A Comparative Study of Induced Residual Stress during Welding of Plate-to-Plate T-jointed Metal Plates (ASTM A572)

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Abstract— Welding represents one of the most complex manufacturing processes in terms of number of variables involved and factors contributing to the final output but it is one of the most important operations of the manufacturing industry. The Objective of this paper is to study the values of residual stresses which were induced during the preparation of the test specimens. The residual stress which was induced during welding operation was measured by two distinguished processes, the incremental hole drilling method and in second method, a multichannel strain indicator device was used to measure residual stresses. Experimental residual stress measurement was performed by placing the strain gauge rosettes. The data received from these strain rosettes were processed by the H-DRILL software. This software directly converted the input strain values into the corresponding residual stress values, and then the strains values were feed into the MCSI device to collect the result.

Keywords: Mild Steel (ASTM A572 Grade 50 type 1), Residual Stress, FCAW, SAW, plate-to-plate T-joint, Weld design, H-DRILL, Multichannel strain indicator

I. INTRODUCTION

According to the American Welding Society (AWS), "A weld is a localized coalescence of metals or non-metals produced either by heating the materials to the welding temperature, with or without the application of pressure or by the application of pressure alone and with or without the use of filler material."

Welding is generally considered to be a highly effective and efficient means of connecting not only steel plates and sections but various materials together to fabricate a structure also. During fabrication of steel structures, residual stresses were induced in the welded structures and these stresses are always present in the welding sections due to non-uniform temperature distributions followed by different cooling rates in various parts of the steel sections[10].

For decades, common structural steel and tubular materials have been extensively used in the fabrication of high-rise steel buildings, heavy duty bridges and heavily loaded structures in order to exploit their excellent and consistent mechanical properties[6].As a widely used manufacturing operation, welding offers a number of technical defiances to the community which is directly associated with welding, i.e. specially shop floor engineers engaged in manufacturing of structures integrated through welding. During the joining of components of a structure together by welding, the highly localized thermal gradients from welding result in high magnitude residual stresses of the order of yield strength of the material within and around the weld region, along with significant deformation/distortion of the structures to be welded. Both weld residual stress and distortion can significantly impair the performance and reliability of the welded joints as well as the welded structures[4].Therefore, they must be critically dealt with during design and manufacturing phases, to ensure intended in-service use of the welded structures.

The residual stresses can be induced in a component as a result of,

- Non-uniform plastic deformation during various manufacturing processes, such as rolling, forming etc.
- Non-uniform plastic deformation during cooling and heating operations.
- During cooling procedure, uncontrolled cooling of component from elevated temperatures results in phase transformations.
- Non-compatibility of the selected procedure with the material.

II. OBJECTIVE AND SCOPE

The scope of this research work is confined to T-joint welded structures and bridges. In order to exploit full structural benefits offered by the structural steel material, it is very crucial to examine comprehensively and properly quantify all the possible effects on these steel materials after completion of the welding processes. This investigation helps in determining the effects of different clamping conditions on residual stress formation/distortion patterns.

This research is consisting the investigations of weld induced residual stress fields and distortion patterns, the influence of various process and geometric parameters on weld induced residual stresses, effects of tack weld orientation and welding process sequence.

Various aspects and subtasks during the research are defined as:

A. Task A: Experimental Investigation

1) Task A_1

Medium Manganese Low Alloy Steel plates confirming to the standard ASTM A572[5] Grade 50 Type 1 were used to fabricate four welded Sections in T-Joint of three different thicknesses.

2) Task A_2

During the welding phase, surface temperatures of these four test specimens were measured at specific locations near to the junctions of flange and web by deploying thermocouples.

3) Task A_3

After welding phase, surface residual stresses were measured with the hole-drilling method according as per the guidelines described in the standard ASTM E837[1].

B. Task B: Numerical Investigation

1) Task B_1

Full scale shop floor experiments with proper instrumentation and data acquisition to find residual stress using the hole drilling method and the reading of the strain gauge rosettes were processed by using H-DRILL ver.2 software.

2) *Task B_2*

Investigation of the corresponding effects of various geometric and welding process parameters on weld induced residual stresses. The geometric parameter includes plate thickness whereas the welding process parameters include the variation of heat input by varying the welding speed and by manipulating the welding process parameters.

