Clearance for Welded Joints

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ABSTRACT

Inadequate clearance can affect weld quality and efficiency. In extreme cases, obstructions may cause a lack of fusion between the base metal and the weld metal, causing a reduction in strength. Although flux cored arc welding (FCAW) and gas metal arc welding (GMAW) have replaced shielded metal arc welding (SMAW) as the primary fabrication processes for structural steel fabrication, existing clearance recommendations are based on the SMAW process. Because the geometry of a FCAW or GMAW welding gun is much different from that of a SMAW electrode, the historic values recommended for the SMAW process may not apply to FCAW and GMAW.

Experimental specimens were fabricated with the FCAW process to determine practical limits on connection geometry for welding joints with limited access. Each specimen was evaluated by sectioning and etching the weld at two locations along the length. Two weld clearance issues are addressed: (1) fillet welding near obstructions and (2) doubler plate welds.

The obstructed fillet weld specimens were used to determine the minimum clearance requirements for joints welded with the FCAW process. The cross-sectioned welds showed that as the distance between the weld and the obstruction plate decreased, both the production efficiency and the penetration into the base metal decreased. Revised clearance recommendations for FCAW and GMAW welding were proposed.

The doubler plate specimens were used to provide information regarding the root-pass penetration for square-cut plates, based on the plate thickness and the distance from the inner surface of the flange to the edge of the plate. The results of this study, which was limited to only eight specimens, validated the common practice of cutting the edge square at doubler plates less than ⅜ in. thick. For doubler plates thicker than ¼ in., a groove angle, α, of 15° to 30° may be required to ensure consistent weld quality.

Keywords: welded joints, FCAW, GMAW, doubler plates, weld clearance.

INTRODUCTION

Although strength is the primary consideration for welded joints, proper joint clearance is required to ensure high-quality welds. Inadequate clearance can affect weld quality and efficiency, leading to increased costs and delayed schedules. In extreme cases, obstructions may cause a lack of fusion between the base metal and the weld metal, causing a reduction in strength.

Welder and Equipment Access

The area near the weld must be clear, with enough room for equipment and welder access. For this purpose, Shaw (1996) recommended "at least 18 in. of clear space around the joint." This clearance should be maintained until the inspection has been completed. For field welding, erectors can provide project-specific clearance requirements based on their personnel and equipment.

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Electrode Positioning Clearance

In addition to welder and equipment access, clearance must also be provided for electrode positioning. For proper fusion and penetration, the welder must be able to direct the arc against the base metal. When an obstruction is present, the electrode is forced into a nonoptimal position, potentially causing lower penetration and difficulty achieving the correct weld profile.

Fillet Welding Near Obstructions

The recommended electrode clearance for shielded metal arc welding (SMAW) welding is shown in Figure 8-11 of the 15th Edition *Steel Construction Manual* (AISC, 2017), which is reproduced here as Figure 1. For horizontal welds, the AISC *Manual* recommends a 30° electrode angle, with an absolute minimum angle of 27° (based on a 2-to-1 slope). These recommendations were first included in the AISC publication, *Structural Shop Drafting* (AISC, 1953), with the additional comment that "the root of the weld shall be visible to the operator." Similar clearances were proposed by Priest (1943) and Grover (1946) more than seven decades ago, when SMAW was the prevalent welding process for steel structures.

A special condition is shown in AISC *Manual* Figure 8-12 (shown here as Figure 2), where weld access is available at the member end. In this case, the clearance is independent of the flange width, and the angle between the electrode and the longitudinal weld axis is critical. For further information, see Part 8 of the AISC *Manual*, where a 20° minimum electrode angle is recommended for straight electrodes.

An additional parameter that may affect weld clearance requirements is the "banking" of weld metal to counteract the effect of gravity for welds made in the horizontal position. To obtain equal-leg fillet welds, the welder typically rotates the electrode toward the horizontal surface so the arc is directed more toward the vertical surface. Based on this, a vertical obstruction may be more critical than a horizontal obstruction in the welding of joints in the horizontal position.

AISC Design Guide 21, *Welded Connections—A Primer for Engineers* (Miller, 2017), describes the different processes and where they are commonly used. Flux cored arc welding (FCAW) is the most common process for welding steel structures. Many shops now use gas-shielded flux cored arc welding (FCAW-G) or gas metal arc welding (GMAW) in production, and self-shielded flux-cored arc welding (FCAW-S) is the most used process for field welding.

As shown in Figure 3, the geometry of a FCAW or GMAW welding gun is much different from that of a SMAW "stick" electrode. Additionally, electrode manipulation techniques may be different between the processes. Therefore, the historic values previously recommended for the SMAW process may not apply to FCAW and GMAW.

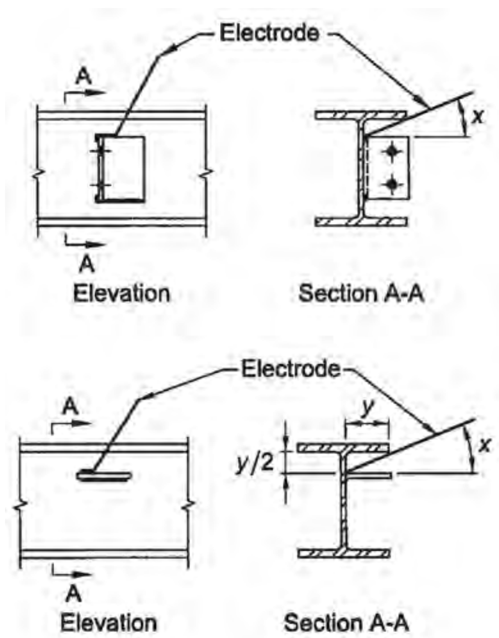


Fig. 1. Clearances for SMAW welding.

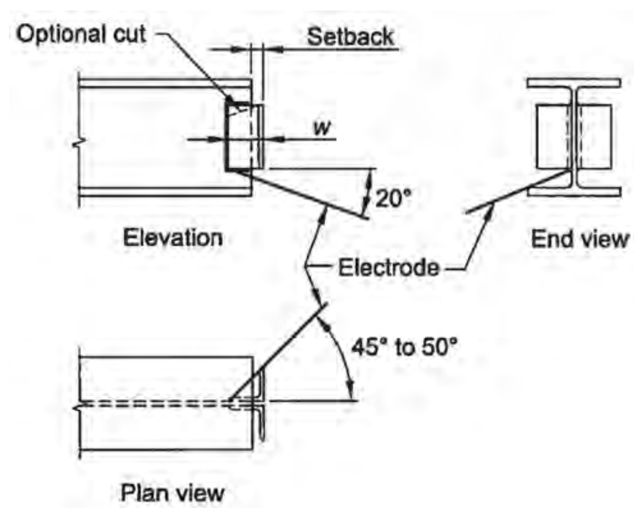


Fig. 2. Clearances for welding near the end of members.

(a) (b)

Fig. 3. Fillet weld joints using the FCAW-G process: (a) unobstructed; (b) obstructed.

Groove Welds

The main function of a weld preparation is to facilitate the required weld metal penetration. The preparation must provide adequate access so the arc can be directed against the base metal. Figure 4(a) shows a T-joint with a square groove preparation that is not prequalified because the arc cannot be directed against the base metal. A similar detail is shown for a corner joint in Figure 4(b). For relatively thin materials, the corner joint is prequalified because arc access is not obstructed as it is for the T-joint. A prequalified T-joint with a single-bevel weld preparation is shown in Figure 4(c), where the arc can be easily directed against the beveled surface.

