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Application of Optimization Techniques in Enhancing the Mechanical Properties of Mild Steel SAE10XX Welds

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Abstract

In order to enhance the mechanical properties of steel structures and reduce their frequent failures, there is a need to increase the quality of welded steel joints. Proper monitoring of key welding parameters that affect the welding process can produce quality weldments with good mechanical properties. In this research, the optimization of mechanical properties of welded mild steel SAE10XX joints was carried out using the shielded metal arc welding (SMAW). Three independent variables—welding speed, welding current, and arc voltage—were studied at 3 levels in the Central Composite Design (CCD) of the Response Surface Methodology (RSM) to ascertain their influence on the three responses: tensile strength, impact strength, and hardness. The quadratic model was more suitable to fit the experimental data. The welded joint optimum hardness, tensile strength, and impact strength were obtained as 165.628 BHN, 551.090 N/mm², and 0.90 J/mm², respectively, at a current of 103.396 A, a speed of 246.019 mm/min, and a voltage of 221.696 V. From the analysis of variance (ANOVA) carried out, the models' R^2 values were 0.9167, 0.9910, and 0.9962, respectively, for the hardness, tensile strength, and impact strength models, which showed that the models' ability to predict the mechanical properties in the welding process is high. The resulting weldment exhibits high tensile, hardness, and impact values, indicative of its robustness and suitability for applications requiring resilience.

1.0 Introduction

Welding is a crucial aspect of engineering practices and plays a critical role in the manufacturing sector. Construction and manufacturing industries rely on welding to join alloys and steels in creating modern structures, machine parts, and vehicle bodies for the automobile industry, among many other applications [1]. However, despite these advantages, welded joints are often susceptible to defects like porosity and cracking when exposed to certain environments due to their high corrosion tendency [2-3]. Cracks in welded joints result from factors like thermal and residual stresses, properties of the material, improper welding parameters, and environmental factors [4]. Cracks can significantly weaken welded joints, compromising their mechanical performance, and making these joints the most vulnerable points in a structure [5].Improving the properties of weldments to enhance the reliability and integrity of welded steel materials and reduce the rate of corrosion has become a subject of interest for manufacturers and researchers. Many researchers [6-7] have investigated the influence of weld parameters on the corrosion and mechanical properties of mild steel, though their studies were localized to specific environments and cannot be generalized. Afolabi [8] studied the influence of welding parameters—power input, weld geometry, welding speed, and post-weld heat treatment—on the corrosion behavior of stainless steel in a chloride medium. The results revealed that all the considered parameters significantly influenced the material's corrosion rate. Chuka et al. [9] studied the influence of weld parameters on the corrosion behavior and mechanism of mild steel in five different environments and observed that weld parameters affect the corrosion rate of mild steel in all environments. The values of weld parameters that can produce quality weldments in one environment may not produce desirable weld properties in another environment with different corrosion-causing agents [10-11].Environmental conditions dynamically influence corrosion rates and ultimately affect the mechanical properties of welded joints. Therefore, a more generalized welding parameter iteration should be sought to achieve desirable weld joint properties across different environments [12]. Lofinmakin et al. [13] report that improving weld quality critically depends on the careful selection of welding parameters, considering their key effect on the performance of the welded joint. Hutsaylyuk et al [14] emphasize that manufacturers recognize these parameters as major components of established welding procedures influencing the corrosion resistance and mechanical strength of welded joints. Sada and Achebo [15] list factors such as weld current, travel speed, weld voltage, cooling rate, heat input, shielding gas flow, and electrode size, stating that randomly employing these parameters can negatively impact the heat-affected zone (HAZ), resulting in inadequate penetration and improper weld bead geometry. However, Szusta et al. [16] that achieving reliable and strong joints depends greatly on optimizing welding parameters to suit specific materials and desired functions. According to Prabhakar et al. [17], for a weldment with desirable corrosion control and mechanical properties, the optimization of key weld parameters is crucial. The optimization of suitable experimental data can help control weld parameters to guarantee good weldment.

