Weld Quality and Inspection

1. REJECTION VS. PREVENTION

The structural welding of buildings and bridges enjoys a good reputation in the sense that weld failures of a catastrophic nature have not occurred. But, it is not uncommon to find welds which have failed in the sense that they did not meet final inspection requirements.

There are many reasons why welds may be rejected at final inspection. Before repairing the weld, however, several very appropriate questions should be resolved. For example, it is always good policy to review the inspection methods; to look for and insist upon some reliable correlation between the reasons for rejection and the service conditions. When such correlation does exist, prompt action should be taken to correct the rejected welds and to prevent their recurrence. If, on the other hand, the inspection methods are unrealistic or inappropriate, they should be replaced.

When weld rejection is justified, a person can be certain that somebody either did not know what his job was, or just did not do it properly. There is a logical explanation for any serious weld defect, and there is an equally logical remedy and correction. Many weld defects are related to procedures and can be visually detected as the job progresses.

Early detection of weld defects permits economical correction. If left for final inspection after the job is complete, a major loss of time and money usually results. Performance standards on the production floor and the erection site are needed to assure the quality of the weld being produced.

2. WHAT IS A GOOD WELD?

To a great many people, the answer to "What is a good weld?" would be, "Any weld that passes final inspection." We can hardly blame production-minded people for going along with this answer. But is this a good answer when you realize that frequently there is little or no connection between the defects found during inspection and the performance of the weld in service? (See Section 1.1, an Introduction to Welded Design.)

An improved definition would be, "A good weld is any weld which will continue indefinitely to do the job for which it was intended." The problem with this definition is that we do not have any thoroughly satisfactory nondestructive testing device that can provide a "yes" or "no" answer. Instead, we look for, and hope not to find, weld defects. If they are found, the weld is judged "good" or "bad" as we think the defects may or may not influence its performance in service.

3. WHAT IS THE SOLUTION?

First, find out what these defects are and what causes them. Second, set up welding procedures that will eliminate them. This is not as difficult as it might appear. It does, however, mean that a great many small, but important, details must be spelled out and accounted for.

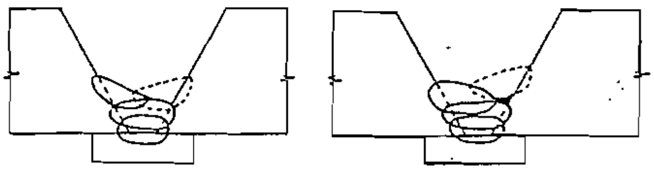
It is encouraging to note that good qualified weldors and welding machine operators understand the importance of these small details. They are also generally capable of predicting exactly what final inspection will reveal. A conscientious weldor or welding operator can provide full-time visual inspection. Since he sees every bead, he is better informed than any inspector who only sees a finished weld or some small portion of the weld as it is being made.

4. WHEN DOES INSPECTION START?

The decision to inspect only after welding is completed is extremely dangerous and not the best way to assure product quality. This puts the inspector in the position of a combination physician-coroner with the dubious distinction of being the one to declare the weld dead or alive, and if dead, to decide "the cause of death."

A better approach to quality control allows inspection to provide constant checkups as welding progresses—preventive inspection. This promotes early detection of symptoms and correction of procedures as well as minor flaws, both of which might otherwise lead to serious defects. When this approach is followed, final inspection becomes a routine function to confirm the fact that good welding procedures have been employed and that objectionable defects have not been permitted to occur.

Inspection should start before the first arc is struck and should not be the sole responsibility of an inspector *per se*. Everyone involved in the preparation and production of a welded connection or joint should at least visually inspect his own work to make sure that



(a) No problem for next pass to fuse properly into side of joint and weld

(b) Not enough room left between side of joint and last pass; will not fuse properly; may trap slag

FIG. 1 The conscientious weldor visually inspects each bead as it is made. He knows that bad bead contour, poor wash-in at the edges or uneven edges are symptoms of trouble and takes steps to correct them before they produce weld rejects.

it has been done properly and in a manner consistent with the established standards of quality. This goes for people who prepare plate edges, assembly men, weld tackers, welding operators, weldors' helpers, and everyone whose efforts can in any way affect the quality of the welds.

5. RECOGNIZE SMALL DEFECTS AND CORRECT THEM

Perhaps the most common weld rejections occur as a result of radiographic inspection. This method has the ability to expose lack of fusion and/or slag inclusions that would not be apparent to visual final inspection techniques.

With very few exceptions, a good, conscientious weldor can tell by visual inspection whether or not he is getting good fusion, Figure 1. This includes what he sees as he makes the bead as well as what he sees when the bead is concluded. Bad bead contour, poor wash-in at the edges or uneven edges are all indications of poor fusion at the moment, or that it will occur on subsequent beads.

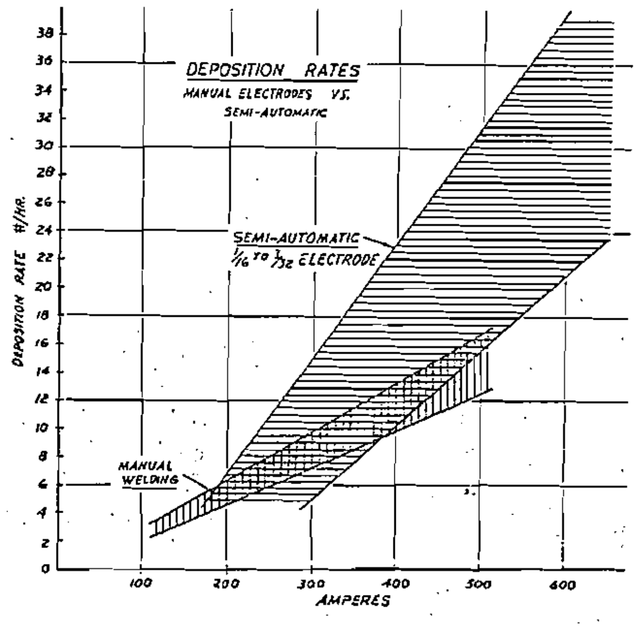


FIG. 2 Correct application of the various semi-automatic welding processes can tremendously increase deposition rate and lower costs.