Doubler Plate Welds

AISC Design Guide 13, *Stiffening of Wide-Flange Columns at Moment Connection: Wind and Seismic Applications* (Carter, 1999), discusses several different weld configurations for web doubler plates, including both fillet- and groove-welded joints. For the groove-welded option, a typical weld detail is shown in Figure 5, which is similar to Figures 4(a) and 4(c). Doubler plates for structures designed in accordance with the AISC *Seismic Provisions* (AISC, 2016) must be welded according to Section 4.3 of AWS D1.8 (AWS, 2016). In this case, only groove welding is allowed, and the variables defined in D1.8 must be followed.

For nonseismic design, the plate edge is often located at the tangent point of the column fillet ($R = 0$). However, detailing the joint with an encroachment onto the fillet ($R < 0$), as shown in AISC *Manual* Figure 10-3, can reduce the weld metal. In addition to the cost savings, reductions in weld metal can decrease flange rotations caused by weld shrinkage.

For thick doubler plates, a groove angle, α, of 30° is common, but angles as low as 15° have been used successfully.

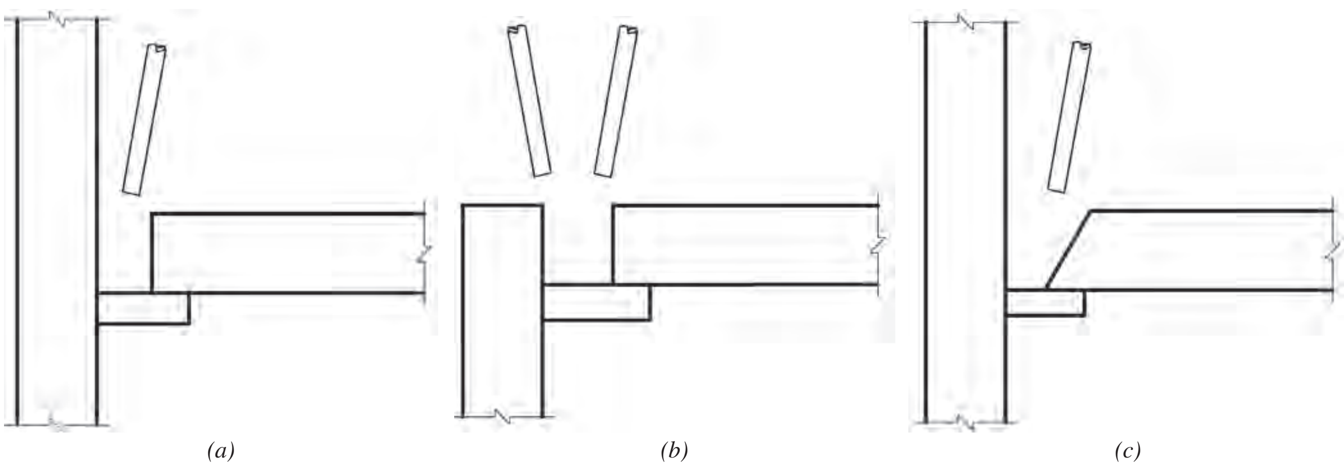


Fig. 4. Arc access: (a) not prequalified; (b) prequalified for limited thickness; (c) prequalified for unlimited thickness.

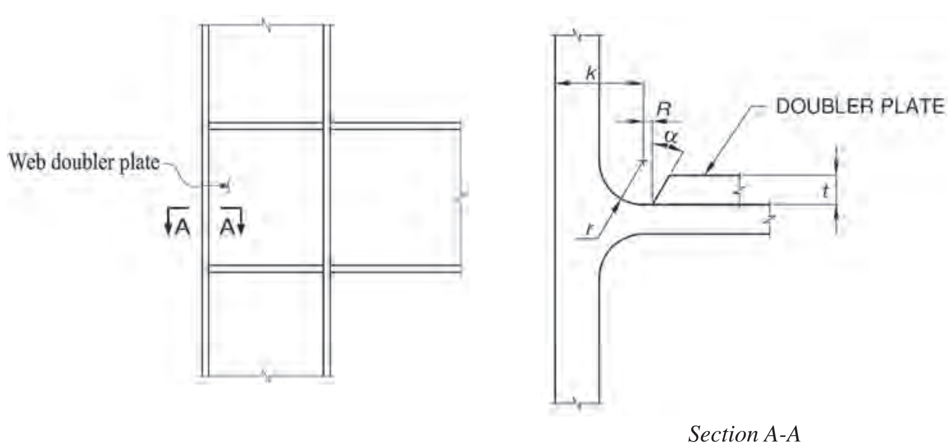


Fig. 5. Doubler plate groove welds.

For thin doubler plates, square-cut plates ($\alpha = 0°$) are often used to eliminate the plate preparation and reduce the weld metal volume. Square-cut preparations must be limited to thin plates because proper fusion between the weld metal and the doubler plate is attained by weld penetration into the doubler plate, essentially melting the plate corner and creating a groove angle as the weld progresses. Current fabrication practices vary, but generally, plates less than ⅜ in. thick are cut square and plates ⅜ in. and thicker are beveled; however, the author is not aware of any published recommendations for this detail.

OBJECTIVES

The objective of this research is to determine practical limits on connection geometry for welding joints with limited access. Two weld clearance issues are addressed:

1. *Fillet welding near obstructions.* The obstructed fillet weld specimens were used to determine the minimum clearance requirements for joints welded with the FCAW process.
2. *Doubler plate welds.* The doubler plate specimens were used to provide information regarding the root-pass penetration for square-cut plates based on the plate thickness and the distance from the inner surface of the flange to the edge of the plate. These specimens were also used to determine the effect of joint geometric constraints on the fusion into the doubler plate edge.

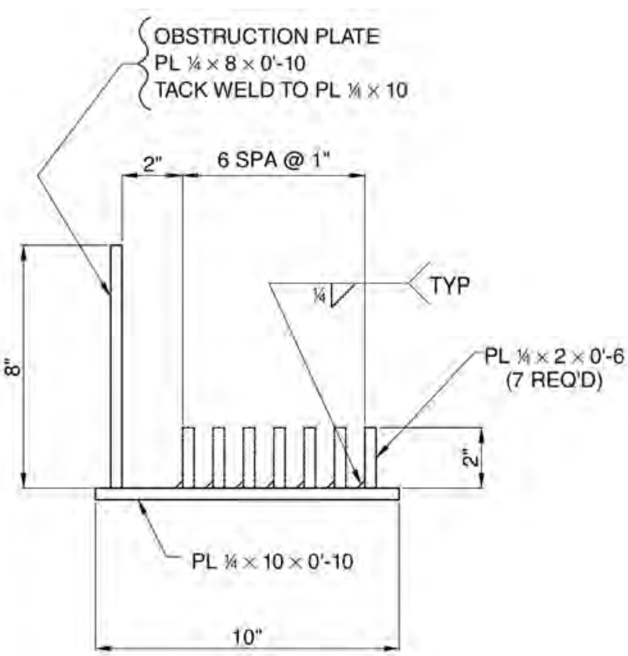


Fig. 6. Weld clearance specimen detail.