3) *Task B_3*

Comparison was carried out between the measured and predicted values of residual stresses present on the surfaces of these four T-sections. In the present research, major areas of interest were:

– Effect on temperatures as-well-as residual stresses in vicinity of flange/web junctions due to metal thickness variations, and
– Representation of residual stress pattern for the welded sections.

III. MATERIAL

The American Iron and Steel Institute (AISI) defines carbon steel as, “Steel is considered as carbon steel when no minimum content is specified or required for chromium, cobalt, nickel, titanium or any other element to be added to obtain a desired alloying effect.”

Basically, steel is an alloy of iron (Fe) and Carbon (C) and some other elements to get the desired mechanical and chemical properties in it. Carbon steels generally contains up to 2.14% total alloying elements and can be classified according to their carbon content, as:-

1) Low Carbon Steels,
2) Medium Carbon Steels,
3) High Carbon Steels, and
4) Ultra High Carbon Steels.

This research is carried out on low carbon medium manganese low alloy mild steel as it is most used steel in structural and heavy fabrication industry and other area. We have chosen mild steel as per the acceptance criteria defined in ASTM A572[5] Gr 50 Type 1for this objective. The alloying specifications of this steel are given in the table 3.1

	C	Mn	S	P	Si	C_{EQ}
Value (%)	0.23	1.50	0.045	0.045	0.40	0.42

Table 3.1: Chemical composition of ASTM A572 material

The yield strength of ASTM A572 Grade 50 Type 1 mild steel is 345 N/mm^2; i.e. It is called S345 material. In order to obtain the actual data of physical properties of S345 material, a total nine samples of different thickness (6mm, 10mm and 16mm) were prepared and tensile tests were carried out as per the guidelines described in the standard EN ISO 6892-1 on a universal testing machine as shown in fig3.1.

The stress-strain curves are computed and plotted by the plotting unit of UTM. These curves are illustrated in Fig3.5 and mechanical properties of the steel plates and welding electrodes are summarized in table3.2. EN ISO 1993-1-12[7,8,9] specifies the following ductility criteria for steel materials with various steel grade.

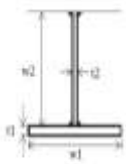
Fig. 3.1: FIE make Universal Testing Machine (Model UTE 40)

Four test specimens, namely C1 to C4 were prepared from the steel plates by cutting and welding two plates together. Summary of the mechanical properties of steel plates and welding electrodes using for the experimental investigation is shown in table3.2 and the details of various cross-sectional dimensions of these sections are shown in fig3.4.

Item Name	Young's Modulus (kN/mm^2)	Yield Strength (f_y) (N/mm^2)	Tensile Strength (f_u) (N/mm^2)	f_u/f_y	Electrode Wire Diameter
6 mm Thick Plate	210.8	418.3	437.6	1.05	-
10 mm Thick Plate	215.3	415.9	440.8	1.06	-
16 mm Thick Plate	209.5	421.2	450.7	1.07	-
E71T-1C (FCAW Wire)	-	390.5	449.1	1.15	1.6 mm
EM12K (SAW Wire)	-	395.1	450.4	1.14	2.0 mm

Table 3.2: Mechanical Properties of S345 Steel Plates& electrodes

The details of each specimen is given in the table 3.3



Section	Plate 1 Thickness t1	Plate 2 Thickness t2	Plate 1 Width w1	Plate 2 Width w2	Length L	Welding Method
C1	5.83	9.93	119.5	119.6	899.0	FCAW
C2	5.83	9.94	149.5	149.5	1000.5	FCAW
C3	9.93	15.98	200.2	199.7	1250.0	SAW
C4	9.93	15.91	251.5	250.6	1450.5	SAW

