO_2 first choice, and straight CO_2 second choice
* (AWS) ER70S-3 solid wire Cat part #1U-5368

Considerations when using (GMAW) Gas Metal Arc Welding

Base metal cleanliness is more critical when using GMAW than when using SMAW. The fluxing compounds present in SMAW cleanse the molten weld deposit of oxides and gas forming compounds. Such fluxing slags are not present in GMAW.

GMAW is a gas shielded welding process and porosity may occur if too much or too little gas shielding flow is used. The gas shield can also be blown away by air movement, or by fans running in the welding area. The welder must not have too much or too little distance from the welding gun to the piece being welded. These are variables to consider when deciding whether to use GMAW or SMAW.

SENR05120003

Stick Electrode Shielded Metal Arc Welding (SMAW)

Fundamentals of the Process

Definition

Shielded Metal Arc Welding is an arc welding process wherein coalescence is produced by heating with an electric arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the electrode covering. Pressure is not used and filler metal is obtained from the electrode.

Slang Names

1. Stick/manual metal arc.

Process Principles

1. Heat source - heat of the arc.
2. Shielding gas - slag formed by the decomposition of the flux.
3. Filler metal - comes from core wire.
4. Flux - contains deoxidizers/slag formed/ionizing elements to stabilize the arc/iron powder for higher deposition.

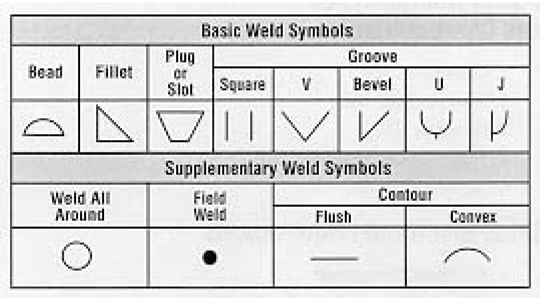

Figure 1

Methods of Application

1. Manual - most widely used - approximately 90%
2. Semiautomatic - not used
3. Machine
4. Automatic - gravity/massive/firecracker

Electrical Requirements

Welding Circuit

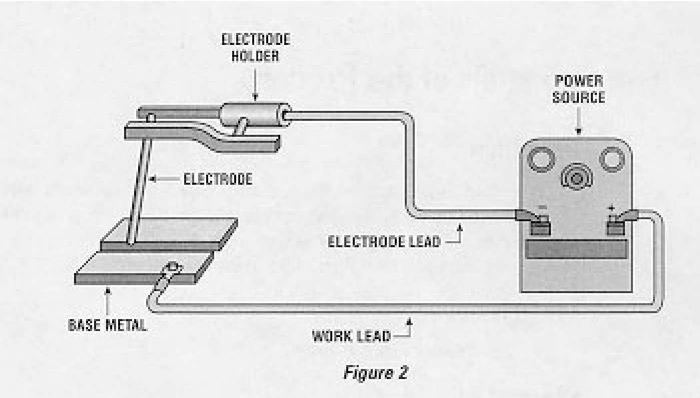

Figure 2

Welding Current types

1. A.C.
2. D.C.E.N. (straight) polarity.
3. D.C.E.P. (reverse) polarity.

Power Source Types and Characteristics

1. Generator (DC)
2. Transformer (AC)
3. Rectifier (DC)
4. Transformer Rectifier (AC/DC)
5. Alternators (AC)

Other Electrical Requirements

1. Multiple Operators

Other Equipment Requirements

Additional Equipment Necessary

1. Helmet/gloves/leathers
2. Chipping hammer/wire brush
3. Grinder for repair

Setup of Equipment

The manner in which equipment is set up in preparation for welding is an important consideration, both from the safety standpoint and for the speed and ease with which the weld can be made.

Welding should be done in a specially prepared welding area if at all possible. It is usually quicker and easier and always safer and more convenient to carry the work to the welder rather than carry the welder to the work. If welding must be done in places other than the regular welding areas, extra attention should be given to safety precautions, and other workmen in the area should be notified that welding will be going on.

Adequate ventilation and lighting and a source of sufficient power must be provided. The welding machine should be located close enough to the work to assure free and easy manipulation of the electrode holder and cable. Cable connections must be made soundly and the ground cable clamp must be attached securely to the work to assure an uninterrupted flow of current. The ground clamp should always be placed on the piece being welded; current must never be allowed to flow through bearings, hydraulic cylinders or other precision surfaces. If this occurs, minute pits will form at the points of contact and cause excessive wear.

Whenever possible, the work should be positioned so the face of the weld being made and the axis of the weld will be within 10° of horizontal. In this position, higher amperages and deposition rates can be used, the puddle of molten metal is easier to control, and the welder is in a more comfortable position. In addition, more welding skill is generally required for welding in positions other than flat and horizontal.

Striking an Arc

An arc is struck by momentarily touching the work with the electrode. When the arc is struck, there is a tendency for the electrode to stick to the work because of the sudden rush of current caused by the short-circuiting of the welding machine. To avoid this sticking or freezing of the electrode, a motion similar to that used to strike a match should be employed (Figure 3). After the arc is struck, a slightly longer than normal arc should be held until the parent metal is heated to the melting point and the proper size puddle of molten metal is formed. When it is necessary to restrike an arc to continue an uncompleted weld, the recommended procedure is to strike the arc at the forward or cold end of the crater and move the electrode rearward over the crater and then forward again to continue the weld. This procedure fills the crater and avoids porosity in the weld and trapping of slag.

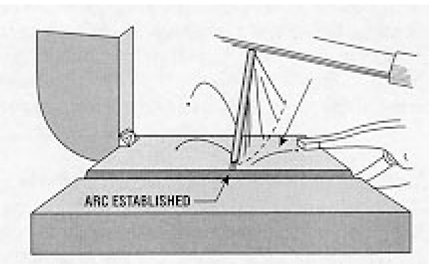

Figure 3 - Arcs must be struck carefully to keep electrode from sticking.

Controlling the Arc

The two primary factors involved in manipulating the arc are the length of the arc and the amperage of the welding current being used. The arc must be long enough so the diverging arc stream covers the width of the puddle and a good gas shield is maintained. An arc that is too long will tend to swing sideways, causing excessive spattering, and will result in an imperfect gas shield, allowing elements in the air to come into contact with the molten metal. This gives rise to a very irregular weld bead with poor penetration (Figure 4). Too short an arc, on the other hand, will not heat the parent metal sufficiently and may short out and cause the electrode to stick to the work. An arc of the proper length produces a steady transfer of metal from the electrode to the puddle with little spatter and tendency for the electrode to stick. An arc length approximately equal to the core diameter of the electrode will usually produce these characteristics.

The proper amperage to be used will vary with different welding situations depending on the type of material being welded, the type and size of electrode, etc. In general the recommendations of the electrode manufacturer should be followed. Too low a welding current will not generate enough heat to melt the parent metal sufficiently. This will result in excessive piling up of weld metal and an overlapping bead with poor penetration (Figure 4). Too high a current will give rise to excessive spattering, an irregular deposit of weld metal, and undercutting along edges of the weld (Figure 4).

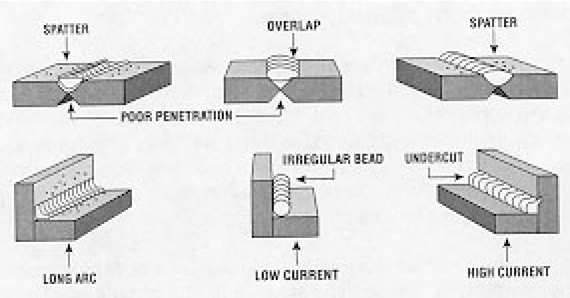

Figure 4 - Arc length and welding current must be controlled for sound welding beads.

Deflection of the arc arising from concentrations of the magnetic field set up in the work can be controlled in a number of ways.

. Place the ground connection at the start of the weld if back blow is a problem; place it at the end of the weld if forward blow is a problem.
. Weld toward a heavy tack or a weld already made.
. Hold as short an arc as possible so the force of the arc offsets the arc blow.
. Reduce the current, reverse the polarity, or switch to AC current.

Manipulating the Electrode

Once a good arc is established and maintained, the electrode must be held and moved properly to assure a sound weld through the control of the puddle of molten metal. Primary factors here are electrode angle, travel speed, and weaving of the electrode. Travel speed should be such that a flat or slightly convex bead is deposited. If travel speed is too fast, a small, irregular bead with a concave surface will result. If travel is too slow a heavy convex bead with overlapping edges will result. Generally, travel speed has to be reduced for vertical and overhead welding.

The quality of a weld can be affected to a large degree by the angle at which the electrode is held to the work. For normal flat welds, the electrode should be perpendicular to the surface of the joint and inclined in the direction of travel. The amount of inclination will affect the penetration, with greater inclination giving less penetration. Fillet welds require different electrode angles for successive passes, and the position of the joint will further affect angle requirements. Specific recommendations for individual types of welds will be made in the following sections.

It is often desirable to lay a weld deposit that is wider than can be obtained with a single bead. This is accomplished by weaving the tip of the electrode back and forth over the joint as the electrode travels along the joint. There are many weave patterns used in welding; the important requirements are that the motion is uniform and the weaves are close enough together to assure good fusion at all points in the deposit. Again, specific recommendations will be made in the following sections.

In addition to widening the weld deposit, weaving helps to work impurities to the top of the puddle of molten metal and can be used to control contour and undercutting, as well as heat input and temperature in a joint. Control of heat input and temperature by weaving is especially useful in vertical and overhead welding. Disadvantages of weaving include the possibility of losing the gas shield and a possible increase in distortion from warping. Low hydrogen electrodes should not be weaved more than two times the diameter of the electrode in order to avoid breaking the gas shield.

Certain environmental factors affect the welder's ability to manipulate the electrode and control the puddle. The welding area should be orderly, well lighted and well ventilated. For welding in close or restricted quarters, such as inside the draft tube of a scraper, additional illumination and additional ventilation in the form of a small fan located near the work area is desirable. The welding helmet should be kept clean of smoke and weld spatter.

All welding should be done from a comfortable position so the welder can hold a steady arc and feed the electrode into the joint at a constant rate. Both hands should be free to grip the electrode holder and guide the electrode or steady the work as necessary. If the joint is in a hard-to-reach or awkward location, the electrode may be bent in such a manner that the proper electrode angle and arc length can be held from a more relaxed position (Figure 5.)

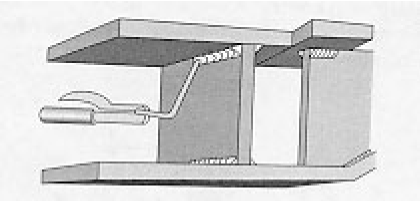

Figure 5 - Electrodes can be bent for welding in hard-to-reach locations

When the bead is started, a slightly longer than normal arc should be held until a sufficient amount of parent metal melts to form a puddle of the proper size. Then the arc length is shortened and travel is begun (Figure 6). At the end of the weld, the bead is stopped by shortening the arc and momentarily backing to fill the crater and then whipping the electrode sharply backward to break the arc. If the bead must be stopped along the length of the weld for any reason (to change the electrode, for instance) the electrode should be whipped to the side, leaving an unfilled crater in which to begin the bead. It is often useful to check for proper electrode selection, arc control and electrode manipulation by welding on a scrap before welding the joint. The scrap should be in the same position as the joint.

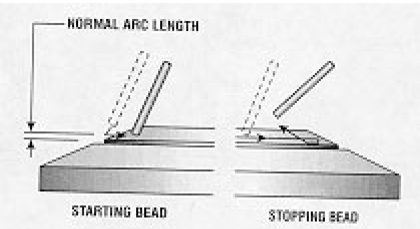

Figure 6 - Control of the arc is important at the start and finish of a joint.

Tack Welding

Tack welding permits accurate positioning of members without special fixtures or clamping devices and controls distortion arising from cooling welds. Tack welds should be made with the same electrode and in the same manner prescribed for the final weld. All members of a weldment should be tacked together before any final welds are made. The following procedure is recommended for making tack welds:

> **1.** Hold the member in position and make the first tack weld on the end of the member so the member can be repositioned slightly, if necessary (Figure 7). The first tack should be strong enough to hold the member in position.

