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Optimization of Tensile Strength of Butt Joint Weldment on Mild Steel Plate Using Response Surface Methodology

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Abstract

The service life of engineering structure is mostly affected by the quality and strength of the welded joints. Tensile tests are performed for several reasons. The results are used in selecting materials for engineering applications. Tensile properties are frequently included in material specifications to ensure quality. The tests are measured during development of new materials and processes, so that different materials and processes can be compared. The objective of this study is to predict and optimize the tensile strength of a butt joint weldment on mild steel plate using Response Surface Methodology (RSM). The RSM was applied to predict and optimize the maximum tensile strength of a butt joint weldment on an I-section mild steel plate using Tungsten Inert Gas (TIG) welding process. The mild steel plate was cut into dimension 60mm x 40mm x 10mm with a power hacksaw, grinded and cleaned before the welding process. The experimental matrix was made of twenty (20) runs, generated by the design expert 11.1.0.1 software adopting the central composite design. The response (tensile strength) was measured and then modelled using the RSM. The result obtained show that the current and voltage has a very strong influence on the tensile strength. Based on the findings, the maximum tensile strength of 450Mpa was attained at the welding voltage (V) of 24V, current of 170A and gas flow rate of 13lit/min respectively. This study will serve as a guide to welding operators on parameter settings selection.

Keywords: Mild steel plate, Response Surface Methodology (RSM), Tensile test, Contour plot, Surface plot.

1 | Introduction

Steel is an important engineering material. It has found applications in many areas such as vehicle parts, truck bed floors, automobile doors, domestic appliances etc. It is capable of presenting economically a very wide range of mechanical and other properties. Mild steel is cheap and malleable but has a relatively low tensile strength. Surface hardness can be increased through carburizing which involves heating the alloys in a carbon rich environment. Tungsten Inert Gas (TIG) welding has turn out to be the process of choice for exotic metals and joints of high quality, as well as totally defined welds that can be prepared on any weldable metal [1]. In general, the quality of a welded joint in terms of different features like mechanical properties is directly influenced by the weld input process parameters. By varying the input process parameters combination, the output sometimes produces different welded joints with significant variation in their mechanical properties.

