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ORIGINAL RESEARCH ARTICLE

PARAMETRIC OPTIMIZATION AND DETERMINATION OF A SUITABLE WELDING PROCESS FOR STAINLESS STEEL-MILD STEEL DISSIMILAR METALS WELD

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ABSTRACT

Difficulties associated with dissimilar metals welding differ remarkably and can be minimized with the selection of a suitable joining process, modification of the joining technique, and the adoption of optimal process parameters. This study investigates the suitability of three fusion welding processes (gas tungsten arc welding (GTAW), gas metal arc weld (GMAW), and shielded metal arc welding (SMAW)) in the welding of stainless steel to mild steel plates based on their mechanical properties and observed weld defects. Gas tungsten arc welding (GTAW) process which turned out to be the most suitable of the three, recording the least imperfections, an efficiency in mechanical properties of 8% higher compared to the other processes, furthermore analyzed using the response surface methodology (RSM) to obtain a models of the input and output relationship, as well as the optimal process parameters was conducted. An optimal parameters of 461.88N/mm² for the tensile strength and 31.65% for the Elongation was observed at the combined input parameters of 200 amp, 15 volt, 20 l/min, and 2.4mm for the weld current, arc voltage, gas flow rate and filler rod respectively. Therefore, the application of optimal process parameters along with a compatible weld process is recommended in the welding of dissimilar metals to guarantee excellent weld qualities.

1.0 Introduction

The increasing application of new structures with tailored engineering properties in the manufacturing industry has given rise to the joining of metals with entirely different materials and properties. This combination of different materials not only allows the use of metals with specific properties to be utilized in a more functional and efficient manner, but it also allows for a whole new structure possessing unique mechanical properties to be created. These materials often possess good compatibility in terms of properties as it relates to the service conditions necessities (Das et al., 2014; Kas et al., 2009).

The joining of dissimilar metals cannot be compared to that of similar or identical metals (Bhattacharya et al., 2016; Satyanarayana et al., 2005). Many factors such as the dissimilar metals composition, its properties (chemical and metallurgical), the selection of suitable filler material, the joint design, and the welding process affects both the choice of the welding processes and the quality of the welded joints. Additionally, the proper selection of a suitable joining process, filler material, and process parameter, to an acceptable weld joint design is a major determinant for obtaining a reliable weld quality (Tusek et al., 2001). Electric arc welding, amongst which are: gas metal arc welding (GMAW), the gas tungsten arc welding (GTAW) and shield metal arc welding (SMAW), are the most prominent fusion welding processes employed for dissimilar metals (Lin et al., 2010). Martinsen (2015), Bang (2013) and Dong (2012), reported that the formation of brittle intermetallic compounds (IMC) resulting from the Heat Affected Zone (HAZ) and the molten pool is minimized with the use of arc welding process. Conversely, Kaewkuekool and Amornsin (2008), Kim (2009), and Wang (2012) revealed aside identifying a suitable welding process, there is the need for compromise in the selection and combination of different process parameters. They reported that the selection of a filler material compatible with the base metal, the application of buttering, and the control of heat input was necessary in reducing the alloy element gradient and carbon migration, and the risk of corrosion. Monika et al. (2013) studied the effect of the heat input on the mechanical properties of a dissimilar (GMAW) welded joints. They observed that the hardness is directly proportional to the heat input but inversely proportional to the tensile strength of the weld. The authors concluded that the mechanical properties of materials with considerable difference in properties welded by the arc welding method, depends greatly on the input process control, the filler material used and the preheat and post-heating condition. Kaewkuekool and Amornsin (2012), carried out a study on the mechanical properties of a dissimilar metal weld between stainless (AISI 304) and low-carbon steel using gas metal arc welding (GMAW) technique along with three different filler metals; GFW304L, 308L [EN12073] and 316L [EN12072]). From the result obtained, the tensile strength and percentage elongation are greatly affected by the weld speed, weld current, as well as filler metal type. Khorrami et al. (2014) studied the suitability of applying filler metals, in the welding of AISI 430 ferritic stainless steel weld and plain carbon steel) using the GTAW process. They reported that a reasonable improvement in the mechanical properties (hardness and Ultimate tensile strength) was observed in the weld having filler metals compared to the autogenously weld. They reported further that applying a filler metal compatible to the dissimilar metals being joined enhances the mechanical properties of the joint. Mvola and Kah, (2017) in their study examining the effects and components of shielding gas mixtures in fusion welding, asserted that the appropriate selection of shielding gases and the control of the gas flow rate was capable of increasing productivity in the welding industry along with improving the quality of the weld. Chuaiphan et al. (2013) carried out a study to investigate the most suitable of the welding processes; gas tungsten arc welding (GTAW) and shield metal arc welding (SMAW) in terms of toughness for 15 mm thick stainless steel to carbon steel plates dissimilar welded joints. They reported that aside the pitting corrosion potential displayed by the GTAW welded joint, the SMAW weld had a higher weld metal toughness. Teker et al. (2011) pointed out that in the welding of ferrite steel and quenched, and tempered steel using GMAW-P and GMAW, a superior tensile strength, less grain growth, and a narrow heat affected zone was recorded in the GMAW_P welded compared to the GMAW welded joint. This they ascribed to the better heat control, a finer fusion zone, and higher fusion hardness attributes of the GMAW-P welding process. Kumar and Sundarrajan, (2009) applied the Taguchi method in determining the optimal mechanical properties of a (Al-Mg-Si) aluminum alloy welded using TIG welding process as well as the effect of the pulsed TIG welding parameters. Their findings which compared the TIG weld to the parent metal revealed had a lower notch tensile strength and impact toughness. The objective of this study is to compare three different welding processes in the joining of mild steel to austenitic stainless steel (304) plates (10mm thickness) and evaluate the optimal welding parameters for the selected weld process.

