Gas Metal Arc Welding Parameters Effect on Properties of Tailored Orbital Weld of SS304 and BS1387

M N Ayof, N I S Hussein* and M Z Mohd Noh
Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

*E-mail: izan@utem.edu.my

Abstract. Dissimilar material pipes in a power plant boiler water piping system are used to transmit water at various temperatures, either in extremely high temperature water or room temperature water. In this study, tailored orbital welding of dissimilar material of Stainless Steel (SS) 304 and British Steel (BS) 1387 were performed by Gas Metal Arc Welding (GMAW) with automated fixed nozzle-rotational jig. This study focused on GMAW parameters variation effects on mechanical properties of SS304 and BS1387 dissimilar material tailored orbital welding. The weldment quality was tested by performing non-destructive dye penetrant test. The tensile strength and microhardness were studied to verify the influence of welding parameters variations. Design of Experiment (DOE) was employed to generate process parameter using Response Surface Methodology (RSM) method. Welding parameters that were arc current, arc voltage and travel speed as input response, whilst, tensile strength and microhardness as output response. Results from non-destructive test showed no major defect occurred. The tensile strength and microhardness increased when arc current and voltage increased and travel speed decreased. Microhardness at weldment was higher than base material.

1. Introduction

Welding is a versatile joining process that is applicable to almost all types of materials. It is one of the permanent joining processes that produce coalescence of the material by heating workpiece to the melting temperature with or without the existence of pressure or by the application of pressure itself and with or without the use of filler material for metal or non-metallic materials. Welding technique has been widely used in various industries such as automotive, oil and gas, aerospace, and many others. There are various types of welding and it differs according to the heat source, process and type of welded material such as, shielded metal arc welding (SMAW), gas metal arc welding (GMAW), gas tungsten arc welding (GTAW) and laser welding. In many industries, welding plays an important role in reducing the production cycle time, thus reducing the delivery time [1]. Orbital welding is a joining process of tubes of similar thickness. It was one of the major improvements in pipe welding technology since 1980s. The orbital arc welding produces high quality of welded seams and has good repeatability. It is an expansion to manual welding process as it increases speed and ensures repeatability [1].

Tailored orbital (TO) is welded tubular product made of tube from different materials of different thickness or coatings to component or other tubes, depending on the application in taking advantages in cost, weight and function. If the material joint is different to each other, it is also known as dissimilar metal joint (DMJ). The advantages of TO technology are it can help to improve the production processes as they reduce material requirements and steps, reduce overall part weight, improve functionality, reduce costs and allow greater forming freedom [2].

One of the most common industries that apply tailored orbital welding (TOW) is in power plant boiler system as an example shown in Figure 1. In power plant industry, there are various components or systems operating at different service conditions hence appropriate materials are used for high temperatures or low temperatures condition [3-7]. Materials used are selected depending on the requirement of working environment; high temperature require high properties steel such as stainless steel (SS) and low properties steel such as carbon steel (CS) for low temperature is necessary [3]. Due to economic pressure, the application of TOW is essential in power plant because it is able to minimize requirement on high performance steel and maximize steel capabilities at appropriate area [8][6-7].

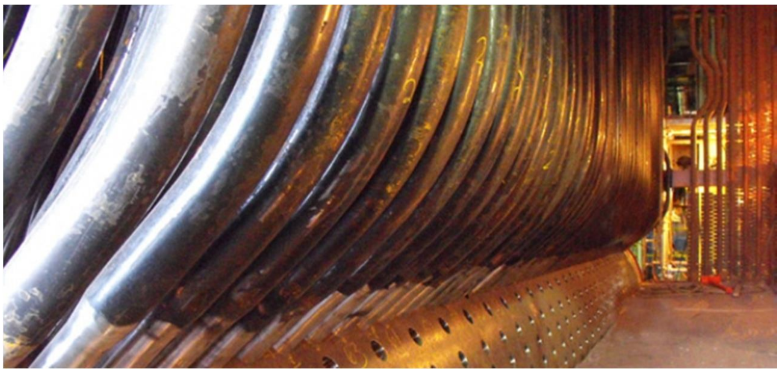

Figure 1. Example of TOW application in power plant [9]

