FLARE GROOVE WELDS TO HSS CORNERS

by

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Introduction

Flare groove welds arise when a convex surface makes up the joint preparation in a partial joint penetration (PJP) groove weld. These welds occur when one or both components of a joint consist of a round bar or 90° bend in a formed section, for example a hollow structural section (HSS). The fabrication of HSS structures involves joints where flare bevel, and to a lesser extent, flare V-groove welds are common. The deposition of sound weld metal to the bottom of the flare is very difficult, because the welding puddle bridges between the two surfaces and then penetration into the root is inhibited. Hence, the extent of root penetration in flare groove welds is dependent on the angle between the fusion faces, and, therefore, the outside corner radius or profile of an HSS is a major parameter determining the geometry of the weld. With the quality of the weld being difficult to control, specifications in many cases require fabricators to demonstrate the effective weld throats being produced by sectioning random lengths of production welds for each weld procedure. By performing trial welds and sectioning, larger weld sizes can be justified relative to values given in specifications that provide prequalified PJPs, thereby allowing higher joint design loads. However, extra costs will be incurred in the fabrication stage.

The specifications listed below give the following design guidance for flare welds:

<u>AISC LRFD (1999)</u>

AISC establishes the effective throat when the weld is flush (tangent) to the surface of a bar or 90° bend in a formed section, as a ratio of radius to effective throat, as follows:

Type of Weld	Radius of Bar or Bend (R)	Effective Throat Thickness
Flare bevel groove	All	$^{5}/_{16}$R
Flare V-groove	All	$^{1}/_{2}$R [a]
[a] Use 3/8R for gas metal arc welding (except short-circuiting transfer process) when R ≥ 1 in. (25mm) Note: R = radius of bar.		

<u>AWS D1.1/D1.1M:2002</u>

Similar to AISC, AWS D1.1 provides the table below for effective throat size, E, of welds filled flush to the surface of round bar, a 90° bend in a formed section, or a rectangular tube.

Flare Bevel Groove Welds	Flare V-groove Welds
$^{5}/_{16}$R	$^{1}/_{2}$R *
* Use 3/8R for GMAW (except GMAW-S) process when R is ½ in. (12mm) or greater.	

CSA W59 (1989)

In Section 4.3.1.6, effective throats are prequalified for flare bevel and flare V-groove welds on solid bars, but not for HSS. For HSS, the effective throat thickness needs to be established by means of trial welds and sectioning. The prequalified effective throat thickness for welds on solid bars is similar to the AISC and AWS specifications, as follows:

Flare Bevel Groove Welds	Flare V-groove Welds
All Diameter Bars	
0.3R	$^{1}/_{2}$R *
Not applicable to GMAW using the short-circuiting transfer mode of metal deposition. * Except 0.4R for GMAW process with bar sizes 25mm (1 in.) and over.	

CSA W59 Draft (2001)

The 8th edition of CSA Standard W59 is to be published imminently. The section on flare welds has been completely rewritten and expanded significantly to cover flare bevel and flare V-groove welds in butt joints and flare bevel groove welds in T-joints with several configurations of both being taken as prequalified. The concept of a flare bevel fillet weld is also introduced for the first time.

In the new W59, for T-joints with square/rectangular HSS members having radii > 3/8", a prequalified flare bevel groove weld need not be filled flush to the tangent to the curve of the flare that is perpendicular to the planar surface. A designer will now have the option of a weld within the flare, flush with it or extended beyond it by means of a fillet. For design purposes, the effective throat shall be indicated by specifying a weld face, W = d (given in the specification) x E.

For flare bevel groove welds in T-joints using round bars, tubing or HSS members, when filled flush, the effective throats are given by W59 (2001) as:

Flare Bevel Groove Welds	Flare V-groove Welds
0.3R	0.5R *
Not applicable to GMAW using the short-circuiting transfer mode of metal deposition. * Except 0.375R for GMAW process with R ≥ ½ in. Note: R = radius of round bar, tubing, or measured corner radius of HSS member.	

Experimental Work

A research project has been performed to examine flare groove weld geometries more closely and establish the relationship to three prime variables: HSS wall thickness/corner shape, weld process and welding position. The aim was to quantify the weld effective throat size by joint variables for specific welding situations, thereby possibly allowing prequalified joints with larger effective throats.

The three HSS sizes for the study had wall thicknesses ranging from 3/16” to 3/8”, representing a range of possible corner profiles. Tubing, from two Canadian producers, was cold-formed, square HSS to ASTM A500 Grade C (ASTM, 2001). Four weld processes (FCAW-G (with shielding gas), FCAW-S (without shielding gas), GMAW and SMAW) were used to make the test welds, using just single pass welds. These processes are the predominant processes used in the welding of such joints by fabrication shops. Welding Procedure Specifications (WPSs) associated with each particular process were prescribed to reflect prevalent shop practices and were the result of considerable consultation amongst the project Oversight Committee. The final WPSs were targeted to be “somewhat below the median” (i.e., conservative) for a typical fabrication shop. Each HSS size was used to produce flare bevel and flare V-groove welded specimens made by four different weld processes and four different welding positions (horizontal (H), flat (F), vertical, up or down (V) and overhead (OH)).