2. Materials and Methods

2.1 Materials

The base metals selected for the experiment are stainless steel and mild steel plates with dimensions of 20 mm x 10 mm x 6 mm, along with the following input parameters; weld current (200-240amp), arc voltage (15-25Volts), filler rod (2.0-2.4mm) and gas flow rate (20-24lit/min). Based on the physical, chemical and mechanical-technological properties comparable to those of the base material, 302 stainless steel with chemical composition as shown in Table 1, was selected as the filler material (Hatifi et al., 2014).

Table 1: Chemical Compositions (wt. %) of the Base Metals and Filler Metal

Designation	Fe	C	Si	Mn	S	P	Mo	Cr	Ni
Stainless Steel	71.43	0.058	0.35	1.32	0.007	0.032	0.94	18.52	8.28
Mild Steel	99.31	0.2	0.14	0.4	0.05	0.04		0.24	0.21
Filler Material		0.03	0.6	1.8			0.15	23.4	13

2.1.2 Welding Process

The electric arc welding process comprises of different types, amongst which are the gas tungsten arc, gas metal arc and the sheilded arc welding processes. The gas tungsten arc welding (GTAW) is performed by means of an electric arc generated by the welding machine along with a non-consumable tungsten electrode (Sathish et al., 2012). The gas metal arc welding (GMAW) process on the other hand makes use of an arc along with a servo wire electrode which is automatically feed as it melts into the weld puddle. They both make use of an inert gas, or a gas mixture such as argon, helium, and mixtures of these gases. The shielded metal arc welding (SMAW) process unlike the gas shielded welding processes mentioned above, makes use of a consumable electrode and does not require a shielding gas. However, its covered electrode serves as a source of protection from harmful oxidation. A display of the GTAW and GMAW welding machines is presented in Figures 4a, and 4b respectively.