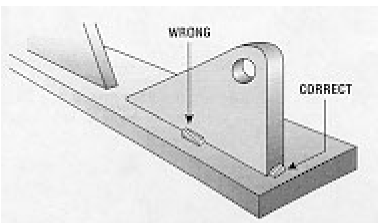

Figure 7

2. Check the alignment with a level or a combination square (Figure 8). Reposition the member if necessary.

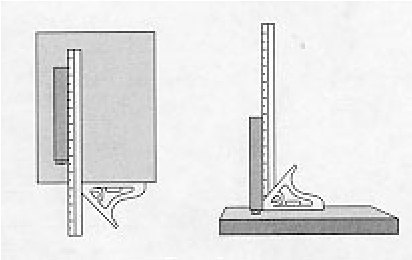

Figure 8

3. Make a second tack weld in a place that will further restrain the member from being distorted when the final welds are made (Figure 9).

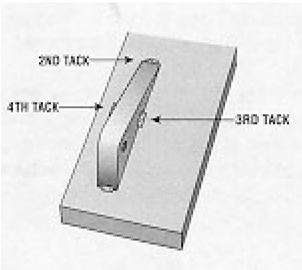

Figure 9

4. Recheck alignment.
5. Make additional tack welds as required to hold the member in position while the final welds are being made (Figure 9).

Tack welds must meet all of the requirements for soundness that apply to final welds. Cracked tack welds must be gouged out and remade. If a cracked tack weld is not completely removed, it will initiate future cracking in the final weld.

Flat and Horizontal Welding

A weld joint is in the flat position when both the axis of the joint and the face of the weld are within 10° of horizontal and the welding is performed on the top of the joint (Figure 10). If the axis of the joint is within 10° of horizontal but the face is between 10° and 90° from horizontal, the joint is said to be in the horizontal position (Figure 10).

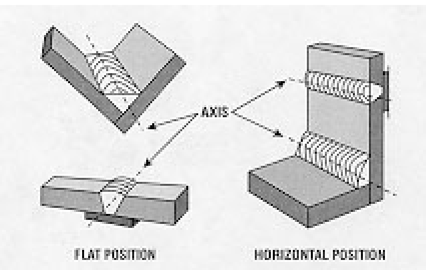

Figure 10 - Flat and Horizontal positions should be used when possible.

For normal flat welds, the electrode should be perpendicular to the surface of the joint and tilted slightly in the direction of travel (Figure 11). For deeper penetration, the electrode should not be tipped in the direction of travel, but rather it should be held perpendicular to the face of the weld so the heat from the arc is directed down into the joint (Figure 11). The weave pattern is the same as for normal flat joints.

For wide gap joints or joints with a poor fit-up, where excessive heat in the joint would cause a melt-through, the electrode should be tilted slightly away from the direction of travel (Figure 11). This angle directs the heat of the arc away from the center of the puddle of molten weld metal and allows the metal to cool more rapidly. The wider weave pattern is used because it also helps the molten weld metal cool more rapidly.

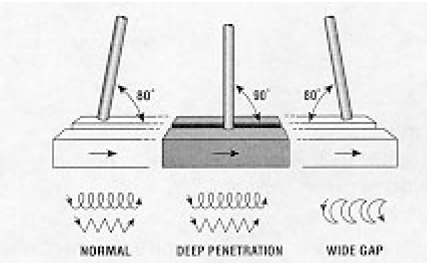

Figure 11 - Several electrode angles and weave patterns cam be used for flat welding.

For horizontal fillet welds, the electrode should be held midway between the horizontal and vertical plates (45° work angle) on the first pass so an equal force from the arc is directed against each surface (Figure 12). The second pass should be deposited against the horizontal plate to form a flat ledge on which the third pass can be laid. The second pass and all subsequent passes that do not contact the vertical plate should be made with a 20° work angle (Figure 12). The third pass and all subsequent passes that do not contact the vertical plate should be made with a 60° work angle. On all passes the electrode should be tilted in the direction of travel (Figure 13) so it makes a 60° angle with the horizontal plate (30° lead angle).

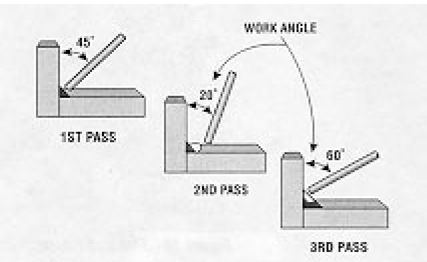

Figure 12 - Different work angles are needed on various passes for horizontal fillet welds.

The weave patterns for horizontal fillet welds utilize the force of the arc to wash molten metal up onto the vertical surface. This technique permits accurate forming of the weld deposit without undercutting (Figure 13).

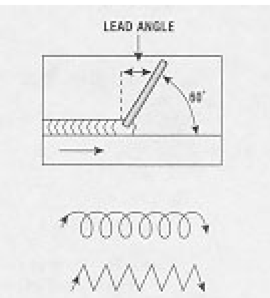

Figure 13 - A 30° lead angle puts the electrode 60° from horizontal

For horizontal butt welds, the electrode holder should be held somewhat below the joint so the electrode is directed slightly upward. The electrode again should be tilted in the direction of travel so it has a lead angle of about 10°. The electrode is directed upward so the force of the arc will hold the puddle of weld metal in position until it freezes. The weave patterns recommended for horizontal fillet welds (Figure 13) should be used for horizontal butt welds, also. This is done so molten metal can be washed up onto the upper surface to prevent undercutting.

Overhead and Vertical Welding

A weld joint is in the overhead position when the axis of the joint is within 10° of horizontal and the welding is performed on the lower side of the joint (Figure 14). If the axis of a joint is between 10° and 90° from horizontal, the joint is said to be in the vertical position (Figure 14). Even thorough a joint inclined at, for instance, 30°, is closer to the horizontal than vertical, it is classified as a vertical weld because the problems encountered are essentially the same as those of a joint that is completely upright.

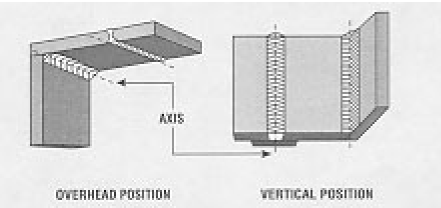

Figure 14 - Vertical and overhead welding is called out-of-position welding.

When working in the overhead and vertical positions, the welder must constantly take steps to counteract the effect of the force of gravity on the puddle of molten metal. The size of the puddle must be limited by reducing welding current, arc length and deposition rate. This keeps molten metal from dropping from the weld or running down over the work. The amount of slag shield must be reduced through proper electrode selection so the weld metal will freeze more quickly and in the proper location. The electrode must be held and moved in such a manner that the force of the arc holds the metal in position until it solidifies. All of these factors reduce welding speed and make it more difficult to obtain a sound weld.

Overhead welding requires the most skill on the part of the welder. For overhead butt joints and overhead fillet welds where the face of the weld is horizontal. The electrode should be held perpendicular to the face and inclined slightly in the direction of travel (Figure 15). For overhead fillets where the face of the weld is other than horizontal, the electrode should be held so most of the heat is directed onto the upper surface (Figure 15). In each case, a circular or triangular weave pattern should be used to agitate the puddle to remove slag and impurities. A series of small beads is easier to run than a single large bead; however, thorough cleaning is necessary after each pass because impurities will not float to the surface of the puddle with the overhead position.

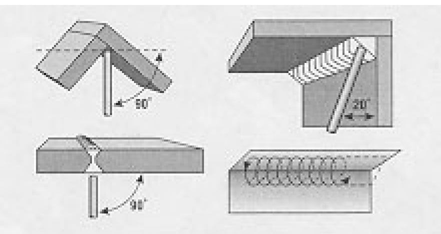

Figure 15 - Overhead butt and fillet joints require considerable skill from the welder.

Vertical welds may be made either upward or downward. Heavy joints are usually welded in the upward direction, while small joints on thin material should be welded downward. Welding downward requires somewhat less skill than welding upward. For both upward and downward vertical welding, the electrode should be held perpendicular to the face of the weld and inclined downward (electrode holder below arc) regardless of direction of travel.

When making a fillet weld in the upward direction, it is advisable to build a ledge or shelf on which to start the weld (Figure 16). The shelf should be built to the desired width with a series of short passes. When the shelf is the desired size, the first pass of the weld should be made, using a weave pattern consisting of a series of inverted V's with the highest point of the pattern in the root of the joint (Figure 16). This pattern spreads heat evenly to control the size of the puddle and allows impurities and flux to float downhill to the brim of the puddle. The bead should be small enough so all flux is kept in a molten or semi-molten state.

The optional weave pattern (Figure 16) gives a smoother bead, but greater care must be taken because slag can easily become entrapped in the center of the pattern.

After the first pass has been made, the bead can be enlarged by using a weave pattern consisting of horizontal passes with an upward swing at each end. The upward swing is used to tie the weld into the base metal without undercutting (Figure 16). When low hydrogen electrodes are used, the weave pattern should be kept as narrow as possible to assure a good gas shield around the arc.

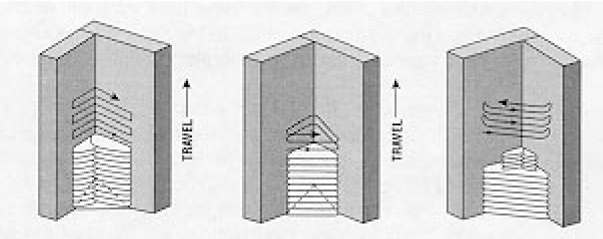

Figure 16 - The proper weave pattern spreads heat and allows good removal of impurities.

Electrodes

Electrodes are usable within a range of amperages. With SMAW welding, the operator has great amount of process control. The operator controls the arc length and uses a manipulating motion to control the arc. Specific welding settings are given in broad ranges. Welders normally listen for a frying or crackling sound, as well as making a visual inspection to confirm proper setting or make adjustments. Learning these skills is what makes and experienced welder.

E7018 Electrode Storage

These electrodes are to be purchased in hermetically sealed containers. After hermetically sealed containers are opened or after electrodes are removed from baking or storage ovens, the electrode exposure to the atmosphere should not exceed 4 hours, maximum. Electrodes that have been wet should not be used. Electrodes exposed to the atmosphere for periods less than 4 hours may be returned to the holding oven maintained at 250°F (120°C) minimum; after a minimum holding period of 4 hours at 250°F minimum the electrodes may then be reissued.

Electrodes exposed to the atmosphere for more than 4 hours must be baked for at least two hours between 500°F (260°C) and 800°F (430°C).

All electrodes shall be placed in a suitable oven at a temperature not exceeding one half of the final baking temperature for a minimum of one half hour prior to increasing the oven temperature to the final baking temperature. Final baking time shall start after the oven reaches final baking temperature.

Nominal electrode size reflects the diameter of the metal rod or core of the electrode. The overall diameter of the electrode with the coating will vary. As the rod diameter increases, the amperage necessary to produce a good weld will increase. Amperage ranges for difference electrode types can vary, even if the diameters are the same. Recommended amperages for electrodes are sometimes printed on the box ends. If no recommended settings are found on the packaging, the manufacturer may provide literature with recommended amperages. If written help cannot be found, consult with an experienced welder to select a starting amperage and make adjustments to get the desired weld bead shape and appearance.

Low hydrogen type electrodes (5, 6, or 8 as the far-right digit) will absorb moisture from the air if not stored properly. Electrodes are stored in ovens at a minimum temperature of 250°F. Electrode ovens are not to be used for food warming or storage of any other items.

Electrodes left out of the heated storage ovens for longer than two hours must be reconditioned in the oven at least 1 hour at 500°F or 4 hours at 250°F. Porosity of hydrogen-induced cracking will result from improper storage and use of the low hydrogen electrodes.