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And so, the essence of a control system in arc welding is necessary to eliminate much of the guess work repeatedly employed by welders to specify welding parameters for a given task [2]. Mohandas et al. [3] investigated the mechanical and metallurgical properties of medium carbon steel using Shielded Metal Arc Welding (SMAW) process with reference to the weld metal, Heat Affected Zone (HAZ) and parent metal. From the results, SMAW of medium carbon steel increased the strength of the welded joint in particular the HAZ, as revealed by lower impact strength, higher tensile strength a d hardness values as compared with the parent and weld metal which is attributed to the fine ferrite matrix and fine pearlite distribution as compared to the weld and parent metal. However, there was a loss of ductility at the welded joint resulting to brittleness of the material. Khourshid and Sabry [4] discussed the effect of welding variables on the mechanical properties of welded 10mm thick low carbon steel plate, using the SMAW method. Welding current, arc voltage, welding speed and electrode diameter were the investigated welding parameters. The welded samples were cut and machined to standard configurations for tensile, impact toughness, and hardness tests. The results showed that the selected welding parameters had significant effects on the mechanical properties of the welded samples. Increases in the arc voltage and welding current resulted in increased hardness and decrease in yield strength, tensile strength and impact toughness. Increasing the welding speed from 40-66.67mm/min caused an increase in the hardness characteristic of the welded samples. Initial decrease in tensile and yield strengths were observed which thereafter increased as the welding speed increases. Ramachandran [5] studied the various effect of the TIG welding on the Austenitic stainless steel 316L on micro structural changes through destructive and nondestructive method and various parameters such as tensile strength, hardness on varying the current, voltage and gas flow ratio respectively. A response surface model was developed by Hooda et al. [6] to predict the tensile strength of inert gas metal arc welding of AISI 1040 medium carbon steel joint. In this research the welding voltage, current, wire speed and gas flow rate were considered as input parameter. The experiment was designed using central composite design matrix. From the experiment they conclude that the optimum values of process parameter such as welding voltage 22.5 V, wire speed 2.4 m/min and gas flow rate 12 l/min for maximum yield strength both transverse and longitudinal remain same but the current value is 190 A and 210 A respectively. Samples of engineering materials are subjected to a wide variety of mechanical tests to measure their strength or other properties of interest. Such samples, called specimens, are often broken or grossly deformed in testing. Among the various mechanical tests conducted are tensile and notch-impact tests. The mechanical properties of welded aluminum 6061pipe using three different types of welds was also studied [7]. Weldments with rotation speed (1800RPM) and travel speed 4mm/min of MIG, TIG and Friction welding were compared. The microstructure of the welds, including the nugget zone and HAZ, has been compared and concluded that the micro hardness values are higher in the weld region of FSW joints compared to MIG and TIG. Furthermore, FSW welds exhibit higher strength values compared to others. The mechanical properties of materials are determined by performing carefully designed laboratory experiments that replicate as nearly as possible the service conditions. In the real life, there are many factors involved in the nature in which loads are applied on a material. The following are some common examples of how these loads might be applied: tensile, compressive and shear, just to name a few. These properties are important in materials selections for mechanical design. Other factors that often complicate the design process include temperature and time factors. Lakshminarayanan et al. [8] and Arunkumar and Ravichandran [9] evaluated the tensile and impact properties, micro-hardness, microstructure, and fracture surface morphology of Continuous Current Gas Tungsten Arc Welding (CCGTAW), Pulsed Current Gas Tungsten Arc Welding (PCGTAW), and Plasma Arc Welding (PAW) joints and investigated that the PAW joints of fss steel shows superior tensile and impact properties when compared with CCGTAW and PCGTAW joints and this is mainly due to lower heat input, finer fusion zone grain diameter, and higher fusion zone hardness. The tensile test is used to access some key mechanical properties such as yield stress, ultimate tensile stress, and modulus of elasticity and ductility of structural materials. It consists of slowly pulling a sample of material uni-axially along its axis with a tensile load until fracture. Two specimen geometries, cylindrical and flat, are recommended by the American Society for Testing and Materials (ASTM) for tensile testing of metals. The choice of specimen geometry and size often depends on the product form in which the materials is to be used or the amount of material available for samples. Flat specimen geometry is preferred when the end product is a thin plate or sheet. Round cross-section specimens are preferred for products such as extruded bars, forgings and castings. Sada [10] used Response

Surface Methodology (RSM) to predict and optimize the weld strength properties (tensile strength and hardness) of a gas tungsten arc welded 10mm thick mild steel plate. To achieve a desired weld quality, the author examined the bead geometry and the mechanical properties related to the weld input parameters. The result showed that current and gas flow rate had the most significant effect on the tensile strength, but on the hardness, the gas flow rate and filler rod had the most significant effect. The result also showed optimal tensile strength of 497.555N/mm2 and Hardness of 192.556BHN at a current of 170.12 amp, voltage of 19.84 volt, gas flow rate of 23.92 l/min and filler rod diameter of 2.4mm. Benyounis and Olabi [11] applied RSM to investigate the effect of laser welding parameters (laser power, welding speed and focal point position) based on four responses (heat input, penetration, bead width and width of HAZ) in CO_2 laser butt-welding of medium carbon steel plates of 5 mm thick. The authors established that the heat input plays an important role in the weld-bead parameters with welding speed having a negative effect while laser power had a positive effect on all the responses. Etin-Osa and Ebhota [12] predicted the weld tensile strength of TIG mild steel welds using RSM, with the purpose of achieving optimum results. The input parameters considered include current, voltage, and gas flow rate. The result showed weld tensile test of 596.218MPa with a desirability value of 95.70% resulting from the optimized process parameters of current of 120.00Amp, voltage of 20.00 volt and gas flow rate of 12.00L/min. Imtiaz et al. [13] optimized the combination of process parameters (traverse speed, rotational speed and tool geometry) while investigating their effect on the mechanical properties of a friction stir welded butt joint configuration of Polycarbonate. The essence is to substantiate the effect of the process parameters on the overall strength of the joint. The results showed that the butt joints fabricated at a traverse speed of 14 mm/min, rotational speed of 1700RPM and with simple cylindrical conical tool geometry yielded the maximum ultimate tensile strength of 51.299MPa. Jafari and Hajikhani [14] carried out a multi objective decision making for impregnability of needle mat using design of experiment technique and RSM while Prastyo et al. [15] worked on the reduction bottle cost of Milkuat LAB 70 ml using optimal parameter setting with Taguchi method. Onyekwere et al. [16] used experimental design and optimization techniques to investigate the best parameter settings for processing bamboo fibre polyester composites. It was found that optimum parameter setting for impact strength was achieved at mercerization treatment and 30wt% fibre content with impact strength of 158.23J/cm. For flexural strength, optimum parameter setting was found to be mercerization treatment at 50 wt % level of fibre content which resulted to flexural strength of 62.7MPa. The optimum parameter setting for tensile strength is observed at mercerized-acetylation treatment at 50 wt% fibre content with tensile strength of 72.96MPa. However, no significant difference, ($P < .005$) was observed in flexural strength, tensile strength and impact strength of mercerized and mercerized-acetylated fibre composites. The above literature has identified various areas of research on welded joints and its effect on materials. The objective of this study is to predict and optimize the tensile strength of a butt joint weldment on mild steel plate from thermal effect of the welding process using RSM.