There are many symptoms of trouble which the weldor can spot. This is the time to correct the condition either by gouging out the questionable portion and/or changing the procedure. The wrong attitude at a time like this is to assume, as some weldors are inclined to, that "the defect can be 'burned out' on the next pass." This is a game of Russian Roulette that invariably pays off only in weld rejects.

6. "PREQUALIFIED JOINTS"

The term "prequalified joints" has led to some misunderstanding and, in a sense, it *is* a misnomer. It is certainly a mistake to think that just because prequalified joints have been used the final results will be completely satisfactory.

The AWS Code for Welding in Building Construction (AWS D1.0-66) and AWS Specifications for Welded Highway and Railway Bridges (AWS D2.0-66) do not suggest that it is that simple. They say that these joints are to be "welded in accordance with Sections 3 and 4," and then they may be considered "prequalified." A careful study of Sections 3 and 4 reveals 12 pages of good sound advice, recommendations, restrictions, etc., all aimed in the direction of producing good welds.

If joints are prepared as "prequalified joints" and all of the requirements of Sections 3 and 4 have been met, it would appear to be nearly impossible to produce welds which would not pass final inspection. Also, it should be understood that prequalified joints have been put in the code and are recommended only because past experience has demonstrated that these joints are capable of producing good weld quality *when they are used together with good welding procedures.*

The establishment of prequalified joints, however, does not preclude the fact that other joint designs can lead to equally satisfactory results. The progressiveminded fabricator or constructor who wishes to use other joint preparations and has valid reasons should be encouraged to do so.

The code allows adoption of alternate joint designs. It also logically requires special tests be performed to prove the acceptability of welds made with the alternate design. In most cases, these special tests, although admittedly time consuming, are worth completing to permit the application of a progressive procedure that leads to improved performance or cost reduction.

7. GOOD COMMUNICATIONS ARE NEEDED

With the broad latitude that welding offers to the designer, it is only natural that bridges and buildings take on a "one of a kind" nature. These connection variations present a challenge which welding is quite capable of meeting. But not without good communications between all interested parties.

Communicating is most important early in the game, especially while welding procedures are being worked out. This is the time for design vs. production discussions to bring up and solve questionable issues before they become points of major disagreement.

8. FIVE P'S OF GOOD STRUCTURAL WELDING

There are five areas which require close attention to assure good weld quality:

1. Process selection (welding process must be right for the job).
2. Preparation (joint preparation must be compatible with the process being used).
3. Procedures (detailed procedures are essential to assure uniform results).
4. Personnel (qualified personnel should be assigned to the job).
5. Prove it (pretest procedures and preparations to prove needed weld quality will result with their use).

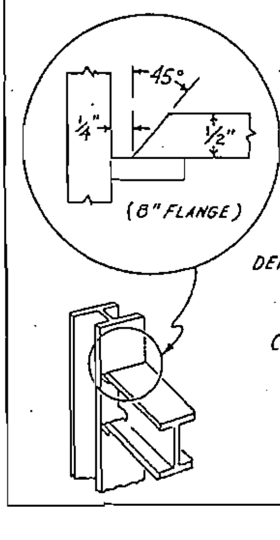
Process Selection

The first and most important step is selecting the best welding process for the job. This is a very challenging decision to make, especially if the job is suited to semi-automatic welding where there are so many different choices. And yet, in this area lies the greatest opportunity for improvement, Figure 2. Since manual welding is inherently slow and expensive and subject to the human element, it is becoming a matter of economic survival to convert whenever possible to a semi-automatic process, Figure 3.

The entire industry is involved in this transition, but the progress is relatively slow. This is due in part to the natural reluctance to accept new methods. It is also true that each of the newer processes has its own peculiarities, advantages and limitations, and all introduce some problems affecting weldor training, joint preparation and welding procedures.

The semi-automatic processes (exclusive of submerged-arc) do not enjoy the "prequalified" status of manual and submerged-arc welding. This should not, however, prevent their use, since the AWS Code and Specifications state, "other welding processes and procedures may be used, provided the contractor qualifies them in accordance with the requirements of Article 502."

Selection of a semi-automatic process may also require joint qualification since appropriate joint prepa-



PROCESS	CORED WIRE	SUB-ARC	MANUAL	MANUAL
WIRE / FLUX	3/32" NS-3M	5/64" L-60 780 FLUX	3/16" & 7/32" E6027	3/16" E6012
CURRENT	325-350	350-375	300-350	200-225
VOLTAGE	30-31	30-31		
POLARITY	DC+	DC+	AC	DC+
DEPOSITION RATE #/HR (100% O.F.)	12-13	10.5-11.0	9.5-10.5	5-6
ARC TIME (MIN.)	3.2	3.8	3.9	8.3
CLEANING TIME (MIN.)	1.0	.7	1.0	2.3
TOTAL TIME (MIN.)	4.2	4.5	4.9	10.6
TIME FACTOR	1.0	1.1	1.2	2.5

FIG. 3 This cost comparison of manual and semi-automatic welding methods demonstrates the important role process selection plays in the control of weld costs.

ration may not be the same as "prequalified manual" or "prequalified submerged-arc joints."