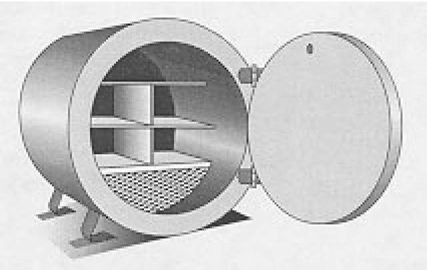

Figure 17 - Electrode storage oven

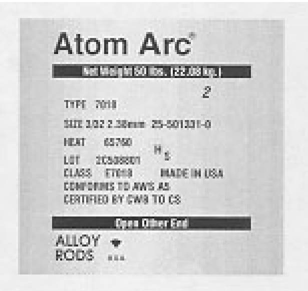

Figure 18 - Label on electrode can

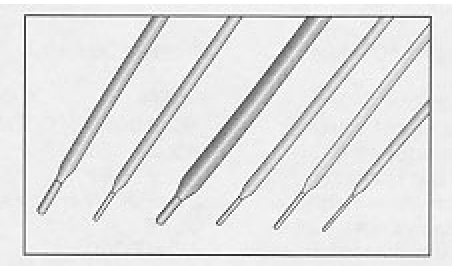

Figure 19 - SMAW electrodes showing classification numbers

For electrode numbers with four digits, the two digits on the left denote tensile strength in thousands of pounds. If the electrode number has five digits, the three digits on the left denote tensile strength. For both, the right hand digit indicates the type of coating, and the second digit from the right indicates the recommended positioning for use.

7018
Tensile

Strength		**Position**	**Coating Type** (Current)
60	(60,000)	1 – All	0 - Cellulose Sodium DC+
70	(70,000)	2 – Flat & Horizontal	1 - Cellulose Potassium AC DC+
80	(80,000)	3 – Flat Only	2 - Titania Sodium AC DC-
90	(90,000)	4 – Not Vertical, Up	3 - Titania – Potassium AC DC+ DC-
100	(100,000)		4 - Titania – Iron Powder AC DC+ DC-
110	(110,000)		5 - Low Hydrogen – Sodium DC+
120	(120,000)		6 - Low Hydrogen – Potassium AC DC+
			7 - Iron Powder – Iron Oxide AC DC-
			8 - Iron Powder – Low Hydrogen AC DC+
			9 - Iron Oxide – Titania - Potassium AC DC+

Welding Rod Classifications

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)

Fourth Digit	**Type of Coating**	**Welding Current**
0	cellulose sodium	DCEP
1	cellulose potassium	AC or DCEP or DCEN
2	titania sodium	AC or DCEN
3	titania potassium	AC or DCEP
4	iron power titania	AC or DCEN or DCEP
5	low hydrogen sodium	DCEP
6	low hydrogen potassium	AC or DCEP
7	iron powder iron oxide	AC or DCEP or DCEN
8	iron powder low hydrogen	AC or DCEP
9	iron oxide sodium	AC or DCEP

DCEP – Direct Current Electrode Positive
DCEN – Direct Current Electrode Negative

Mild Steel (Covered) Electrode Classification SMAW Process

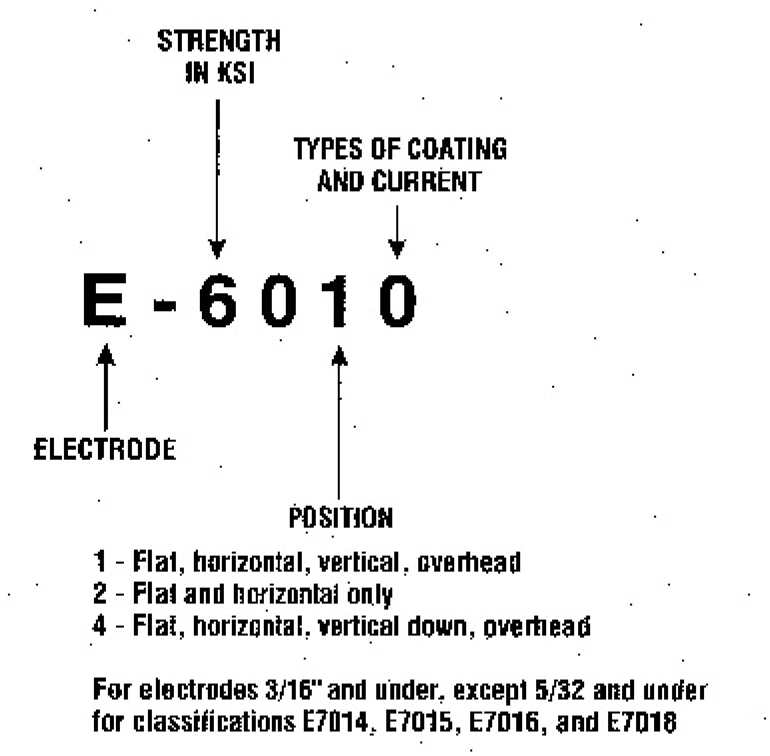
STRENGTH
IN KSI
TYPES OF COATING
AND CURRENT
E - 6 0 1 0
ELECTRODE
POSITION
1 - Flat, horizontal, vertical, overhead
2 - Flat and horizontal only
4 - Flat, horizontal, vertical down, overhead
For electrodes 3/16" and under, except 5/32 and under
for classifications E7014, E7015, E7016, and E7018

Figure 20

Flux Core (FCAW) Flux Cored Arc Welding

Principle Features

The benefits of FCAW are achieved by combining three general features.

1. The productivity of continuos wire welding.
2. The metallurgical benefits that can be derived from flux.
3. A slag that supports and shapes the weld bead.

FCAW combines the characteristics of Shielded Metal Arc Welding (SMAW), Gas Metal Arc Welding (GMAW), and Submerged Arc Welding (SAW).

Advantages of FCAW

Flux Cored Arc Welding has many advantages over the manual SMAW process and provides certain advantages over the SAW and GMAW processes. In many applications, the FCAW process provides high quality weld metal at lower cost with less effort on the part of the welder than SMAW. These advantages can be listed as follows.

***** High quality weld metal deposit.
***** Excellent weld appearance and smooth, uniform welds.
***** Excellent contour of horizontal fillet welds.
***** Many welds weldable over a wide thickness range.
***** High operating factor, easily mechanized.
***** High deposition rate, high current density.
***** Relatively high electrode deposit efficiency.
***** Economical engineering joint design.
***** Visible arc, easy to use.
***** Less precleaning required than GMAW.
***** Up to 4 times greater deposition rate than SMAW.
***** Higher tolerance for contaminants that may cause weld cracking.
***** Resistant to underbead cracking.

Limitations of FCAW

***** FCAW is presently limited to welding ferrous metals and nickel based alloys.
***** The process produces a slag covering which must be removed.
***** FCAW electrode wire is more expensive on a weight basis than solid electrode wires, except for

some high alloys steels.
***** The equipment is more expensive and complex than that required for SMAW; however, increased productivity usually compensates for this.
***** The wire feeder and power source must be fairly close to the point of welding.
***** For gas shielded version, the external gas shield may be adversely affected by breezes and drafts.
***** More smoke and fumes are generated (compared to GMAW and SAW).

Fundamentals of the process

Definition

The Flux-Cored Arc Welding process is a process in which coalescence is produced by heating with an arc between a continuous filler metal (consumable) electrode and the work. Shielding is obtained from a flux contained within the electrode. Additional shielding may or may not be obtained from an externally supplied gas or gas mixture.

Slang names

1. FabCo - Fabshield-Inner Shield - Dual Shield

Process Principles

1. Heat source - an arc between a continuous filler metal electrode and the weld spot.
2. Shielding - is obtained from flux contained within the tubular electrode and with or without additional shielding from an externally supplied gas.
3. Filler metal - is obtained from a continuously-feeding tubular electrode.
4. Flux - will provide deoxidizers, ionizers, purifying agents, and in some cases alloying elements.

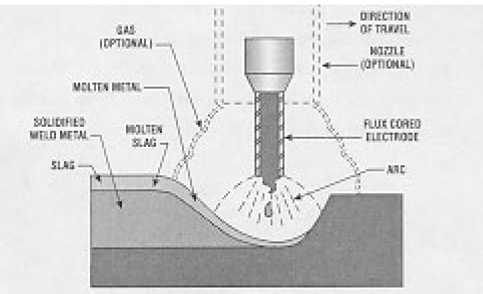

Figure 21

Methods of Application

1. Manual - not applicable.
2. Semiautomatic - most popular method of application.
3. Machine - widely used.
4. Automatic - widely used.

Metals Weldable

Base Metal	Weldability
Cast Iron	Using Special electrode
Low Carbon Steel	Weldable
Low Alloy Steel	Weldable
High and Medium Carbon	Weldable
Alloys Steel	Weldable
Stainless Steel—Selected	Limited Types

Thickness Range

Thickness / Factor	Inch	.005	.015	.062	.125	3/16	1/4	3/8	1/2	3/4	1	2	4	8
	mm	.13	.4	1.6	3.2	4.8	6.4	10	12.7	19	25	51	102	203
Single-pass no prep														
Single-pass prep														
Multi-pass														

Figure 22

Position Capabilities

* Grooves - all positions depending on size and type.
* Fillets - all positions depending on size and type.
* Limitations - would depend on skill of the operator.

Electrical Requirements

Welding Circuit

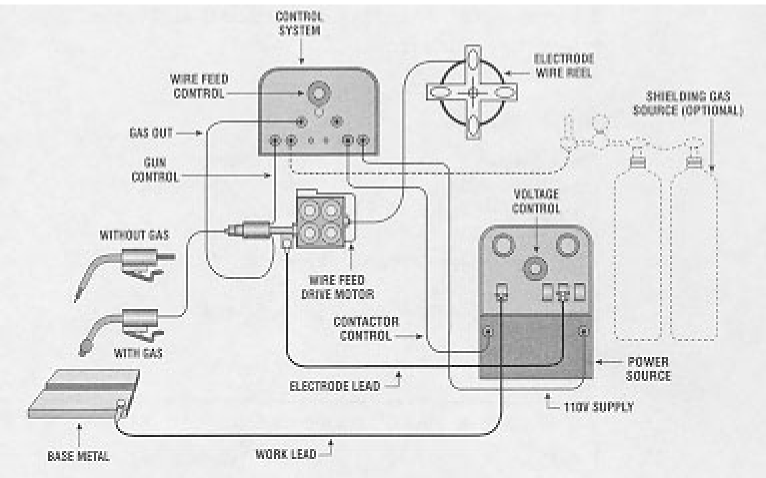

Figure 23

Welding Current Types

* D.C.E.N. or D.C.E.P. depending on type of wire.

Power Source Types and Characteristics

* Constant voltage type with a flat volt amp curve.
* Constant speed system with a constant current machine. The wire feeder is a variable speed system.

Other Equipment Requirements

Additional Equipment Necessary

Welding guns - shielding gas - water cooling system. Welding guns are of two different types. The guns for externally gas shielded wires are identical to the guns for the Gas Metal Arc Process. For the self-shielding electrodes, the guns will contain wire guides that increase the electrical stickout. This is designed to preheat the wire.

Advantages and Disadvantages

Advantages

* High quality welds - high deposition rate.
* Less pre-cleaning required - relatively high travel speeds.
* Easily mechanized.

Disadvantages

* Equipment is more expensive.
* External gas shield.
* May be affected by breezes and drafts.
* Slag must be removed
* Primarily only welds steels.

Mild Steel (Flux Cored) Electrode Classification FCAW Process

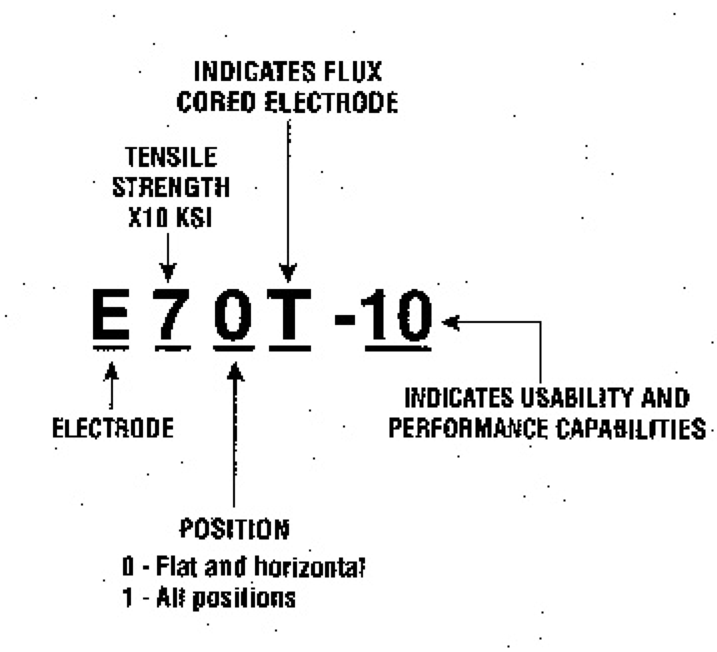

Figure 24

Flux Cored Welding Electrode Classification

AWS Classification	Shielding Gas	Current & Polarity	Tensile Strength Min
E60T-7	None	DC Straight Polarity	67,000
E60T-8	None		62,000
E70T-1	CO2		72,000
E70T-2	None		72,000
E70T-3	None	DC	72,000
E70T-4	CO2	Reverse Polarity	72,000
E70T-5	None		72,000
E70T-6	None		72,000
E70T-G	Not Spec.	Not Spec.	72,000

General Service Information
SERVICE WELDING GUIDE
Media Number -SENR0512-01 **Publication Date -01/10/2001** **Date Updated -04/06/2004**

SENR05120005

MIG (GMAW) Gas Metal Arc Welding

Fundamentals of the Process

Definition

The Gas Metal Arc Welding process uses intense heat of an electrode arc to melt the filler metal and the base metal. The consumable bare solid electrode wire is continuously fed into the arc. The deposited weld metal is formed from metal melted off the end of the electrode wire and transferred through the arc to the work. Shielding gas protects the weld from contamination.

