Center for Transportation Research
The University of Texas at Austin

PROJECT SUMMARY REPORT

Project Summary Report 1501-S
Fillet Welding Procedure Qualification Research
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Evaluation of Fillet Weld Requirements

The motivation for this research was the desire to develop improved procedures for qualifying fillet welds on bridge structures. The current procedure qualification tests prevent the use of active fluxes and other consumables or procedures which may be more applicable to fillet welding. Active fluxes are formulated for limited-pass welding. They contain active deoxidizers, such as manganese, silicon, or both, to improve the resistance to porosity and weld cracking caused by contaminants on or in the base metal. Most fillet welds are single-pass welds applied to unprepared surfaces. The enhanced ability of active fluxes to deoxidize the weld metal is particularly important for fillet welds. The amount of manganese and silicon in the weld metal varies with the arc voltage, and so the arc voltage must be carefully controlled when making multipass welds with active fluxes. The change in the amount of silicon and manganese when the arc voltage is changed is used as an index to differentiate between active and inactive or neutral fluxes. More active fluxes will show a larger change in deposited weld metal chemistry for an incremental change in voltage.

The fillet weld qualification requirements in the current bridge welding code, ANSI/AASHTO/AWS D1.5-96, henceforth "AWS D1.5," specify that fillet welding procedures be qualified using a groove weld specimen (AWS D1.5, Section 5.10). A large groove weld is used to produce the test specimens. The weld is designed to provide as near as possible a weld that is undiluted by the base metal. Fillet welds are often single pass welds that contain a considerable amount of base metal in the cast welds. A typical small fillet weld will have more dilution of weld metal with base metal than the material at the center of the large groove weld used in the standard test. In addition to the difference in the amount of dilution, the groove weld microstructure will be refined in subsequent passes; single-pass fillet welds undergo no refinement. In practice, welding procedures that give good test results for a groove weld may not necessarily produce the best fillet welds. In particular, fabricators have reported that the heat input required to produce a groove weld specimen that will pass the specified tests is too high for many fillet welds. This requirement is particularly problematic with T-joints welded simultaneously on both sides, where the total heat input to the welded area is greatly increased. There are anecdotal reports that fillet welds made with procedures that pass the qualification tests have failed in the field.

The research investigated the behavior of fillet welds to determine what requirements if any should be imposed upon the fabricator to ensure the satisfactory performance of fillet welds used in bridges. The research was restricted to welds made using the submerged-arc process.

What We Did...

The research examined the performance of fillet welds made with a matrix of consumables and heat inputs. Different fabricators made the weld specimens using consumables they normally use in their shop. All of the consumables were from the Lincoln Electric Company. The weld matrix is shown in Table 1. The fabricator that provided the weathering specimens uses this set of consumables for all his submerged-arc welds. This set of consumables was included since the fabricator does the majority of the steel bridges in Texas. The two heat input ranges used for each set of consumables bound the values that would be used in normal fabrication. The high heat input values used for the active flux were much higher than the fabricator would use in normal practice. Two-sided as well as single-sided welds were included in the fabrication of the T-bend and the fillet weld shear specimens. These welds simulate the welding of a stiffener to web. The 3/8 and 1/2 in. thick plates forming the stem of the T, the simulated stiffener, were used to determine the influence on the additional heat input from the weld on the opposite side upon the weld properties.

Each fabricator produced three specialized fillet weld test specimens. A transverse shear specimen similar to the specimen in AWS B4.0-92 was used to measure the shear strength of the weld. A T-bend specimen, which has been used by the Georgia and California departments of transportation and also used to evaluate fillets welds used on the new high performance 70 grade bridge steel, was used to measure the ductility of the welds. A weld root Charpy V-notch, WRCVN, specimen was utilized to measure the notch toughness of a simulated fillet weld. In addition, a standard AWS groove weld qualification specimen was made using weathering consumables at the high and low heat input in order to compare the results of the specialized fillet weld tests with the standard AWS specimen. Three replicate specimens were tested for each condition. The factorial experimental results were analyzed using analysis of variance method.

What We Found...

The results of the tests indicated that the strength and ductility measured in the shear and T-bend specimens were similar. The T-bend specimen did not provide meaningful test results. However, it did provide a means of assessing the depth of penetration of the weld procedure.