Table 3.3: Dimensions of the various specimens

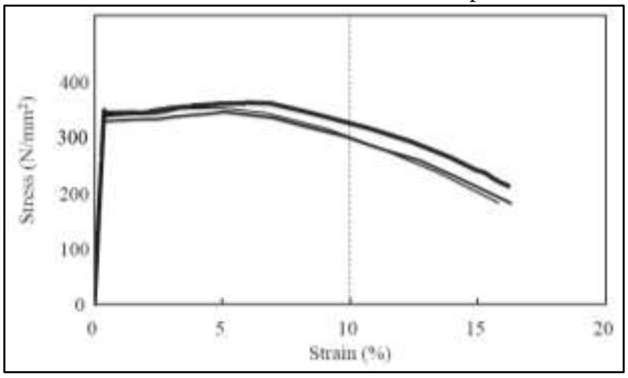


Fig. 3.2: Calculated stress strain curves of S345 steel plates

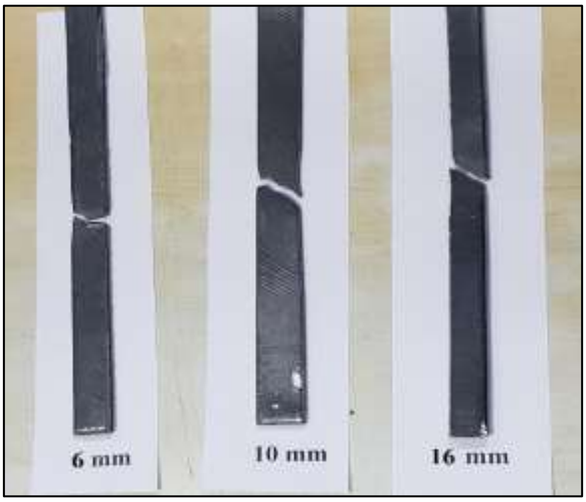


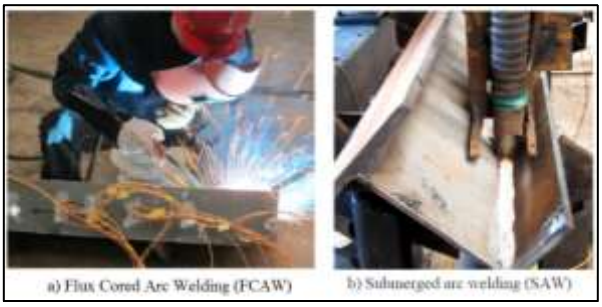
Fig. 3.3: Image of fractured test strips of various thickness

The result of tensile testing of all strips is shown collectively in the Fig3.2.and the fractured test strips are shown in the Fig3.3Theresults shown that all the steel plates meets the ductility criteria and thus, these steel plates are readily qualified to be high strength steel materials as per the specifications described in the standard EN 1993-1-1 and 12[8].

IV. Welding and Joint Selection

The two different welding processes, i.e. Flux cored arc welding (FCAW) & Submerged arc welding (SAW) processes which were adopted in fabrication of test specimens are shown in Fig4.1(a) and Fig4.1(b) respectively. Flux cored arc welding (FCAW) is performed manually while submerged arc welding (SAW) is carried out on the semi-automatic welding station. In welding of each specimen, two fillet weld runs, i.e. one weld run per side was carried out by the qualified welders and a preheating temperature between 120°C to 150°C was adopted and maintained to avoid weld imperfections and cold hydrogen cracking[2].

FCAW operation was conducted manually by qualified welders while SAW process was conducted with an semi-automatic machine operated by qualified welding operators.



a) Flux Cored Arc Welding (FCAW) b) Submerged arc welding (SAW)

The welding electrodes were in the form of wires. The welding electrodes E71T-1C and EM12K were employed for FCAW and SAW respectively accordance to AWS A5.36[4] and AWS A5.17[3]. Detailed welding parameters of the two processes are presented in Table3.4.

The T welding joint was selected for the test. It is one of the easy to perform and most used type of joint in welding which is found its application in many fields. This joint is subjected to both compression and tension along with bending. Two fillet weld runs were carried out for fabrication of test specimens in controlled conditions. Welding operation was carried out by qualified welders and welding machine operators.

Sections	Pre Heating Temp (°C)	Welding Method	Welding Parameters			Welding Efficiency (η)
			Current (A)	Voltage (V)	Speed (mm/s)	
C1	120 - 150	FCAW	236	29.0	5.0	0.85
C2	120 - 150	FCAW	270	30.5	6.3	0.85
C3	120 - 150	SAW	450	34.0	5.4	0.95
C4	120 - 150	SAW	450	36.0	5.6	0.95

Table 3.4: Welding parameters

V. Experimental Setup

First, the incremental hole drilling method is used to measure residual stresses.The hole drilling method is a semi destructive method for measuring residual stress induced by the welding process. In this method, a small hole is drilled into the test specimen through the center of a strain gauge rosette shown in fig5.1 by the RS200 milling guide.