2 | Research Methodology

The material used in this study is mild steel plate bought locally and moved to the Department of Production Engineering welding and fabrication workshop, University of Benin, Benin City, Edo State, Nigeria. The mild steel plate was cut into dimension 80mm x 40mm x 10mm with a power hacksaw, grinded and cleaned before the welding process. Two pieces of the mild steel plate were welded together using the input process parameters contained in TIG welding machine to form an I-section. 100% Argon gas was the shielding gas. The input process parameters comprises of the welding voltage, welding current, and Gas flow rate.

These input parameters were chosen out of the numerous parameters population because they represent the factors that contributed majorly to the process output. It is imperative to know that some factors do have strong influence on the response, others may have moderate effects and some no effects at all. The purpose of a well-designed experiment is to specify which set of factors in the process affects the process performance most, and then identify best levels for these factors capable of giving the desired quality level. The layout of the input process parameters was made into a matrix design. The Design matrix represented in *Fig. 1* shows the random distribution of the input parameters.

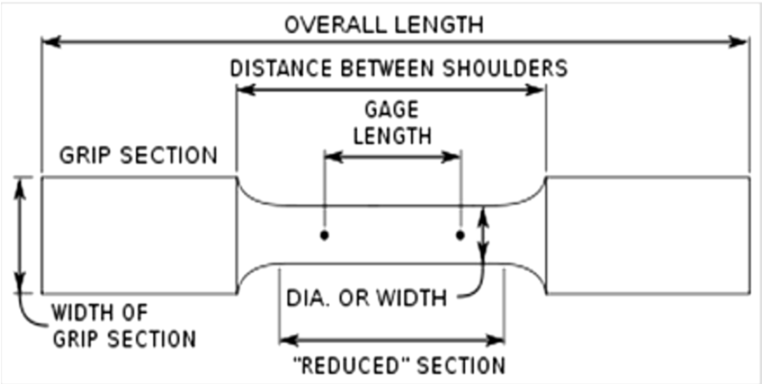

Fig. 1. Test specimen.

The range of the process parameters is shown in *Table 1*:

Table 1. Experimental factors and levels.

Factor	Units	Low Level (-1)	High Level (+1)
A – Current	I	120	170
B – Voltage	V	18	24
Gas Flow Rate	percent	13	16

The variables used were current (x_1), voltage (x_2) and gas flow rate (x_3) each at low (-1) and high (+1) coded levels. These limits were set based on the pilot study carried out prior the experimental runs. The actual levels of the variables for CCD experiments were selected based on the initial levels as the center points. A total of 20 experimental trials generated by the design expert 11.1.0.1 software adopting the central composite design were performed. The experimental data were analyzed according to the response surface regression procedure to fit the second-order polynomial equation in which the level of significance (p-value) of all coefficients was < 0.05. The Analysis of Variance (ANOVA) was carried out to estimate the effects of process variables such as welding current, voltage and gas flow rate and their possible interaction effects on the maximum tensile strength in the response surface regression procedure.

