# Proposed Working Stresses for Fillet Welds in Building Construction

T. R. HIGGINS AND F. R. PREECE

DESPITE THE ADVANCES in the art of welding which have taken place in the past 40 years and a greater emphasis on quality control today, the working stress provision for fillet welds, with only minor modifications, is the same now as when the AWS Code for Fusion Welding and Gas Cutting in Building Construction was first published in 1928. At that time a shear stress of 11.3 ksi was permitted on the throat of fillet welds.

Later, when covered electrodes of specified strength were required by the Code, tests reported by Godfrey and Mount* indicated a 20 percent increase in the strength of fillet welds made with these electrodes. The allowable stress value was raised to 13.6 ksi. This stress is that currently permitted in building construction for fillet welds made with E60XX electrodes on A36 steel.

When the AWS Building Code was revised in 1963 to include steels with a specified yield point up to 50 ksi, a working stress for fillet welds made with E70XX electrodes was added, equal to $70 \times 13.6/60$, or 15.8 ksi.

Meanwhile, the allowable stress for tension and compression on groove welds had been raised from 13 and 15 ksi, respectively, to that permitted in design of the base metal, namely to 22 ksi for steel associated with a fillet weld stress of 13.6 ksi.

Support for the working stress provisions contained in the 1928 AWS Building Code was provided by the results of a program of 1395 tests, covering various size welds arranged in 55 elemental fillet and groove weld forms. These test results are presented in the Report of Structural Steel Welding Committee, published by the American Welding Society, September 1931. Base metal for the specimens was Open Hearth Structural Steel for Buildings, ASTM A9, having a specified yield stress of 30 ksi and a tensile strength of 55 ksi. Both gas and manual metal arc welding were studied. Arc welding electrodes were the then-current bare wire type. While mechanical properties were not specified for these electrodes, the weighted average tensile strength for the groove weld specimens was 49.6 ksi.

* *Godfrey, J. H., and Mount, E. H., "Pilot Tests on Covered Electrode Welds," Welding Journal, 19 (4), Research Suppl., 133-s to 136-s (1940).*

*T. R. Higgins was until recently Director of Engineering and Research, American Institute of Steel Construction. He is now a structural engineering consultant, New York, N. Y.*

*F. R. Preece is Executive Vice President, Testing Engineers Incorporated, Oakland, Calif.*

*This paper is reprinted from Welding Journal, New York, N. Y., October, 1968.*

## NEED FOR UP-DATING

Today, steels having a yield point as high as 100 ksi and electrodes of comparable strength are available and are being used in building construction. While electrodes having mechanical properties at least equal to those of the parts to be joined with full-penetration groove welds are generally required, the mechanical properties of fillet welds need not equal those of the base metal provided proper adjustment is made in weld size.

In the case of widely differing weld and base metal strengths consideration must, of course, be given to the influence of dilution upon the strength of the deposited weld metal.

A study looking toward an updating of the AISC Specification for the Design, Fabrication and Erection of Structural Steel for Buildings, to cover steel having a yield stress as high as 100 ksi, emphasized the need for a simple, rational system of working stress provisions covering the entire range of fillet weld application.

## PROGRAM OF TESTS

Compatibility between the AISC Specification and the AWS Building Code in matters relating to welding being a principle of long standing, before undertaking a study of the problem in depth a Task Committee of the AWS Structural Welding Committee, headed by Dr. A. Amirikian, Chairman of the parent committee, was asked to develop a suitable program. The range of tests recommended is outlined in Table 1. A total of

**Table 1. Test Program**

| Base Metal | Electrode Classification | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | E60XX Weld Size (in.) | | E70XX Weld Size (in.) | | | E90XX Weld Size (in.) | | | E110XX Weld Size (in.) | | |
| | 1/4 | 3/8 | 1/4 | 3/8 | 1/2 | 1/4 | 3/8 | 1/2 | 1/4 | 3/8 | 1/2 |
| | Longitudinal fillet welds | | | | | | | | | | |
| A36 | X | X | X | X | X | X | | | | | |
| A441 | | | X | X | X | X | X | X | X | | |
| A514 | | | X | X | X | X | X | X | X | X | X |
| | Transverse fillet welds | | | | | | | | | | |
| A36 | | | X | | | | | | | | |
| A441 | | | X | | | X | | | | | |
| A514 | | | X | | | X | | | X | | |

168 tests was scheduled. Whereas the investigation covered in the 1931 report also included unsymmetrical lap joints and joint forms comprising a combination of longitudinal and transverse fillet welds, as well as intermittent fillet welds, it was felt that longitudinal and transverse specimens similar, respectively, to those shown as Figs. D3 and D4 in the AWS Building Code, would suffice to bracket the full range of application.