PROCEDURE

To determine the effect of clearance on the quality of welded joints, specimens were fabricated, sectioned and inspected. All specimens were fabricated by AISC-certified fabricators using the FCAW-G process. Because the equipment for GMAW is similar to that of FCAW-G, the clearance requirements are similar. Due to the absence of a gas nozzle, less clearance is required for the FCAW-S process. Each shop selected a welder to participate in the project based on an average level of skill and experience. Each weld was visually inspected by the fabricator, and any deficiencies were noted. The selected welders completed a questionnaire, and the engineering/production managers were interviewed for further information. All specimens were sectioned by cold-sawing at two locations perpendicular to the weld. The saw-cut sections were macro-etched with a 10% Nital etchant, which consists of 10 ml nitric acid and 90 ml ethyl alcohol. Etching reveals the grain structure, allowing the boundaries of the weld metal, base metal, and heat affected zone to be identified. Further information on the procedures is provided in the sections, "Fillet Welding Near Obstructions" and "Doubler Plate Welds." The welding procedure specifications for each participating fabricator are listed in Appendix A.

FILLET WELDING NEAR OBSTRUCTIONS

This part of the project studied clearance requirements by sectioning specimens that were welded at various distances from an obstruction plate. Three fabricators each welded specimens in three different positions for a total of nine specimens.

Procedure

The weld clearance specimens used a ¼- × 8-in. plate to simulate an obstruction. Each specimen was fabricated with seven test welds, as shown in Figure 6. The outermost ¼- × 2-in. plate was welded first, and the assembly sequence progressed toward the obstruction plate. Figure 7 shows the weld sequences, labeled location 1 through location 7, with location 7 closest to the obstruction plate.

One large fabricator and two medium-size fabricators participated in this part the project. Each fabricator supplied three specimens, with two specimens welded in the horizontal position and one specimen welded in the vertical position. For the specimens welded in the horizontal position, position A was oriented with the obstruction plate in the vertical direction, and position B had the obstruction plate in the horizontal direction as shown in Figures 8(a) and 8(b), respectively. A specimen welded in the vertical-position, designated position C, is shown in Figure 8(c).

Each specimen was identified with the designation, FPC-L, where F is the fabricator number, P is the welding position, C designates the cross-sectional cut location along the weld length, and L is the weld location number. After sectioning and etching the specimens, the weld leg sizes and effective throat dimensions were measured from a digital image in AutoCAD software.

RESULTS

Representative samples of the sectioned fillet weld specimens for each welding position are shown in Figure 9. The digitally measured weld leg sizes and effective throat dimensions are listed in Table B-1 of Appendix B. The measured dimensions, shown in Figure 7, are the effective throat, E, and the fillet weld leg sizes, w_1 and w_2.

As indicated in Table B-1, several of the weld leg measurements are less than the specified size of ¼ in. However, these welds passed the fabricator's visual inspection and meet the visual inspection acceptance criteria requirements of AWS D1.1 (AWS, 2015) Table 6.1, which allows a minimum size of ¼ in. – 3⁄32 in. = 0.156 in. over 10% of the weld

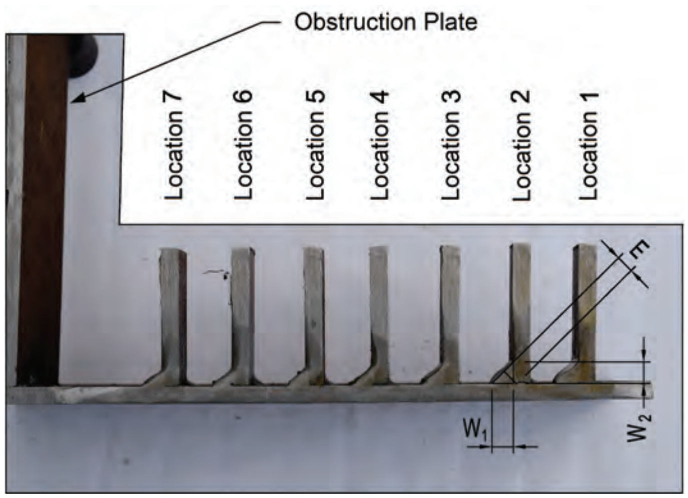


Fig 7. Section of a completed weld clearance specimen.

(a) (b) (c)

Fig. 8. Specimen positions: (a) position A; (b) position B; (c) position C.

(a) Location 3

(b) Location 7

Position A

(c) Location 1

(d) Location 7

Position B

(e) Location 5

(f) Location 7

Position C

Fig. 9. Fillet weld specimens.

length. Based on the specified leg size, the theoretical effective throat is:

$$E_t = \frac{\text{¼ in.}}{\sqrt{2}} = 0.177 \text{ in.}$$

Specimen 1B2-3 is the only weld with a measured effective throat less than 0.177 in. At this section, the measured dimension is only 4% less than the theoretical value. A reduction in the effective throat at this location could be predicted by evaluating the slightly undersized leg 1. Because leg 1 was undersized over less than 10% of the weld length, the slightly undersized effective throat can be considered within tolerance.

The welds for specimens 1A1-1, 1A1-2, 1A2-1, 1A2-2, 1B1-1, 1B1-2, 1B2-1 and 1B2-2 were rejected by the inspector without repair. The rejected welds were in positions 1 and 2, which were farthest from the obstruction plate. Several of the rejected specimens have undersized weld legs; however, the effective throat dimensions for these specimens are greater than the theoretical values.

As the distance between the weld and the obstruction plate decreases, the electrode angle changes, causing the arc to be increasingly directed toward the ¼- × 10-in. plate and away from the ¼- × 2-in. plates. This causes an increase in the leg aspect ratio, w_1/w_2, and a decrease in the penetration into the base metal at leg 2. The leg aspect ratios for each specimen are listed in Table A-1. The mean values for all specimens are plotted in Figure 10, which shows approximately equal leg sizes for locations 1 through 5. For locations 6 and 7, the mean value for w_1 is approximately 15 to 20% greater than w_2. This effect is clearly demonstrated in Figures 11(a), 11(b) and 11(c), which were welded in position C at locations 5, 6 and 7, respectively. In this case, the aspect ratios for locations 5, 6 and 7 are 1.20, 1.25 and 1.70, respectively.

Generally, all welds showed good fusion at both plates; however, the penetration depth at the ¼- × 2-in. plates (leg 2) decreased as the distance between the weld and the obstruction plate decreased. The specimen in Figure 9(c), at location 1, showed normal root penetration. For the weld closest to the obstruction plate, Figure 9(d) shows less penetration at leg 2.

A measure of the efficiency reduction is the area ratio, A_m/A_t, where A_m is the weld metal area calculated with the measured leg sizes and A_t is the theoretical weld metal area calculated with the specified leg size. The area ratios for each specimen are listed in Table A-1. And the mean values for all specimens are plotted in Figure 12. At location 1, A_m is approximately 20% more than A_t. As the distance between the weld and the obstruction plate decreases the area ratio shows an upward trend to a maximum mean value of 1.33 at location 5.