Slang names

Microwire/MIG/Wire Welding/Carbon Dioxide Welding.

Process Principles

1. **Heat source** - electric arc between electrode (wire) and the work.
2. **Shielding** - an external gas supply.
3. **Filler metal** - fed automatically from a spool or reel.
4. **Flux** - not applicable.

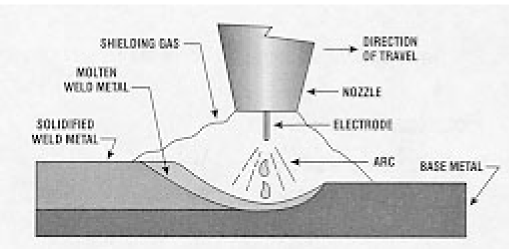

Figure 25

Transfer Modes with G.M.A.W.

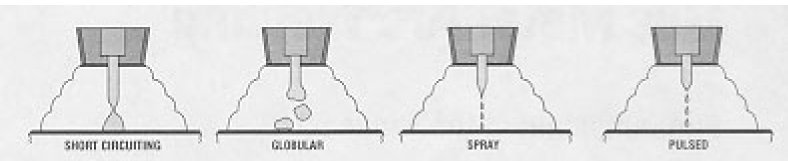

Figure 26

* Short circuiting -

CO_2 or AR/CO_2, low amperage and voltage, all positions.

* Globular -

CO_2 or AR/CO_2, higher amperage and voltage, flat and horizontal.

* Spray -

AR/O_2, high amperage and voltage, flat and horizontal.

* Pulsed -

AR/O_2, Various amperage levels, spray transfer, all positions.

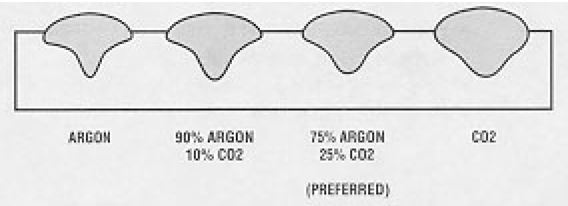

Figure 27

Bead on plat penetration diagrams for various shield gases.

Position Capabilities

* Grooves - all position capabilities.
* Fillets - all position capabilities.
* Limitations - type of transfer/skill of operator/wire size.

Electrical Requirements

Welding Circuit

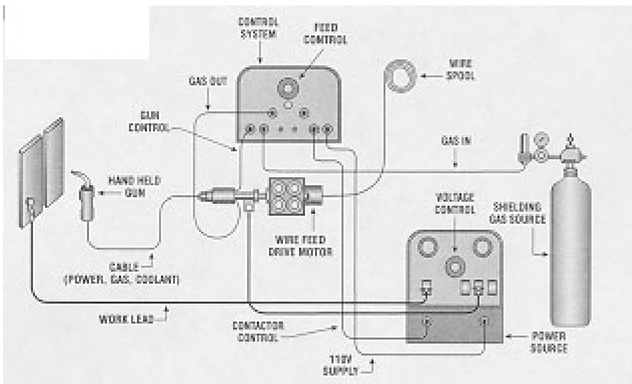

Figure 28

Welding Current Types

* D.C.E.P. - normal type of current used.
* D.C.E.N. - can be used with special electrodes.
* AC - has not been successfully used.

Power Source Types and Characteristics

* Constant Voltage - 100% duty cycle with a flat volt/amp curve.

Other Equipment Requirements

Additional Equipment Necessary

* Wire feed system.
* Welding gun and cable assembly.

Mild Steel (Solid) Electrode Classification GMAW, GTAW, and PAW

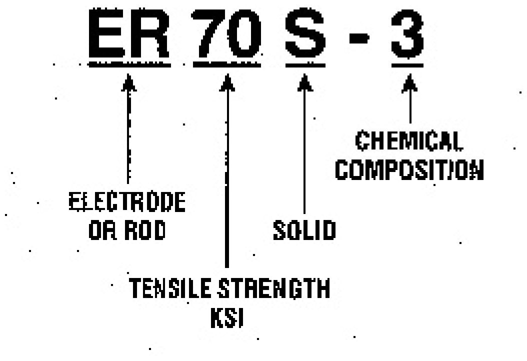

Figure 29

Air-Arc

Introduction

The Air-Arc process is most frequently used to gouge-out defective welds in preparation for repair welding, although the process can also be used to prep a joint prior to welding. The process is also referred to as the Arcair process, referring to the Arcair brand name. The arc-air process has no Caterpillar specification and is not called out on any print.

Process and Materials

The air-arc process uses a carbon-graphite electrode, usually copper-colored, that is gradually consumed by the arc. The arc melts the metal to be removed and compressed air is used to blow the molten metal off the part. An electrode holder is used to clamp the electrode and to direct the compressed air down the electrode.

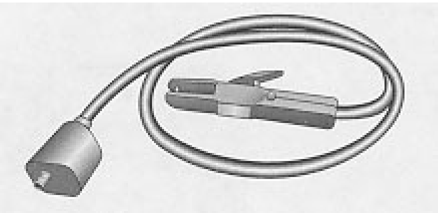

Figure 30 - Electrode Holder

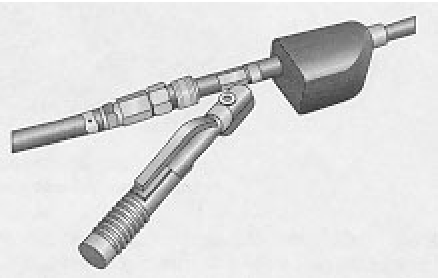

Figure 31 - Air and Power Connections

The electrode holder ids connected to compressed air using a quick-disconnect fitting. The electrical current is furnished by clamping the air-arc connector in the jaws of a stick-weld cable.

Although individual machines may have different switches that must be placed in proper position to enable air-arc gouging, air-arc is generally done with very few changes from the normal production welding processes.

Amperage is the variable that is set by the operator, depending on the electrode size. In order to set the amperage, control must be removed from the wire feeder boxes and given to the power source. This is usually done with a local/remote output switch on the front of the power source that is switched to the LOCAL position. Once LOCAL control is selected, the amperage can be controlled using the rheostat output dial.

A toggle switch is used to select the voltage parameters for the power source. This switch is put in the CC mode, setting up the power source for constant current. On power sources that do not have constant current capabilities, the mode switch, if present, is left in the normal position.

The third and last switch to be changed is the process switch. This switch can be an unmarked switch on the front of the power source. When this switch is placed in the air-arc or stick position, the power source will immediately supply an open-circuit voltage capable of creating an arc.

Figure 32 - Lincoln DC600 power source and switches for air-arc.

Unlike a stick electrode holder the air-arc holder has a rotating disk with air ports that direct air down the electrode, and a valve to turn the air on or off. The air ports are located behind the electrode to force the molten metal out in front of the electrode. This necessitates moving the disk or repositioning the electrode each time the direction of travel is changed.

The electrode is always "hot" once the proper machine settings have been selected.

To start the gouging process, the air valve is opened and the electrode is touched to the workpiece. The electrode is moved along the part to gouge a shallow channel in the part. Several passes may be required to complete the gouging.

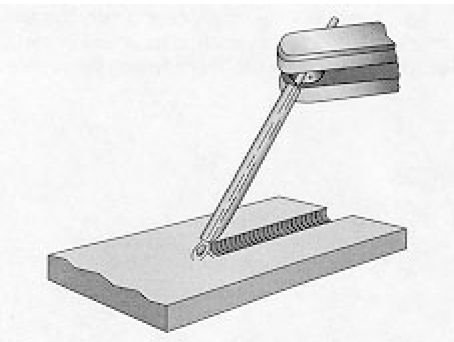

Figure 33 - Proper position of air ports and electrode.

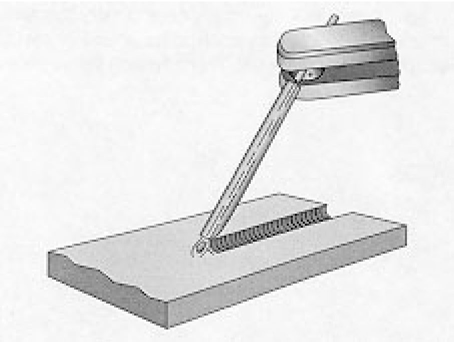

Figure 34 - New and used air-arc electrodes.

The dross or slag formed during the removal process must be removed before repair welding begins. The air-arc electrodes tend to leave carbon and copper deposits in the groove which will cause additional weld defects if not cleaned out prior to welding.

The only adjustable air-arc variables are the amperage and airflow. Airflow can be varied using the on-off valve. The air valve is normally used fully open, but can be partially closed to control airborne sparks and slag in tight areas. The air-arc process is very tolerant of amperage variations, and the operator can use this fact to control the speed of metal removal. This is very helpful in following defects in the joint. The following table shows ranges for various size electrodes.

Size	Min	Mid	Max
3/16	110	155	200
1/4	150	250	350
5/16	200	325	450
3/8	300	425	550

Welding Repair Methods

The preferred Welding process for repair of earthmoving equipment is GMAW Gas Metal Arc Welding or what is commonly known as MIG welding or, FCAW Flux Cored Arc Welding. If these welding processes are not available or not practical, SMAW is the process you will have to use.

Considerations for Repair of Cracked or Defective Welds

* Selection of material and welding procedure.
* The welding repair process has to be selected with regard to base material cleanliness and the environmental conditions (indoors or outdoors).
* Develop a weld procedure that will include welding process, welding parameters, filler metal, welding sequence, and any other specific information concerning the welding joint technique.
* Weld repair process, use DC, reverse polarity (i.e. electrode is positive (+), ground is negative (-) for either GMAW, FCAW or SMAW.
* Before welding of arc-airing, the area to be repaired must be at least 21° C (70° F), and the surface must be dry and free of moisture, paint and grease.
* This can be accomplished by acclimating in a heated workshop or preheating.
* Don't let surfaces get above comfortable hand temperature to prevent distortion to bore surfaces. Bores can be cooled with compressed air to help prevent overheating.
* Protect finish bores and surfaces from spatter when welding or air arcing.

NOTE: - in proximity of finished bores and diameters.

* Note about grounding - ground connection must be located where welding current will not arc through critical surfaces. (e.g. roller bearings, duo-cone seals, polished shaft/rods, etc) and locate ground as close to work as possible to eliminate arc blow. Turn tractor disconnect key to off position before welding or air arcing.
* Remove flaw or crack completely using air arc method or by grinding. It is critical that flaw is completely removed or the repair could fail. Refer to "Crack Preparation" in this section.
* Use dye penetrant to confirm removal of flaw.
* Grind area that was air arced to remove slag and carbon pickup.
* Reweld area where flaw was removed.
* Remove spatter from welded area and grind toes of welds to a smooth transition. (see Figure 35).
* Hammer peening the welds to improve the residual stress state.

In general, a weld repair will have, at best, the same fatigue life as the original detail. However, a repair made under difficult circumstances (poor access, out of position, outdoors, etc.) may have a shorter life.

Crack Preparation

1. Cracks must be completely removed with an air carbon arc torch or similar tool.
2. When a crack is removed with an air carbon arc tool, make sure the procedure does not cover up the cracks. A dye-penetrant can be used to check if the crack is completely removed down to a solid metal.