Figure 4a: GTAW Welding Machine

Figure 4b: MIG/MAG Welding Machine

2.2 Method

The workpiece interface (stainless steel and carbon steel) was bevelled, to conceal the nickel content effect associated with the austenitic stainless steel, and to allow for sufficient application of filler metal, before fitting the metals together to form a groove as shown in Figure 1.

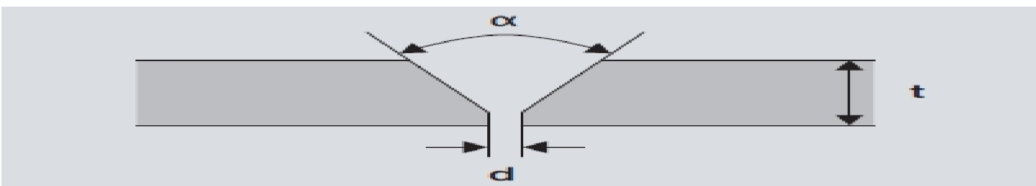

Figure 1: Schematic Representation of the Welded Joint

The labels ά, represent the bevel angle, d; the gap, and t; the thickness. The experiment was performed using the three different welding techniques: gas metal arc welding (GMAW), the gas tungsten arc welding (GTAW), and shielded metal arc welding (SMAW) with argon gas as the inert gas with a bevel angle of 90° and gap of 2 mm. The welded specimens from each of

the welding processes were subjected to visual inspection and tensile tests to ascertain the performance of the different welding processes. Observations for surface defects made with the naked eye and x-ray flaw detector were obtained and tabulated as shown in Table 2.
Prior to the experiment, the base materials were grouped into three (A, B, and C), for the three welding processes GTAW, GMAW, and SMAW respectively. And with the application of the central composite design of the response surface methodology using the Design Expert Software, thirty (30) experimental runs were generated.

2.2.1 Tensile test

To evaluate the transverse tensile properties (tensile strength and percentage elongation) of the stainless steel/mild steel dissimilar welds, the welded plates were machined to a tensile specimen shape according to ASTM standards and thereafter tested for tensile strength, and percentage elongation using a Universal Testing Machine (UTM) according to their groups (GTAW, GMAW, and SMAW).

2.2.2 Response surface methodology (RSM)

The response surface methodology is employed on the concept of identifying the relationship between the response or dependent variable "y" and the relevant input or independent variables $x_1, x_2,\ldots,x_k$ (Hicks 1993). The response surface is expressed as shown in Equation (1) on the assumption that the variables are continuous, controllable and measurable not ignoring a level of negligible error ε.

$$y = f(x_1, x_2, x_3 \ldots, x_k) + \varepsilon \tag{1}$$

With the Response surface methodology (RSM), the experimental data was used in developing the empirical models for the experiment, establishing the independent and response variable relationship with the aid of the second order quadratic model given in Equation (2).

$$y = \beta_o + \sum_{i=1} \beta_i x_i + \sum_{j=1}^{k} \beta_{ii} x_i^2 + \sum \sum_{ij}^{k} \beta_{ij} x_i x_j + \varepsilon \qquad \text{for } i < j \tag{2}$$

The coefficient of the polynomial denoted by "β" is estimated using the least squares method.

2.2.2.1 Analysis of variance ANOVA

The ANOVA test is performed to establish the suitability of the model, with the following parameters R^2 representing coefficient of determination, Adjusted R^2, the P value required to be < 0.05 identifies the significant model terms.

3. Results and Discussion

For visual inspection and radiographic test, seven (7) of the welded samples from the different welding processes were observed for surface defects with the naked eye and an x-ray flaw detector and their results tabulated as shown in Table 3.

Table 2: Visual Inspection and X-ray Radiographic Test Results.

