Quality Control

To make a good weld requires not only a knowledge of the proper procedures but also a knowledge of how to recognize a good weld, how to recognize faults in a weld, and how to correct those faults. Failure at this point can be harmful to the quality of welding and can substantially increase its cost.

Inspection If standard welding procedures are used as specified, the end result can be virtually guaranteed. To get the best results, therefore, the best time to inspect a weld is while it is being made. A check of edge preparation, electrode type and size, current, and travel speed used, as well as surface appearance of the completed weld, can indicate to a qualified inspector the strength of the weld.

A good surface has no cracks and no serious undercut, overlap, surface holes, or slag inclusions. The ripples and width of bead should be uniform, with butt welds flush or slightly above the plate surface and without excessive buildup. Fillet welds should have equal legs on each plate. If there is more than a slight variation from these standards, a check should be made on plate preparation, gap limits, polarity, current, speed, electrode angle, and other techniques of welding.

Weld spatter Weld spatter is an appearance defect of no consequence to the structural function of the weld. Excessive spatter is not necessary, however, and its appearance on a weld-

TABLE 28-16 Designation of Arc-Welding-Electrode Usability

AWS classification	Current and polarity	Arc type	Penetration	Covering and slag	Iron powder, %*
EXX10. . .	d-c reverse	Digging	Deep	Cellulose-sodium	0–10
EXXX1. . .	a-c and d-c reverse	Digging	Deep	Cellulose-potassium	0
EXXX2. . .	a-c and d-c straight	Medium	Medium	Rutile-sodium	D-10
EXXX3. . .	a-c and d-c straight and reverse	Soft	Light	Rutile-potassium	0–10
EXXX4. . .	a-c and d-c straight and reverse	Soft	Light	Rutile-iron powder	25–40
EXXX5. . .	d-c reverse	Medium	Medium	Low H_2-sodium	0
EXXX6. . .	a-c and d-c reverse	Medium	Medium	Low H_2-potassium	0
EXXX8. . .	a-c and d-c reverse	Medium	Medium	Low H_2-iron powder	25–40
EXX20. . .	a-c and d-c straight and reverse	Medium	Medium	Iron oxide-sodium	0
EXX24. . .	a-c and d-c straight and reverse	Soft	Light	Rutile-iron powder	50
EXX27. . .	a-c and d-c straight and reverse	Medium	Medium	Iron oxide-iron powder	50
EXX28. . .	a-c and d-c reverse	Medium	Medium	Low H_2-iron powder	50

*Based on covering weight.

ment is not pleasing. It may be caused by (1) too high a welding current, (2) wrong electrode, (3) wrong polarity, (4) too large an electrode, (5) wrong electrode angle, or (6) arc blow.

To eliminate weld spatter, (1) select the proper current setting for the diameter of the electrode and the plate thickness, (2) be sure that the electrode does not have an inherent spatter-producing characteristic, (3) check the polarity switch to determine if the polarity is correct for the electrode, (4) use an electrode of the proper diameter for the plate thickness, (5) correct the electrode angle for the procedure used, and (6) see the discussion on arc blow for corrections.

Undercut Unless it is serious, undercut is more of an appearance defect than a structural detriment. However, some inspection agencies will not accept undercut of any type and demand that it be chipped out and the joint rewelded. For this reason, undercut should be avoided. It may be caused by welding current being too high, improper electrode manipulation, or too large an electrode. Undercutting may be reduced by using correct welding current, travel speed, and size of electrode. A uniform weave of the electrode will tend to prevent undercutting when making butt welds. Excessive weaving will cause undercut and should be avoided.

Poor fusion Poor fusion is sometimes associated with incomplete penetration and is probably a structural fault. Proper fusion is essential to full-strength welds. It should be the concern of both the welder and the inspector that correct procedures are used to obtain the required fusion. Poor fusion may be caused by improper current setting, improper welding technique, failure to prepare the joint properly, or wrong size of welding electrode used.

Heavier plates require more current for a given electrode than small plates; therefore, sufficiently high welding current should be used to ensure correct deposition of weld metal with a good penetration of the base metal. In welding, the sides of the joint should be melted thoroughly. In preparing the joint, the face of the groove should be clean and free of foreign material. The weld material should be deposited to ensure good fusion between the plates, and an electrode sufficiently small to reach the bottom of the groove should be used.

Cracks There are different kinds of cracks in welds, some of which are more serious than others. All types of cracks should be examined to determine what corrective measure, if any, are needed. The most common cracks in and about a weld joint are crater cracks, underbead cracks, and longitudinal cracks. Cracks in the piece of metal along the edge of the weld are sometimes referred to as toe cracks; there are also hairline cracks across the weld and microcracks.