One of the most effective and robust statistical tool for studying the interactive influence of process parameters is the Response Surface Methodology (RSM) [18]. RSM can effectively model complex nonlinear interactions and produce very reliable results. Additionally, the systematic experimental design inherent in RSM minimizes the number of required trials compared to traditional methods, thereby conserving time and resources [19].
In order to produce welded steel joints with enhanced reliability and integrity, this study employs the Central Composite Design (CCD) of the Response Surface Methodology (RSM) to investigate the effects of three key welding parameters—welding speed, welding current, and arc voltage—on the mechanical properties of welded mild steel SAE10XX joints. The optimization of these parameters using the shielded metal arc welding (SMAW) will help in identifying optimal conditions that significantly improve tensile strength, impact strength, and hardness. The findings from this study will greatly contribute to the development of weldments with high mechanical properties and thus prevent the rising cases of failures of steel structures.

2. Materials and Method

The rectangular mild steel bar, and mild steel electrode wire (ER70S-6), were purchased at Onitsha Main Market, Nigeria. The equipment used included a commercial arc welding machine (Fronius Model NW2200), digital weighing balance, grinding machine, digital optical thermometers, thermocouple devices, universal testing machine, impact testing machine (Model 6701, capacity 120 ft. LB), electronic compact scale (Model BL20001), Brinell hardness testing machine, and guillotine shear (EDWARDS, model 3.25/300). Mild steel bars were welded using a Fronius NW2200 machine. The chemical composition was analyzed using optical emission spectroscopy (OES) and confirmed with atomic absorption spectroscopy (AAS). The chemical composition of the steel is presented in Table 1.

Table 1:Chemical composition of the mild steel sample

Element	Carbon	Manganese	Silicon	Sulphur	Phosphorus	Iron
Percentage	0.18	0.65	0.03	0.04	0.023	99.08

Joint tensile strength was evaluated with a universal testing machine, while toughness was measured using an impact testing machine (Model 6701) [20]. Hardness was assessed with a Brinell hardness tester.

2.1 Experimental Design of Welding Parameters.

The experimental study was designed using Response Surface Methodology (RSM) with a Central Composite Design (CCD) in Design Expert-DX13, considering multiple factor interactions. The RSM was based on the Central Composite Design (CCD), where independent variables were varied at five different levels (-α, -1, 0, +1, +α), resulting in a total of twenty experimental samples. This approach provided two replicates for both the factorial points and axial (star) points to increase the experiment's accuracy. α was determined using Equation 1 [21].

$$\alpha = (2^k)^{1/4} \quad (1)$$

where k is the number of independent variables. The axial points (X_{axial}) were determined using Equation 2 [21].

$$X_{axial} = X_{centre} \pm \alpha \quad (2)$$

where X_{centre} (the centre point value) is calculated using Equation 3 [21]

$$X_{centre} = \frac{X_{low}+X_{high}}{2} \quad (3)$$

The number of experimental runs (N) is given according to Equation 4 [21].

$$N = 2k(k-1) + X_{centre} (4)$$

where k represents the number of independent variables used and X_{centre} is the center point.
The welding parameters and their levels considered in the study are presented in Table 2.

Table 2: Factors and levels used for the welding parameter

Welding Parameters	Symbol	Unit	Levels		
			Low (-)	Centre (o)	High (+)
Current	X_1	Amp	90	100	110
Speed	X_2	mm/min	200	300	400
Voltage	X_3	Volts	220	225	230

The interaction between these factors was investigated, and optimization was performed to achieve the desired outcomes.

2.3 Optimization using Centre Composite Design (CCD)

Response Surface Methodology was used to optimize the welding operations, with welding current, voltage, and speed as independent variables to maximize the tensile strength, hardness, and impact strength of the weldment. The CCD was used to study the effects of the variables on their responses and subsequently in the optimization studies. This method is suitable for fitting a quadratic surface and it helps to optimize the effective parameters with a minimum number of experiments, as well as to analyze the interaction between the parameters [22].

The response was formulated as a function of the three independent variables based on the quadratic model according to Equation 5 [23].

$$Y = b_0 + \sum_{i=1}^{n} b_i X_i + \sum b_{ii} X_i^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} b_{ij} X_i X_j + \varepsilon \quad (5)$$

The response is denoted by Y, while b_0, b_i, b_{ii}, and b_{ij} are the constant, linear, quadratic, and interactive coefficients, respectively. The independent variables are denoted by X_i and X_j, while ε represents the model error. A statistical analysis was performed using Analysis of Variance (ANOVA) based on the p-value and F-value was carried out to test for the models' adequacy. The significance of each term was assessed to determine its goodness of fit. Response surfaces were generated to examine the individual and interactive effects of the test variables on the tensile strength, hardness, and impact strength of the weldment. The optimal values of the test variables were initially obtained in coded units and then converted to uncoded units.