There are various steel combinations in dissimilar material such as between CS and SS, ferritic steel and SS, and martensitic steel and austenitic stainless steel, and it depends on its application. CS and SS is the most common steel combination in TOW process applied at power plant due to economic and technical reason. Akbari and Sattari-Far [3] performed dissimilar material of CS A106B and SS A240-TP304 to carry out failure analysis on instance steam generators of power plants, Hajiannia et al. [4] used CS A 335 and SS 347 to replicate the heat exchangers of power plant and Lee et. al. [6] utilized CS SPPS 42 and SS304 as both materials were commonly found in power plant due to economic and technical reasons.

In TOW, welding is the most common method used as heat source. GTAW was used by Akbari and Sattari-Far [3], Hajiannia et al. [4] and Lee et al. [6] to perform TOW. The GTAW is able to produce high quality weld. However, it requires high skill welder to control both hands and increased agility. In order to attract the interest of power plant industries, GMAW was used as heat source for this research study. The study of TO welding using GMAW was performed using SS wire as filler material. The study was carried out by automatic feeding of a continuous consumable electrode and fixed nozzle-rotational jig. Thus, dependence on high skill welder was replaced by the usage of fixed nozzle-rotational jig.

The objectives of the study are to correlate the effect of different GMAW parameters on the tensile strength and microhardness variations of the TOW of SS304 and BS1387.

2. Experimental Methods

2.1. Material

The materials used in this experiment were two different types of pipe material with the same outside diameter (OD), different inside diameter (ID) and different thickness. The pipe materials used were SS304 and BS1387. The SS304 had 60.0mm OD, 56.40mm ID and 3.60mm thickness. Meanwhile, BS1387 had 60.00mm OD, 57.00mm ID and 3.00mm thickness. The filler material used in this experiment was ER 308L SS with 1.2 mm diameter.

2.2. Design of Experiment
The welding parameters were generated by using RSM; Box Behnken function in the Design Expert software. The three input variables or factors were welding current (A), welding voltage (V) and travel speed (RPM), and the two output variables or response, were tensile strength (MPa) and Vickers microhardness (HV). Each factor was subjected to two levels which were low and high levels. Table 1 shows the level of factors for the GMAW processes. By having three input variables and two output variables with five centre points per block, the total runs generated were 17 runs, or set of parameters.

Table 1. Levels of parameters factors for GMAW processes

Input variables (Factors)	Units	Low Level (-1)	High Level (+1)
Arc Current	A	150	170
Arc Voltage	V	17	21.5
Travel Speed	RPM	2	4

2.3. Welding Process
Pipes were held on the rotational jig with 90° or perpendicular to the welding nozzle and with 20.0 mm distance. The nozzle set on the centre of weld line. The shielding gas that was used in this experiment was a mix of 80% argon and 20 % CO_2. Rotational jig was used in this experiment to hold and rotate the pipe to perform tailored orbital welding. The rotational jig used was ANYEKE welding positioned APL-100 model. The rotational jig was connected to the welding machine used. The welding machine used was Fronius TransSynergic 4000 GMAW machine with VR 4000 wire feed system.

2.4. Dye Penetrant Test
The dye penetrant test was conducted according to AWS D1, with the following steps; pre-cleaning the surface using the Cleaner to clean the surface and make the surface smooth enough to wipe off the penetrant without leaving residue. Then, applying the penetrant, with light layer sprayed on the pipe with around 50.0 mm distance. The penetrant was let to permeate into crack and voids if any for 30 minutes. After 30 minutes, the penetrant was removed using cleaner and cloth. Then, applying the developer with light layer sprayed on the pipe with distance around 50.0 mm. The developer was dried for 30 minutes. Then, the pipe was evaluated and checked for any defects appeared.

2.5. Tensile Testing and Microhardness Measurement
For tensile test, these pipes were cut into dimensions in accordance with ASTM E8M-4 tension test specimens for large-diameter tubular products. AG-I Shimadzu Universal Testing Machine was employed.