While these various cracks appear in different parts of the weld and result from different causes, the basic fault which leads to such structural defects, if eliminated, will result in crack-free welds. Causes of cracks include (1) base metal not of a weldable-grade material, (2) weld joints improperly prepared, (3) wrong welding procedures, (4) too rigid welds, and (5) too small or wrongly shaped welds. Corrective measures to eliminate cracking are:

1. Avoid a high-sulfur, high-phosphorus steel. If it is necessary to weld this type of base metal, use a low-hydrogen electrode. High-alloy or high-carbon steels should be preheated prior to welding.

2. In preparing joints for welding, space the members uniformly so that the gap is even. In some cases this may mean there is a $\frac{1}{32}$-in gap in the welding groove; in other cases the parts may be welded closely together. The size of the weldment and the welding problem at hand will determine the gap spacing.

3. Be sure that the welding procedure is such to provide sound welds of good fusion. The welding sequence should allow the open ends of the weldment to move as long as possible. Avoid stringer bead welding if cracking is a problem; instead, use a weaving technique to make a full-sized weld, doing the job by sections 8 or 10 in long. Crater cracks may be eliminated by filling the weld crater at the end of each weld or by using the backstep method to end the weld on top of a finished bead instead of on plate metal. Change to a less penetrating electrode. Weld uphill 4° on the first pass to increase the weld section. Decrease the welding current and speed. Use a low-hydrogen electrode.

4. Be sure that the structure to be welded has been designed properly and a welding procedure developed to eliminate rigid joints.

5. Always be sure that the weld bead is of sufficient strength to withstand the stresses which might develop during the heat of welding. Do not use too small a weld bead between heavy plates. Be sure to use welds of sufficient size on all joints. Make the bead shape slightly more convex, because concave beads crack more readily than convex beads. A short arc length helps make beads more convex.

Porosity Porosity in welds does not too seriously affect the weld strength, unless the weld is extremely porous. Surface holes in the weld bead are undesirable from an appearance standpoint. The other common forms of porosity, aside from surface holes commonly referred to as blowholes, are gas pockets and slag inclusions. One of the major causes of porosity is poor base metal. Improper welding procedure also results in porosity of weld metal. Porosity may be an inherent defect of the welding electrode being used. To reduce or avoid porosity:

1. Be sure the base metal is one that will produce a porosity-free weld. High-sulfur, phosphorus, and silicon steels sometimes produce gaseous combinations which tend to make blowholes and gas pockets. Nonferrous material, high in oxygen, also tends to result in porous welds. Segregations and impurities in the base metal will contribute to porosity.
2. Change the welding procedure. Do not use excessive welding currents, but be sure that each layer of weld metal is completely free of slag and flux before depositing another layer. Puddle the weld, keeping the metal molten sufficiently long to allow entrapped gases to escape. Decrease current and use a short arc. Most low-hydrogen electrodes will be found helpful in eliminating porosity.

Moisture pickup Electrodes exposed to damp atmosphere may pick up moisture which, when excessive, may cause undercut, rough welds, porosity, or cracking. This condition is usually corrected by storing the electrodes in a cabinet or room heated to about 10° F above the surrounding atmosphere. If the electrodes have become wet, they may be dried by removing them from the box and spreading them out to dry at a temperature of 200° F for 1 hr.

Arc blow Arc blow is a phenomenon encountered when welding with direct current. Direct current flowing through the electrode and plate sets up magnetic fields around the electrode which tend to deflect the arc from its intended path. The arc may be deflected to the side, but usually it is deflected either forward or backward from the direction of travel. Back blow is encountered when welding toward the ground connection, toward the end of a joint, or into a corner. Forward blow is encountered when welding away from the ground at the start of the joint. The conditions may become so severe that a satisfactory weld cannot be made, and incomplete fusion and excessive weld spatter are the results. When welding with iron-powder electrodes or other heavily coated electrodes that produce large slag coverings, forward blow is especially troublesome, since the forward fanning of the arc permits the heavy slag deposit on the crater to run forward under the arc.

The bending of the arc under these conditions, either forward or backward, is caused by the effects of an unbalanced magnetic field. When there is a greater concentration of magnetic flux on one side of the arc than the other, the arc always bends away from the greatest concentration.