3. Results and Discussion

3.1.1 Effect of Factors on Mechanical Test

Table 3 displays the results of the tensile test, hardness test, and impact test of the welded mild steel for the 20 runs (based on Equation 4) of the combined factors (X_1: current, X_2: speed, and X_3: voltage).

Table 3:Central Composite Design matrix and the responses

	Factors			Responses		
Run	X_1 Current (Amp)	X_2 Speed (mm/min)	X_3 Voltage (Volt)	Hardness test (BHN)	Tensile test (MPa)	Impact test (J/mm^2)
1	110	400	220	165	553	0.912
2	100	300	225	166	548	0.910
3	100	300	225	164	544	0.882
4	100	300	225	166	548	0.917
5	110	200	220	167	529	0.744
6	100	300	225	166	538	0.878

7	117	300	225	167	568	0.919
8	110	200	230	168	532	0.982
9	90	200	230	165	548	0.903
10	90	200	220	166	541	0.936
11	110	400	230	166	526	0.875
12	83	300	225	168	517	0.728
13	100	468	225	167	560	1.020
14	100	131	225	166	553	0.826
15	90	400	230	165	548	0.917
16	90	400	220	166	548	0.917
17	100	300	225	168	521	0.977
18	100	300	225	167	529	0.962
19	100	300	216	166	548	0.910
20	100	300	233	167	565	1.110

Table 4 obtained from the RSM model shows the analysis of variance for the quadratic hardness model shown in Equation 5.

$$H = 1025.84 - 4.75882X_1 - 5.69373X_3 - 0.00075X_1X_2 + 0.015X_1X_3 - 0.001X_2X_3 + 0.0060021X_1^2 + 0.002172X_3^2 \quad (5)$$

where, H is hardness value, X_1 is current, X_2 is welding speed, and X_3 is voltage. The developed model shows the effect of the interaction of the various factors on the hardness of the welded joints. High hardness is an extremely desirable property in design and welded materials. It determines the suitability of a material or an indicator of metal microstructure, which influences how effective a heat-treating process is for a given application [24]. Table 4 provides a summary of the analysis of variance (ANOVA) for the quadratic model of hardness, highlighting the significance of each factor and their interactions.

Table 4:Analysis of variance summary for Quadratic model of Hardness

	SS	DF	MS	FP	P	
Model	20.35	9	2.26	12.23	0.0003	Significant
X_1-Current	2.36	1	2.36	12.78	0.0050	Significant
X_2-Speed	0.2929	1	0.2929	1.58	0.2368	Not Significant
X_3-Voltage	0.9926	1	0.9926	5.37	0.0430	Significant
X_1X_2	4.50	1	4.50	24.34	0.0006	Significant
X_1X_3	4.50	1	4.50	24.34	0.0006	Significant
X_2X_3	2.00	1	2.00	10.82	0.0082	Significant
X_1^2	5.19	1	5.19	28.08	0.0003	Significant
X_2^2	0.0704	1	0.0704	0.3806	0.5511	Not Significant
X_3^2	0.8768	1	0.8768	4.74	0.0545	Significant
Residual	1.85	10	0.1849			
Lack of Fit	0.5157	5	0.1031	0.3868	0.8397	Not significant
Pure Error	1.33	5	0.2667			
Cor Total	22.20	19				

The model F-value of 12.23 signifies that the model is significant, with only a 0.03% probability. Such a high F-value could be due to random variation while P-values below 0.05 indicate significant model terms. Specifically, the terms for current (X_1), voltage (X_3), and the interaction terms (X_1X_2, X_1X_3, X_2X_3) are significant, along with the quadratic term for current (X_1^2). The Lack of Fit F-value of 0.39 suggests that the Lack of Fit is not significant relative to the pure error, with an 83.97% probability that this high Lack of Fit F-value is due to random variation. This implies that the model fits the data well, and the residuals are mainly due to random error rather than a poor model fit.

The fit statistics for the hardness test are presented in Table 5. The Predicted R^2 of 0.7375 is in reasonable agreement with the Adjusted R^2 of 0.8417. Additionally, the high correlation coefficient of 0.9167 indicates that the generated model is very reliable and can effectively predict the hardness of the welded mild steel..

Table 5: Fit Statistics Summary of Hardness

Std. Dev.	0.4300	R^2	0.9167
Mean	166.30	Adjusted R^2	0.8417
C.V. %	0.2586	Predicted R^2	0.7375
		Adeq Precision	13.2204

The 3D surface plots for hardness are presented in Figures 1a-1c.