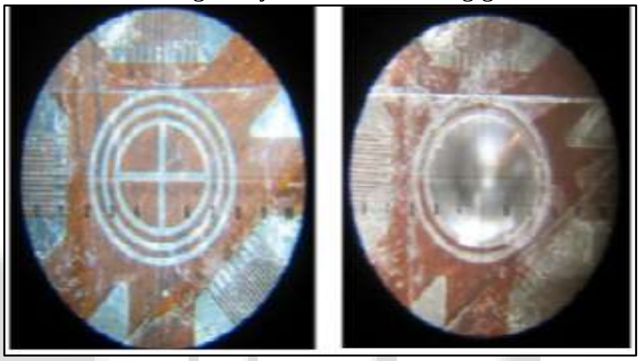


Fig. 5.1: Rosette before and after hole drilling

The RS200 milling guide was used in this experimental investigation. This sophisticated machine is used for measuring the residual stress in the specimens. this is a high- precision instrument which perform the analysis of residual stress by the hole-drilling method. Image of RS200 mounted on the test specimen is shown in the fig5.2

Fig. 5.2: RS200 milling machine

Each of four specimen was obtained from the steel plates which are qualified as per the acceptance criteria of ASTM A572[5] grade 50. Both child plates P1 and P2 were welded by FCAW and SAW welding procedures by the qualified welders. Total six strain gauge rosettes were attached along with three grids on the plate P1 as shown in fig5.3 and The fitment details of the rosettes was described in the table5.1

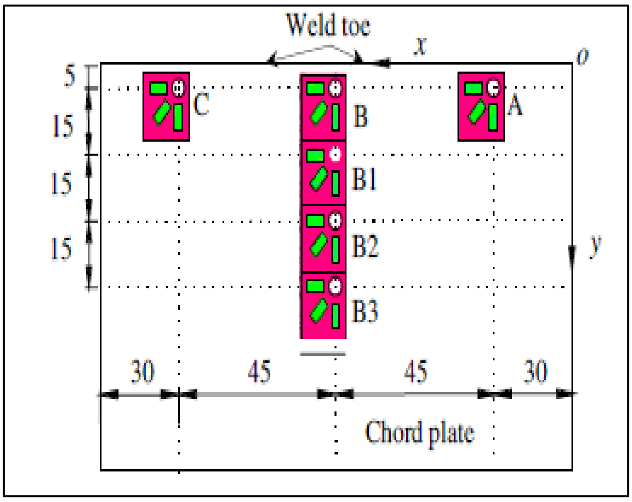


Fig. 5.3: Position of the installed rosettes on the plate

Strain Gauge	Dimensions	
	X direction	Y Direction
A	30	5
B	75	5
B1	75	20
B2	75	35
B3	75	50
C	120	5

Table 5.1: Position of the installed rosettes on the plate

This activity was performed on all the four test specimens. To illustrate the fitment of the strain gauge rosettes on the plate P1 on the upper surface of the plate P1, orthogonal view of the test sample was shown in the fig5.4

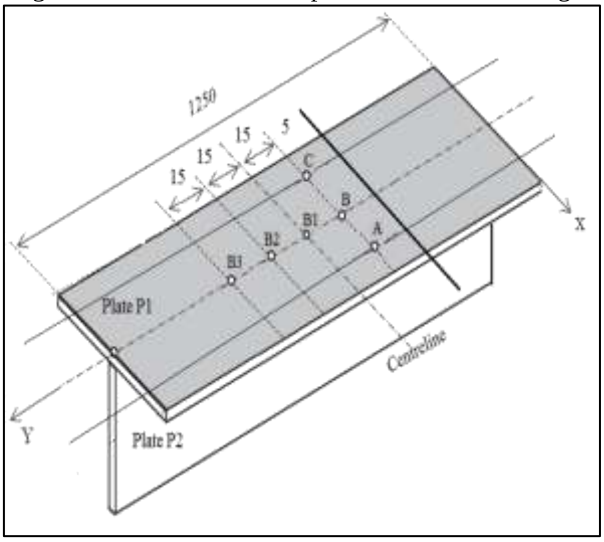


Fig. 5.4: Position of the installed rosettes on the plate

The values of corresponding strains were recorded during the drilling operation for the different measuring points. A software H-DRILL version 2.2 was used to convert the values the recorded strain from strain gauge rosette into residual stresses according to the principles defined in the standard ASTM E837-13a[1]. This software directly converted the strain values to the corresponding residual stress values. The final and processed data by the H-DRILL software is shown in the fig5.5