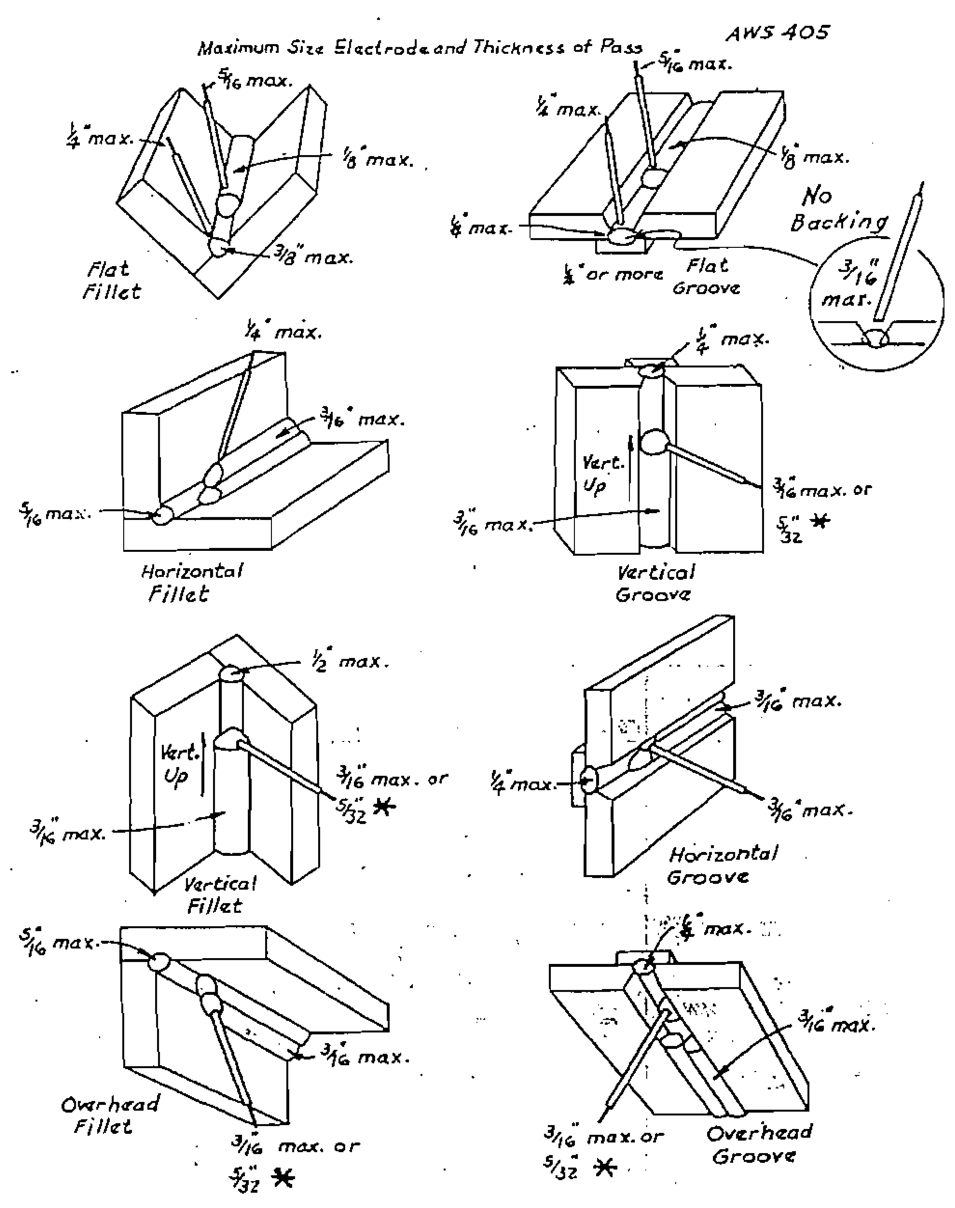
Where conditions permit, the use of full-automatic welding provides even greater economy and control of weld quality.

Preparation

Acceptable butt joint preparations are nothing more than a compromise between the included angle of bevel and the root spacing dimension. A large included angle will permit a smaller root spacing; conversely, a small included angle requires a larger root spacing. The type of joint, the welding position, and the process being used will all influence the bevel and root spacing. All of these factors have been taken into consideration in the prequalified joints.

The joints detailed in the appendix of the code book indicate a nominal dimension for bevel and root spacing. Since the joint design (bevel angle root spacing) must provide access of the arc to the base of the joint, it is important to understand that the dimensions of the root opening and groove angle of the joints are minimum values. (All of this and more is covered in the fine print of the specification.) Also see Section 7.3 on Joint Design.

Not only must the root spacing and bevel be



* If Exx 14, 15, 16, or 18 electrode is used.

FIG. 4 The code book places specific limits on electrode size for specific joint designs and weld positions.

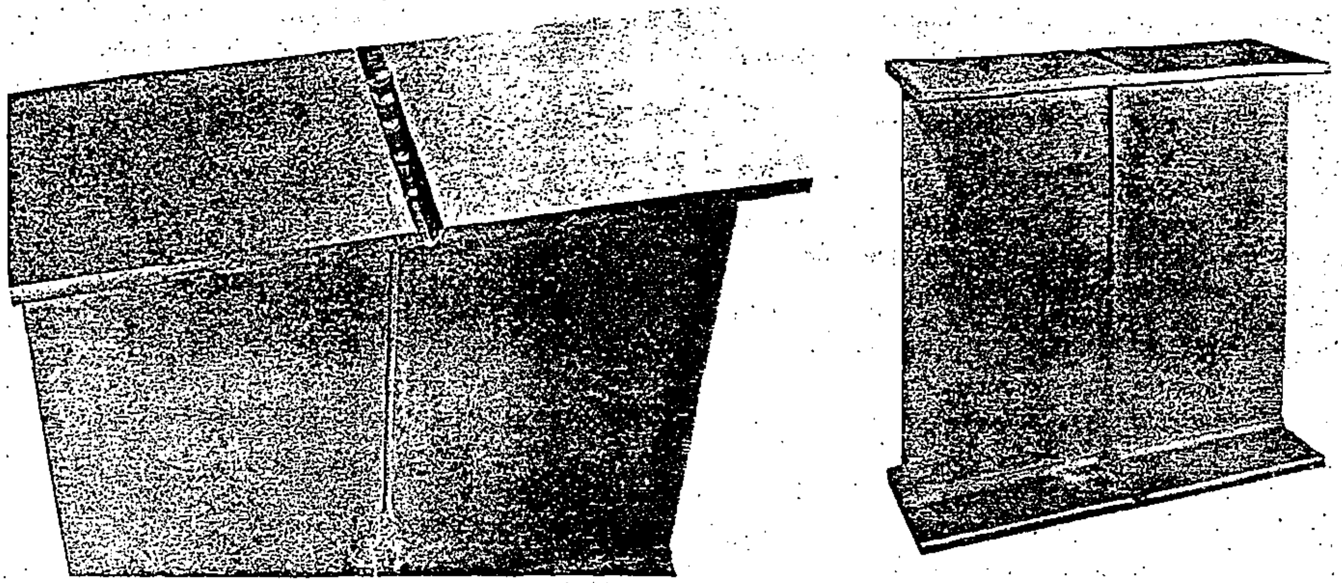


FIG. 5 Mock-up welds, such as shown here, provide a first-hand check of welding procedures before they reach the production floor. They can later be used as workmanship samples.

treated as minimum dimensions, but the electrode size must be compatible with the combination being used. Here again, the AWS Code and AWS Specification specifies maximum permissible electrode sizes which may be used under certain conditions Figure 4.