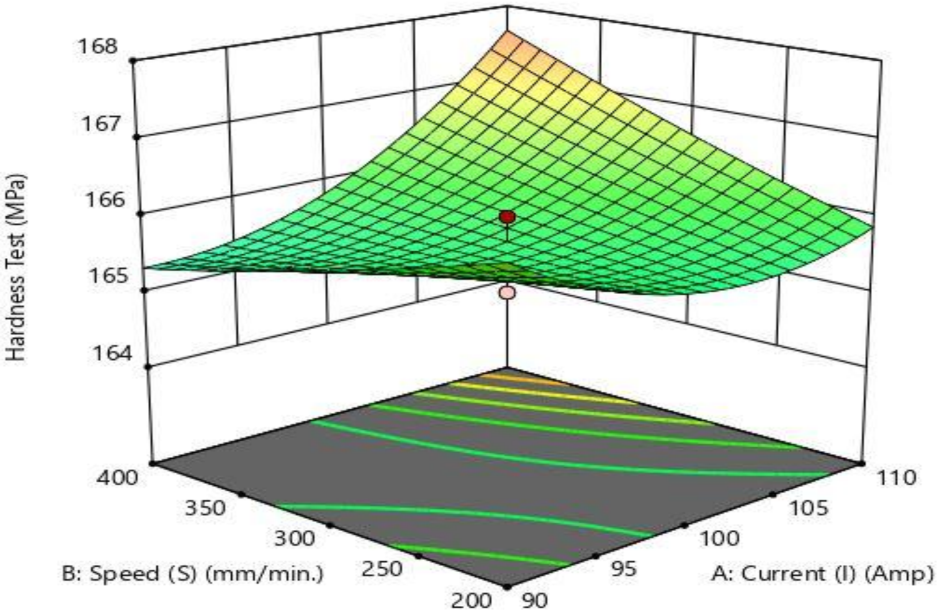

Figure 1a: 3D plot of the influence of current and speed on hardness

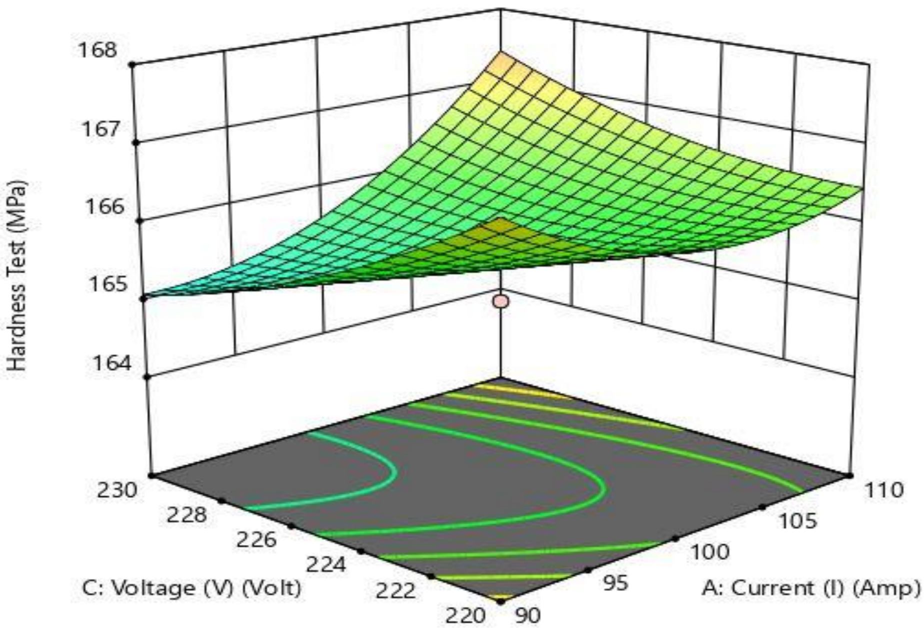

Figure 1b: 3D plot of the influence of current and voltage on hardness

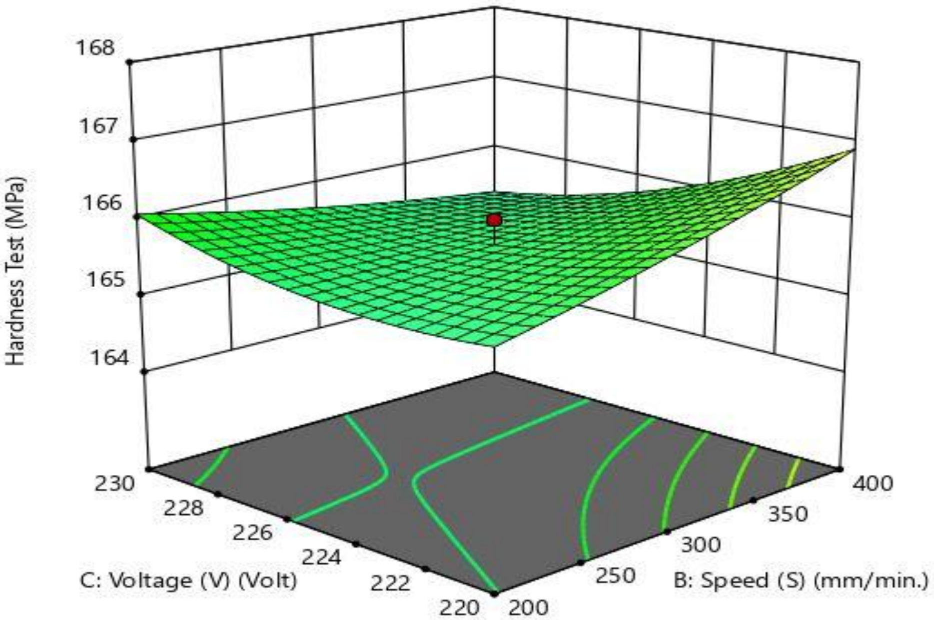

Figure 1c: 3D plot of the influence of speed and voltage on hardness

Hardness is influenced by both current and speed, as depicted in Figure 1a. A maximum hardness of 165.21 BHN was achieved at a current of 92.5383A and a speed of 319.839 mm/min. Similarly, Figure 1b illustrates that hardness rises with increasing current and voltage, with a maximum of 165.21 BHN attained at a current of 92.5383A and a voltage of 227.545V. Furthermore, Figure 1c indicates that the maximum hardness of 167.5 BHN occurred at a current of 92.5383A, a speed of 319.839 mm/min, and a voltage of 227.545V. These figures collectively demonstrate that hardness increases with higher current, speed, and voltage.

3.1.2 Effect of factors on Tensile Strength

Table 6 obtained from the RSM model shows the analysis of variance for the quadratic tensile strength model shown in Equation 6.

$$Tensile = 8400.8 + 11.8X_1 - 79.365X_3 - 0.01475X_1X_2 + 0.04X_1X_3 - 0.01X_2X_3 - 0.082441X_1^2 - 0.000311757X_2^2 + 0.172282X_3^2 \quad (6)$$

where, X_1 is current, X_2 is speed, and X_3 is voltage. Equation 6 indicates that tensile strength is a function of current, speed and voltage. Based on statistical analysis using CCD techniques, the significance of the model between the factors; welding current, speed, and voltage with respect to tensile strength is presented in Table 6.