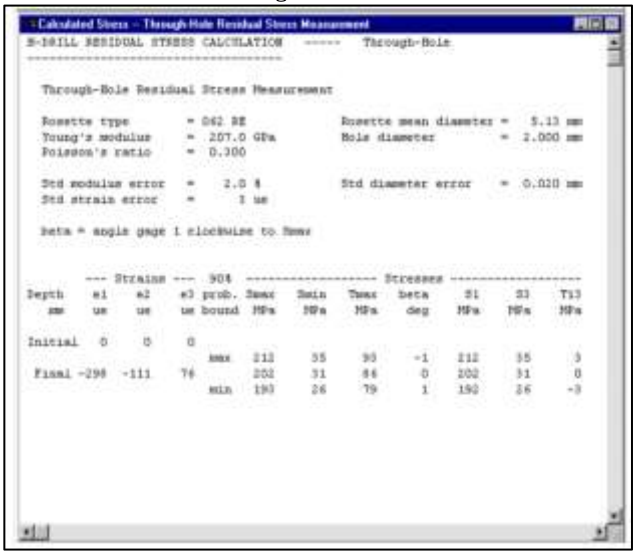


Fig. 5.5: Residual Stress displayed in numeric form

Then, values of strains recorded during the drilling procedure for the different measuring points. Input data received directly from the rosettes and complied by microprocessor. After compilation of input data, results are displayed on output display. These strain values directly processed by Multi Channel Strain Indicator device and result is shown on output Screen.

The results related to the distribution of residual stress along the weld toe, the effects of, plate thickness and brace plate cutting are presented in the table4.7

Stress at Points (MPa)	C1	C2	C3	C4
A	0	0	0	0
B	110	113	85	121
B1	65	67	68	81
B2	67	63	17	28
B3	32.8	36.5	34	18
C	0	0	0	0

Table 4.7: Results obtained from MCSI

VI. Result

Values of strains were recorded by the strain gauge rosettes during hole drilling at various points and data was provided to the H-DRILL software which converts these strain values into the corresponding values of induced residual stresses. Cross sectional distribution of measured residual stresses obtained from the H-DRILL software is illustrated in the fig6.1 and 3D plots of residual stresses in welded specimens are shown in the fig6.2 while graphical representation of data provided by MCSI is shown in fig 6.3