The first inspection action considered vitally important is to check the joint preperation before welding. Make sure that the joint preparation corresponds to the joint details as specified on the procedure. Be sure that the joint has been properly assembled and correct fit-up and root spacing obtained.

Procedures

The important welded connections of any structure deserve a well planned, thoroughly investigated and completely detailed welding procedure.

Reliable welding procedures are best obtained through first-hand experience. In the structural field, it is often helpful to produce a full scale mock-up of the actual joint prior to its release to the production floor. If possible, use the identical steel, same type, chemistry, sizes and shapes that will be used on the job. Figure 5 contains examples of "mock-up" welds.

A procedure properly developed under these conditions would include:

1. Identification of the joint.
2. Joint dimension details and tolerances.
3. Identification of the welding process.
4. Type and size of electrode.

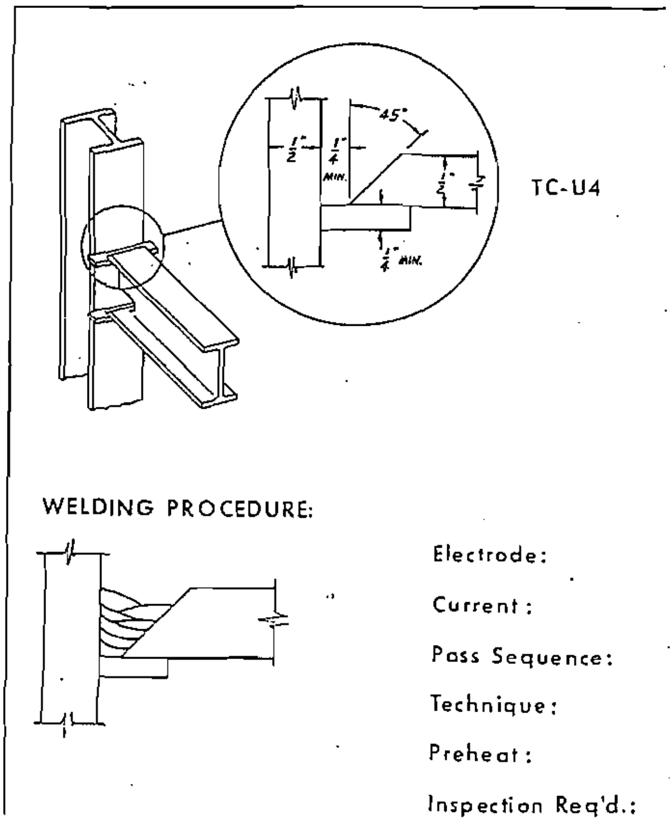


FIG. 6 A completely detailed welding procedure helps guarantee uniform weld quality. It provides a road map for the weldor and a check list with which inspection can check weldor performance. In some cases more details will be required than are shown in this example.

5. Type of flux, gas, etc. (as required).
6. Current and voltage (with changes as required for different passes).
7. Preheat and interpass temperature.
8. Pass sequence (show sketch if necessary).
9. Type of inspection required.
10. Any comments or information that will help the weldor, such as special techniques, electrode angles, weld bead placement, etc., Figure 6.

This method of establishing the welding procedure takes time. It, nevertheless, is an almost foolproof approach to guaranteeing weld quality since it provides firsthand experience, workmanship samples, samples for destructive testing and positive evidence that the adopted procedure can produce the required results. And perhaps most important of all, it gives all weldors one "proved procedure" so that the job is no longer subject to the multiple choice of several weldors.

Personnel

In the case of manual welding, it is true that the weld quality cannot be any better than the skill of the weldor. This skill should be evaluated before the man is permitted to do any actual welding.

The simple and relatively inexpensive device for doing this is the AWS weldor qualification test, Figure