	GTAW		GMAW		SMAW	
Samples	Visual Inspection	X-ray radiographic	Visual Inspection	X-ray radiographic	Visual Inspection	X-ray radiographic
1	No imperfection	No imperfection	No imperfection	No imperfection	incomplete penetration	Undercut porosity
2	Blow hole	Spatter porosity	No imperfection	No imperfection	incomplete penetration	spatter lack of fusion
3	No imperfection	No imperfection	Spatter	incomplete penetration	incomplete penetration	spatter lack of fusion
4	No imperfection	No imperfection	incomplete penetration	Undercut porosity	incomplete penetration	Undercut porosity
5	Spatter	incomplete penetration	incomplete penetration	Undercut porosity	incomplete penetration	Undercut porosity
6	No imperfection	No imperfection	incomplete penetration	Lack of fusion	incomplete penetration	Lack of fusion
7	No imperfection	No imperfection	incomplete penetration	Undercut porosity	incomplete penetration	Undercut porosity

The results from the visual inspection and x-ray radiographic test shows that there was little or no defects observed on the GTAW welded plates compared to the other two processes. However, defects like lack of penetration, undercut at both the root and the face, a lack of sidewall fusion, blowhole, porosity, etc. were observed in the GMAW welds and higher in the shield metal arc welded plates.

3.1 Tensile Strength

The transverse tensile properties (tensile strength and percentage elongation) of the stainless steel/mild steel dissimilar welded specimens were evaluated according to their groupings (GTAW, GMAW and SMAW), and the results along with the average is presented in Table 3. Figure 2 shows the GTAW welded dissimilar metal joint before and after the tensile test.

Figure 2: Mild steel/stainless steel dissimilar welded Joint before and after tensile test

Table 3: Expérimental data

Exp No	GTAW WELDED JOINTS		GMAW WELDED JOINTS		SMAW WELDED JOINTS	
	Tensile Strength (Mpa	Percentage Elongation	Tensile Strength (Mpa)	Percentage Elongation	Tensile Strength (Mpa)	Percentage Elongation
1	494.0	29.9	496.5	28.4	490.2	27.6
2	496.3	28.3	494.6	26.8	490.4	26.0
3	496.4	25.8	495.6	24.3	491.0	23.5
4	495.9	36.0	494.6	34.5	490.2	33.7
5	496.3	32.8	495.2	31.3	490.7	30.5
6	496.2	31.0	495.1	29.5	490.6	28.7
7	496.8	33.5	494.2	32.0	490.5	31.2
8	489.9	29.5	489.0	28.5	484.4	27.3
9	485.9	33.5	484.8	32.0	480.3	31.2
10	483.4	27.6	481.1	26.1	477.2	25.3
11	462.3	33.6	460.3	32.1	466.3	31.3
12	490.0	28.9	488.2	27.4	484.2	26.6
13	480.3	33.0	481.3	31.5	475.8	30.7
14	495.0	35.0	478.2	33.5	481.6	32.7
15	468.7	33.9	467.5	32.4	473.1	31.6
16	469.6	29.9	468.7	28.4	469.2	27.6
17	460.3	30.0	459.1	28.5	464.7	27.7
18	486.3	31.3	485.4	29.8	480.8	29.0
19	494.6	30.1	493.3	28.6	488.9	27.8
20	496.1	29.0	495.2	27.5	490.6	26.7
21	472.3	29.7	473.3	28.2	467.8	27.4
22	488.1	30.4	480.1	28.9	479.1	28.1
23	477.8	29.2	475.4	27.7	473.6	26.9
24	490.0	29.0	472.9	27.5	476.5	26.7
25	485.0	29.3	485.5	27.8	480.5	27.0
26	475.7	31.5	475.8	30.0	470.7	29.2
27	492.3	30.0	491.1	28.5	486.7	27.7
28	482.1	33.0	481.2	31.5	479.5	30.7
29	486.3	28.0	485.5	26.5	480.9	25.7
30	480.2	27.0	478.2	25.5	478.2	24.7
AVE	485.5	30.6	483.2	29.1	480.8	28.4

Table 4 shows the results for the tensile test of the welded plates. It was observed that average tensile strengths and elongations were 485.5 N/mm^2 and 30.6% for the GTAW welds, 483.2 N/mm2 and 29.1% for the GMAW welds, and 480.8 N/mm2 and 28.4% for the SMAW welds. The results show that the weld performance of the GTAW process, performed better with a weld strength and elongation 0.5% and 5.2% respectively, compared with GMAW having 1.2% and 7.7% respectively compared to the SMAW techniques.