For microhardness test, the sample was cut and the test was conducted in accordance with ASTM E92 for Vickers test. The microhardness test was performed by using Mitutoyo HR-523 machine, Vickers Microhardness Tester. The microhardness measurement was carried out by applying a load of 0.1 kgf with 15 sec dwell time.

3. Results and Discussion

3.1. Macrostructure
From the 17 samples, there was no major defect on the surface of the weldment. However, there are mostly series of red dot at the start-end of the weldment. Figure 2 shows sample 1 (160 A, 19.25 V and 3 RPM) with red dots at the start-end weldment. Dwivedi and Sharan [10] claimed that the red dot appearance indicates pits or porosity and series of red dots indicates crack or cold shuts. Based on the dye penetrant results, some samples had series of red dots while some had single red dot at start-end point. This indicates porosity and crack had occurred during the welding process, due to lack of fusion or inadequate weld at start-end point as supported by Siegel [11]. However, no significant porosity or crack was observed at the cross section of the weldment (Figure 3).

Figure 2. Sample no.1 of TOW with 160 A, 19.25 V and 3 RPM as parameter shows red dots at the start-end.

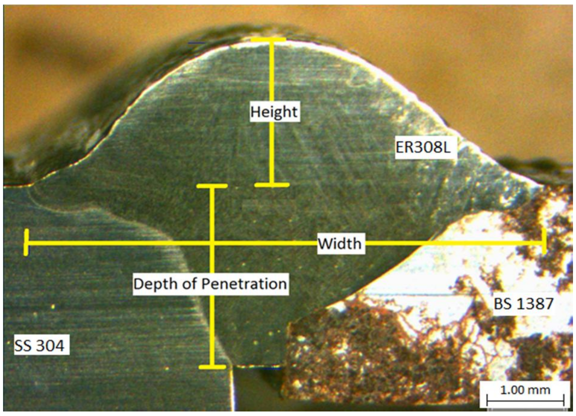

Figure 3. Cross section of the weldment of SS304 and BS1387.

3.2. Base Material Characterization

Base materials were charactierized by using tensile test and microhardness test to determine the tensile properties and microhardness values. The results were used as the benchmark for the weldment results later. Table 2 shows the tensile properties and microhardness values for SS304 and BS1387. The SS304 had 683.785 MPa tensile strength and 217.6 HV microhardness. Meanwhile, BS1387 had 390.766 MPa and 187.1 HV microhardness. However, BS1387 had lower elasticity with 5160.36 MPa Young's Modulus as compared to SS304 which had 5364.67 MPa Young's Modulus.

Table 2. Tensile Properties and microhardness of SS304 and BS1387 base material

Base Material	Tensile Properties		Microhardness Vickers (HV)
	Tensile Strength (MPa)	Young's Modulus (MPa)	
SS304	683.785	5364.67	217.6
BS1387	390.766	5160.36	187.1

3.3. Process-properties Relationship

Response Surface Methodology (RSM) was used to analyse the result obtained from the welding process and to understand the relationship between welding parameters with mechanical properties of TOW. The factors were welding current, welding voltage and travel speed, while responses were tensile strength. The design also analysed which factor influenced respond the most. All analysis was done by using Design Expert software. From this experiment, the highest tensile strength value was 351.35 MPa from sample 7. Meanwhile, the lowest tensile value was 249.79 MPa from sample 11. The highest microhardness value of weldment was 249.32 HV from sample 12, and the lowest microhardness value was 178.46 HV from sample 14.

3.4. Tensile Strength

3.4.1. Polynomial Equation for RSM Tensile Strength Model
In Design Expert 7 software, the appropriate polynomial equations were determined. It represented the relationship between the input parameters and the output response. It was done by carrying out SMSS and 'lack of fit' test. Both analyses suggested the quadratic equations to model and calculate the relationship between input parameters and micro results. The quadratic equation was the most significant with 0.0209 p-value for SMSS and 0.7187 p-value for lack of fit test.