Summary of AWS Weldor Qualification Test Requirements

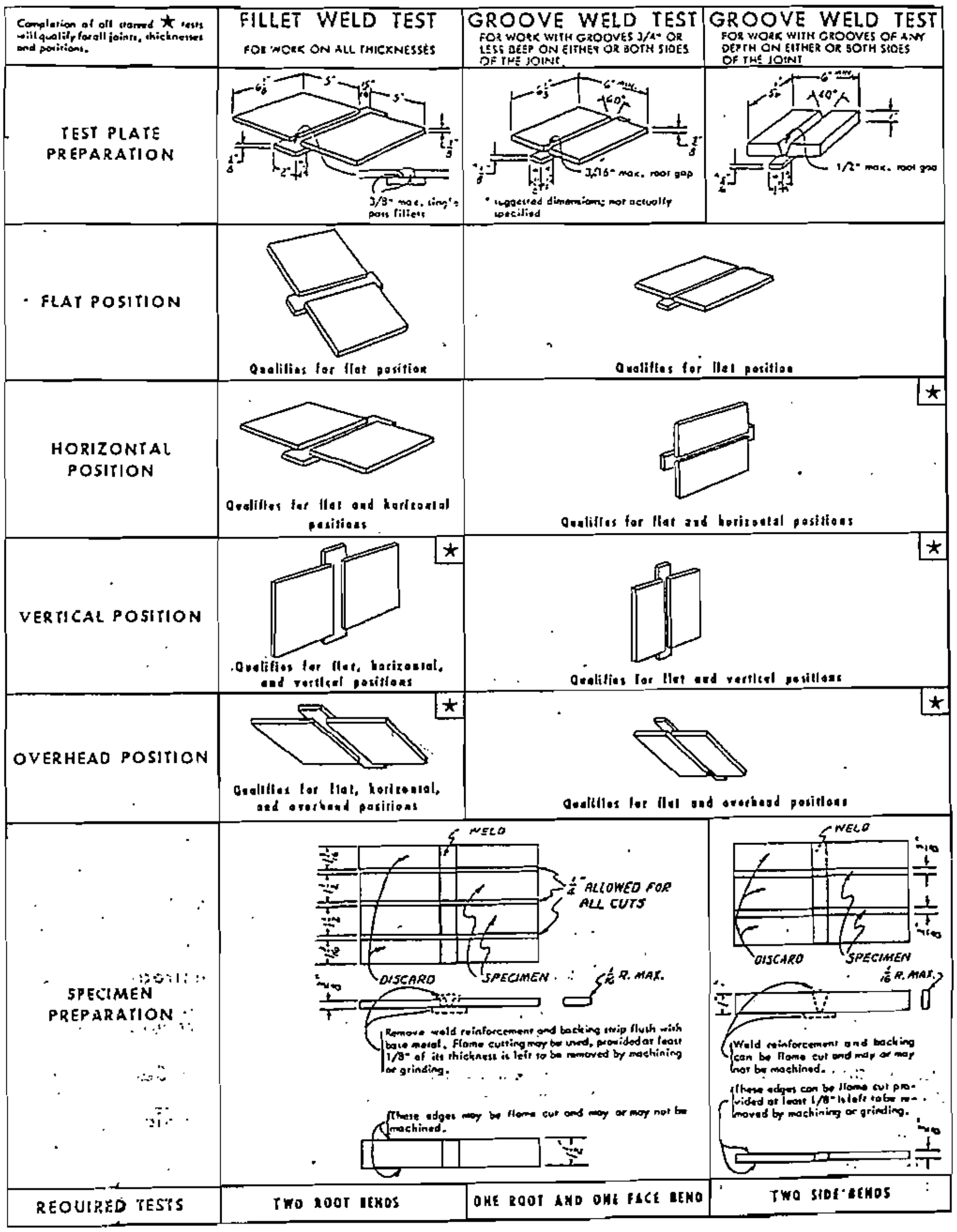


FIG. 7 AWS Weldor Qualification Test requirements are completely detailed in the code books.

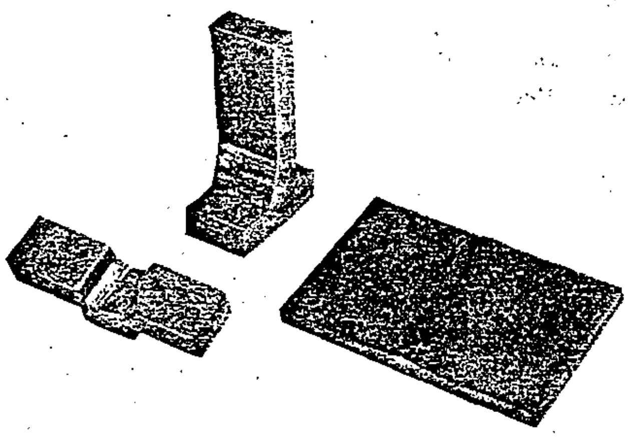


FIG. 8 Sample welds, such as those shown, made under typical conditions should be made and subjected to the various types of destructive and nondestructive tests needed to establish the degree of quality required for the job. With this approach, many tests can be applied that might be impractical or impossible to use during final inspection.

7. This test is usually adequate. But in a great many instances, it is questionable whether this simple test establishes the ability of the weldor to do the actual job and proves that he can make the welds on the job that will satisfy final inspection requirements.

For example, if the weldor will be required to make vertical butt welds on ¾" thick plate and final inspection calls for radiographic inspection (Section 409 of the Bridge Specifications), will the AWS weldor qualification test prove the weldor can produce these welds in a satisfactory manner? Obviously, it will not because radiographic inspection is not normally called for in the AWS weldor qualification test. The test becomes more meaningful if radiographic inspection is added to the normal testing requirements.

The contractor is in the best position to evaluate the actual skill required for the job as opposed to the skill required to pass an AWS weldor qualification test. When the actual job demands more of the man than he would otherwise be able to demonstrate on a standard weldor qualification test, the contractor for his own protection is justified in requiring more realistic tests.

Most semi-automatic processes present some problems relative to weldor training. If, however, the process has been properly selected for the job and correct welding procedures have been worked out, weldor training should not pose a difficult problem. With competent instruction, this can be handled as a joint weldor-training, weldor-qualification program.

The question of properly qualified personnel also involves people other than weldors, and attention should be given to their training also.

Pretest It

Once a welding procedure has been established, nobody should be more eager to prove it than the contractor, and nobody is in a better position to do so. Mock-up sample welds made under typical conditions can be subjected to all kinds of destructive and nondestructive tests, Figure 8. Many of these tests would be completely impractical or even impossible as a final inspection requirement. Testing at this stage is relatively inexpensive, and the latitude is much broader than would be permitted or desired as final inspection. Maximum testing at this time gives assurance that final inspection can be held to a minimum.

9. PREVENTIVE INSPECTION

In summary, it should be universally recognized that inspection after welding, while often essential, is somewhat too late. Any excessive weld cracks, undercuts, undersize welds, poor fusion or other defects detected that late will be expensive to correct. All parties concerned should insist on good welding, supervision, conscientious qualified weldors, and a thorough system of preventive inspection.

Preventive inspection, in which everyone concerned should share responsibility, involves a systematic observation of welding practices and adherence to specifications before, during, and after welding in order to visually detect and stop any occurrences that may result in substandard welds. The check list that follows will aid in developing this pattern of operation.

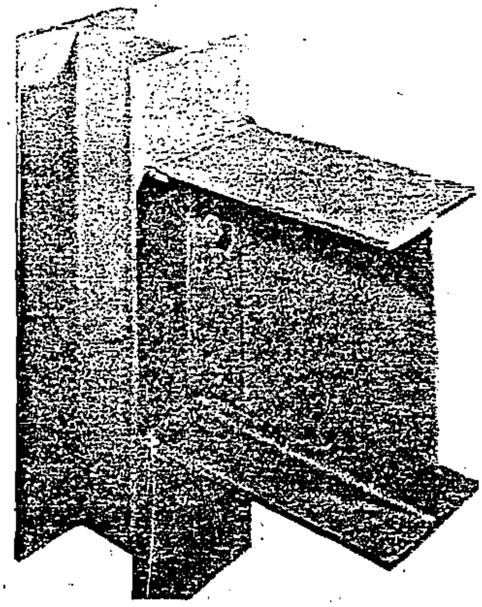


FIG. 9 This "mock-up" beam-to-column connection was made with scrap ends, prepared and assembled to specifications then welded to work out procedure details.