One of the welders reported no problems except that the angle of the welding gun was restricted for welding in the

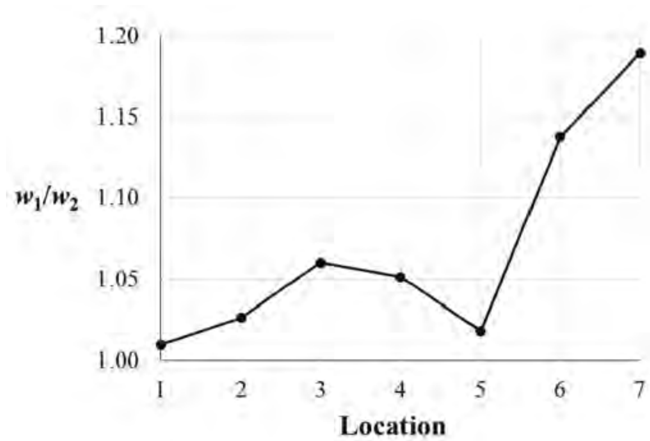


Fig. 10. Mean leg aspect ratio, w_1/w_2, *for each weld location.*

(a) (b) (c)

Fig. 11. Fillet weld specimens—position C: (a) location 5; (b) location 6; (c) location 7.

vertical position at location 7. This affected the weld leg ratio and the production efficiency. The welder for another fabricator noted that, for all three welding positions, weld quality and production efficiency was affected only for welds at locations 6 and 7. Although the production efficiency was perceived to be the primary issue, the welder also expressed concerns regarding the potential effects on the weld fusion and penetration.

Conclusions

The cross-sectioned welds showed that as the distance between the weld and the obstruction plate decreased, both the production efficiency and the penetration into the base metal parallel to the obstruction plate (at leg 2) decreased. Another issue at location 7, where the welds are 2 in. from the obstruction plate, is the limited access for measuring the weld size with a standard gage. Although the penetration at leg 2 was generally low at location 6, where the welds are 3 in. from the obstruction plate, the measured effective throats exceeded the nominal values. This is because the decrease in penetration was compensated by an increase in weld metal. In interviews, welders expressed concerns regarding the potential effects of the obstruction on the weld fusion and penetration at locations 6 and 7, which may have caused them to increase the weld metal deposited.

Recommendations

Suggested clearances for FCAW and GMAW fillet welds are shown in Figure 13. The minimum values correspond to clearances required to maintain the expected weld strength based on proper fusion and weld throat size. The recommended values provide enough clearance to ensure normal production efficiency. Two joint geometries are considered: case 1, where the welded element is parallel to the obstruction, and case 2, where the welded element is perpendicular to the obstruction.

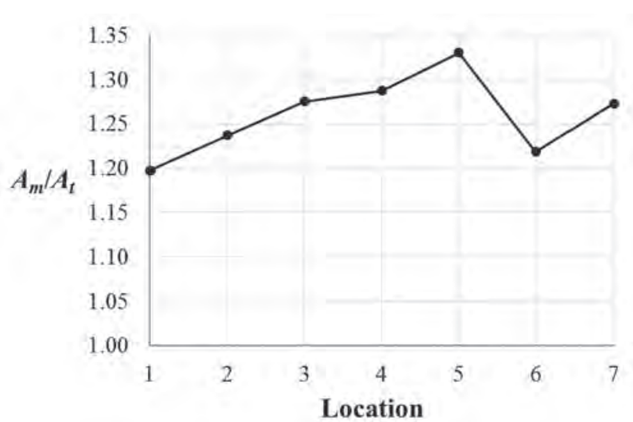
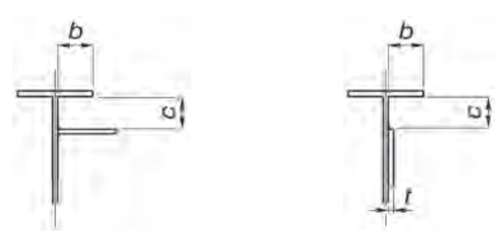


Fig. 12. Mean area ratio, A_m/A_t, for each weld location.

- Case 1: When welding near wide obstructions (large *b*-dimension), the welder's hand and the welding gun must fit into the opening while allowing enough room for proper electrode manipulation. For this geometry, the required clearance, c_{min}, is the minimum of $b/2$ and 4 in. This should be considered the absolute minimum clearance. As with the SMAW process, a 30° electrode angle is recommended for optimum production efficiency, resulting in the 0.6*b* clearance recommendation.
- Case 2: This configuration does not require the entire welding gun to fit within the clearance dimension, allowing less restrictive clearances. Due to the high heat input with the FCAW and GMAW processes and the increased access between the gas nozzle and the weld surface, c_{min} is dependent on the plate thickness, *t*. If these requirements cannot be met, the plate edge can be beveled as shown in Figure 5, with a fillet weld placed along the skewed edge. Some of the recommendations for case 2 are based on the results discussed in the section of this paper on doubler plate welds.

DOUBLER PLATE WELDS

Eight simulated doubler plate specimens were sectioned to evaluate the effect of various geometric parameters on the root-pass penetration for square-cut doubler plates. The specimen variables were the plate thicknesses and the distance from the inner surface of the flange to the edge of the plate.



(a)

Recommended:

$c_{min} = \min(0.6b, 5 \text{ in.})$

Minimum:

$c_{min} = \min(b/2, 4 \text{ in.})$

(b)

$t \le 5/16$ in.:

$c_{min} = 3/4$ in.

$5/16$ in. $< t \le 5/8$ in.:

$c_{min} = \min(b/2, 2 \text{ in.})$

$5/8$ in. $< t$:

Recommended:

$c_{min} = \min(b/2, 3\tfrac{1}{2} \text{ in.})$

Minimum:

$c_{min} = \min(b/2, 2\tfrac{1}{2} \text{ in.})$

Fig. 13. Recommended clearances for FCAW and GMAW fillet welds: (a) case 1; (b) case 2.

Procedure

Eight simulated doubler plate specimens were supplied by a single fabricator. As shown in Figure 14, drop material from a recent project was used for the W-shape, with extension tabs tack-welded to the flange tips to produce the dimensions of a W14×90 column. The specimens are 9 in. long. The root pass was welded in the horizontal position, which is the same as the flat position for the completed groove weld. The simulated doubler plate was square cut ($\alpha = 0°$) with the variable dimensions shown in Figure 15. The distance from the inner surface of the flange to the edge

(a)

(b)

Fig. 14. Doubler plate specimens: (a) ¾-in. specimen; (b) ¼-in. specimen.

of the plate, *x*, was either ⅝ in. or 1¼ in., and four different plate thicknesses were used: ¼, ⅜, ½ and ¾ in. Because the concerns are associated with proper fusion at the plate edge and penetration at the root pass, only the first pass was completed, and the remaining passes required to complete the joint were omitted.

Results

Representative samples of the etched sections are shown in Figures 16, 17, 18 and 19 for the specimens with ¼-, ⅜-, ½- and ¾-in. doubler plate thicknesses, respectively. As shown in Figure 16, all sections with a ¼-in. doubler plate showed good fusion and penetration into both the column and the plate. The heat input from welding melted the plate edge, creating adequate access for the welder to direct the arc toward the base metal.