In welding, magnetic flux is superimposed on the steel and across the gap to be welded. The flux that is in the plate does not cause difficulty, but an unequal concentration of flux across the gap or around the arc will cause the arc to bend away from the heavier concentration. Since the flux passes through steel many times more readily than through air, the flux path tends to stay within the boundaries of the steel plates. For this reason the flux around the electrode, when the electrode is near either end, must all crowd across the gap between the electrode and the end of the plate. This causes a high concentration of flux on one side of the arc at the start and finish of the weld, which tends to make the arc blow away from the ends of the plates—a forward blow at the start end and a back blow at the finish.

The forward blow at the start of a weld is only momentary, for the magnetic flux soon finds an easy path through the weld being put in behind the arc. Since the flux behind the arc is in the plate and weld, the arc is influenced mainly by the flux in front as it crosses the gap, creating a slight back blow for the rest of the weld. At the finish end, the flux ahead of the electrode becomes more crowded as the end approaches, with a corresponding increase in the back blow, becoming very severe at the very end.

The welding current passing through the plates also causes the plates to act as a conductor with a flux field around it. The circles of flux are in planes perpendicular to the plates around the current path, between the electrode and the point at which the plates are grounded. This "ground effect" is most apparent on narrow plates, becoming less noticeable as the plates become wider.

Unless the arc blow is unusually severe, corrective steps will counteract the conditions causing the arc blow. All or only some of the following corrective steps may be necessary:

1. If the machine being used is of the type producing both alternating and direct current, switch to alternating current. Alternating the direction of the flow of current prevents the formation of strong magnetic fields.
2. Current may be reduced.
3. Weld toward a heavy tack or toward a weld already made.
4. Use backstepping on long welds.

5. Place the ground connection as far from the joint to be welded as is possible.
6. If back blow is the problem, place the ground connection at the start of the weld and weld toward a heavy tack.
7. If forward blow causes trouble, place the ground connection at the end of the weld.
8. Wrap the ground cable around the workpiece and pass ground current through it in such a direction that a magnetic field will be set up to neutralize the magnetic field causing the blow.
9. Hold as short an arc as possible to help the arc force counteract the arc blow.

Distortion Control

The stresses in a piece of steel resulting from rolling the steel in the mill; from cutting, forming, and shaping in manufacturing prior to welding; or from the heat cycle of the welding process are many and varied. For the majority of welding applications, they create no problem. The forces tending to cause distortion are present in every weld made, and unless proper techniques are used, the weldment may distort enough that considerable time and money must be spent to correct the distortion.

Three simple rules can be followed which will aid materially in the prevention and control of distortion. In many cases the application of a single rule will be sufficient. In others a combination of the rules may be required.

1. Reduce the effective shrinkage force.
2. Make shrinkage forces work to reduce distortion.
3. Balance shrinkage forces with other forces.

Reduce the effective shrinkage force Do not overweld. Addition of excess weld metal not needed to meet the service requirement of the joint is known as "overwelding." Overwelding causes distortion, as shown in Fig. 28-19*a*, and contributes nothing to the strength and performance of the joint. Hence it is actually a waste of time and money. Weld metal should be kept at a minimum, consistent with the service requirements of the joint.

For conventional fillet weld for a T joint, the strength is determined by the effective throat. In Fig. 28-19*b* there is an excess of weld metal above the line *AA* which does not increase the strength but obviously increases the effective shrinkage force. Less shrinkage force may be obtained with no loss of strength by making a flat or concave weld. Less weld metal means less distortion.

It is possible to reduce the effective shrinkage force through proper edge preparation. To obtain the proper fusion at the root of the weld with a minimum of weld metal, the bevel should not exceed 30°. Proper fitup is also important; the plates to be welded should be spaced 1⁄32 to 1⁄16 in apart. A minimum amount of weld metal will then be needed to produce a strong joint.

Use few passes. This is another way to make an intelligent use of weld metal. Distortion in the lateral direction is always a major problem. Use of one or two passes with large electrodes reduces distortion in this direction. In general, lateral distortion is approximately 1° per pass.

In some cases, however, distortion in the longitudinal direction is a problem. In such cases, because of the greater ability of a small bead to stretch longitudinally compared with a large bead, the number of passes should be increased rather than decreased. This apparently paradoxical relationship is a function of the thickness of the plate and its natural resistance to distortion. There is inherent rigidity against the longitudinal bending of a plate, provided that the plate is thick enough. Light gage sheets have little rigidity in this direction and will therefore buckle easily. Unless the two plates to be welded are restrained, there is no lateral rigidity whatsoever, since each of the two plates is free to move angularly with relation to another; so lateral distortion is more common.

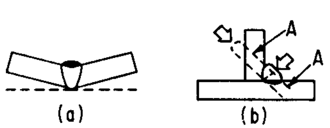

Fig. 28-19 Effects of overwelding.