NOTE: All slag or foreign material must be removed from the crack before a check is made with a dye-penetrant.

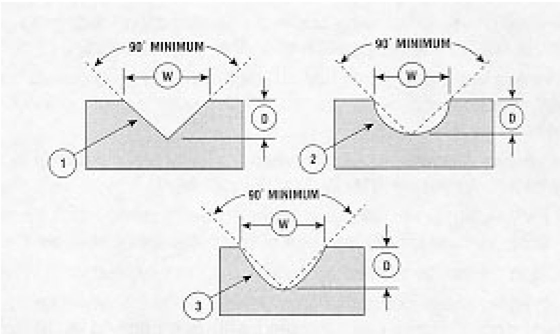

Figure 35 - Four types of welds and four joint configurations are used.

3. Width (W) must be two times as wide as depth (D). If the crack extends through the plate, refer to Welding Procedure in this instruction.

4. The groove angle will vary depending on the procedure used to make the groove. V-grooves (1), U-grooves (2), or other radius preparation (3) can be used.

Local Grinding

Toe grinding is normally done to improve the fatigue properties of the weldment by reducing the stress concentration at the weld toe detail. The grinding procedure should produce a smooth concave profile as shown in Figure 36. Toe grinding can be assumed to improve the fatigue strength of the weldment by 30% (a factor of 2.2 over the life of the weldment).

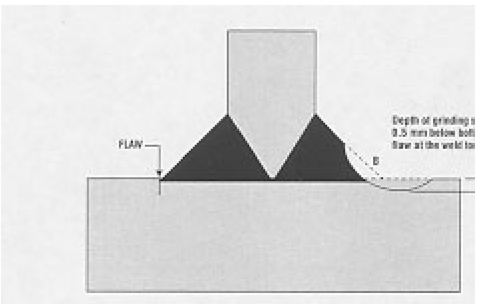

Figure 36 - Toe grinding detail to improve fatigue life.

General Service Information
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SENR05120008

Types of Welds and Joints

The four types of welds commonly used in service work are the bead, the groove, the fillet and the plug (Figure 37). The bead weld is a weld deposited in an unbroken string on a surface. The groove weld is a weld made in the space between two surfaces to be joined. The fillet weld is a weld of approximately triangular cross section that is used to join the two surfaces at an angle. The plug weld is a weld made through a plate to join it to another surface.

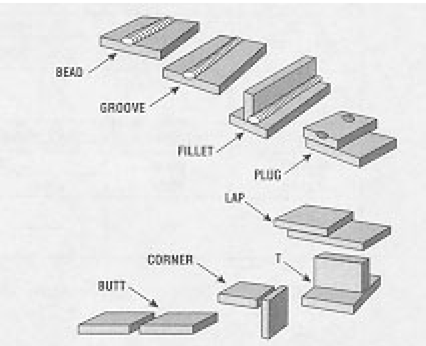

Figure 37 - Four types of welds and four joint configurations are used.

Four types of joints are commonly employed in this type of welding: the lap joint, the T joint, the corner joint and the butt joint. (Figure 37). These joints can be combined with variations in groove configuration to give the common service welding joints shown in Figure 38.

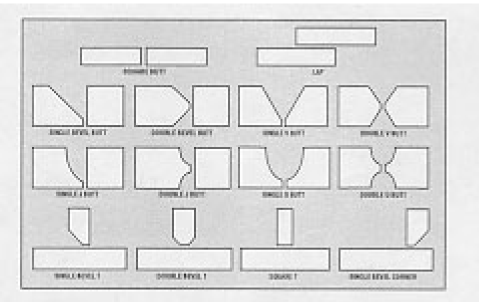

Figure 38 - Joints can be combined with groove styles for many welds.

Welding Symbols

Welding symbols are commonly understood by all welders. Basic weld symbols and supplementary symbols are shown in Figure 39. The weld symbol indicates the type of weld desired. A complete welding symbol, however, indicates the location, size and finish of the weld and gives other specifications and information.

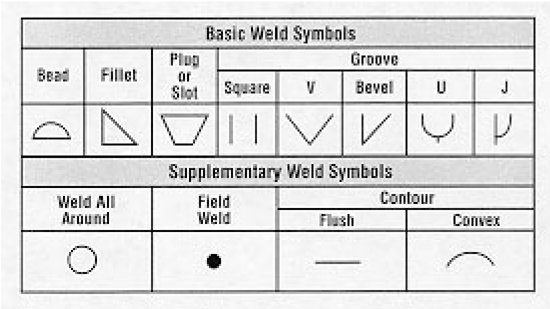

Figure 39 - Basic and Supplementary Weld Symbols

The eight elements of the welding symbol are: 1) the reference line, 2) the arrow, 3) the basic weld symbols, 4) the weld size, 5) the supplementary symbols, 6) the finish symbols, 7) the tail, and 8) the specification. A typical welding symbol is shown in Figure 40. A weld symbol placed below the reference line goes on the other side of the joint. A summary of standard welding symbols published by the American Welding Society is shown on Page 6. Refer also to Sections I through VIII of the AWS Standard Welding Symbols Code.

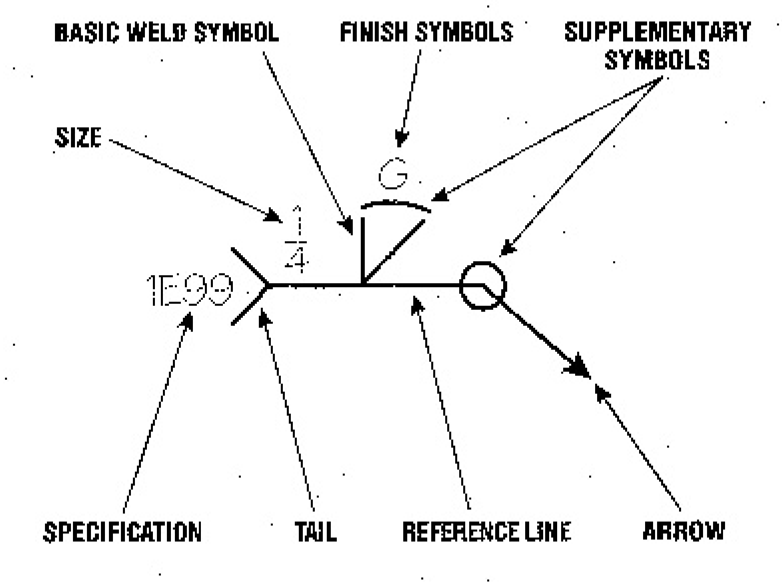

Figure 40 - The welding symbol gives location, size and finish of weld.

Types of Electrodes

Electrodes used in arc welding can be classified according to operating characteristics, type of coating and characteristics of deposited metal. AWS specifications group electrodes in series (E45 Series, E60 Series, etc.) according to the minimum tensile strength of the deposited metal. The deposited metal from E80 Series electrodes, for example, has a minimum tensile strength of 80,000 psi in stress relieved condition. Each series is further subdivided according to welding position, coating composition and welding current. These are indicated by the last two digits in the classification number.

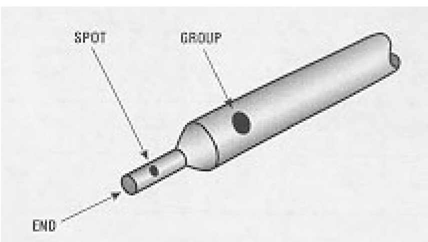

Figure 41 - Electrodes formerly were marked according to a AWS color code.

Chart B - Electrode Coatings

Final Digit	Type of Coating	Welding Current
1	cellulose potassium	AC or DC reverse
2	titania sodium	DC straight or AC
3	titania potassium	AC or DC
4	iron powder titania	AC or DC
5	low hydrogen sodium	DC reverse
6	low hydrogen potassium	AC or DC reverse
7	iron powder iron oxide	AC or DC
8	low hydrogen iron powder	AC or DC straight