3 | Results and Discussion

Twenty (20) experimental runs were carried out. Each experimental runs comprises of the welding input parameters which are the welding current, voltage and gas flow rate. The response (tensile strength) was measured and the responses tabulated accordingly as shown in *Table* .

Before focusing on modeling the response as a function of the factors varied in this RSM experiment, it will be good to assess the impact of the blocking via a simple scatter plot. The correlation grid that pops up with the Graph Columns can be very interesting. First off, it was observed that it exhibits red along the diagonal - indicating the complete ($r = 1$) correlation of any variable with itself (Run vs Run, etc). The graph in *Fig. 2* is used to visually show or compare in the cases whereby more than one blocks are selected for our design, to see if there is a difference between block 1 and 2 or as the case may be and to see how strong the correlation between blocks factors and responses are?

Table 2. Design matrix showing the real values and the experimental values.

Std	Block	Run	Space Type	Factor 1 A: Current I	Factor 2 B: Voltage V	Factor 3 C:Gas Flow Rate Lit/min	Response 1 Tensile Strength Mpa
4	Block 1	1	Center	145	21	14.5	315.789
6	Block 1	2	Center	145	21	14.5	319.298
5	Block 1	3	Center	145	21	14.5	324.561
8	Block 1	4	Center	145	21	14.5	319.298
3	Block 1	5	Center	145	21	14.5	322.807
19	Block 1	6	Center	145	21	14.5	324.561
18	Block 1	7	Axial	145	15.95	14.5	350.877
17	Block 1	8	Axial	145	26.05	14.5	456.14
12	Block 1	9	Axial	102.96	21	14.5	280.702
13	Block 1	10	Axial	187.04	21	14.5	398.421
16	Block 1	11	Axial	145	21	11.96	368.421
9	Block 1	12	Axial	145	21	17.02	456.14
7	Block 1	13	Factorial	120	18	13	263.158
1	Block 1	14	Factorial	120	24	13	403.509
10	Block 1	15	Factorial	170	18	13	298.246
15	Block 1	16	Factorial	170	24	13	526.316
20	Block 1	17	Factorial	120	18	16	385.965
2	Block 1	18	Factorial	120	24	16	298.246
14	Block 1	19	Factorial	170	18	16	438.596
11	Block 1	20	Factorial	170	24	16	511.404

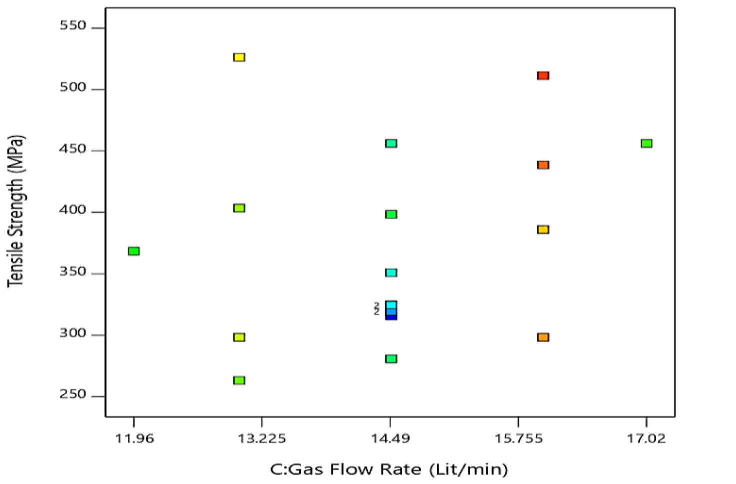

Fig. 2. Graph columns feature for design layout.