High heat input double-sided dart welds with an active flux produced complete penetration with a 3/8 in. web. Cracking across the weld occurred in these specimens. However, the ductility of the single-sided high heat input weld was the least cracked. The hardness of the higher heat input welds was less than the lower heat input and the double-sided welds produced the lowest hardness. The variation of hardness with heat input was largest in the welds using an active flux. The double-sided high heat input fillet weld on a 3/8 in. stem produced the lowest weld hardness with active and neutral fluxes. The specimens using the weathering flux showed smaller variation in weld hardness with changes in heat input. The estimated tensile strength for the weld with lowest hardness is 84 ksi, far above the required strength of 70 ksi.

The results of the weld shear strength tests showed for all consumables that the low-heat welds are stronger and harder than high-heat welds and single-sided welds are stronger and harder than dart welds. Both the calculated shear strength and the tensile strength corresponding to the hardness are well above the nominal tensile strength of 70 ksi for all speci-mens tested. The measured shear strengths were as large as two to four times the nominal value of 0.6 x 70 = 42 ksi.

For all three sets of consumables, no effect of heat input was found within the dart-welded specimens. This finding may have to do with the effect of dart welding on actual heat input. It is possible that although raising the heat input may change weld strength, once a "saturation" heat input is reached there will be no more effect from further heat input increases. If this is so, then dart welding will have no additional effect on a weld whose heat input is already high.

The active flux specimens gave the lowest absorbed energy in the WRCVN tests. A comparison of the low heat input results is shown in Figure 1.

The WRCVN, PQR, and certificate Charpy that the consumable manufacturer reported results are essentially the same for the active and neutral fluxes. Only the weathering consumables show a significant difference between the WRCVN specimens and the groove weld test plate specimens performed for PQR and certification testing. The heat input had little effect on the results from either the WRCVN or the normal CVN test specimens.

The weathering consumable WRCVN specimens had different properties from standard AWS CVN specimens. The pattern of results from WRCVN tests was shifted approximately 20°C to 40°C (35°F to 70°F) higher then the standard AWS CVN specimens. The WRCVN specimens should reflect fillet weld properties more accurately because they are taken from the root of what is in essence a multiple-pass fillet weld. If the pattern seen among the weathering specimens can be extrapolated to other consumables, then the standard test overestimates weld toughness. Medlock (1998) demonstrates that standard AWS CVN test results are not representative of production groove welds, and typically have higher toughness values than production welds. Fillet welds differ even more from the standard test weld, and so are even less likely to be adequately represented by the standard test.

Table 1: Welding parameters

Consumable Designation	Flux	Electrode	Heat Inputs(kJ/in)	
			Low	High
Neutral Flux	960	L-613/32" wire	35.7	50.4
Active Flux	780	L-615/64" wire	32.9	48.7
Weathering	860	LA-753/32" wire	34.6	48.0

The Researchers Recommend...

The results of this research indicate that the tensile strength requirements of the weld certification tests are adequate to ensure the strength of fillet welds. Based upon these results, the weld qualification tests presently required in AWS D1.5 are not necessary to ensure the strength of a fillet weld. The T-bend specimen did not provide a useful measure of the strength or ductility of a fillet weld. The T-weldment does provide a simple means to evaluate the influence of double-sided weld upon the geometry of the weld and melt-through of the stem. The WRCVN specimen provides a convenient method of characterizing the toughness of the fillet weld root material. The WRCVN toughness may be comparable to or less than the toughness measured in the standard all-weld metal tests. The WRCVN test is recommended as a simple means to ensure that the fillet weld toughness is adequate. Toughness comparable to the base metal should be sufficient for the root of the fillet. The base metal is directly adjacent to the weld metal at the root of the weld. Consequently, a fracture will propagate in either the weld or base metal, whichever has the lowest toughness. There is no benefit to having the weld metal toughness significantly tougher than the base metal. A weld root toughness corresponding to the non-fracture-critical base metal requirement for 4-inch plates in Temperature Zone III should be adequate for all bridges. For example, the required toughness for Gr. 50 steel would be 20 ft-lbs at 10° F, per ASTM A 709 Table S1.2.