3.2 Optimization

In developing the optimal equations in terms of actual factors for maximizing the responses, experimental data obtained as recorded in Table 3, was employed. The results were further analyzed using the response surface methodology (RSM), and mathematical models of the responses as shown in equations 1 and 2 were obtained.

TENSILE STRENGTH $= +660.26227 - 3.24914 * \mathrm{X}(1) + 12.10708 * \mathrm{X}(2) + 1.23333 * \mathrm{X}(3) + 2.24479 * \mathrm{X}(4) + 0.018083 * \big(\mathrm{X}(1) * \mathrm{X}(2)\big) + 0.124375\big(\mathrm{X}(1) * \mathrm{X}(3)\big) + 0.225521 * (\mathrm{X}(1) * \mathrm{X}(4) - 0.419375 * \big(\mathrm{X}(2) * \mathrm{X}(3)\big) - 1.58125 * \big(\mathrm{X}(2) * \mathrm{X}(4)\big) - 1.67187 * \big(\mathrm{X}(3) * \mathrm{X}(4)\big) - 0.001745 * \mathrm{X}(1)^2 - 0.057083 * \mathrm{X}(2)^2 - 0.134896 * \mathrm{X}(3)^2 + 4.98698 * \mathrm{X}(4)^2$ (1)

PERCENTAGE ELONGATION $= +159676 - 0.186620 * \mathrm{X}(1) - 4.77625 * \mathrm{X}(2) - 5.58333 * \mathrm{X}(3) + 0.760417 * \mathrm{X}(4) + 0.002542 * \big(\mathrm{X}(1) * \mathrm{X}(2)\big) + 0.008437\big(\mathrm{X}(1) * \mathrm{X}(3)\big) - 0.067188 * (\mathrm{X}(1) * \mathrm{X}(4) + 0.021875 * \big(\mathrm{X}(2) * \mathrm{X}(3)\big) + 0.928125 * \big(\mathrm{X}(2) * \mathrm{X}(4)\big) - 0.742188 * \big(\mathrm{X}(3) * \mathrm{X}(4)\big) + 0.000287 * \mathrm{X}(1)^2 + 0.031833 * \mathrm{X}(2)^2 + 0.125521 * \mathrm{X}(3)^2 + 1.153646 * \mathrm{X}(4)^2$ (2)

The variables X_1, X_2, X_3, and X_4 in the équations, represent the process parameters; weld current, arc voltage, filler rod diameter and gas flow rate respectively.
The strength of the models was analyzed using analysis of variance (ANOVA) test, the results as shown in Figure 3, shows that the models are significant and that the tensile strength and elongation is greatly influence by the weld current. This mostly attributable to its influence on the bead shape, the depth of penetration, the deposition rate, and the rate at which electrode is melted (Sada 2018).

Response 1: Ultimate Tensile Strength

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	2444.19	14	174.59	3.12	0.0181	significant
A-Weld Current	276.76	1	276.76	4.95	0.0419	
B-Weld Voltage	342.77	1	342.77	6.13	0.0257	
C-Gas Flow Rate	78.84	1	78.84	1.41	0.2536	
D-Filler Rod	0.0417	1	0.0417	0.0007	0.9786	
AB	117.72	1	117.72	2.10	0.1675	
AC	891.02	1	891.02	15.93	0.0012	
AD	117.18	1	117.18	2.09	0.1684	
BC	281.40	1	281.40	5.03	0.0404	
BD	160.02	1	160.02	2.86	0.1114	
CD	28.62	1	28.62	0.5117	0.4854	
A²	67.68	1	67.68	1.21	0.2887	
B²	55.86	1	55.86	0.9986	0.3335	
C²	7.99	1	7.99	0.1428	0.7108	
D²	17.46	1	17.46	0.3122	0.5846	
Residual	839.09	15	55.94			
Lack of Fit	518.01	10	51.80	0.8067	0.6399	not significant
Pure Error	321.07	5	64.21			
Cor Total	3283.28	29				