The welding heat did not have the same effect on the thicker specimens. Many of the ⅜-, ½- and ¾-in. specimens had adequate fusion and significant penetration, as shown for the ⅜-in. doubler plate specimen shown in Figure 17(b)

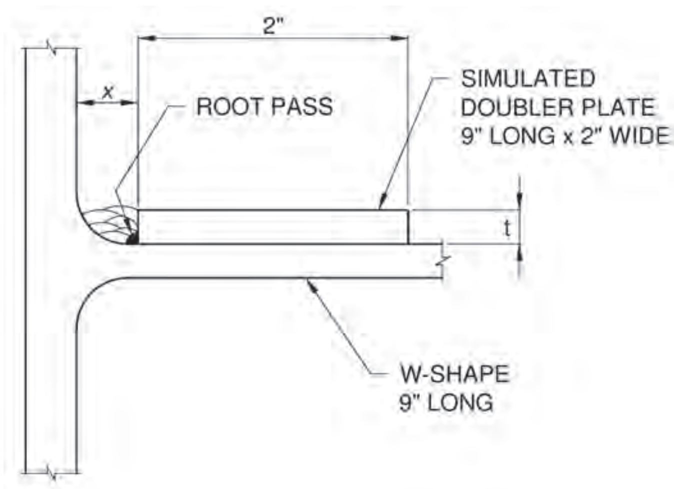


Fig. 15. Doubler plate specimen dimensions.

(a) (b)

Fig. 16. ¼-in. doubler plate specimen: (a) x = *1¼ in.; (b)* x = *⅝ in.*

and the ¾-in. doubler plate specimen shown in Figure 19(a). However, the specimens in Figures 17(c), 18(b), 19(b) and 19(c) had a lack of root penetration, and the specimens in Figures 18(c) and 19(b) had a low penetration depth at the doubler plate. Although these problems were more prevalent for the specimens with x = ⅝ in., they were also present for the specimens with x = 1¼ in.

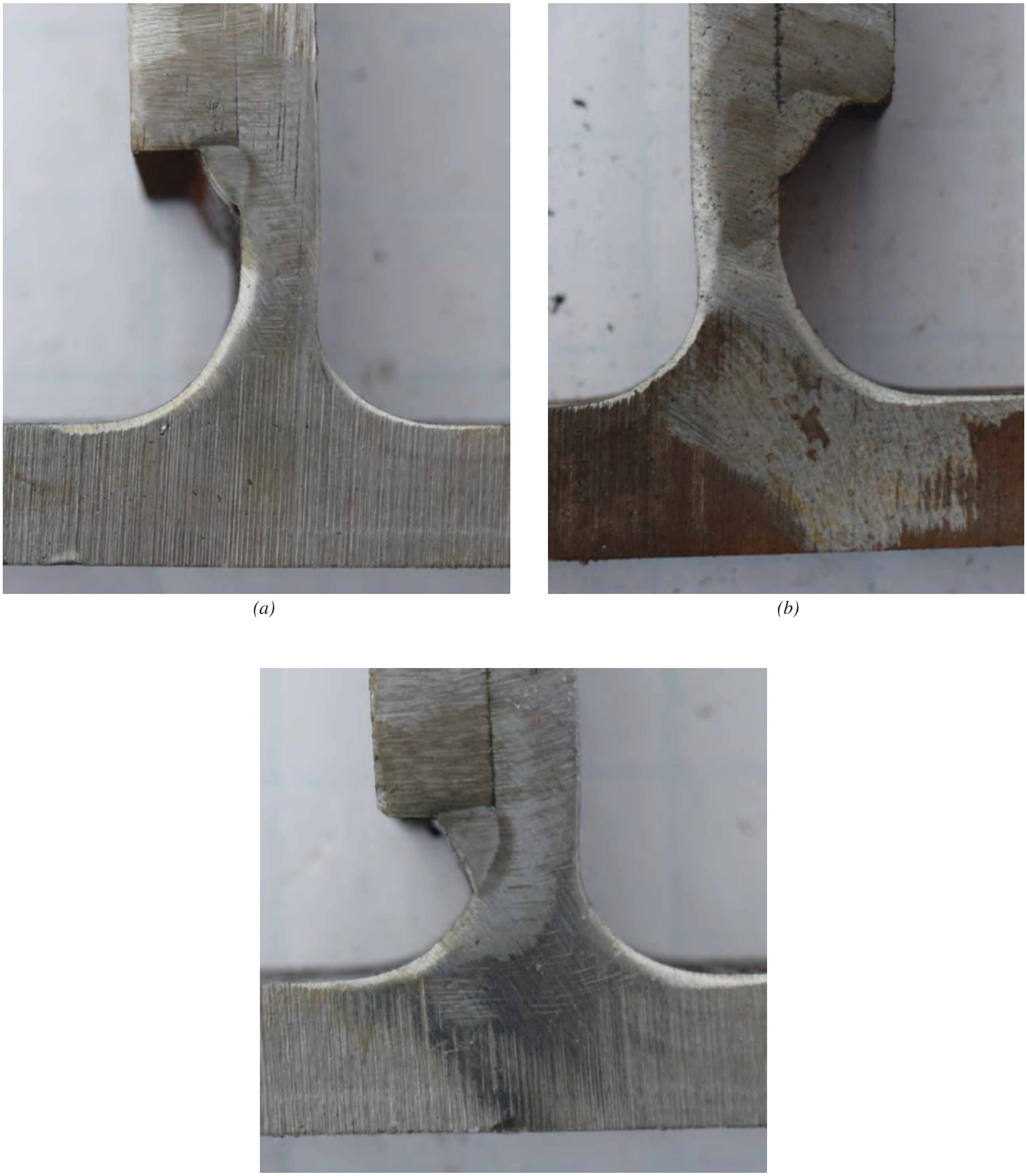
Conclusions

Adequate fusion and penetration can be consistently obtained for ¼-in. square-cut ($\alpha = 0°$) doubler plates welded with the FCAW process. However, portions of the weld at some of the thicker (⅜, ½ and ¾ in.) plates showed a lack of root penetration. Because proper electrode positioning is

(a)

(b) *(c)*

Fig. 17. ⅜-in. doubler plate specimens: (a) x *= 1¼ in.; (b)* x *= ⅝ in.; (c)* x *= ⅝ in.*



(a) (b) (c)

Fig. 18. ½-in. doubler plate specimens: (a) x = 1¼ in.; (b) x = 1¼ in.; (c) x = ⅝ in.

(a)

(b)

(c)

Fig. 19. ¾-in. doubler plate specimens: (a) x = *1¼ in.; (b)* x = *⅝ in.; (c)* x = *⅝ in.*

gained by melting the edge of the thinner plates, varying the root opening, R (Figure 5), had no observable effect on the weld quality.

Recommendations

Based on the results of this study, which was limited to only eight specimens, the common practice of cutting the edge square ($\alpha = 0°$) at doubler plates less than ⅜ in. thick has been validated. Because the root opening, R, had no observable effect on the weld quality, $R \leq 0$ is recommended for doubler plates less than ⅜ in. thick.

For doubler plates thicker than ¼ in., a beveled edge preparation with a groove angle, α, of 15° to 30° may be required to ensure consistent weld quality. Based on the results of the ¼-in. doubler plate specimens, it is expected that a ¼-in. root face could be used for these joints to reduce the weld metal while maintaining weld quality. It is believed that $R \leq 0$ will be acceptable for this condition.

CONCLUSIONS

Inadequate clearance can affect weld quality and efficiency. In extreme cases, obstructions may cause a lack of fusion between the base metal and the weld metal, causing a reduction in strength. Although FCAW and GMAW have replaced SMAW as the primary fabrication processes for structural steel fabrication, existing clearance recommendations are based on the SMAW process. Because the geometry of a FCAW or GMAW welding gun is much different from that of a SMAW "stick" electrode and because electrode manipulation techniques may be different between the processes, the historic values recommended for the SMAW process may not apply to FCAW and GMAW.