The ANOVA obtained from *Table 3* with P-value of 0.0001 less than 0.0500 shows that the model source for the tensile strength test is statistically significant. It is instructive to note that ANOVA is a statistical tool used to determine if there are any significant differences of means among two (2) or more groups. The Model F-value of 46.12 obtained from the above result show that the model is significant. The implication is that there is only a 0.01% chance that an F-value this large could occur due to noise. In this case A, B, C, AB, AC, BC, B^2, C^2 are significant model terms. The Lack of Fit F-value of 41.26 implies the Lack of Fit is significant. There is only a 0.05% chance that a Lack of Fit F-value this large could occur due to noise.

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Table 3. ANOVA for quadratic model.

Response 1: Tensile Strength						
Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model		9	11997.81	46.12	<0.0001	significant
A-Current		1	28298.85	108.77	<0.0001	
B-Voltage		1	20607.36	79.21	<0.0001	
C-Gas Flow Rate		1	6288.42	24.17	0.0006	
AB		1	7703.26	29.61	0.0003	
AC		1	1455.14	5.59	0.0396	
BC		1	18367.93	70.60	<0.0001	
A2		1	693.01	2.66	0.1337	
B2		1	12565.58	48.30	<0.0001	
C2		1	15343.42	58.97	<0.0001	
Residual		10	260.17			
Lack of Fit		5	508.03	41.26	0.0005	significant
Pure Error		5	12.31			
Cor Total		19				

Table 4. Model summary showing highest and lowest values of factors.

Name	Units	Type	Changes	Std. Dev.	Low	High
Current	I	Factor	E	0	120	170
Voltage	V	Factor	E	0	18	24
Gas flow rate	Lit/min	Factor	E	0	13	16
Tensile strength	Mpa	Response		16.1298	263.158	526.316

Result of *Table 4* revealed that the model is of the quadratic type which requires the polynomial analysis order as depicted by a typical response surface design. The minimum value of tensile strength was observed to be 263.158MPa with a maximum value of 526.316MPa and standard deviation of 16.1298. *Table 5* depicts the model summary statistics for the tensile test.

Table 5. Model summary statistics for tensile test.

Std. Dev.	0.1413	R^2	0.9711
Mean	3.59	Adjusted R^2	0.9450
C.V. %	3.94	Predicted R^2	0.7686
		Adequate Precision	19.0828

The statistics result observed in *Table 5* show the coefficient of determination (R-Squared) values of 0.9711. This demonstrate the strength of RSM and its ability to maximize the weld tensile strength. The Adjusted (R-Squared) values of 0.9450 indicates a model with 94.50% reliability. Besides, the Adequate Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Adequate precision values of 19.08 as gotten in *Table 5* indicate an adequate signal. The implication of this results is that the model employed can be used to navigate the design space and maximize the weld tensile test. The contour plots of tensile strength as a function of current and voltage is shown in *Fig. 3* while the response surface plot showing the interactive effect of input variables (current, voltage and gas flow rate) and the response variables (tensile strength) is shown in *Fig. 4*. The response surface curves were plotted to understand the interaction of the variables and to determine the optimum level of each variable for maximum response.

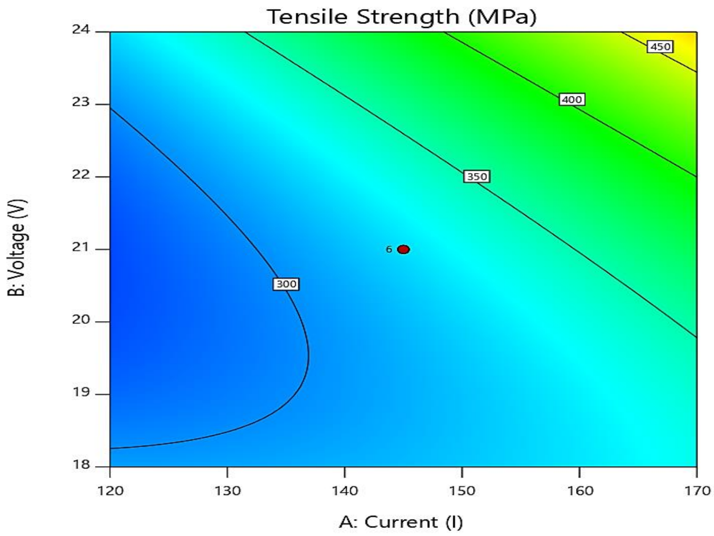

Fig. 3. Isoresponse contour plots showing effect of current, voltage and gas flow rate and their interactive effect on the tensile strength of mild steel plate.