Response 2: Percentage Elongation

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	143.14	14	10.22	4.73	0.0025	significant
A-Weld Current	35.77	1	35.77	16.55	0.0010	
B-Weld Voltage	0.0504	1	0.0504	0.0233	0.8806	
C-Gas Flow Rate	6.83	1	6.83	3.16	0.0958	
D-Filler Rod	0.1204	1	0.1204	0.0557	0.8166	
AB	2.33	1	2.33	1.08	0.3160	
AC	4.10	1	4.10	1.90	0.1886	
AD	10.40	1	10.40	4.81	0.0444	
BC	0.7656	1	0.7656	0.3543	0.5606	
BD	55.13	1	55.13	25.51	0.0001	
CD	5.64	1	5.64	2.61	0.1270	
A²	1.83	1	1.83	0.8470	0.3720	
B²	17.37	1	17.37	8.04	0.0125	
C²	6.91	1	6.91	3.20	0.0939	
D²	1.66	1	1.66	0.7670	0.3950	
Residual	32.42	15	2.16			
Lack of Fit	21.63	10	2.16	1.00	0.5337	not significant
Pure Error	10.79	5	2.16			
Cor Total	175.56	29				

Figure 3: ANOVA of the Responses

The mathematical model obtained in Equations 1 and 2, were further employed in carrying out the prediction of the responses. Predicted values obtained of the responses were compared to that of the experimental values by performing a plot of the predicted response against the observed values for each of the responses as shown in Figure 4a and 4b.

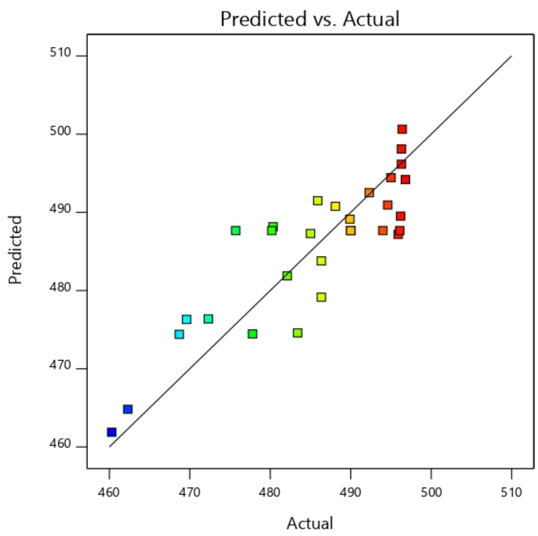

Figure 4a: Plots of predicted versus actual values of tensile strength

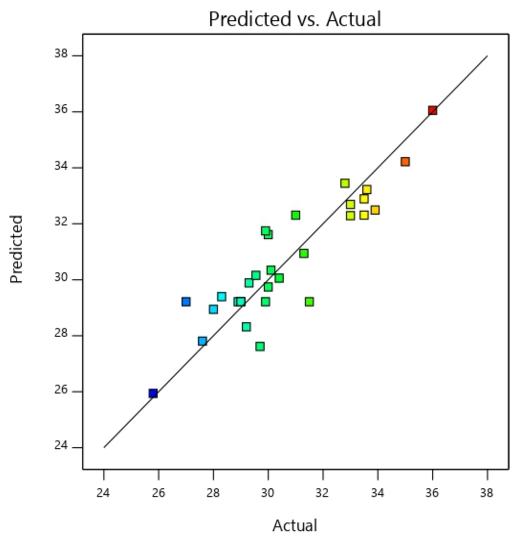

Figure 4b: Plots of predicted versus actual values for percentage elongation

The straight-line graph shows that the errors are uniformly distributed. An indication that there's a significant correlation between the experimental and predicted response values (Sada 2018).