Experimental specimens were fabricated with the FCAW process to determine practical limits on connection geometry for welding joints with limited access. Each specimen was evaluated by sectioning and etching the weld at two locations along the length. Two weld clearance issues are addressed: (1) fillet welding near obstructions and (2) doubler plate welds.

The obstructed fillet weld specimens were used to determine clearance requirements for joints welded with the FCAW process. This part of the project studied clearance requirements by evaluating specimens that were welded at various distances from an obstruction plate. The cross-sectioned welds showed that as the distance between the weld and the obstruction plate decreased, both the production efficiency and the penetration into the base metal decreased. Revised clearance recommendations for FCAW and GMAW welding were proposed for two joint geometries: case 1, where the welded element is parallel to the obstruction, and case 2, where the welded element is perpendicular to the obstruction. These suggested clearances are shown in Figure 13.

The doubler plate specimens were used to evaluate the effect of various geometric parameters on the root-pass penetration for square-cut doubler plates. The specimen variables were the plate thicknesses and the distance from the inner surface of the flange to the edge of the plate. Based on the results of this study, which was limited to only eight specimens, the common practice of cutting the edge square ($\alpha = 0°$) at doubler plates less than ⅜ in. thick has been validated. Because the root opening, R, had no observable effect on the weld quality, $R \leq 0$ is recommended for doubler plates less than ⅜ in. thick. For doubler plates thicker than ¼ in., a groove angle, α, of 15° to 30° may be required to ensure consistent weld quality. It is expected that a ¼-in. root face could be used for these joints to reduce the weld metal while maintaining weld quality.

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530 South "C" Street
Pensacola, FL 32502

North Alabama Fabricating Company Inc.
4632 Richard Arrington Jr. Blvd. North
Birmingham, AL 35212

Structural Steel Services Inc.
6210 Saint Louis Street
Meridian, MS 39307

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APPENDIX A
WELDING PROCEDURE SPECIFICATIONS

Fabricator 1

AWS - Prequalified Welding Procedure Specification (pWPS)

Company name
Welding process FCAW
Process type Semi-automatic

Joint design used

Joint type TC - T or corner joint
Joint design Single bevel groove (4)
Backing Yes
Backing material Steel
Root opening (R)* (in.) 1/4, +1/16, -0 (+1/4, 1/16)
Root face (f)* (in.) n/a
Groove angle (a)* (deg.) 45, +10, -0 (+10, -5)
Radius (J - U)* (deg.) n/a
Back gouging No
Back gouging method n/a

* Datum: As Detailed (As Fit-Up)

Base metals

Spec., type or grade AWS D1.1 Table 3.1 Group II
Thickness: Groove (in.) T1:unlimited T2:unlimited
Fillet (in.) All
Diameter (Pipe) (in.) Unlimited

Filler metals

AWS Specification 5.20
AWS Classification E71T-1C-H8

Shielding

Flux -
Electrode-flux (class) -
Gas composition CO_2 (A5.32 SG-C)
Gas flow rate (cfh) 25-45
Gas cup size (in.) 1/2-3/4

Identification #
Originated by
Date
Authorized by
Date

Position

Welding position: Groove All
Fillet All
Vertical progression Up

Electrical characteristics

Transfer mode (GMAW) Spray
Current type DCEP
Other Constant Voltage (CV) power supply

Technique

Stringer or weave bead Stringer or Weave
Multi/single pass (per side) Single or Multiple
Number of electrodes Single electrode
Spacing: Longitudinal (in.) -
Lateral (in.) -
Angle (deg.) -
Contact tube to work (in.) 0.5 - 1
Peening Not permitted
Interpass cleaning Brushing or grinding

Preheat

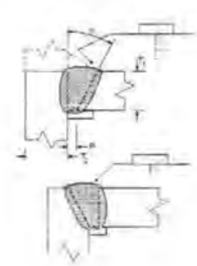
Preheat temp.: Min. (°F) See notes
Interpass temp.: Min. (°F) See notes
Max. (°F) See notes

Post weld heat treatment

Temperature (°F) None
Time (hrs) -

Welding procedure

Layer	Pass	Process	Filler metal class	Filler metal diameter (in.)	Current type / polarity	Amps	Wire feed speed (in./min)	Volts	Travel speed (in./min)	Joint details
1	All	FCAW	E71T-1C-H8	0.045	DCEP	150-290	200-500	24-29	6-15	
1	All	FCAW	E71T-1C-H8	0.052	DCEP	165-300	200-500	25-29	6-15	



Notes

Designation TC-U4a-GF

PREHEAT/INTERPASS
For thickness 1/8 to 3/4(in.): 32(°F). Preheat to 70(°F) if the base metal temperature is below 32(°F).
Over 3/4 thru 1-1/2(in.): 150(°F).
Over 1-1/2 thru 2-1/2(in.): 225(°F).
Over 2-1/2(in.): 300(°F).
See additional information page for further limitations

Signature 1
Name
Date

Signature 2
Name Signature
Date

Signature 3
Name Signature
Date

Signature 4
Name Signature
Date

Fabricator 2

Welding Procedure Specification

FCAW-1F

WPS No. FCAW-1F Revision 10 Date 9/12/14 By

Authorized By Date 10/20/1998 Prequalified ☒

Welding Process(es) FCAW Type: Manual ☐ Machine ☐ Semi-Auto ☒ Auto ☐

Supporting PQR(s) N/A

JOINT

Type T-Joint

Backing Yes ☐ No ☒ Single Weld ☒ Double Weld ☒

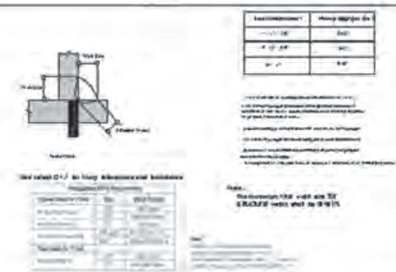
Backing Material N/A

Root Opening See Note 5 Root Face Dimension N/A

Groove Angle 90 Radius (J-U) N/A

Back Gouge Yes ☐ No ☒

Method N/A



BASE METALS

Material Spec. AWS Grp I or II to AWS Grp I or II

Type or Grade AWS Grp I or II to AWS Grp I or II

Thickness: Groove ( ) -

Fillet ( )Unlimited - Unlimited

Diameter (Pipe,) 1" - Unlimited

POSITION

Position of Groove Flat Fillet ALL

Vertical Progression: ☒ Up ☐ Down

ELECTRICAL CHARACTERISTICS

Transfer Mode (GMAW):

Short-Circuiting ☐ Globular ☒ Spray ☐

Current: AC ☐ DCEP ☒ DCEN ☐ Pulsed ☐

Other Constant Voltage

Tungsten Electrode (GTAW):

Size N/A Type N/A

FILLER METALS

AWS Specification A5.20

AWS Classification E71-T1or E71-T5

SHIELDING

Flux N/A

Gas CO2

Composition 100%

Electrode-Flux (Class) N/A

Flow Rate 35-45 CFH

Gas Cup Size 1/2 to 3/4 in.