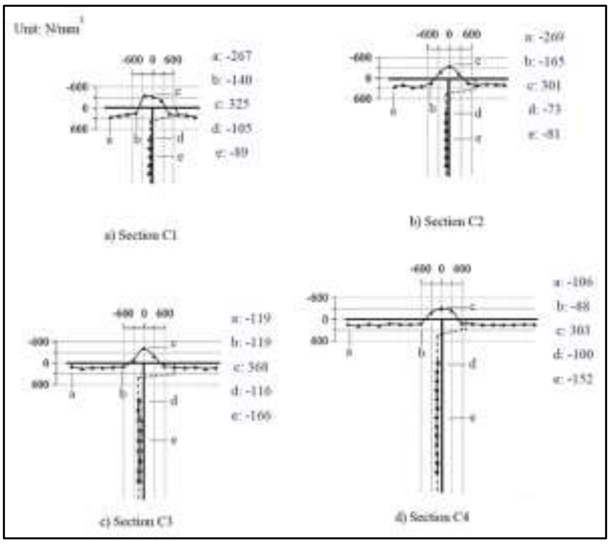


Fig. 6.1: Distribution of the residual stresses at various points

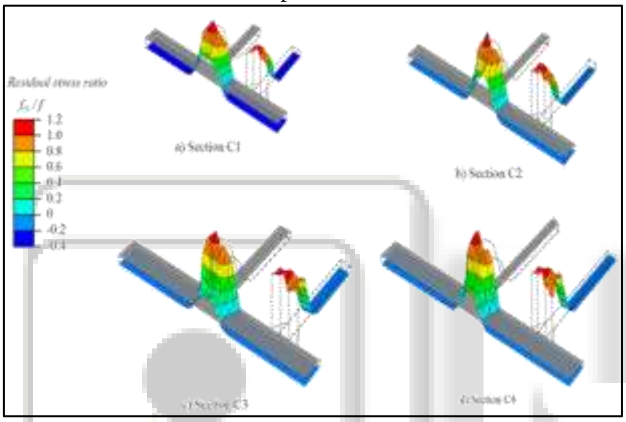


Fig. 6.2: 3D representation of measured residual stress

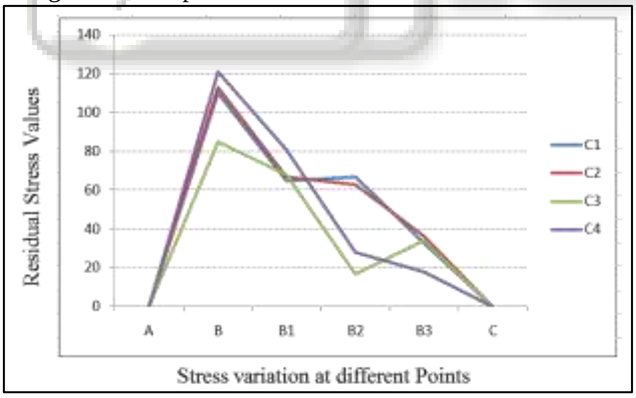


Fig. 6.3: Variation of residual stresses at given points

The comparison made between the data provided by both methods are given in fig6.4

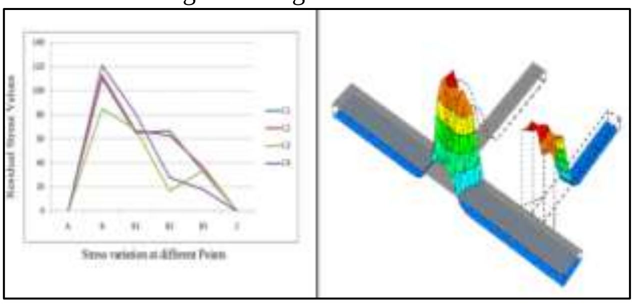


Fig. 6.4: Comparison of data

VII. Conclusion

In this research work, we have demonstrated the result of carefully designed experimental study to determine the distribution of induced residual stress in the vicinity of the welded T-joint test specimens.

The result signifies that the residual stress around the weld is one third of tensile strength and half of the yield strength. It also indicates that residual stress increases as the thickness of plate increases and decreases as distance increases from the weld toe.

Reference

[1] ASTM E837-13a. 2015. Standard Test Method for Determining Residual Stresses by the Hole-Drilling-gauge method, ASTM International.

[2] American Welding Society, 2011. Specification for low alloy steel electrodes and fluxes for submerged arc welding, structural welding code – steel, Miami, United States: American Welding Society.

[3] American Welding Society, 2011. Specification for carbon steel electrodes and fluxes for submerged arc welding, structural welding code – steel, Miami, United States: American Welding Society.

[4] American Welding Society, 2011. Specification for carbon and low alloy steel flux cored electrodes for flux cored arc welding and metal cored electrodes for gas metal arc welding, structural welding code – steel, Miami, United States: American Welding Society.

[5] ASTM A572, Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel, United States, ASTM International, 2015.

[6] Bjorhovde R. Development and use of high performance Steel. J Construction Steel Resource 2004; 114(4):441-51.

[7] CEN, EN-1993-1-1:2005, Eurocode 3: Design of steel structures – Part 1-1: General rules and rules for building, Brussels, Belgium: European Committee for standardization; 2005.

[8] CEN, EN-1993-1-12:2005, Eurocode 3: Design of steel structures – Part 1-2: General rules and rules for building, Brussels, Belgium: European Committee for standardization; 2005.

[9] CEN, EN-1993-1-12:2007, Eurocode 3: Design of steel structures – Part 1-12: Additional rules and rules for the extension of EN 1993 up to S700, Brussels, Belgium: European Committee for standardization; 2007.

[10] Lee C.K., Chiew S.P., Jin Jiang, 2012. “Residual stress study of welded high strength steel thin-walled plate-to-plate joints, Part1: Experimental study” Thin-Walled Structures 56; pp. 103-112.