3.4.2. ANOVA Analysis of the Response Surface Quadratic Model for Tensile Strength
ANOVA analysis for the quadratic model for tensile is shown in Table 3. The "Model F Value" of 4.89 implied that the model was significant. There was only 2.41 % chance that a "Model F-value" this large could occur due to noise. This implied that the model did represent the data within the required 90% confidence interval. The most significant was model term C (travel speed) with p-value of 0.0365. However, model term A (arc current) and model term B (arc voltage) were not significant with p-value 0.7598 and 0.4167, respectively. Model term A and B were included in the analysis for keeping the model hierarchy because interaction model term AB and C^2 was significant with p-value of 0.0060 and 0.0069 respectively.

Table 3. ANOVA analysis of the quadratic model for tensile strength

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	13224.97	9	1469.44	4.89	0.0241	Significant
A-Arc Current	30.38	1	30.38	0.10	0.7598	
B-Arc Voltage	223.94	1	223.94	0.74	0.4167	
C-Travel Speed	2001.12	1	2001.12	6.66	0.0365	
AB	4556.25	1	4556.25	15.16	0.0060	
AC	18.69	1	18.69	0.06	0.8103	
BC	677.27	1	677.27	2.25	0.1771	
A^2	479.86	1	479.86	1.60	0.2469	
B^2	1079.09	1	1079.09	3.59	0.1000	
C^2	4284.48	1	4284.48	14.25	0.0069	
Residual	2104.35	7	300.62			
Lack of Fit	549.49	3	183.16	0.47	0.7187	not significant
Pure Error	1554.86	4	388.71			
Cor Total	15329.32	16				
				R^2	0.8627	
				Adj. R^2	0.6862	
				Pred. R^2	0.2680	
				Adeq. R^2	8.183	

The accuracy of this model was also supported by the lack of fit analysis. The "Lack of Fit F-value" was 0.47 and implied that the Lack of Fit was not significant relative to the pure error. There was 71.87% chance that a "Lack of Fit F-value" this large could occur due to noise. The non-significant lack of fit was good because it made the model fit. The value coefficient of determination, R^2 was 0.8627 hence, the value of correlation coefficient, r was 0.9288 which was higher than 0.8. A correlation greater than 0.8 was generally described as strong. The value of Pred. R^2 of 0.2680 was not close to the Adj. R^2 of 0.6862 as one might normally expected. This may indicate a large block effect or a possible problem with model and/or data. However, Adeq. Precision indicated the measured signal to noise ratio was desirable, which was greater than 4. The ratio was 8.183 thus indicated an adequate signal and the model can be used to navigate the design space.

There were three variables, welding current, voltage and travel speed. However, only travel speed was significant to the model but welding current and voltage was included in the model for keeping the model hierarchy. It was because the interaction between welding current, voltage and travel speed was significant.

3.4.3. Significant Factors Influencing Tensile Strength

The significant factors influencing tensile strength value were determined by using ANOVA analysis of the quadratic model for response – tensile strength, Table 3. Based on the p-value less than 0.05, travel speed (C), interaction between current and voltage (AB) and travel speed quadratic term (C^2) were the significant influencing factors of the tensile strength.

3.4.4. Effect of Travel Speed (C) on Tensile Strength

Based on Table 3, travel speed p-value was 0.0365, which was less than 0.05 and was classified as one of the significant factors influencing tensile strength. The travel speed main factor curve in Figure 4 shows that as the tensile strength decreased from 339.74 MPa to around 280 MPa, the travel speed increased from 2 RPM to 3 RPM. However, as the tensile strength increased after passing 3 RPM until maximum 4 RPM, with tensile strength value 308.12 MPa. Similar result was found by Talabi et al. [12], as they increased the travel speed, the tensile strength decreased and at certain speed and further increase in the travel speed, the tensile strength increased.

Effect of travel speed showed that the increased in travel speed decreased the tensile strength value. Similar result was found by Ampaiboon et al. [13] whereas the maximum UTS of welded joint was obtained by lowest travel speed and increasing the travel speed decreased the tensile strength gradually.