3.3 Numerical optimization

To ascertain the desirability of the overall model, numerical optimization was performed using the design expert software. The responses were optimized and their corresponding optimum input process parameter values were determined. Figure 5 shows the Ramp Results of the optimal response parameters.

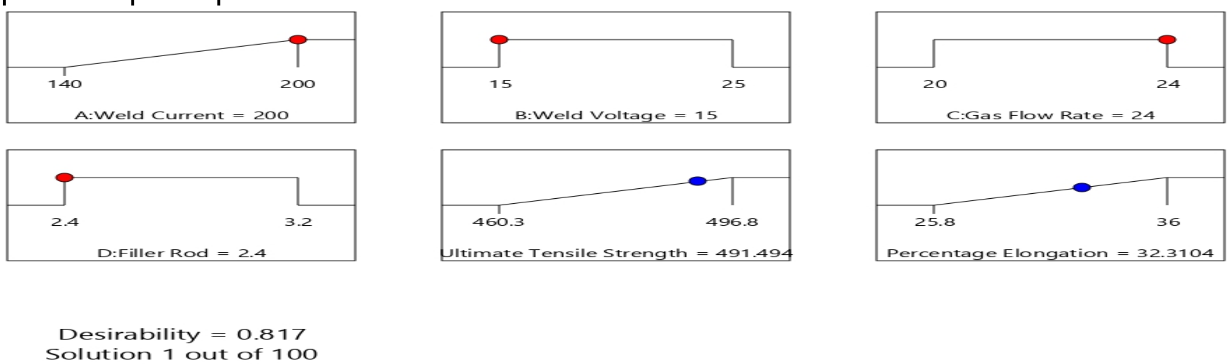

Figure 5: Ramp showing the optimal response parameters

4. Conclusions

Comparative study of the different welding processes based on the tensile properties; tensile strength and Percentage elongation, showed that the GTAW weld performed better with higher tensile strength and elongation while the shielded had the least output. The experiment not only confirms the GTAW welding process as the most suitable technique for the welding of stainless steel to mild steel dissimilar metals in comparison to the gas metal arc welding and shielded metal arc welding processes. It also confirms that stainless steel filler metal is an appropriate filler material for the joining of mild steel to stainless steel. Further analysis of the GTAW weld process using the response surface methodology showed that the weld current is the most significant model term and the optimal tensile strength of 491.49N/mm^2 and Elongation of 32.31% can be obtained at a welding current of 200 amp, voltage 15 volt, gas flow rate 24 l/min and filter rod of 2.4mm.

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Reference

Bang, H., Bang, H., Song, H. and Joo, S. 2013. Joint properties of dissimilar Al6061-T6 aluminum alloy/Ti-6%Al-4%V titanium alloy by gas tungsten arc welding assisted hybrid friction stir welding. Materials and Design, 51: 544-551.

Bhattacharya, A. and Sanchit, S. 2016. Dissimilar GTAW between AISI 304 and AISI 4340 steel. multi-response optimization by analytic hierarchy process. Proceedings of the institution of mechanical engineers. Part E; Journal of Processing Mechanical Engineering, 231(4): 824-835.

Chuaiphan, W., Somrerk, C., A., Niltawach, C. and Sornil, B. 2013. Dissimilar welding between AISI 304 stainless steel and AISI 1020 Carbon Steel Pates. Applied Mechanics and Materials, 268: 283-290.