Table 6:Analysis of variance summary for Quadratic model of Tensile Strength

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	3705.38	9	411.71	121.74	< 0.0001	Significant
X_1-Current	17.49	1	17.49	5.17	0.0463	Significant
X_2-Speed	1.80	1	1.80	0.5315	0.4827	Not significant
X_3-Voltage	239.80	1	239.80	70.91	< 0.0001	Significant
X1X2	1740.50	1	1740.50	514.65	< 0.0001	Significant
X1X3	32.00	1	32.00	9.46	0.0117	Significant
X2X3	200.00	1	200.00	59.14	< 0.0001	Significant
$X_1$2	979.46	1	979.46	289.62	< 0.0001	Significant
X22	140.07	1	140.07	41.42	< 0.0001	Significant
X32	267.34	1	267.34	79.05	< 0.0001	Significant

The model F-value of 121.74 indicates that the model is highly significant, with less than a 0.01% chance that such a large F-value could arise from noise. P-values below 0.05 show that the model terms are significant. In this model, all terms are significant except for X_2 (speed). This includes current (X_1), voltage (X_3), and their interaction terms (X_1X_2, X_1X_3, X_2X_3), as well as the quadratic terms for current (X_1^2), speed (X_2^2), and voltage (X_3^2).
Table 7 displays the fit statistics for the tensile strength. It demonstrates that the Predicted R^2 of 0.9305 and the Adjusted R^2 of 0.9828 are reasonably in agreement. The generated model can accurately predict the tensile strength of the welded mild steel, as evidenced by the high correlation coefficient of 0.9910.