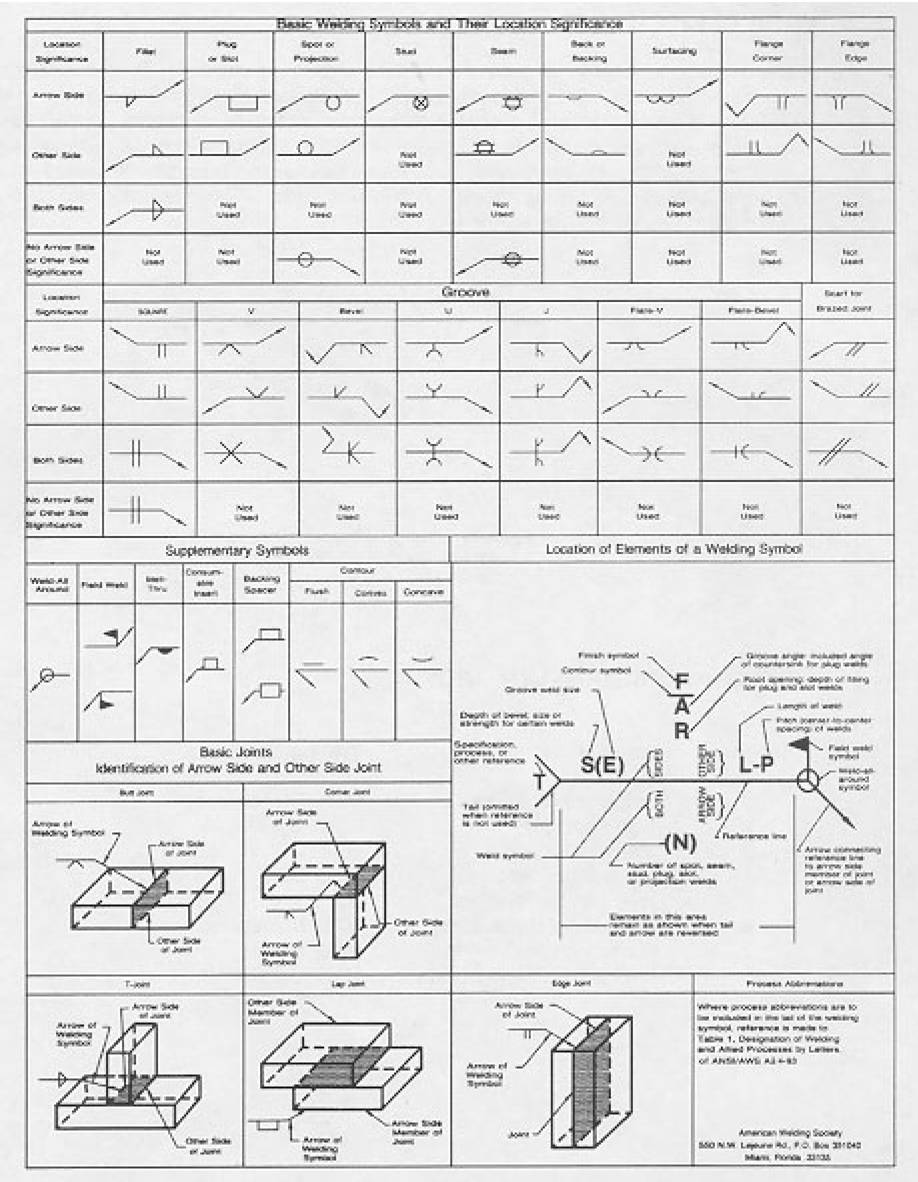

Figure 42a - American Welding Society Basic/Typical Welding Symbols Chart

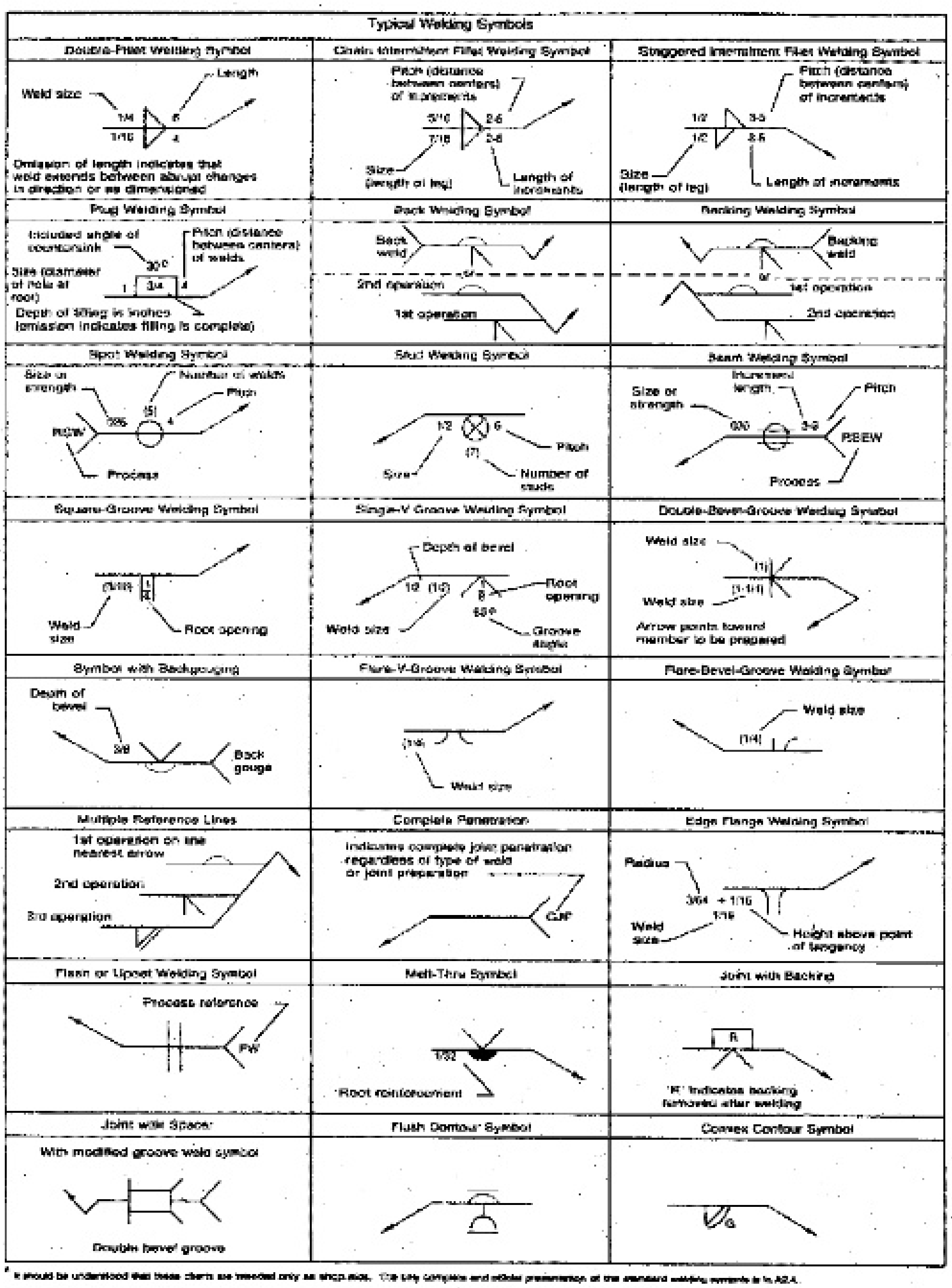

Figure 42b - American Welding Society Basic/Typical Welding Symbols Chart

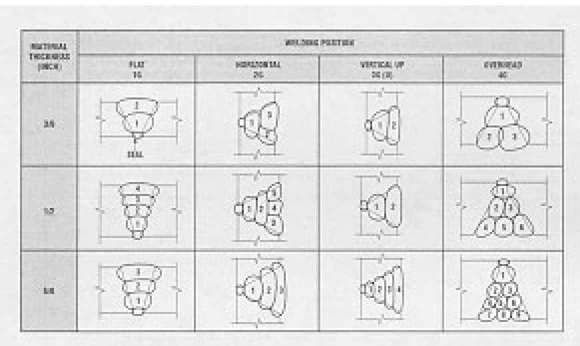

Figure 43 - Welding Position

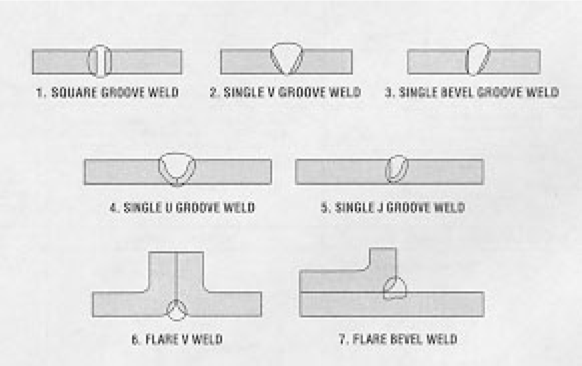

Figure 44 - Seven basic groove welds

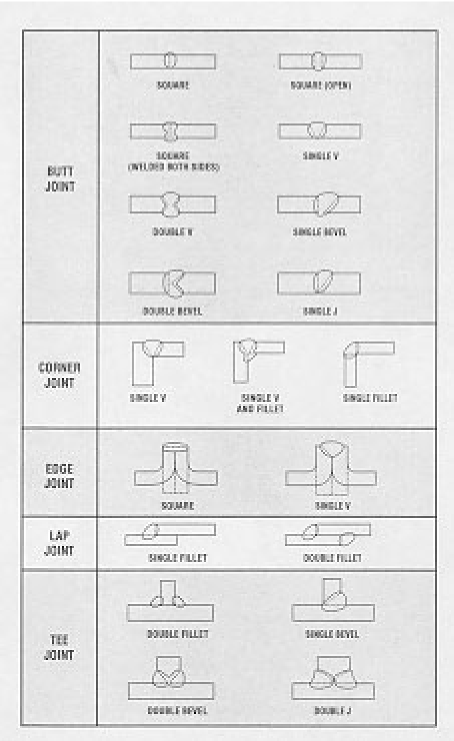

Figure 45 - Some Typical Weld Joints

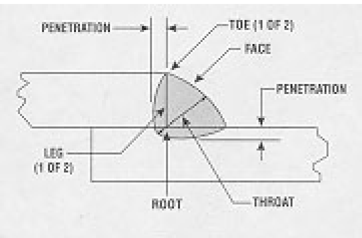

Figure 46

Weld Defects

Repairing Cracks and Defective Welds

Cracks often develop in components that are used for unusually severe applications or are approaching the limit of their service life. Defective welds, on the other hand, are usually caused by careless welders who fail to use good welding techniques. The most common defects in welds are: underbead cracks, slag inclusions, porosity (gas holes and pockets), cold lap, undercut and slugged welds. The procedures for repairing cracks and replacing defective welds are similar.

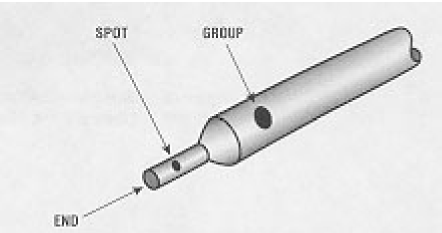

Figure 47 - Underbead cracks are caused by hydrogen gas being absorbed by the seal.

Underbead cracks occur between the weld deposit and the parent metal or in the heat affected zone under the weld deposit in carbon steels (Figure 47). The cracks are usually caused by hydrogen gas being absorbed by the parent metal and being released as the metal cools. The gas builds up pressure in the minute voids of the parent metal and forces the metal to crack. Underbead cracking is most common with steels having a carbon content in excess of 0.30%, but it often occurs when low carbon steels are welded in ambient temperatures below 32° F without preheating to remove moisture.

Underbead cracks are not visible from the surface of the joint and can be detected only by X-ray or magnetic particle inspection. Using hydrogen electrodes that have been stored properly to keep them dry will eliminate most underbead cracking.

Slag inclusion refers to entrapment of slag within the weld metal (Figure 48). The inclusions arise mainly from failure to clean the weld deposit before the next pass is made. Too slow a travel speed also causes slag inclusions, because the volume of slag becomes too large to be floated out of the puddle of molten metal.

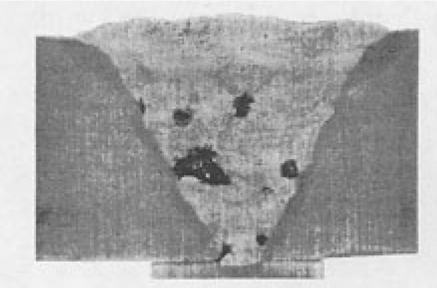

Figure 48 - Slag inclusions arise from failure to clean the weld deposit.

Porosity usually is caused by the oxidation of foreign matter such as grease or paint that has been left on the joint (Figure 49). The foreign matter is vaporized by the molten metal and forms gas pockets in the weld deposit. Porosity can also be caused by excessive moisture in any type of electrode coating or by excessive magnetic arc blow. Careful cleaning of joints prior to welding, using dry electrodes and controlling arc blow will prevent porosity.

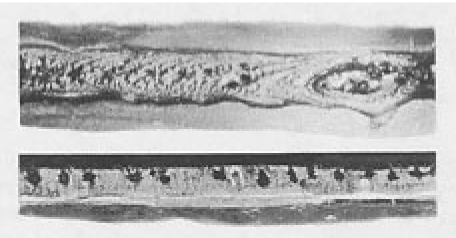

Figure 49 - Porosity is caused by oxidation of foreign matter on the joint.

Cold lap is caused by improper fusion of the weld metal to the parent metal, arising from insufficient heating of the joint members (Figure 50). Instead of bonding to the parent metal, the weld deposit lies on top of it, giving rise to a definite crack or void. Cold lap can be prevented by proper manipulation of the electrode to bring all parts of the joint up to a molten state. A slightly longer arc or slightly higher welding current will also help to combat the problem of cold lap by increasing the amount of heat liberated at the joint.

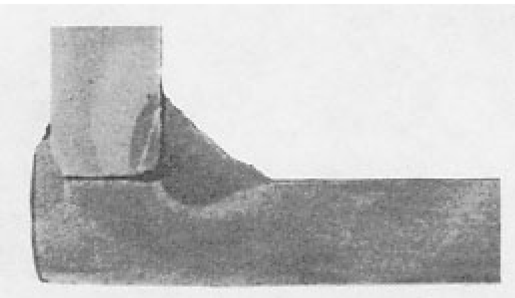

Figure 50 - Cold lap is improper fusion of parent metal and weld.

An undercut is a groove melted in the parent metal adjacent to the toe of a weld that is not filled with weld metal (Figure 51). Undercutting occurs most often in other than flat positions and is caused by excessive heat in the joint, coupled with failure to wash the weld metal up onto the vertical plate. It can be prevented by reducing the welding current or shortening the arc and by manipulating the electrode properly. Undercuts can be remedies by making another pass on the joint to fill the groove in the parent metal with weld metal.

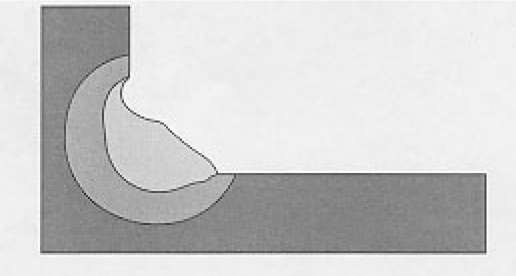

Figure 51- Undercuts will arise from excessive heat in the joint.

A slugged weld is a weld made in a joint with a wide gap that has small pieces of steel placed in the gap to fill up space (Figure 52). The external appearance of a slugged weld may be perfect, but the joint is weakened considerably because of improper fusion of the slug to the parent metal and poor penetration of the weld metal. Besides being a shoddy practice, weld slugging contributes nothing at all to the welding speed or electrode economy. If a back-up plate is used with a wide gap joint (Figure 53), a larger electrode can be used and the joint can be welded properly in less time than it can be if slugs are added. Slugging a weld is an intolerably poor welding technique and should never be employed in any type of service welding.

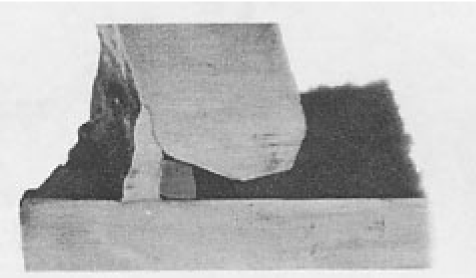

Figure 52- A slugged weld has small pieces of steel in the gap to fill up space.