Recognizing that the failure stress for longitudinal welds would be lower than that for transverse welds, the scope of testing for the former was more comprehensive. For each combination of base metal, electrode classification, and size and type of weld a total of six tests were required, three of which would be made by an eastern fabricator and three by a West Coast fabricator.

In every case the cross-sectional area of the connected parts was proportioned to assure weld failure before rupture of any part. At the same time the thickness of parts was limited by the required size of weld, in conformance with provisions in the present AWS Building Code. The dimensions of the several specimens, as prepared for loading, are shown in Figs. 1 and 2.

All specimens were made in the presence of an inspector from an independent testing agency who reported the heat number of each piece of steel in a given specimen; the electrode size, type and manufacturer; the current characteristics; the speed of electrode travel; and the interpass temperature. Samples taken from each heat number and each box of electrodes, along with the specimens prepared by each fabricator, were shipped to the laboratory of Testing Engineers, Inc., Oakland, Calif. Here the specimens were milled for testing and all tests were performed.

Prior to the final design of the longitudinal fillet weld specimens, the effect of weld length upon weld strength was investigated. Specimens similar to those shown in Fig. 1 were fabricated using 1/4-in. fillets. The length of the welds, after milling, were, respectively, 6, 8, 12 and 16 times the weld size.

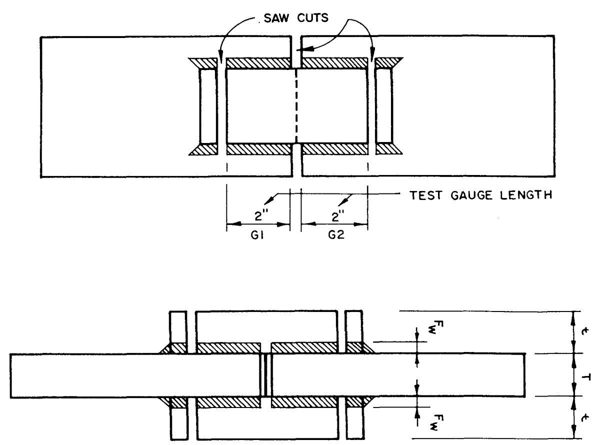


*Fig. 1. Longitudinal fillet weld test with dimension schedule as follows:*

| | | | |
|---|---|---|---|
| *Weld size (FW), in.* | 1/4 | 3/8 | 1/2 |
| *Main plate thickness (T), in.* | 3/4 | 1 | 1 1/4 |
| *Splice plate thickness (t), in.* | 3/4 | 1 | 1 1/4 |

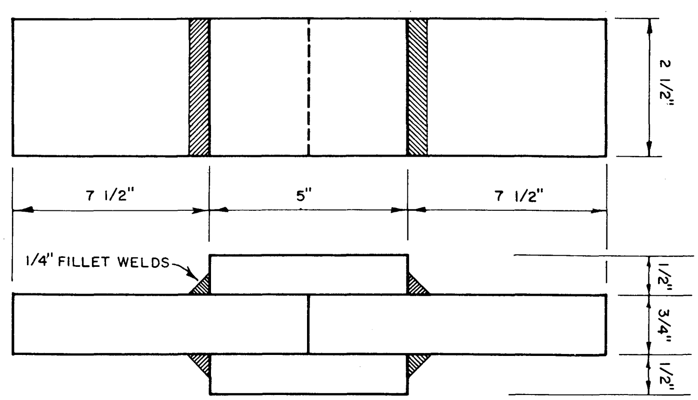


*Fig. 2. Transverse fillet weld test*

**Table 2. Effect of Weld Length on Weld Strength**

| Each Weld Length (in.) | Total Weld Length (in.) | Ultimate Test Load, (lbs) | Weld Strength (lbs/lin. in.) |
|---|---|---|---|
| 1½ | 6 | 74,750 | 12,500 |
| 2 | 8 | 101,500 | 12,700 |
| 3 | 12 | 153,500 | 12,800 |
| 4 | 16 | 206,000 | 12,900 |

As seen in Table 2, there was a slight trend toward increased unit strength as the length of weld was increased. However, this amounted to only 3 percent over the range investigated. Based upon this observation, a constant milled length of 2 in. was chosen for all subsequent longitudinal specimens. This amounted to 8 times the ¼-in. weld size, and 4 times the ½-in. weld size, and would, if anything, yield values on the conservative side.