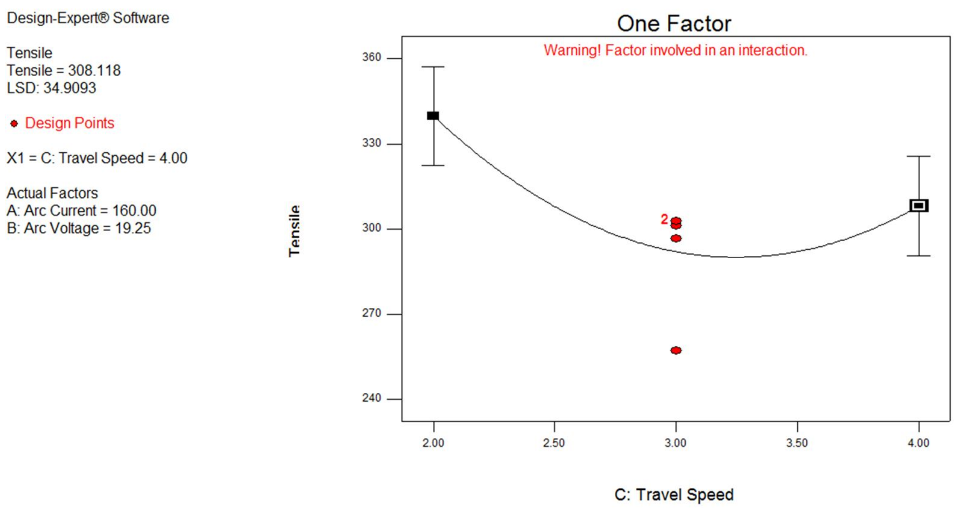

Figure 4. Behaviour of weldment tensile strength in response to variation of welding travel speed

3.4.5. Effect of Interaction between Arc Current and Arc Voltage (AB) on Tensile Strength

The ANOVA analysis revealed that the interaction between arc current and arc voltage (AB) is the most significant factor on tensile with p-value of 0.006. Figure 5 shows the interaction between arc current and arc voltage with respect to the weldment tensile strength. At low arc voltage, 17.0 V, the variation in arc current, increased the weldment tensile strength value, from 245.71 MPa to 317.11 MPa. However, at high arc voltage, 21.5 V, variation in arc current decreased the weldment tensile strength value from 323.79 MPa to 260.19 MPa. This indicated that the interaction between arc current and arc voltage significantly affected the weldment tensile strength value.

The effect of arc voltage on tensile strength is the increase in arc current which lead to the increase in tensile strength value. Similar result was found by Ampaiboon et al. [13] which focused on the effect of welding parameters on ultimate tensile strength. Maximum UTS of welded joint was obtained by highest voltage value. It is also supported by Ragu Nathan et al. [14] that the weldment is comparatively stronger due to strong carbide or nitride element formation which has limited solubility in ferrite and austenite.

Therefore, at low voltage, the increased in the arc current resulted in the tensile strength value to increase. However, at high voltage, variation in arc current significantly decreased the tensile strength value. Similar results were observed by Hussein et al. [15].This was because at high voltage produced wider, flatter and less penetration as compared to low voltage welding. As mentioned by Rohit and A.K. [16], the depth of penetration was at maximum for optimum arc voltage.