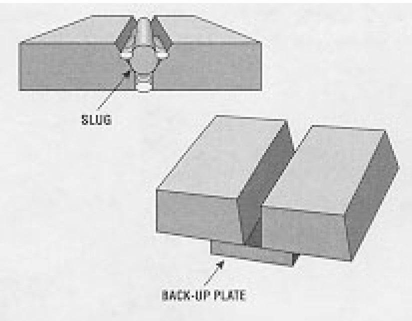

Figure 53- A back-up plate will allow a wide gap joint to be welded properly.

Cracks and defective welds (except undercuts) must be removed completely, and the resulting gap must be filled with a sound weld deposit in order to restore a component to its original strength. Any portion of a crack that is left will initiate further cracking in the new weld. The best way to remove a crack or a defective weld is to grind it out with a portable grinder or gouge it out with an Arcair torch. The grinding or gouging must extend at least an inch past the visible ends of a crack in order to remove all traces of the crack and any fatigued metal.

Reinforcing Plates and Hard Surfacing

Installing Reinforcing Plates

Machine components fail primarily because of a localized overstressed condition. This overstressing is caused either by overloading, which stretches, compresses or bends the member, or by repeated flexing which cracks the member without visible bending. The former may occur, for example, in a track roller frame, the latter in a scraper gooseneck. In either case, the stresses can be reduced by properly applying reinforcements to the weak section. Improper application may have the opposite effect. High stresses usually occur at definite, predictable locations in machine members, although the locations are not always apparent until a failure occurs.

The understanding and application of several basic rules will help in the successful design and installation of reinforcing plates:

Rule 1 - Avoid sudden changes in cross-sectional area. Notches, sharp corners, and abrupt changes in area give rise to points of stress concentration. Reinforcements should be designed to enable loads to be transmitted smoothly through the reinforcement and from the reinforcement to the machine component (Figure 54). Notches and cracks should be filled with weld metal; corners should be curved with a generous radius; changes in width or thickness of plates should be gradual; ends should be tapered.

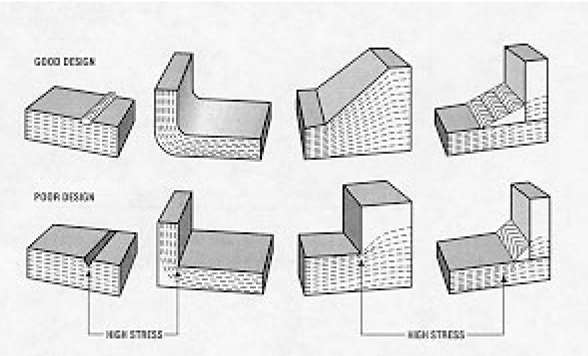

Figure 54 - Changes in cross sectional area must be made smoothly and gradually.

Several examples of well designed reinforcement plates are shown in Figure 55. Note the tapered ends and rounded corners. In most cases, tapered plates add the same strength to beams subjected to bending stresses as rectangular plates do (Figure 56). The tapered plates weigh about half as much as rectangular plates and require no more time to install.

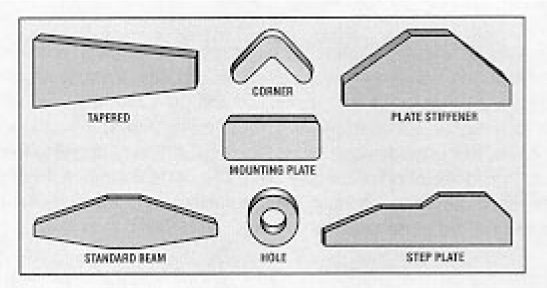

Figure 55 - Properly designed reinforcements have tapered ends and rounded corners.

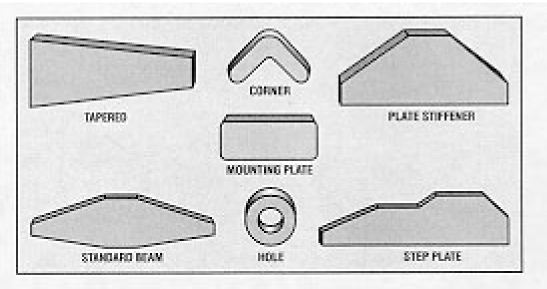

Figure 56 - Rectangular reinforcing plates add no more strength than tapered plates.

Rule 2 - Place reinforcements as far as possible from the neutral axis for bending loads. The neutral axis of a beam is located on a line of zero stress, which is usually at or near the center of the beam. Reinforcing plates of a given thickness will be most effective when placed as far as possible from the neutral axis (Figure 57). Note that plates added to the top and bottom of a beam parallel to the neutral axis add considerable more strength than plates of the same thickness added to the sides of the beam.

Location Of Plates	Relative Strength	Comments
4.0" × 4.0"	1.00	Strength of original beam is taken as 1.00.
.75" / .75"	1.91	Adding 0.75" plates on top and bottom of beam almost doubles strength.
.50" / .50"	1.56	Adding 0.50" plates on top and bottom increases strength more than adding 1.0" plates on sides.
1.0" / 1.0"	1.50	Adding 1.0" plates on each side increases strength only 50 percent.
.50" / .50"	1.25	Adding 0.50" plates on each side increases strength only 25 percent.

Figure 57 - Bending Load Reinforcements

Rule 3 - Use a circular or box section for torsional loads. Reinforcements for shafts subjected to torsional stresses should be continuous around the shaft and should run the full length that is in torsion. (Figure 58). Square sections should be reinforced by adding plates on all sides. Rectangular sections are strengthened by adding plates to the opposite sides that are closest together. I-beams, channels and angles should be reinforced in such a manner that the final section is boxed. In all cases, the circular or boxed section is much stronger in torsion and is preferred for torsional loads.

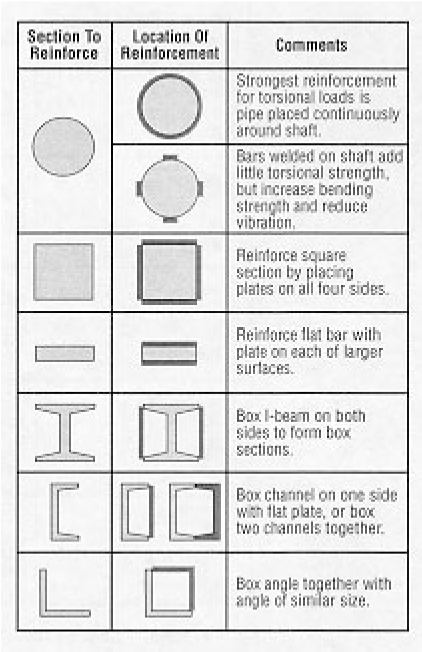

Figure 58 - Torsional Load Reinforcements

Rule 4 - Consider the effect on the entire beam before adding a reinforcement. Relatively small reinforcing plates added to a beam may reduce the stresses directly under the plate, but they have a tendency to increase stresses at each end of the beam (Figure 59). A long tapered plate is much better because it spreads the load uniformly through the beam instead of concentrating it in two spots.

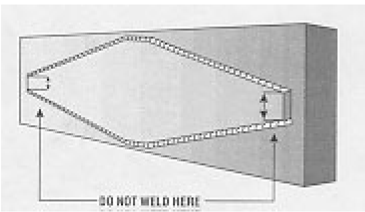

Figure 59 - Long reinforcing plates distribute the load evenly along the beam.

Rule 5 - Avoid making transverse welds at the ends of reinforcements. Transverse welds create high stress areas that usually lead to cracking. Once a crack has formed, it will progress across the beam until it eventually causes a failure. The end of the reinforcing plate should be left open (Figure 60). Again, the ends are tapered to spread the load over a greater area of the beam.

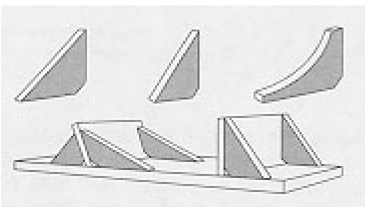

Figure 60 - Transverse welds at the end of reinforcing plates should be avoided.

Rule 6 - Use gusset reinforcements to reduce stresses in sharp corners and other small areas. Gussets should be designed and installed so the forces are distributed and transmitted uniformly and are not concentrated in one spot. Gussets can be triangular or they can be designed with a radius (Figure 61). They should not be welded in the sharp corners created by the machine components and the gusset. Welding in these areas creates localized overstressed conditions that originate cracks. The thickness of the gusset should be about the same as or slightly less than the thickness of the plates it is reinforcing. If possible, the gusset should be welded on both the inside and outside.

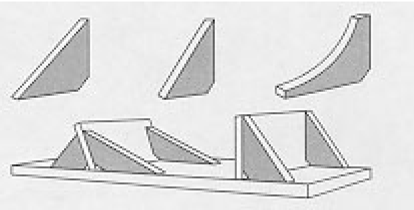

Figure 61 - Gussets reduce stresses in sharp corners and other small areas.

Controlling Heat Distortion

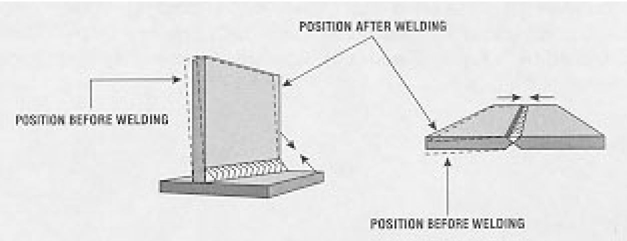

Figure 62 - Members can be pulled into alignment by shrinking of the weld.

Distortion due to thermal expansion and contraction is a problem with all types of welds. There are three basic methods of minimizing distortion: peening, jigs and fixtures, and special welding techniques. With the first method, the weld metal is stretched immediately after it is deposited by a series of hammer blows. Peening has limited application in service welding, however, because of the lack of precision possible with hand peening and the possibility of strain hardening the weld metal. When the work is clamped in a special jig or fixture, the clamping force overcomes the force of thermal contraction of the weld deposit, and the deposit itself stretches. This method, too, has limited application in service welding because of the expense of special jigs and the difficulty of clamping large components.

Special techniques in the positioning of welding members and special pass sequence is usually the simplest method for controlling distortion in service welding. Members can be positioned initially somewhat out of alignment, and the shrinking of the weld deposit can be relied upon to pull the member into the proper position (Figure 62). A pass sequence that builds the deposit up equally on each side of the joint will allow contractive forces to balance each other and prevent distortion (Figure 63). Sufficient tack welding will greatly reduce distortion when the final weld is made. In each case, no attempt is made to eliminate the expansion and contraction; rather, the forces are utilized to give the desired final shape to the joint.

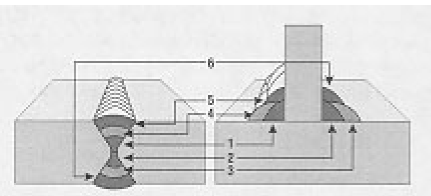

Figure 63 - A proper pass sequence allows contractive forces to balance each other.

The controlled expansion and contraction of metal has another application in service maintenance and reconditioning work - heat straightening. Large components such as track roller frames that are slightly bent can be straightened easily by controlled heating and cooling. The principle involved is based on upsetting the metal or making it shorter and thicker in the area where heat is applied. (Figure 64). If the outer or convex side of the bend is heated, the heated area expands. If the inner or concave side of the bend is kept relatively cool, however, the heated area cannot expand lengthwise as much as it wants to because of the rigidity of the cooler portion. The heated area, therefore, expands outward and becomes thicker. When the heated area cools, it contracts and effectively shortens the convex side of the bent beam. This shortening counteracts the bend and straightens the beam. If one heating and cooling operation does not bend the beam enough, the process can be repeated on either side of the original area.

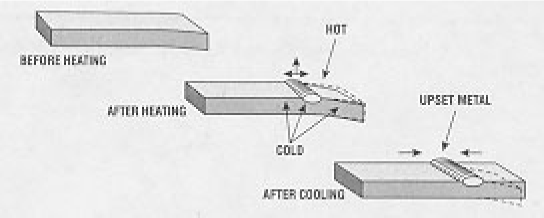

Figure 64 - If metal is forced to expand unevenly when heated, it becomes "upset".