Based upon the results of this study, the following recommended changes to the specifications are proposed:

1. The consumable supplier shall perform the following tests annually:
   a. Two weld certification tests, one at the highest and the other at the lowest weld heat input recommended by the manufacturer. If the fabricator stays within these heat inputs, no groove weld qualification testing is required by the fabricator. The essential variables are those defined in AWS D1.5-96 Section 5.12.2, "Maximum-Minimum Heat Input."
   b. A WRCVN test plate shall be welded using the maximum and minimum heat input recommended. The average of three specimens from each test weld should be equal to or greater than the non-fracture-critical base metal requirement for 4-inch plates in Temperature Zone III. For 36-ksi material, the requirement for 50-ksi material should be used.
2. The fabricator shall perform the T-weldment test described below every 5 years or whenever the essential variables are changed. The fillet weld T-weldment is similar to the fillet weld soundness test required in AWS D1.5-96 Section 5.10, with the following exceptions.
   a. The plate thickness shown in AWS D1.5-96 Figure 5.8 shall be doubled.
   b. The welds shall be made at the highest heat input in the WPS.
   c. If two-sided dart welding will be used in the production weld, the same method should be used for fabricating the T-weldment.
   d. The spacing of the electrodes in a two-sided weld shall be the minimum specified in the WPS.
   e. A T-weld test is required for each weld size, or for the minimum and maximum weld sizes.
   f. The welds are to be sectioned in accordance with AWS D1.5-96 Section 5.10.3 and tested in accordance with Section 5.19.3. In addition, the maximum penetration of each weld shall not exceed 1/3 of the thickness of the T-stem (dimension T_2 in AWS D1.5-96 Figure 5.8).

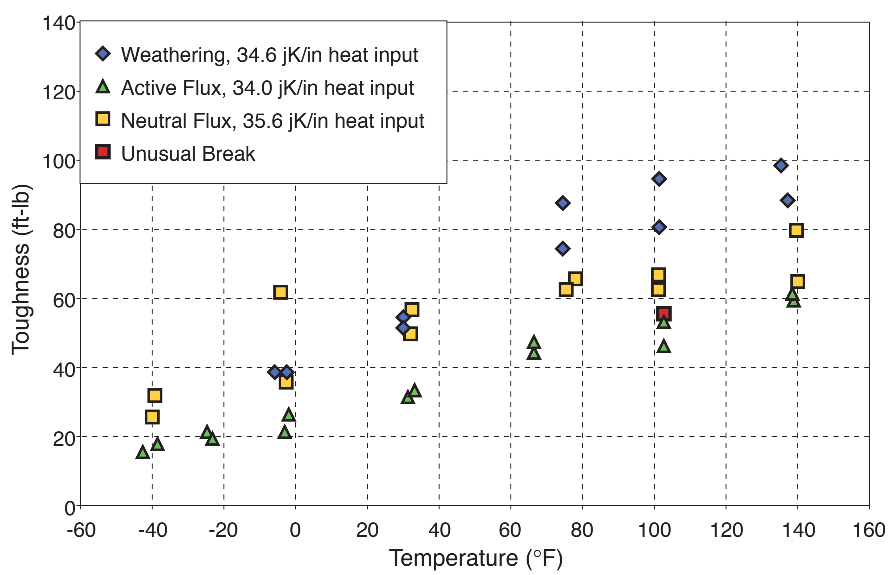

Figure 1: WRCVN Test Results

For More Details...

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The research is documented in the following report:

1501-1 *Evaluation of Fillet Weld Qualification Requirements,* October 1999.

To obtain copies of a report: CTR Library, Center for Transportation Research,
(512) 232-3138, email: ctrlib@uts.cc.utexas.edu

TxDOT Implementation Status
January 2002

The results from this research will be formally presented to the AASHTO/AWS committee that writes the AASHTO/AWS D1.5 Bridge Welding Code. This Code governs bridge welding in the US and includes requirements for qualification of fillet welding procedures. Dr. Karl Frank has already made a preliminary presentation to the committee, and the committee has been provided with copies of the research results. It is expected that the results from this research effort will be adopted to facilitate improvement of the way fillet welding procedures are covered under this Code.

For more information please contact Tom Yarbrough, P.E., RTI Research Engineer, at (512) 465-7685 or email at tyarbro@dot.state.tx.us.

Your Involvement Is Welcome!

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