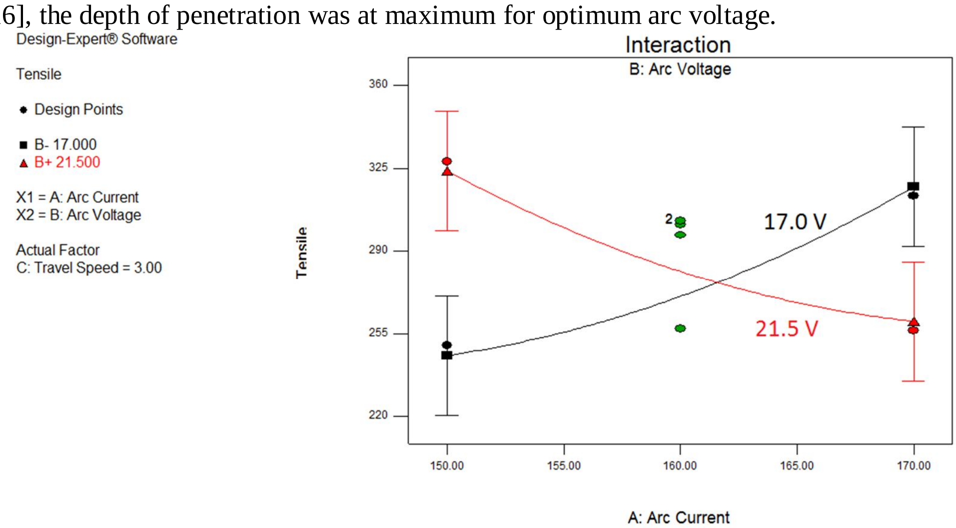

Figure 5. Interaction between arc current and arc voltage with respect to welding tensile strength

3.5. Microhardness

The significant factors influencing hardness were also determined by using ANOVA analysis of the quadratic model for response – microhardness. Based on the p-value less than 0.05, arc current (A), interaction between current and voltage (AB), interaction between current and travel speed (AC), interaction between voltage and travel speed (BC), arc voltage quadratic term (B^2), travel speed quadratic term (C^2) and interaction between current and voltage quadratic term (AB^2) were the significant influencing factors of the microhardness. As the arc current increased from 150 A to 170 A, microhardness of the weld decreased from 253.75 HV to 213.97 HV. Similar result was found by Bodude and Momohjimoh [17] as they increased the current value with constant voltage, the hardness decreased.

Increased in arc voltage from 17 V to 21.5 V led to insignificant change of weldment microhardness from 213 HV to only 214 HV. However, the quadratic term of voltage (B^2) in the ANOVA analysis, from Table 4, indicated that p-value less than 0.05 reflected the significance of the quadratic term value. The main effect graph indicated that the maximum microhardness of 238.29 HV was obtained at 19.25 V before it started to drop. Bodude and Momohjimoh [17] also studied the effect of welding voltage with constant current on microhardness value. As the voltage increased from 100 V to 220 V at 100 A, the microhardness value decreased. An increase in travel speed from 2 RPM to 4 RPM led to subtle change of weldment microhardness from 220 HV to only 223 HV. However, the quadratic term of travel speed (C^2) in the ANOVA analysis, from Table 4, indicated that p-value less than 0.05 reflected the significance of the quadratic term value. This was also indicated by the main effect graph where the highest microhardness value, at 3 RPM was 238.29 HV before it started to drop. Similar result was found by Kenchireddy et al. [18] as they increased the travel speed, the microhardness increased and started to drop at certain speed.

Table 4. ANOVA analysis of the quadratic model for response hardness

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	8337.69	10	833.77	26.34	0.0004	significant
A-Arc Current	1582.20	1	1582.20	49.98	0.0004	
B-Arc Voltage	2.91	1	2.91	0.09	0.7721	
C-Travel Speed	18.07	1	18.07	0.57	0.4785	
AB	759.21	1	759.21	23.98	0.0027	
AC	430.40	1	430.40	13.60	0.0102	
BC	1305.15	1	1305.15	41.23	0.0007	
A^2	86.56	1	86.56	2.73	0.1493	
B^2	2577.08	1	2577.08	81.41	0.0001	
C^2	1189.11	1	1189.11	37.57	0.0009	
AB^2	1186.97	1	1186.97	37.50	0.0009	
Residual	189.92	6	31.65			
Lack of Fit	15.07	2	7.54	0.17	0.8476	not significant
Pure Error	174.85	4	43.71			
Cor Total	8527.61	16				
				R^2	0.9777	
				Adj. R^2	0.9406	
				Pred. R^2	0.8973	
				Adeq. R^2	15.940	