Check List of Items That Influence Weld Quality

Points to be Visually Checked for Before, During and After Welding

● ○ ○ Check Before Welding
○ ● ○ Check During Welding
○ ○ ● Check After Welding

(1) Proper Included Angle

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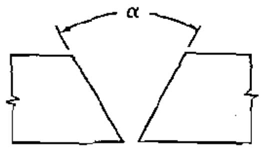

The included angle must be sufficient to allow electrode to reach root of joint, and to ensure fusion to side walls on multiple passes. In general, the greater this angle the more weld metal will be required.

(2) Proper Root Opening (Fit-Up)

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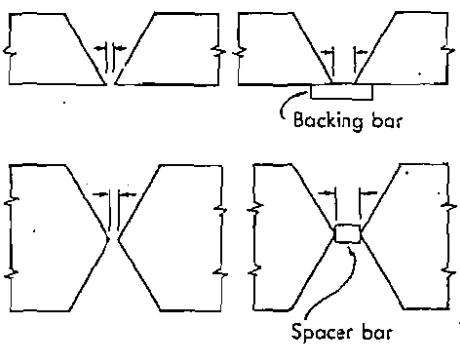

Without a backing bar, there is a possibility of burning through on the first pass; so, the root opening is reduced slightly. Lack of fusion of the root pass to the very bottom of the joint is no real problem because the joint must be back gouged before the pass may be made on the back side.

With a backing bar, the root opening is increased to allow proper fusion into the backing bar, since it will not be back gouged; also there is no burn-through.

With a spacer bar, it serves as a backing bar but must be back gouged before welding on the back side to ensure sound fusion.

(3) Proper Root Face

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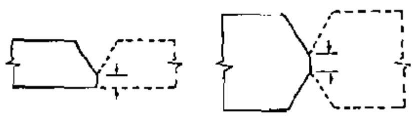
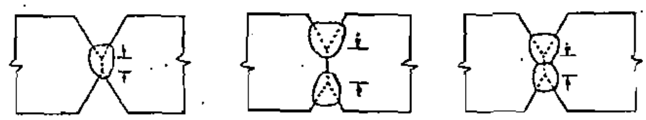


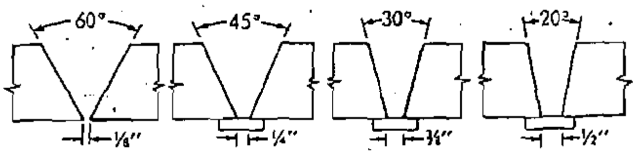
A root face is usually specified in joints welded by the submerged-arc process to prevent burn-through on the first or root pass; therefore, there is a minimum limit to this dimension. There is also a maximum limit so that the back pass, when made, will fuse with the first root pass to provide a sound joint. This fusion of root and back passes can be checked after welding, if the joint runs out to an exposed edge of the plate and onto run-off bars.



(a) Too small root face; burn-through (b) Too large root face; lack of penetration (c) Proper root face; proper penetration

The above items, included angle (1) and root opening (2), go hand in hand to ensure clearance for the electrode to enter the joint sufficiently for proper fusion at the root, and yet not require excessive weld metal.

In general, as the included angle is decreased to reduce the amount of weld metal, the root must be opened up to maintain proper fusion of weld metal at the joint root. For any given thickness of plate, there is a range in the combination of included angle and root opening that will result in a minimum amount of weld metal consistent with the required weld quality.



(4) Proper Alignment

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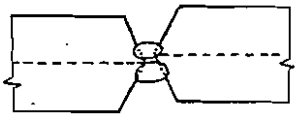

Misalignment of plates being joined may result in an unpenetrated portion between root and back passes. This would require more back gouging.

(5) Cleanliness of Joint

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Joint and plate surface must be clean of dirt, rust, and moisture. This is especially important on those surfaces to be fused with the deposited weld metal.

(6) Proper Type and Size of Electrode

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Electrodes must suit the metal being joined, the welding position, the function of the weld, the plate thickness, the size of the joint, etc. Where standard procedures specify the electrodes, periodic checks should be made to ensure their use.

(7) Proper Welding Current and Polarity

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Welding current and polarity must suit the type electrode used and the joint to be made.

(8) Proper Tack Welds

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These should be small and long, if posible, so they won't interfere with subsequent submerged-arc welds. On heavy plates, low-hydrogen electrodes should be used.

(9) Good Fusion

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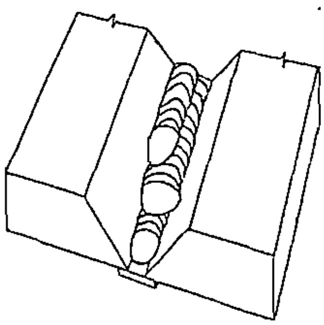

Each pass should fuse properly into any backing plate, preceding pass, or adjacent plate metal. No unfilled or unfused pockets should be left between weld beads.

(10) Proper Preheat and Interpass Temperature

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The need for preheat and required temperature level depends on the plate thickness, the grade of steel, the welding process, and ambient temperatures. Where these conditions dictate the need, periodical checks should be made to ensure adherence to requirements.

(11) Proper Sequencing of Passes

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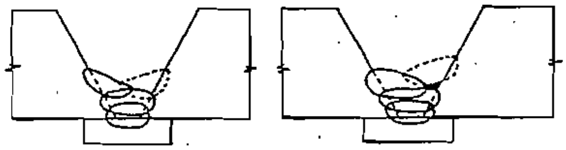

(a) No problem for next pass to fuse properly into side of joint and weld

(b) Not enough room left between side of joint and last pass; will not fuse properly; may trap slag

The sequencing of passes should be such that no unfused portion results, nor distortion.

(12) Proper Travel Speed

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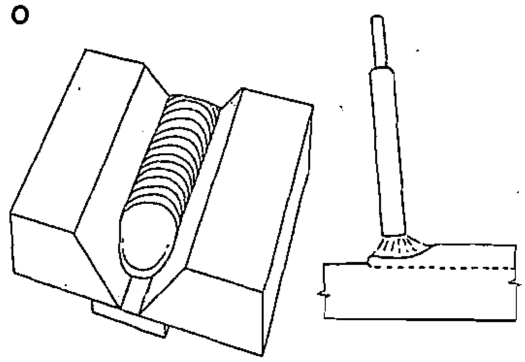
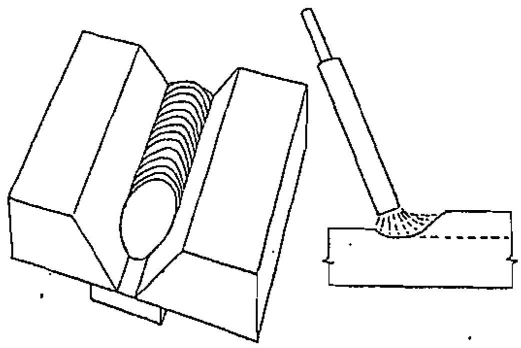


If travel speed is too slow, molten weld metal and slag will tend to run ahead and start to cool; the main body of weld metal will run over this without the arc penetrating far enough, and the trapped slag will reduce fusion.