Fig. 3 is a plot of tensile strength as a function of current and voltage at a mid-level slice of gas flow rate. This slice includes six center points as indicated by the dot at the middle of the contour plot. By replicating center points, you get a very good power of prediction at the middle of your experimental region. The contour plots in *Fig. 3* show the predicted optimization region of weld tensile test. The yellow region represents the area with the strongest tensile test. It was also observed that the weld current had a stronger effect on the tensile test. To examine the effects of combine variables such as the weld current and voltage at constant gas flow rate of 13 L/min, on the weld tensile test, the 3D surface plots presented in *Fig. 4* was employed.

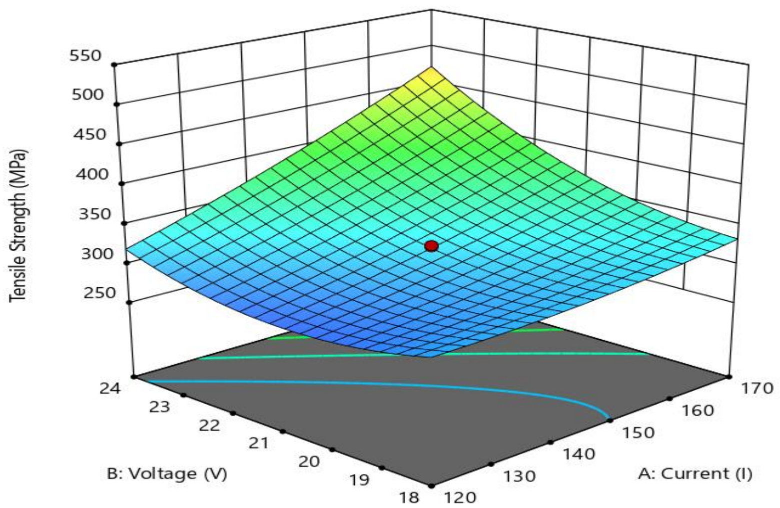

Fig. 4. Response surface plots showing effect of current, voltage and gas flow rate and their interactive effect on the tensile strength of mild steel plate.

The 3D surface plot shows the relationship between the input variables (current, voltage and gas flow rate) and the response variables (tensile strength). It is a 3 dimensional surface plot which was employed to give a clearer concept of the response surface. Although not as useful as the contour plot for establishing responses values and coordinates, this view may provide a clearer view of the surface. The presence of a coloured hole at the middle of the upper surface gave a clue that more points lightly shaded for easier identification fell below the surface. From the 3D surface plot provided in *Fig. 4*, it was also observed that an increase in current, significantly influence the tensile strength. The green area on the 3D mat represents the area with good tensile strength, while the blue area indicate the lowest tensile

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region. To maximize the tensile strength, process parameters that would result to responses in the green zone should be targeted. The achieved maximum desirability obtained point out that it is possible to reach maximum tensile strength of 450Mpa. The maximum tensile strength of 450Mpa was attained at the welding voltage (V) of 24V, current of 170A and gas flow rate of 13lit/min respectively which compared favourably well with the optimal tensile strength of 497.555N/mm^2 observed at a current of 170.12Amp, voltage 19.84 volt, gas flow rate 23.92 l/min by Sada [10] and weld tensile test of 596.218MPa observed at a current of 120.00Amp, voltage of 20.00 volt and gas flow rate of 12.00 L/min by Etin-Osa and Ebhota [12].

4 | Conclusion

The Central Composite Design in RSM employed was effective in carrying out the prediction and optimization process to predict and optimized the maximum tensile strength of a butt joint weldment on an I-section mild steel plate using TIG welding process. The optimum values for the responses (tensile strength), as well as their corresponding input parameters were obtained. Using the RSM, the tensile strength was modeled with quadratic regression model as functions of the process parameters of current, voltage and gas flow rate. Model adequacy checks was carried out through the use of the ANOVA. The study revealed that the current and voltage employed has a very strong influence on the tensile strength of the welded material. Based on the findings, it is summarized that the tensile strength reaches optimum value of 450Mpa when the welding voltage is 24V, current is 170A and gas flow rate is 13lit/min respectively.