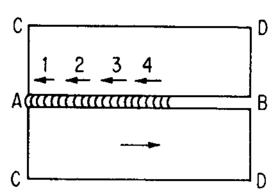

Fig. 28-20 Schematic diagram of the backstep welding technique.

Another means of reducing the effective shrinkage force is to place the weld as close as possible to the neutral axis so that it does not have sufficient leverage to pull the plates out of alignment. To reduce the effective shrinkage force further by minimizing the amount of weld metal, intermittent welds may in many cases be used instead of continuous welds. It is often possible to use up to two-thirds less weld metal and still obtain the strength required. The use of intermittent welds also distributes the heat more widely throughout the structure.

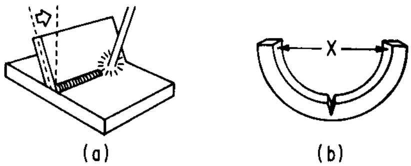

Fig. 28-21 Using shrinkage forces to advantage: *(a)* by inclining a plate before welding, *(b)* by spacing parts.

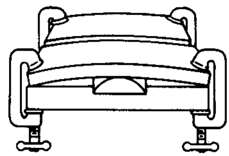

Fig. 28-22 Prebending parts before welding to use shrinkage force.

If the job requires a continuous weld, it is possible to reduce the effective shrinkage force by the "backstep" technique. With this technique, the general direction of welding progression is, for example, from left to right, but each bead is deposited from right to left as shown in Fig. 28-20. As bead is applied, the heat from the weld along the edges causes expansion there, which temporarily separates the plates at end *B;* but as the heat moves out across the plate to *C,* the expansion along the outer edges *CD* brings the plate back together. This occurs when the first bead is laid. The same will be true with each successive bead as it is laid, the plates expanding less and less with each bead because of the locking effect of each weld.

Make shrinkage forces work to minimize distortion Figure 28-21*a* shows a T weld being made with the vertical plates out of alignment before the weld is deposited. When the weld shrinks, it will pull the vertical plate to its correct 90° position. Another method is to space parts before welding. Experience indicates how much space should be allowed for any given job so the parts will be in correct alignment after welding is completed. The distance between the two segments of Fig. 28-21*b* was to be accurately controlled. Correct spacing of the parts prior to welding allowed them to be pulled into the correct position by the shrinkage forces of the welding.

Shrinkage force can be put to work in many cases by prebending or prespringing the parts to be welded. For example, when the plates in Fig. 28-22 are sprung away from the weld side, the counterforce exerted by the clamps overcomes most of the shrinkage tendency of the weld metal, causing it to yield. But when the clamps are removed, there is still a slight tendency for the weld to contract, and this contraction or shrinkage force pulls the plates into exact alignment.

Balance shrinkage forces with other forces Often the structural nature of parts to be welded provides sufficiently rigid balancing forces to offset welding shrinkage forces. This is particularly true in heavy sections where there is inherent rigidity because of the arrangement of the parts. If, however, these natural balancing forces are not present, it is necessary to balance the shrinkage forces in the weld metal in order to prevent distortion. This balancing can be accomplished by the use of a proper welding sequence which places weld metal at different points about the structure so that as one section of weld metal shrinks it will counteract the shrinkage forces in the welds already made. A simple example of this is shown in Fig. 28-23.

Another application of this principle is the staggering of intermittent welds applied in a sequence, as shown in Fig. 28-24. Here, the shrinkage force of weld 1 is balanced by that of weld 2; the shrinkage force of weld 2 is balanced by that of weld 3, etc.

Peening the bead actually stretches it, counteracting its tendency to contract and shrink as it cools. Peening should be used with great care, however, for too much peening may damage the weld metal.

The most important method of avoiding distortion is the use of clamps, jigs, or fixtures to hold the work in a rigid position during welding. In this way the shrinkage forces of the weld are balanced with sufficient counterforces to minimize distortion. What actually happens is that the balancing forces of the jig or fixture cause the weld metal itself to stretch, thus preventing most of the distortion.

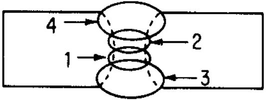

Fig. 28-23 Welding sequence to balance one shrinkage force with another.

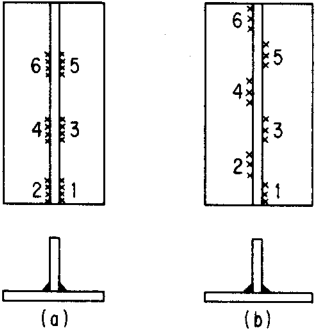

Fig. 28-24 Use of intermittent welds to balance shrinkage force.