TECHNIQUE

Stringer or Weave Bead Both

Multi-pass or Single Pass (per side) Both

Number of Electrodes 1

Electrode Spacing: Longitudinal N/A

Lateral N/A

Angle N/A

Contact Tube to Work Distance 1/2 to 3/4

Peening Not Allowed

Interpass Cleaning Brushing or Grinding

PREHEAT

Preheat Temp., Min. See Note 2

Thickness	Temperature
Up to 3/4"	32
Over 3/4" to 1-1/2"	50
Over 1-1/2" to 2-1/2"	150
Over 2-1/2"	225

Interpass Temp., Min. See Note 3 Max. 400

POSTWELD HEAT TREATMENT PWHT Required ☐

Temp. N/A Time N/A

WELDING PROCEDURE

Layer/Pass	Process	Filler Metal Class	Diameter	Cur. Type	Amps or WFS	Volts	Travel Speed	Other Notes
1 - OUT	FCAW	E71-T1orE71-T5	.045	DCEP	165 - 270	24 - 32	15 - 21 ipm	
1 - OUT	FCAW	E71-T1orE71-T5	.052	DCEP	220 - 405	25 - 35	20 - 30 ipm	
1 - OUT	FCAW	E71-T1orE71-T5	1/16 in	DCEP	300 - 500	28 - 36	20 - 30 ipm	

Fabricator 3

AWS D1.1 Prequalified Welding Procedure Specification (WPS)

WPS No. **TFillet** Date **5/18/2015** Rev. No. **0** Page 1 of 2

Prepared By: Date 5/18/2015

Welding Process(es)/Type(s) **FCAW/Semiautomatic**

Joint Design Used
Weld Type Fillet welds
Fillet Type T-joint
Double Welded No
Backing Yes Material Base Metal
Root Opening 3/16 in. Root Face N/A
Groove Angle N/A Radius N/A
Back Gouging No Method N/A

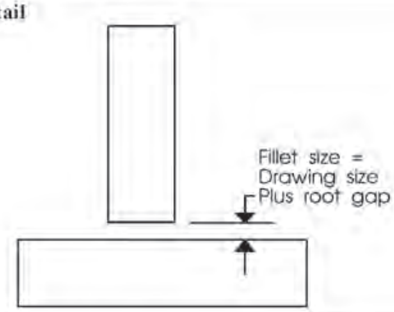
Base Metals
Base Metal ASTM A 572, Grade 50
Thickness: Groove N/A
Thickness: Fillet 1/8 in. min.
Pipe Diameter 3/8 in. min.
Groups I & II

Filler Metals
AWS Specification 5.20
AWS Classification E71T-1
Weld Size 5/16 in.

Shielding
Gas 100% CO2 Flow Rate 32-60 CFH
Gas Cup Size 5/8-3/4
Electrode-Flux (Class) N/A
Flux Trade Name N/A

Preheat
Preheat Temperature, Min. 32°F
Interpass Temperature, Min. 32°F Max. 500°F
Minimum Preheat and Interpass Temperatures for given thickness:
1/8" thru 3/4" incl.: 32°F (70°F if less than 32°F)
Over 3/4" thru 1-1/2" incl.: 50°F
Over 1-1/2" thru 2-1/2" incl.: 150°F
Over 2-1/2": 225°F

Joint Detail



Position
Weld Position: Fillet All Positions
Weld Position: Groove N/A
Vertical Progression Vertical up
5/16

Electrical Characteristics
Power Source
Output Constant Voltage
Current / Polarity DCEP (reverse)
Transfer Mode Globular arc
Tungsten Electrode: Type N/A
Tungsten Electrode: Size N/A

Technique
Stringer or Weave Bead Stringer or weave bead
Multi/Single Pass Single or multipass
Number of Electrodes 1
Electrode Spacing: Longitudinal N/A
Lateral N/A Angle N/A
Contact Tube to Work Distance 3/8 to 3/4
Peening Not allowed.
Interpass Cleaning Chipping hammer, wire brush and grind as needed.

Postweld Heat Treatment
Temperature None
Time (hr.) None

Welding Procedure

Pass or Weld Layer(s)	Process	Filler Metal AWS Classification	Filler Metal Size (in.)	Current Type & Polarity	Current Amps	Volts	Travel Speed (in/min)
ALL	FCAW	E71T-1	0.052	DCEP (reverse)	220 - 270	26-30	12 - 20
ALL	FCAW	E71T-1	0.045	DCEP (reverse)	200 - 240	25-28	9 - 15

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APPENDIX B
WELDING NEAR OBSTRUCTIONS MEASURED WELD DIMENSIONS

Table B-1. Measured Specimen Dimensions

Specimen	w_1	w_2	E	w_1/w_2	A_m	A_m/A_t
1A1-1	0.33	0.31	0.23	1.06	0.051	1.64
1A1-2	0.30	0.31	0.25	0.97	0.047	1.49
1A1-3	0.29	0.28	0.21	1.04	0.041	1.30
1A1-4	0.25	0.23	0.19	1.09	0.029	0.92
1A1-5	0.24	0.27	0.21	0.89	0.032	1.04
1A1-6	0.26	0.24	0.20	1.08	0.031	1.00
1A1-7	0.29	0.24	0.20	1.21	0.035	1.11
1A2-1	0.26	0.27	0.21	0.96	0.035	1.12
1A2-2	0.26	0.31	0.22	0.84	0.040	1.29
1A2-3	0.28	0.24	0.20	1.17	0.034	1.08
1A2-4	0.29	0.30	0.23	0.97	0.044	1.39
1A2-5	0.28	0.26	0.22	1.08	0.036	1.16
1A2-6	0.27	0.24	0.20	1.13	0.032	1.04
1A2-7	0.30	0.28	0.25	1.07	0.042	1.34
1B1-1	0.20	0.26	0.19	0.77	0.026	0.83
1B1-2	0.20	0.30	0.20	0.67	0.030	0.96
1B1-3	0.28	0.27	0.20	1.04	0.038	1.21
1B1-4	0.24	0.26	0.20	0.92	0.031	1.00
1B1-5	0.24	0.30	0.20	0.80	0.036	1.15
1B1-6	0.26	0.29	0.21	0.90	0.038	1.21
1B1-7	0.27	0.25	0.21	1.08	0.034	1.08
1B2-1	0.21	0.24	0.19	0.88	0.025	0.81
1B2-2	0.21	0.26	0.21	0.81	0.027	0.87
1B2-3	0.24	0.25	0.17	0.96	0.030	0.96
1B2-4	0.27	0.24	0.18	1.13	0.032	1.04
1B2-5	0.25	0.27	0.20	0.93	0.034	1.08
1B2-6	0.26	0.25	0.18	1.04	0.033	1.04
1B2-7	0.24	0.22	0.18	1.09	0.026	0.84
1C1-1	0.26	0.29	0.21	0.90	0.038	1.21
1C1-2	0.25	0.23	0.21	1.09	0.029	0.92
1C1-3	0.27	0.24	0.21	1.13	0.032	1.04
1C1-4	0.24	0.28	0.22	0.86	0.034	1.08
1C1-5	0.27	0.23	0.21	1.17	0.031	0.99
1C1-6	0.23	0.25	0.23	0.92	0.029	0.92
1C1-7	0.26	0.22	0.21	1.18	0.029	0.92
1C2-1	0.20	0.23	0.19	0.87	0.023	0.74
1C2-2	0.22	0.25	0.19	0.88	0.028	0.88
1C2-3	0.24	0.21	0.19	1.14	0.025	0.81
1C2-4	0.21	0.23	0.20	0.91	0.024	0.77
1C2-5	0.27	0.28	0.22	0.96	0.038	1.21
1C2-6	0.25	0.25	0.22	1.00	0.031	1.00
1C2-7	0.25	0.21	0.19	1.19	0.026	0.84
2A1-1	0.29	0.28	0.20	1.04	0.041	1.30
2A1-2	0.27	0.30	0.22	0.90	0.041	1.30
2A1-3	0.27	0.30	0.21	0.90	0.041	1.30
2A1-4	0.29	0.32	0.21	0.91	0.046	1.48
2A1-5	0.29	0.32	0.21	0.91	0.046	1.48
2A1-6	0.25	0.29	0.19	0.86	0.036	1.16
2A1-7	0.29	0.25	0.21	1.16	0.036	1.16
2A2-1	0.25	0.27	0.18	0.93	0.034	1.08
2A2-2	0.24	0.27	0.20	0.89	0.032	1.04
2A2-3	0.28	0.30	0.20	0.93	0.042	1.34
2A2-4	0.27	0.30	0.20	0.90	0.041	1.30
2A2-5	0.26	0.29	0.20	0.90	0.038	1.21
2A2-6	0.28	0.30	0.21	0.93	0.042	1.34
2A2-7	0.27	0.24	0.18	1.13	0.032	1.04
2B1-1	0.28	0.28	0.22	1.00	0.039	1.25
2B1-2	0.33	0.28	0.21	1.18	0.046	1.48
2B1-3	0.34	0.31	0.23	1.10	0.053	1.69
2B1-4	0.38	0.26	0.21	1.46	0.049	1.58
2B1-5	0.34	0.28	0.23	1.21	0.048	1.52
2B1-6	0.34	0.23	0.20	1.48	0.039	1.25
2B1-7	0.33	0.29	0.23	1.14	0.048	1.53
2B2-1	0.28	0.27	0.21	1.04	0.038	1.21
2B2-2	0.31	0.25	0.22	1.24	0.039	1.24
2B2-3	0.34	0.27	0.23	1.26	0.046	1.47
2B2-4	0.38	0.27	0.22	1.41	0.051	1.64
2B2-5	0.32	0.26	0.21	1.23	0.042	1.33
2B2-6	0.35	0.21	0.19	1.67	0.037	1.18
2B2-7	0.34	0.28	0.23	1.21	0.048	1.52