## DISCUSSION OF TEST RESULTS

All specimens failed in the welds, even when the mechanical properties of the weld metal exceeded those of the base metal by a substantial amount. Figure 3 indicates the major type of stress, its distribution, and the resulting strain experienced by the two types of welds. The state of stress (predominantly shear) produces a greater strain, $\epsilon$, in the longitudinal fillet weld than that produced by the combination of shear and bending in the transverse fillet weld. This amounted to as much as 10 percent of the weld length, as seen at the saw-cut end of the unbroken weld in Fig. 4.

The failure plane of the longitudinal welds generally was at an angle less than 45 degrees to the plane of a leg. The failure plane of the transverse fillet welds was even closer to the plane of a leg—namely, the leg parallel to the applied load—as seen in Fig. 5. Whereas the failure surface of the transverse welds was relatively smooth, that of the longitudinal welds consisted of a series of helical-shape tears, as seen in Fig. 6.

Macro-etched cross sections through unfailed fillet welds exhibited little penetration below the root—Fig. 7. In fact, examination of the broken specimens disclosed one or two cases where complete root penetration was slightly lacking.

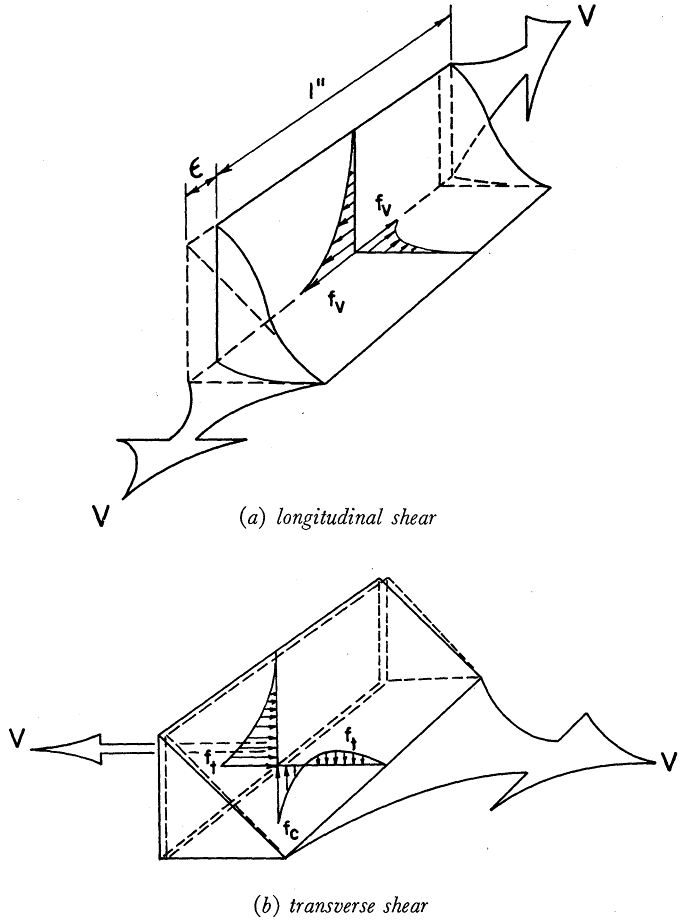


*Fig. 3. Fillet welds in shear*

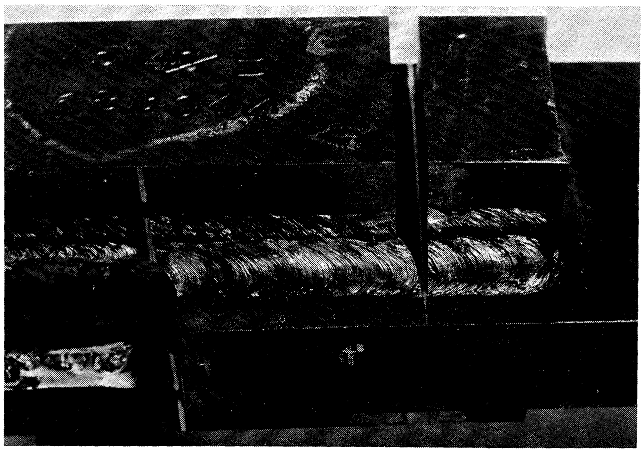

*Fig. 4. Unbroken longitudinal fillet weld specimen showing shear strain*

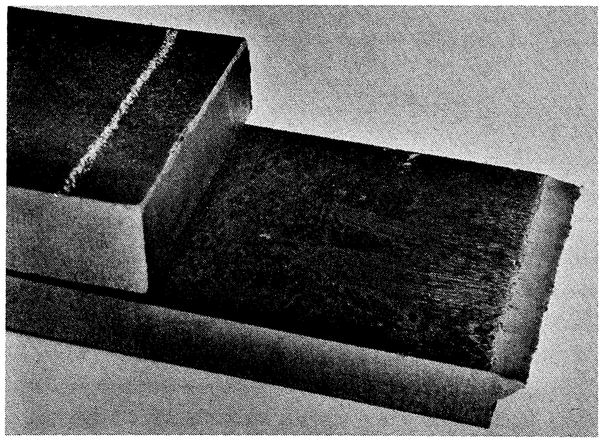

*Fig. 5. Transverse fillet weld specimen after failure*

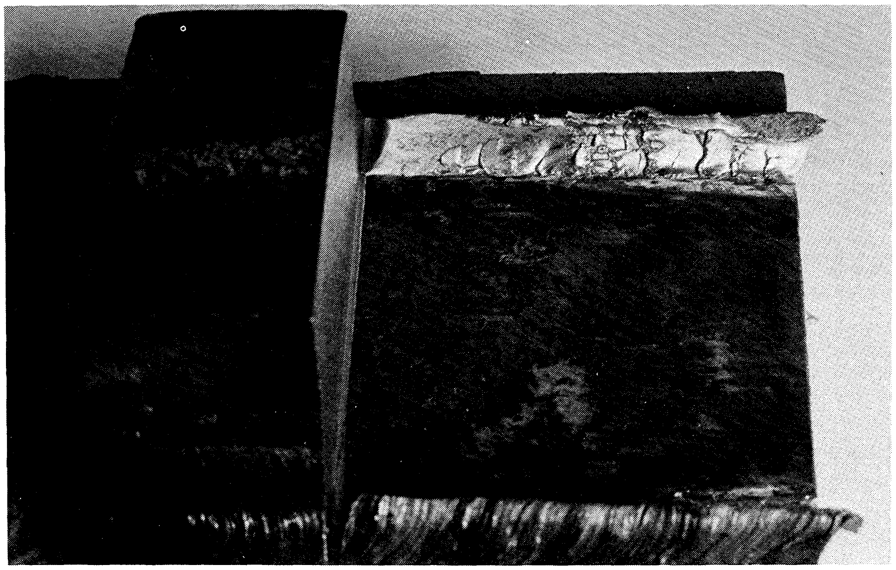

*Fig. 6. Failure surface of longitudinal fillet weld*

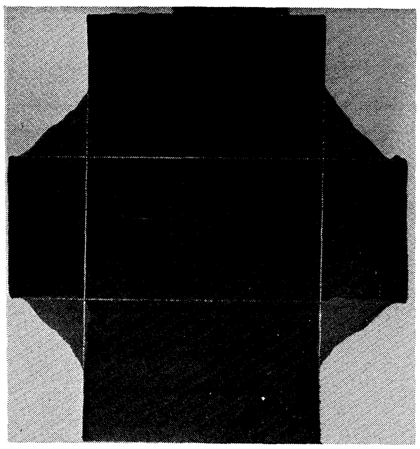

*Fig. 7. Macro-etched cross sections through unfailed fillet welds*

Scatter in test results between duplicate specimens was less than in the 1931 report. As a basis for evaluating observed strength, the recorded test load was divided by the total area of the failure surface. This area was computed by taking the average of four width measurements on each of the ruptured welds and multiplying it by the total length of ruptured welds.

### EFFECT OF DILUTION

In order to determine the extent to which the strength of a fillet weld might be influenced by dilution when the mechanical properties of the deposited weld metal are different than those of the base metal, combinations of strong base metal with weaker weld metals and strong weld metal with milder base metal were both included in the program.