Interaction between arc current and arc voltage (AB) on microhardness was one of the main factors influencing microhardness value, with 0.0027 p-value. The interaction between arc current and arc voltage with respect to the weldment hardness showed that at low voltage, 17.0 V, the variation in arc current resulted in decreased of weldment microhardness value, from 217.82 HV to 197.93 HV. However, at high voltage, 21.5 V, variation in arc current significantly changed in weldment microhardness. It increased from 191.47 HV to 227.97 HV. This indicated strong interaction between two parameters. The ANOVA analysis revealed that the interaction between arc current and travel speed (AC) influenced the microhardness value. The interaction between arc current and travel speed with respect to the weldment microhardness showed that at low travel speed, 2 RPM, the variation in arc current resulted in minimal changes of weldment microhardness value, from 225.07 HV to 206.04 HV. However, at high travel speed, 4 RPM, variation in arc current significantly changed in weldment microhardness. It decreased from 248.82 HV to 188.30 HV. This indicated that arc current significantly affected the weldment microhardness with interaction of travel speed.

4. Conclusion

This study made a significant contribution to the field of knowledge related to TOW of dissimilar material of SS304 and BS1387 using GMAW as heat source. This study has found that the parameters used were able to produce good quality weldment on dissimilar material of SS304 and BS1387. The quality of the weldment was visually observed using dye penetrant method and the result shows no major defect on the weldment. However, there were a few flaws at start-end point on the weldment due to lack of fusion. Still, the other parts of weldment had no defect and were used for specimen preparation. The results of RSM indicated that the welding parameters did affect the mechanical properties of weldment. The tensile strength increased when the arc current and arc voltage increased and travel speed decreased. Similarly, the microhardness values also increased when the arc current and arc voltage increased and travel speed decreased.

Acknowledgement
Authors would like to thank the Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka for providing facilities for this research to be conducted successfully. This research has been funded by the Ministry of Higher Education of Malaysia through a research grant with the reference number of FRGS/1/2015/TK03/FKP/02/F00280.

References

[1] Vandewynckéle A, Vaamonde E, Fontán M, Herwig P, Mascioletti A 2013 *Physics Procedia* **41** 144 – 152
[2] Chan S.M, Chan L C, Lee T C 2003 *J. Materials Processing Technology* **132** (1 - 3) 95 - 101
[3] Akbari D, Sattari-Far I 2009 *Int. J. Pressure Vessels and Piping*, 86(11), pp.769–776
[4] Hajiannia I, Shamanian M, Kasiri M 2013 *Materials and Design* **50** 566 - 573
[5] Joseph A, Rai S K, Jayakumar T, Murugan N, 2005 *Int. J. Pressure Vessels and Piping* **82**(9) 700 - 705
[6] Lee J, Han S, Kim K, Kim H, Lee U 2013 *Engineering Failure Analysis* **34** 300 - 307
[7] Zhao L, Liang J, Zhong Q, Yang C, Sun B, Du J 2014 *Advances in Engineering Software* **68** 70 - 79
[8] Bendick W, Gabriel J, Hahn B, Vandenberghe B 2007 *Int. J. Pressure Vessels and Piping* **84**(1-2) 13 - 20
[9] National Boiler Service 2016 *Boiler Generating Banks*
[10] Dwivedi S N, Sharan A 2003 *J. Materials Processing Technology* **141**(2) 155 - 162
[11] Siegel R 2004 *Inspection Trend* 17 - 20
[12] Talabi S I, Owolabi O.B, Adebisi JA, Yahaya T 2014 *Advances in Production Engineering and Management* **9**(4) 181 – 186
[13] Ampaiboon A, Lasunon O, Bubphachot B 2015 *The Scientific World Journal* **5**
[14] Ragu Nathan S, Balasubramanian V, Malarvizhi S, Rao A.G 2015 *Defence Technology* **11** 1 - 10
[15] Hussein N I S, Ayof M N, Nordin, S 2015 *Int. J. Materials, Mechanics and Manufacturing* **4**(1) 56 - 59
[16] Rohit J, A K. J 2014 *Int. J. Eng. Research and Application* **4**(6) 106 - 111.
[17] Bodude M A, Momohjimoh I 2015 *J. Materials Characterization and Engineering* **3** 142 - 153
[18] Kenchireddy K M, Jayadeva C T, Sreenivasan A 2014 *Global Journal of Engineering Science and Researches* **1**(3) 36 42