Final welding of the HSS-to-HSS-to-plate assemblies was carried out by Walters Inc., a high-performance fabricator certified to CSA W47.1-92 (CSA, 1992). All welds were made by a certified welder and visually inspected by a certified inspector. Prior to depositing a particular test weld, trial welds to verify the welding parameters were made. The complete documentation for each test weld is available in 72 Procedure Qualification Records (PQRs), which are a part of the Final Report on this project (Packer and Frater, 2003). As an aid to collecting welding parameters, a computerized data acquisition system was supplied by the welding engineer. Figure 1 shows the welding of a particular specimen in the overhead position.

Figure 1: Overhead welding of test specimen at Walters Inc.

After welding of the test specimens, each was saw-cut by Walters Inc., resulting in a total of 180 weld cross-sections for measurement, all of which were then ground, polished and macro-etched. Next, digital images of each test weld were created, such as shown in Figure 2, then measurements of weld profile dimensions and angles from 180 photographic scanned images were made.

Figure 2: Digital image of a flare bevel weld

Experimental Results and Conclusions

HSS wall thickness T, outside corner radius R, Bend (the arc angle over which the outside corner radius extends) and R/T ratio for the three HSS sections used in the test program are given in the table below. The measured wall thickness, T, in all cases exceeded the 0.93T "design thickness" prescribed by AISC (1997) for ASTM A500 HSS (ASTM, 2001). The corner or bend angle averaged 72.7°, which is considerably less than the popularly-assumed corner radius of 90°. Thus, the corner radius in modern HSS does not meet the flat of the section at a tangent. The corner radius-to-thickness ratio shown in the table varies considerably, but the HSS 4x4x$^3/_{16}$ was produced by one company whereas the other two were produced by another.

HSS Size (in.)		4 x 4 x $^3/_{16}$	4 x 4 x $^1/_4$	6 x 6 x $^3/_8$
Thickness – T	Average (in.)	0.183	0.241	0.372
Radius – R	Average (in.)	0.445	0.466	0.716
Bend (HSS corner)	Average (deg.)	76.2	72.3	69.5
$T/T_{nominal}$		0.976T	0.964T	0.992T
R/T		2.43	1.93	1.92

An analysis of the resulting weld geometric data has shown that the currently specified effective throat sizes, in AWS D1.1/D1.1M:2002 for example, can be made more liberal for most welding processes. Details of the data and its analysis can be obtained elsewhere (Packer and Frater, 2003), but the following prequalified sizes, after inclusion of a suitable safety margin, were recommended, for flat, horizontal, vertical up and overhead welding positions.

• **For flare bevel groove welds,** the following effective throat sizes (E) can be justified, in terms of the HSS outside corner radius (R), depending on the welding process:

$$E = 0.64R - Df \quad \text{for GMAW and FCAW-G} \quad \text{........ (1)}$$

or

$$E = 0.31R - Df \quad \text{for SMAW and FCAW-S} \quad \text{........ (2)}$$

Df is shown on Figure 3. This is the distance that the weld face is set back from the "filled flush line" and must be measured with an appropriate weld gauge. One could conservatively take the largest Df distance measured if the weld was inclined. If the weld is "filled flush" to the face of the HSS, then Df = 0.

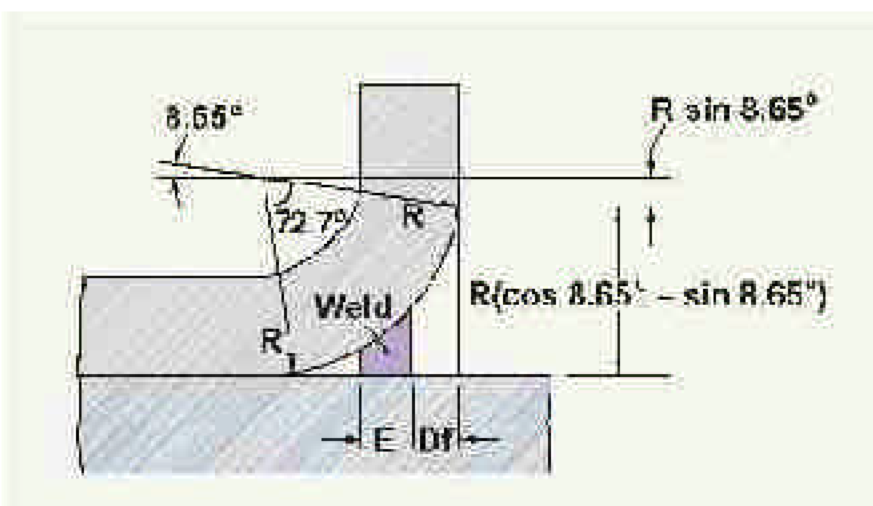

Figure 3: Geometry of partially filled flare bevel welds

• **For flare V-groove welds,** the following effective throat sizes (E) can be justified, in terms of the HSS outside corner radius (R), depending on the welding process:

$$E = 0.73R - Df \quad \text{for GMAW and FCAW-G} \qquad \ldots\ldots\ldots \; (3)$$
or
$$E = 0.61R - Df \quad \text{for SMAW and FCAW-S} \qquad \ldots\ldots\ldots \; (4)$$

Df is as defined above and is similar to Figure 3.

Equations (1) to (4) entail a knowledge of the square or rectangular HSS outside corner radius, R. For North American cold-formed HSS, R = 2T can be assumed. The tube wall thickness, T, can either be measured or have a "design value" assumed, of:

$0.93T_{nominal}$ for ASTM A500 HSS, as specified by AISC (1997), or
$1.00T_{nominal}$ for CAN/CSA-G40.20/G40.21 (CSA, 1998) HSS.

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