A study of the test results revealed that the impact of dilution upon weld strength, which was most pronounced with the ¼-in. welds, was less than had been expected. For example, ¼-in. fillet welds made with E110XX electrodes on steel having a tensile strength 36 percent less than that required for E110XX electrodes were only 8 percent weaker than those deposited by the same electrodes on A514 steel. Conversely, ¼-in. fillet welds made with E70XX electrodes on A514 steel having a tensile strength 65 percent greater than that required of the electrodes were only 2 percent stronger than those deposited on steel having approximately the same mechanical properties as the electrodes.

### CONCLUSIONS

Obviously, a system of working stresses for fillet welds dependent upon a given spread between electrode and base metal mechanical properties, would be too involved for everyday use. On the basis of the evidence developed it was concluded by the AISC Advisory Specification Committee that:

1. Steels having a tensile strength roughly comparable to that required of an electrode classification can be regarded as "matching" steels.
2. A single working stress provision, suitable for the proportioning of fillet welds made with any class electrode upon one of its matching steels, can be expressed in terms of the specified tensile strength of the electrode classification.
3. Such a working stress can be economically used when welding on stronger steels.
4. Fillet welds made with electrodes having a tensile strength substantially lower than that of a steel part which they are required to connect, should be pro-

**Table 3. Average and Minimum Safety Factors**

| Reported by Testing Engineers, Inc., 1968 | | | | | |
|---|---|---|---|---|---|
| | | Factor of Safety Using Stress on Throat Area Equal to 0.3 Tensile Strength of Electrode | | | |
| | | Long. Welds[a] | | Trans. Welds[a] | |
| Base Metal | Electrode Class | Avg. | Min. | Avg. | Min. |
| A36 | E60XX | 2.88 | 2.67 | | |
| A441 | E70XX | 2.95 | 2.67 | 4.62 | 4.06 |
| A514 | E110X | 2.41 | 2.21 | 3.48 | 3.30 |

| Reported by Structural Steel Welding Committee, 1931 | | | |
|---|---|---|---|
| | | Factor of Safety Using 11.3 ksi on Throat Area | |
| Type of Welds[a] | Test Series No. | Avg. | Min. |
| Long. | 2400 | 3.28 | 2.84 |
| Trans. | 1900 | 4.63 | 2.92 |

[a] *Long—longitudinal; trans—transverse.*

portioned on the basis of the working stress that would be permitted if deposited on a "matching" steel.

Determination of a suitable working stress in terms of the specified tensile strength of an electrode classification must, of course, involve a consideration of factor of safety.

Summarizing the results of tests on the various forms of symmetrical fillet weld specimens, the 1931 Report of Structural Steel Welding Committee observed that, based upon an allowable stress of 11.3 ksi, the average factor of safety for the several forms studied varied from 3.28 to 4.70 with an overall average of 3.80, while the minimum factor of safety ranged from 2.21 to 3.18.

A summary of the average and minimum factors of safety relating the Testing Engineers, Inc. test results to a working stress of 0.3 the specified tensile strength of electrode classification used with a "matching" base metal, is compared in Table 3 with results from similar weld forms reported by the Structural Steel Welding Committee in 1931.

It should be noted that the basic working stress for structural steel design in 1931, which was taken as 0.60 of the specified minimum yield stress of the steel at that time, was $\frac{1}{3}$ of the specified minimum tensile strength of this steel. With today's structural steels the basic stress of 0.60 $F_y$ is closer to $\frac{4}{10}$ the specified tensile strength, tantamount to a 15 to 20 percent reduction in any factor of safety based on tensile strength. Therefore, in comparing the proposed working stresses for fillet welded connections with the value permitted in the 1928 AWS Building Code, on the basis of factor of safety with respect to tensile strength, it is necessary to adjust the factors of safety reported in 1931 by a coefficient equal to $\frac{1}{3} \div \frac{4}{10}$, or 0.83.

On this basis, and in recognition of improvements in the art of welding that have taken place in the past 40 years, the more liberal working stress provision—0.3 times the electrode tensile strength—appears fully justified.

With electrode classifications available having a tensile strength increasing by increments of 10 ksi, the simplicity of a single criterion, in terms of the properties of the weld metal, will prove convenient as new steels are introduced.