Das, C., Bhaduri, A., Srinivasan, G., Shankar, V. and Mathew, S. 2009. Selection of filler wire for and effect of auto tempering on the mechanical properties of dissimilar metal joint between 403 and 304L(N) stainless steels. Journal of Materials Processing Technology, 209 (3): 1428–1435.

Dong, H., Hu, W., Duan, Y., Wang, X. and Dong, C. 2012. Dissimilar metal joining of aluminium alloy to galvanized steel with Al-Si, Al-Cu, Al-Si-Cu and Zn-Al filler wires. Journal of Materials Processing Technology, 212(2): 458-464.

Hatifi, MM., Firdaus, MH. and Razlan, AY. 2014. Modal analysis of dissimilar plate metal joining with different thicknesses using MIG welding. International Journal of Automotive and Mechanical Engineering (IJAME), 9: 1723-1733.

Kaewkuekool, S. and Amornsin, B. 2008. A study of parameters affecting the mechanical properties of dissimilar welding between stainless steel (AISI 304) and low carbon steel. Proceedings of the 1st WSEAS International Conference on MATERIALS SCIENCE (Bucharest, Romania, 2008): 105-109.

Kah, P., Shrestha, M. and Martikainen, J. 2014. Trends in joining dissimilar metals by welding. Applied Mechanics and Materials, 440: 269-276.

Kim, JK., Hong, SG., Kang, KB. and Kang, CY. 2009. Microstructure and high temperature properties of dissimilar weld between ferritic stainless steel and carbon steel. Metals and Materials International, 15: 843.

Kumar, A. and Sundarrajan, S. 2009. Optimization of pulsed TIG welding process parameters on mechanical properties of aa5456 aluminum alloy weldments. Materials and Design, 30: 1288-1297.

Lin, SB., Song, JL., Yang, CL., Fan, CL. and Zhang, DW. 2010. Brazability of dissimilar metals tungsten inert gas butt welding–brazing between aluminum alloy and stainless steel with Al–Cu filler metal. Materials and Design, 31: 2637-2642.

Martinsen, K., Hu, SJ. and Carlson, BE. 2015. Joining of dissimilar materials. CIRP Annals - Manufacturing Technology, 64(2): 679-699.

Monika, K., Bala, MC., Nanda, PK. and Prahalada, KR. 2013. Effect of heat input on the mechanical properties of MIG welded dissimilar joints. International Journal of Engineering Research and Technology, 2: 1406.

Mvola, B. and Paul, K. 2017. Effects of shielding gas control: Welded joint properties in GMAW process optimization. International Journal of Advanced Manufacturing Technology, 88: 2369–2387.

Sada, SO. 2018. Optimization of weld strength properties of tungsten inert gas mild steel welds using the response surface methodology. Nigeria Journal of Technology, 37(2): 407-415.

Satyanarayana, V., Madhusudhan, G. and Mohandas, T. 2005. Dissimilar metal friction welding of austenitic–ferritic stainless steels. Journal of Materials Processing Technology, 160: 128–137.

Sathish, R., Naveen, B., Nijanthan, P., Aun Vasanthan Geethan, K. and Rao, V. S. 2012. Weldability and process parameters optimisation of dissimilar pipe joints using GTAW. International Journal of Engineering Research and Applications, 2(3): 2525-2530.

Tušek, J., Kampuš, Z. and Suban, M. 2001. Welding of tailored blanks of different materials. Journal of Materials Processing Technology, 119: 180-184

Teker, T. and kursuon, T. 2011. Weldability of AISI 430/AISI 1030 steel couples via the synergic controlled pulsed (GMAW-P) and manual gas metal arc (GMAW). Materials and Manufacturing Processes, 26(7): 926-932.

Wang, J., Lu, MX., Zhang, L., Chang, W., Xu, LN. and Hu, LH. 2012. Effect of welding process on the microstructure and properties of dissimilar weld joints between low alloy and duplex stainless steel. International Journal of Minerals, Metallurgy and Materials, 19(6): 518-524