Selecting the Proper Reinforcing Steel

Many types of steels are available for use in reinforcing machine operated under sever conditions. High-strength structural steel, heat treated steel and mild steel are recommended for various field reinforcements and reconditioning procedures. High-strength structural steel is a weldable steel with a minimum yield strength of 45,000 psi and a minimum tensile strength of 70,000 psi. This type of steel is not heat treated. E7018 electrodes are recommended for welding high strength structural steel. Figure 65 gives the names and producers of some commercially available steels that fall into this category as well as some heat treated steels that are considered weldable. E11018 electrodes are recommended for the latter. A mild grade of hot rolled structural steel can also be used as reinforcing material. E60 Series electrodes are recommended for welding mild steel. SAE 1017, SAE 1018, SAE 1020 and SAE 1021 grades fall in this category and are produced by nearly all steel companies.

High Strength Structural Steels

Name	Producer
Algo-Loy 1316	Algoma Steel Corp., Ltd.
Cor-Ten	U.S. Steel Corp.
Clay-Loy	Colorado Fuel and Iron Corp.
Dynalloy	Alan Wood Steel Co.
Ex-Ten 55	U.S. Steel Corp.
Ex-Ten 60	U.S. Steel Corp.
GLX-50-W	Great Lakes Steel Corp.
GLX-55-W	Great Lakes Steel Corp.
GLX-60-W	Great Lakes Steel Corp.
Hi-Steel	Inland Steel Co.
High Strength #1	Armco Steel Corp.
High Strength #4	Armco Steel Corp.
Jalten #2	Jones & Laughlin Steel Corp.
Jalloy #1	Jones & Laughlin Steel Corp.
Kaisaloy #1	Kaiser Steel Corp.
Kaiser Structural High Strength	Kaiser Steel Corp.
Maxeloy	Crucible Steel Co. of America
Medium Manganese	Bethlehem Steel Co.
Manganese Vanadium	Bethlehem Steel Co.
N-A-X High Tensile	Great Lakes Steel Corp. Republic Steel Corp. Sharon Steel Corp. Granite City Steel Co.
N-A-X Finegrain	Great Lakes Steel Corp. Republic Steel Corp. Sharon Steel Corp. Granite City Steel Co.
Republic "M"	Republic Steel Corp.
Stelcoloy "A"	Steel Co. of Canada, Ltd.
Stelcoloy "B"	Steel Co. of Canada, Ltd.
Strenlite	Steel Co. of Canada, Ltd.
Tri-Steel	Inland Steel Co.
Yoloy M Grade A	Youngstown Sheet & Tube Co.
Yoloy M Grade B	Youngstown Sheet & Tube Co.
Tri-Ten	U.S. Steel Corp.

Weldable Heat Treated Steels

Name	Producer
Naxtra 90	Great Lakes Steel Corp.
Naxtra 100	Great Lakes Steel Corp.
T 1	U.S. Steel Corp.

Figure 65 - High Strength Structural Steels and Weldable Heat Treated Steels

Rebuilding By Welding

Components of track roller frames on track-type machines (such as links, rollers and sprockets) that are exposed to considerable wear in the normal course of operation are often rebuilt by welding. In many cases automatic welding equipment is best used for these operations, and specific instructions for this type of rebuilding work is beyond the scope of this book. Refer to the Caterpillar Parts Rebuilding literature listed in the Reference Books section (Page 67) for additional information on these subjects.

Other components such as teeth and cutting edges, which are exposed to the abrasive effects of rock, sand and soil, experience a marked amount of wear. It is usually more economical to replace these components as they become worn, but in some instances it may be desirable to rebuild these parts by welding. In addition, surfaces adjacent to cutting edges and members such as ripper shanks that run in the soil will wear away from the abrasive action of the soil. These surfaces can be restored to their original dimensions by arc welding. The built-up weld deposit on restored surfaces must be strong enough to support a hard overlay deposit and hard enough to resist abrasion. Use E7018 electrodes on modern earthmoving machines where high strength steels are used freely; E7018 electrodes give the best weld buildup material.

The material can be deposited in any position on any of the low and medium carbon steels.

Hardsurfacing

The service life of parts that are subjected to constant abrasion can be extended greatly by hardsurfacing the affected areas with beads of weld. Hardsurfacing is most commonly applied to rebuilt parts, but new components can be treated in the same manner. On parts such as bucket teeth that are exposed to severe wear, the entire area can be covered with a layer of hardsurfacing material. Since the material is hard and brittle, the layer should not be more than 1/8 inch thick. Otherwise, it will have a tendency to crack and break off. The leading edge of a cutting tool may break off if it is extended more than two beads away from the base metal (Figure 66).

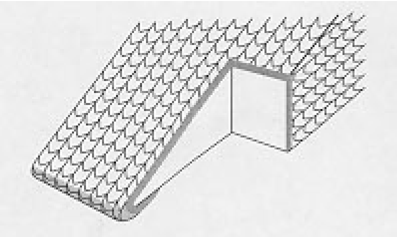

Figure 66 - Service life of parts can be extended by hardsurfacing.

For most applications, a pattern of stinger beads of hardsurfacing material has been found to be more economical. In applications where heavy rocks are being handled, the beads should be placed parallel with the flow of the abrasive material (Figure 67). The parallel beads will support the rocks and protect the base metal while offering the least resistance to flow. Beads may be laid perpendicular to flow in areas that are covered completely. Surfaces exposed to the abrasive action of sand, soil or small stones should be protected with stringer beads that are perpendicular to the flow (Figure 67). The spaces between the beads will fill up with soil and the soft base will be completely protected. Another pattern used frequently is the diamond shaped pattern (Figure 67). This pattern is designed to prevent dirt from packing between the stringer beads and is used where self-cleaning action is desired.

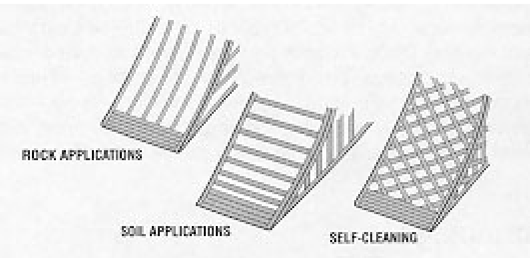

Figure 67 - Different bead patterns are required for various applications.

Reference Books

Reference: Metals and How to Weld Them. Published by The James F. Lincoln Arc Welding Foundation, Cleveland, Ohio.

Reference: Parts Rebuilding - Heat Treating Roller Flanges. (FEO34223-01) Published by Caterpillar Tractor Co., Peoria, Illinois.

Reference: Parts Rebuilding - Reconditioning Dimensions - Track Links, Rollers, Idlers, Carrier Rollers. (FEO34563-04) Published by Caterpillar Tractor Co., Peoria, Illinois.

Reference: Parts Rebuilding - Welding - Rollers, Idlers, Track Links. (FEO33251-05) Published by Caterpillar Tractor Co., Peoria, Illinois.

Reference: Procedure Handbook of Arc Welding Design and Practice. Published by Lincoln Electric Company, Cleveland, Ohio.

Reference: Welding Design and Fabrication. Published monthly by The Industrial Publishing Corporation, Cleveland, Ohio.

Reference: Welding Design and Fabrication Data Book. Published biennially by The Industrial Publishing Corporation, Cleveland, Ohio.

Reference: Welding Engineer. Published monthly by Welding Engineer Publications, Inc., Rochelle, Illinois.

Reference: Welding Handbook. Published by the American Welding Society, New York, New York.

Glossary

Arc Length - The distance from the end of the electrode core to the surface of the puddle of molton metal. **Arc Stream** - Molten particles of electrode material flowing from the electrode to the puddle of molton metal. **Arc Welding** - A process of fusion welding in which the heat from an electric arc is utilized to melt the adjacent surfaces of the pieces to be welded. **Axis (of a Joint)** - A line through the weld deposit in a joint perpendicular to the cross section at its center of gravity. **Back Blow** - Deflection of the arc away from the direction of travel. See Magnetic Arc Blow. **Back-up Plate** - A plate placed behind a wide gap weld joint to retain the molten weld metal and insure complete penetration and fusion at the root of the weld. **Base Metal** - See Parent Metal. **Cold Lap** - A void between the weld deposit and the parent metal caused by insufficient fusion. **Crater** - The depression in a weld deposit caused by displacement of molten weld metal by the force of the arc stream. **Depth of Penetration** - The distance from the surface of the parent metal to the root of the weld. **Electrode Angle** - The angle that the electrode makes with the axis of the joint or the surfaces of the weldment members. **Flat Position** - A joint position where both the axis of the joint and the face of the weld are within 10° of horizontal and the welding is performed on the top of the joint. **Flux** - Fusible material used in welding to dissolve and facilitate removal of oxides and other undesirable substances. **Forward Blow** - Deflection of the arc toward the direction of travel. See Magnetic Arc Blow. **Fusion** - The melting together of parent metal and weld metal. **Fusion Welding** - Welding by melting the adfacent surfaces of pieces to be joined and allowing the molten metal to mix. **Gas Shielding** - The protection of molten weld metal from the air with a cloud of gas which is generated by the vaporization of materials in the electrode coating. **Gouging** - Formation of a chamber or groove by melting and removing a portion of vase metal. **Hardsurfacing** - The deposition of weld metal on metal surface to obtain desired characteristics or dimensions. **Heat Treated Steel** - A steel that has been heated, quenched and tempered, or otherwise trated in such a manner that its surface hardness is greater than in the annealed condition. **High-Strength Structural Steal** - A weldable steel with a minimum yield strength of 45,000 psi and a minimum tensile strength of 70,000 psi. **Horizontal Position** - A joint position where the axis of the joint is within 10° of horizontal and the face of the weld is between 10° and 90° from horizontal. **Interpass Temperature** - In a multiple pass weld, the lowest temperature of the weld metal before the next pass is started. Interpass temperature should be measured two inches in from the start end of the preceding pass. **Low Hydrogen Electrode** - An electrode containing no materials in the coating which will yield hydrogen gas upon vaporization. **Low Carbon Steel** - Steel containing less than 0.30% carbon. **Lead Angle** - The angle between the electrode and a line perpendicular to the axis of the joint. **Magnetic Arc Blow** - Deflection of the arc from its intended path due to concentrations of magnetic force set up in the work by electric current. **Medium Carbon Steel** - Steel containing 0.30% to 0.54% carbon. **Mild Steel** - See Low Carbon Steel. **Neutral Axis** - The line of zero stress in a beam, usually at or near the center of the beam. **Overhead Position** - A joint position where the axis of the joint is within 10% of the horizontal and the welding is performed on the lower side of the joint. **Overlap** - Protrusion of weld metal beyond the bond at the top of a weld. **Parent Metal** - The metal to be welded. **Pass** - A single longitudinal progression of a welding operation along joint. **Porosity** - Gas pockets or voids in the weld metal. **Shielded Arc Welding** - An arc welding process that employs an electrode coated with a material which, when heated, decomposes to form a gas cloud, melts to form a slag covering over the weld or both. The gas cloud and the slag protect the molten weld metal and the arc from elements in the air. **Slag** - Non-metallic solid material composed of electrode flux and impurities from the joint. In a properly made weld, the slag will lie on top of the weld metal. **Slag Inclusion** - The entrapment of slag in weld metal or between weld metal and parent metal. **Slugged Weld** - A weld that has a piece or pieces of material added to it before or during welding resulting in a welded joint that does not comply with design or specification requirements. **Spatter** - The metal particles expelled during welding which do not form part of the weld. **Tack Weld** - A weld - usually short - made to hold parts of a weldment in proper alignment until the final welds are made. **Transverse Weld** - A weld made at approximately right angle to the axis of a beam. **Travel Speed** - The rate at which the electrode is moved along the length of the weld **Underbead Crack** - A crack between the weld deposit and the parent metal or in the heat affected zone under the weld deposit. **Undercut** - A groove melted in the parent metal, adjacent to the toe of a weld, that is not filled with weld metal. **Upsetting Metal** - The process of shortening and thickening metal by means of the application of pressure. In heat straightening, the pressure is obtained from the thermal expansion of the heated metal. **Vertical Position** - A joint position where the axis of the joint is between 10° and 90° from horizontal. **Warping** - An undesirable change in the shape of a weldment due to the forces of expansion and contraction of the weld metal. **Weaving** - Moving the tip of the electrode back and forth over the joint as the electrode travels along the joint to obtain a wider weld deposit and to control heat input in the joint. **Weld Deposit** - The material in a welded joint which was melted during the welding process. The weld deposit consists of both electrode metal and parent metal. **Weldment** - An assembly whose components are joined by welding. **Work Angle** - In horizontal fillet welds, the angle between the electrode and the vertical plate.

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