Conflict of Interest

There is no conflict of interest in connection with this paper, and the material described here is not under publication or consideration for publication elsewhere.

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References

[1] Sathish, R., Naveen, B., Nijanthan, P., Geethan, K. A. V., & Rao, V. S. (2012). Weldability and process parameter optimization of dissimilar pipe joints using GTAW. *International journal of engineering research and applications*, *2*(3), 2525-2530.

[2] Kim, I. S., Son, J. S., Park, C. E., Kim, I. J., & Kim, H. H. (2005). An investigation into an intelligent system for predicting bead geometry in GMA welding process. *Journal of materials processing technology*, *159*(1), 113-118.

[3] Mohandas, T., Reddy, G. M., & Naveed, M. (1999). A comparative evaluation of gas tungsten and shielded metal arc welds of a "ferritic" stainless steel. *Journal of materials processing technology*, *94*(2-3), 133-140.

[4] Khourshid, A. M., & Sabry, I. (2016). Analysis of welded joints using friction stir welding, metal inert gas and tungsten inert gas. *Engineering and technology in India*, *7*(1), 1-7.

[5] Ramachandran, R. (2015). Analysis and experimental investigations of weld characteristics for a TIG welding with SS316l. *International journal of advances in engineering research (IJAER), VOL*, (10), 2454-1796.

[6] Hooda, A., Dhingra, A., & Sharma, S. (2012). Optimization of MIG welding process parameters to predict maximum yield strength in AISI 1040. *International journal of mechanical engineering and Robotics research*, *1*(3), 203-213.

[7] Armentani, E., Esposito, R., & Sepe, R. (2007). The effect of thermal properties and weld efficiency on residual stresses in welding. *Journal of achievements in materials and manufacturing engineering*, *20*(1-2), 319-322.

[8] Lakshminarayanan, A. K., Shanmugam, K., & Balasubramanian, V. (2009). Effect of autogenous arc welding processes on tensile and impact properties of ferritic stainless steel joints. *Journal of iron and steel research, international*, *16*(1), 62-68.

[9] Arunkumar, A., & Ravichandran, S. (2017). Theoretical and experimental analysis of t-joint in TIG welding process. *International journal of scientific engineering and applied science*, *2*(6), 237-246.

[10] Sada, S. O. (2018). Optimization of weld strength properties of tungsten inert gas mild steel welds using the response surface methodology. *Nigerian journal of technology*, *37*(2), 407-415.

[11] Benyounis, K. Y., & Olabi, A. G. (2008). Optimization of different welding processes using statistical and numerical approaches–A reference guide. *Advances in engineering software*, *39*(6), 483-496.

[12] Etin-Osa, C. E., & Ebhota, L. M. (2021). Prediction of optimum weld tensile strength using response surface methodology. *European journal of engineering and technology research*, *6*(3), 146-149.

[13] Imtiaz, A., Tariq, A., Janjua, A. B., Sarfraz, F., & Khawaja, A. U. H. (2021). Parametric optimization of butt welded polycarbonate using response surface methodology. *Mehran university research journal of engineering & technology*, *40*(1), 38-52.

[14] Jafari, H., & Hajikhani, A. (2016). Multi objective decision making for impregnability of needle mat using design of experiment technique and respond surface methodology. *Journal of applied research on industrial engineering*, *3*(1 (4)), 30-38.

[15] Prastyo, Y., Adhi Yatma, W., & Hernadewita, H. (2018). Reduction bottle cost of Milkuat LAB 70 ml using optimal parameter setting with Taguchi method. *Journal of applied research on industrial engineering*, *5*(3), 223-238.

[16] Onyekwere, O. S., Oladeinde, M. H., & Uyanga, K. A. (2020). Optimization of parameter settings to achieve improved tensile and impact strength of bamboo fibre composites. *Journal of applied research on industrial engineering*, *7*(4), 344-364.

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