If travel speed is increased, good fusion will result because the molten weld metal and slag will be forced backward, with the arc digging into the plate.

(13) Absence of Overlap

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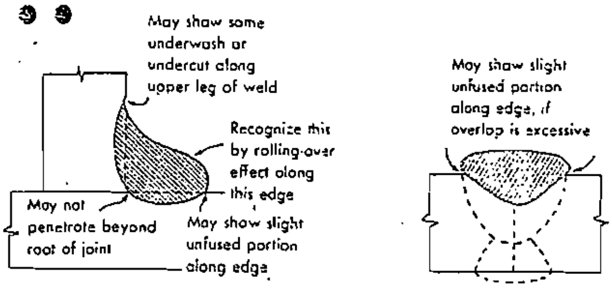
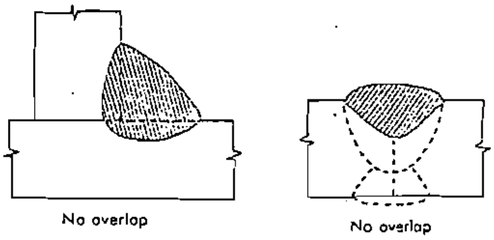


if speed of travel is too slow, the excessive amount of weld metal being deposited will tend to roll over along the edges, preventing proper fusion. This roll-over action is easily noticed during welding. The correction is very simple; increasing the travel speed will achieve the desired effect (below).



(14) In Vertical Welding, Tilt of Crater

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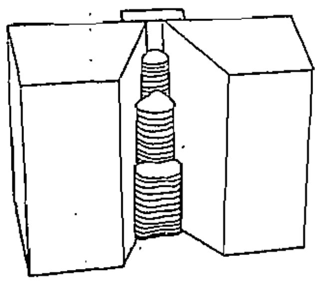
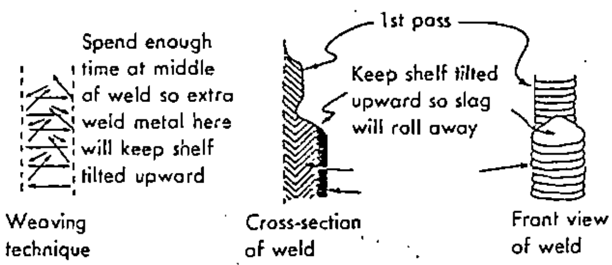
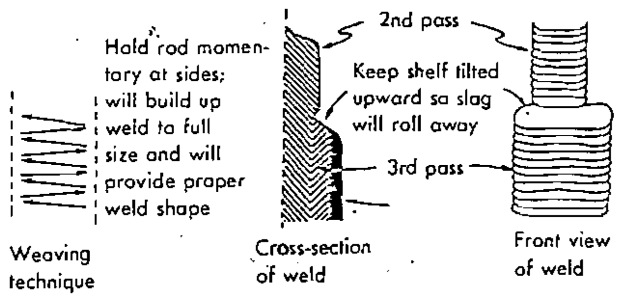
The crater position should be kept tilted slightly so slag will run out toward the front of weld and will not interfere. This will help ensure good fusion.







(15) Filled Craters

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It might be argued that craters are a problem if—

1) they are undersize, i.e. not full throat, and/or

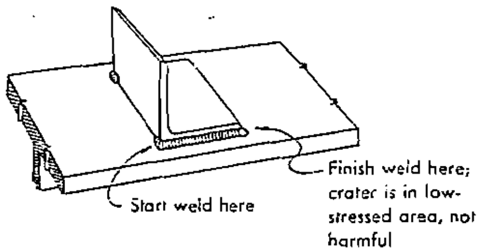
2) they are concave, since they might crack upon cooling; of course, once they cool down to room temperature, this would no longer be a problem.

Normally, on continuous fillet welds, there is no crater problem because each crater is filled by the next weld. The weldor starts his arc at the outer end of the last crater and momentarily swings back into the crater to fill it before going ahead for the next weld.

For a single connection, it is important at the end of the weld not to leave the crater in a highly stressed area. If necessary to do so, extra care should be taken to carefully fill the crater to full throat.

• Example: On a beam-to-column connection using a top connecting plate, the crater of the fillet weld joining the plate to the beam flange should be made full throat.

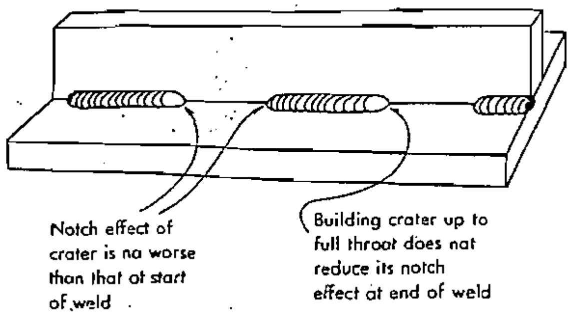
• Example: In shop welding a flexible seat angle to the supporting column flange, the welding sequence should permit the weld to start at the top portion of the seat angle, and carry down along the edge, with the crater at the bottom; as shown.



On intermittent fillet welds, unfilled craters should normally be no problem because:

1. The additional strength obtained by filling the crater would not be needed in this low-stressed joint, for which intermittent fillet welds are sufficient.

2. Any notch effect of an unfilled crater should be no worse than the notch presented by the start end of the fillet weld; shown below. No matter what is done to the crater, it will still represent the termination of the weld, in other words an unwelded portion meeting a welded portion.