Table B-1. Measured Specimen Dimensions (continued)

Specimen	w_1	w_2	E	w_1/w_2	A_m	A_m/A_t
2C1-1	0.24	0.32	0.22	0.75	0.038	1.23
2C1-2	0.25	0.26	0.23	0.96	0.033	1.04
2C1-3	0.25	0.26	0.23	0.96	0.033	1.04
2C1-4	0.25	0.26	0.23	0.96	0.033	1.04
2C1-5	0.31	0.30	0.26	1.03	0.047	1.49
2C1-6	0.30	0.23	0.20	1.30	0.035	1.10
2C1-7	0.40	0.26	0.24	1.54	0.052	1.66
2C2-1	0.40	0.24	0.22	1.67	0.048	1.54
2C2-2	0.30	0.25	0.22	1.20	0.038	1.20
2C2-3	0.27	0.28	0.23	0.96	0.038	1.21
2C2-4	0.27	0.28	0.21	0.96	0.038	1.21
2C2-5	0.26	0.28	0.22	0.93	0.036	1.16
2C2-6	0.26	0.24	0.23	1.08	0.031	1.00
2C2-7	0.23	0.30	0.25	0.77	0.035	1.10
3A1-1	0.28	0.26	0.22	1.08	0.036	1.16
3A1-2	0.36	0.25	0.21	1.44	0.045	1.44
3A1-3	0.34	0.28	0.24	1.21	0.048	1.52
3A1-4	0.32	0.28	0.22	1.14	0.045	1.43
3A1-5	0.36	0.30	0.23	1.20	0.054	1.73
3A1-6	0.35	0.28	0.22	1.25	0.049	1.57
3A1-7	0.39	0.23	0.22	1.70	0.045	1.44
3A2-1	0.24	0.27	0.21	0.89	0.032	1.04
3A2-2	0.34	0.26	0.22	1.31	0.044	1.41
3A2-3	0.35	0.29	0.25	1.21	0.051	1.62
3A2-4	0.31	0.25	0.23	1.24	0.039	1.24
3A2-5	0.38	0.29	0.23	1.31	0.055	1.76
3A2-6	0.35	0.22	0.21	1.59	0.039	1.23
3A2-7	0.39	0.24	0.23	1.63	0.047	1.50

Specimen	w_1	w_2	E	w_1/w_2	A_m	A_m/A_t
3B1-1	0.34	0.30	0.25	1.13	0.051	1.63
3B1-2	0.30	0.28	0.23	1.07	0.042	1.34
3B1-3	0.32	0.29	0.26	1.10	0.046	1.48
3B1-4	0.30	0.31	0.22	0.97	0.047	1.49
3B1-5	0.30	0.32	0.24	0.94	0.048	1.54
3B1-6	0.31	0.29	0.25	1.07	0.045	1.44
3B1-7	0.34	0.27	0.24	1.26	0.046	1.47
3B2-1	0.32	0.29	0.25	1.10	0.046	1.48
3B2-2	0.30	0.31	0.24	0.97	0.047	1.49
3B2-3	0.33	0.28	0.23	1.18	0.046	1.48
3B2-4	0.31	0.30	0.22	1.03	0.047	1.49
3B2-5	0.28	0.31	0.23	0.90	0.043	1.39
3B2-6	0.31	0.31	0.23	1.00	0.048	1.54
3B2-7	0.33	0.27	0.21	1.22	0.045	1.43
3C1-1	0.29	0.26	0.21	1.12	0.038	1.21
3C1-2	0.30	0.29	0.23	1.03	0.044	1.39
3C1-3	0.28	0.28	0.24	1.00	0.039	1.25
3C1-4	0.32	0.31	0.22	1.03	0.050	1.59
3C1-5	0.28	0.29	0.24	0.97	0.041	1.30
3C1-6	0.32	0.28	0.26	1.14	0.045	1.43
3C1-7	0.28	0.31	0.26	0.90	0.043	1.39
3C2-1	0.26	0.26	0.20	1.00	0.034	1.08
3C2-2	0.31	0.30	0.24	1.03	0.047	1.49
3C2-3	0.24	0.30	0.22	0.80	0.036	1.15
3C2-4	0.31	0.30	0.26	1.03	0.047	1.49
3C2-5	0.29	0.30	0.25	0.97	0.044	1.39
3C2-6	0.31	0.30	0.27	1.03	0.047	1.49
3C2-7	0.30	0.32	0.28	0.94	0.048	1.54

Orange-shaded cells indicate a weld that was rejected by the CWI.
Blue-shaded cells indicate that the measured dimension is less than the nominal dimension.
A_m = weld metal area calculated with the measured leg sizes, in.^{2}
A_t = weld metal area calculated with the nominal specified leg size, in.^{2}
E = effective throat, in.
w_1 = fillet weld leg size at the ¼- × 10-in. plate, in.
w_2 = fillet weld leg size at the ¼- × 2-in. plate, in.