(16) Absence of Excessive Undercut

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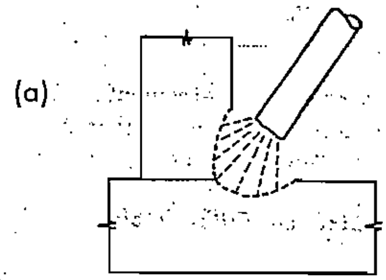
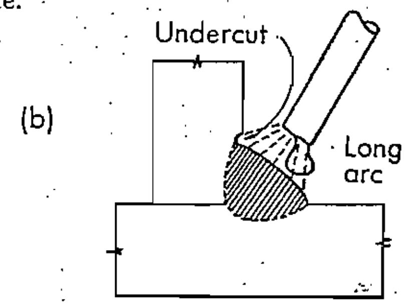
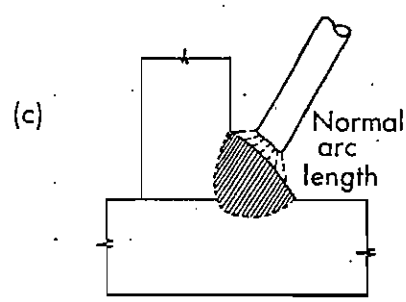


(a) The digging effect of the arc melts a portion of the base plate.



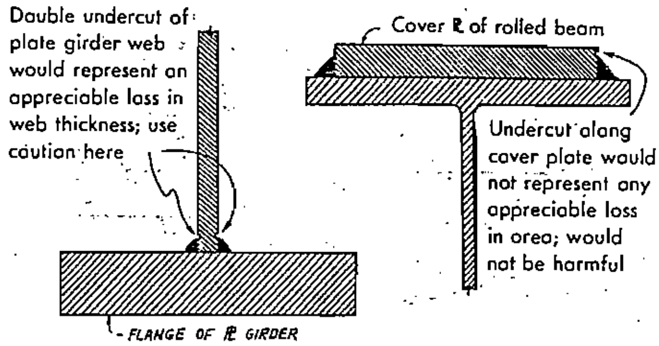
(b) If the arc is too long, the molten weld metal from the end of the electrode may fall short and not completely fill this melted zone, thus leaving an undercut along the upper leg of the weld.



(c) If the arc is shortened to the proper arc length, the molten weld metal from the end of the electrode will completely fill this melted zone and will leave no undercut.

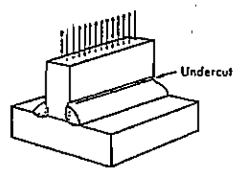
Undercut should not be accepted on a recurring basis since it can be eliminated with proper welding procedure. If, however, undercut does occur, the question to be answered at this point is whether it is harmful and needs repair.

(1st) If the undercut results in a sizeable loss of net section that cannot be allowed.

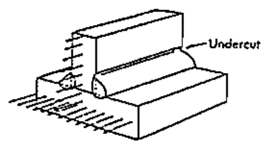


(2nd) If a force must be transferred transverse to the axis of the undercut, which may then act as a notch or stress riser.

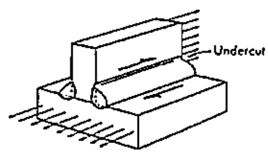
(a) Here the tensile force is applied transverse to the undercut and presents a stress riser. This *would be* harmful.



(b) Here the axial tensile stresses are applied parallel to the undercut and would not present a stress riser. This should *not* be harmful.

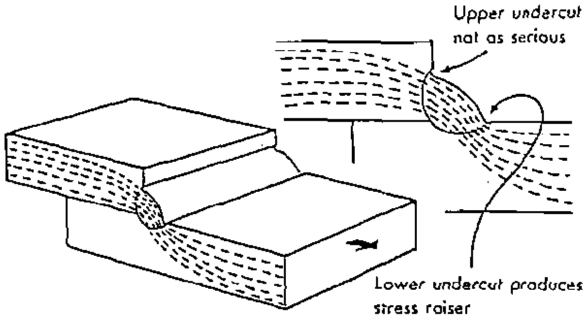


(c) Here the shear force is applied parallel to the undercut and would not present a stress riser. This should *not* be harmful.

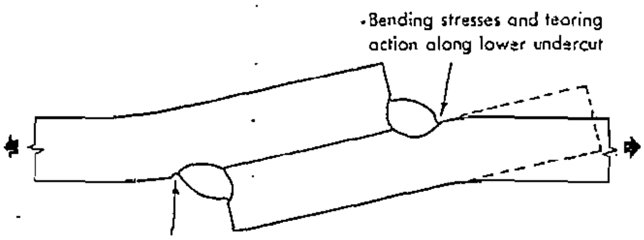


The AWS allows undercut up to 0.01″ in depth if it lies transverse to the applied force, and $\frac{1}{32}$″ if it lies parallel to the force.

• Although both undercuts in this tensile joint are transverse to the notch, the upper undercut undoubtedly has less effect upon producing a stress raiser because the stress flows smoothly below the surface of the root of the notch. On the other hand, the lower undercut does represent a stress raiser because the flow of stress is greatly disturbed as it is forced to pass sharply around the root of the notch.



• In addition, any eccentricity would produce bending stresses in the region of the lower undercut.



(17) Slight Reinforcement on Groove Welds

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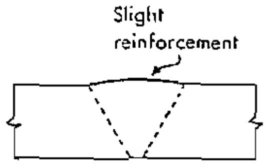

A nominal weld reinforcement (about $\frac{1}{16}''$ above flush) is required. Any more than this is unnecessary and increases the weld cost.

(18) Full Size on Fillet Welds

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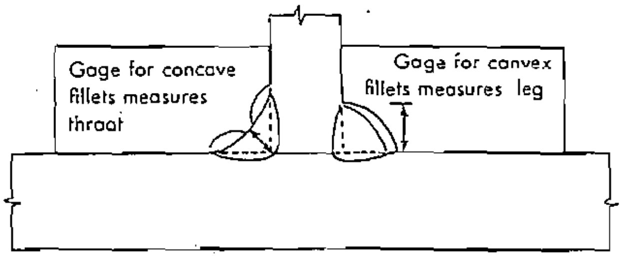

Proper gaging of fillet welds is important to ensure adequate size.

(19) Absence of Cracks

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There should be no cracks of any kind, either in the weld or in the heat-affected zone of the welded plate.