Table 7: Fit Statistics Summary of Tensile Strength

Std. Dev.	1.84	R^2	0.9910
Mean	543.20	Adjusted R^2	0.9828
C.V. %	0.3386	Predicted R^2	0.9305
		Adeq Precision	38.5612

The 3D surface plots for tensile strength are presented in Figure 2 (a-c).

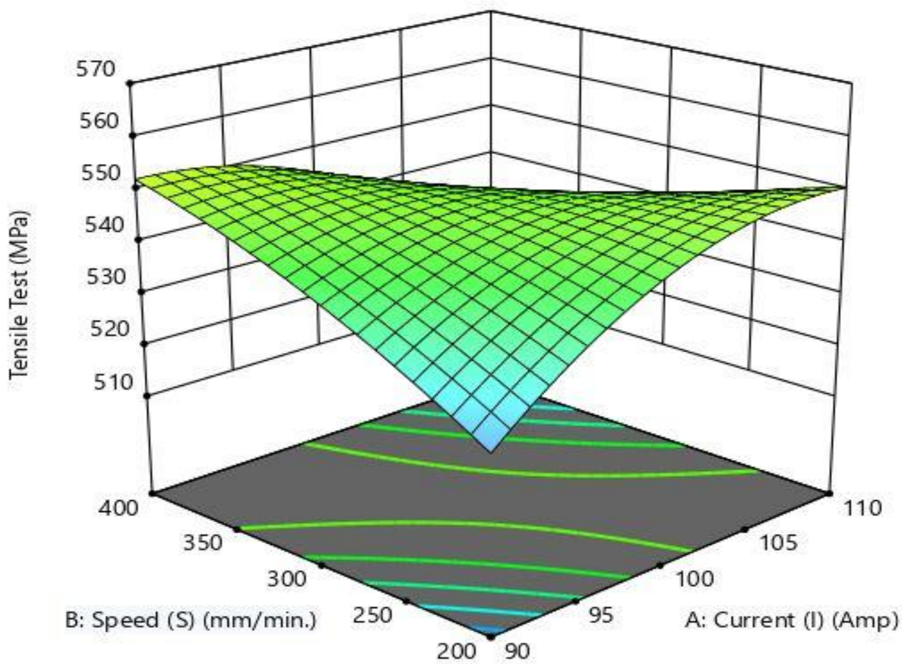

Figure 2a:3D plot of the influence of current and speed on tensile strength

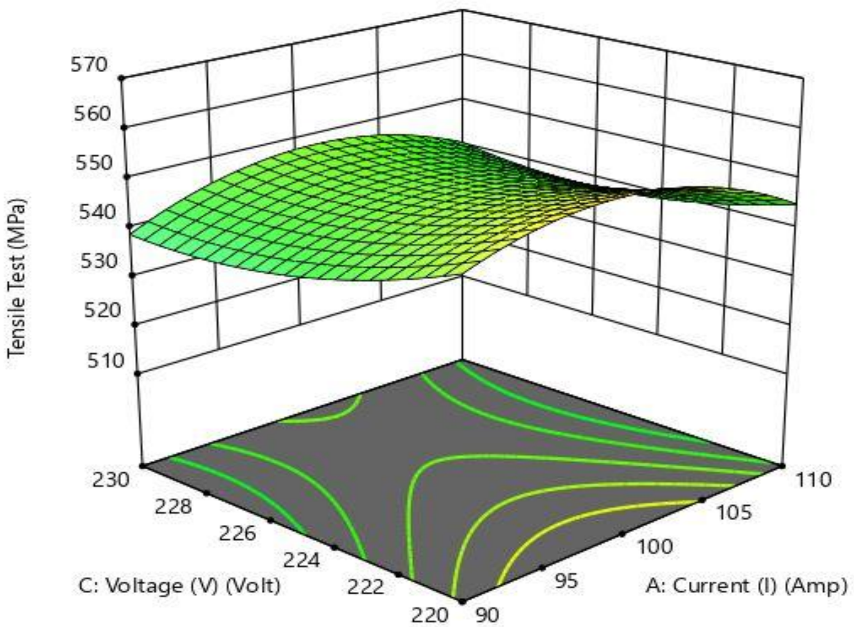

Figure 2b:3D plot of the influence of current and voltage on tensile

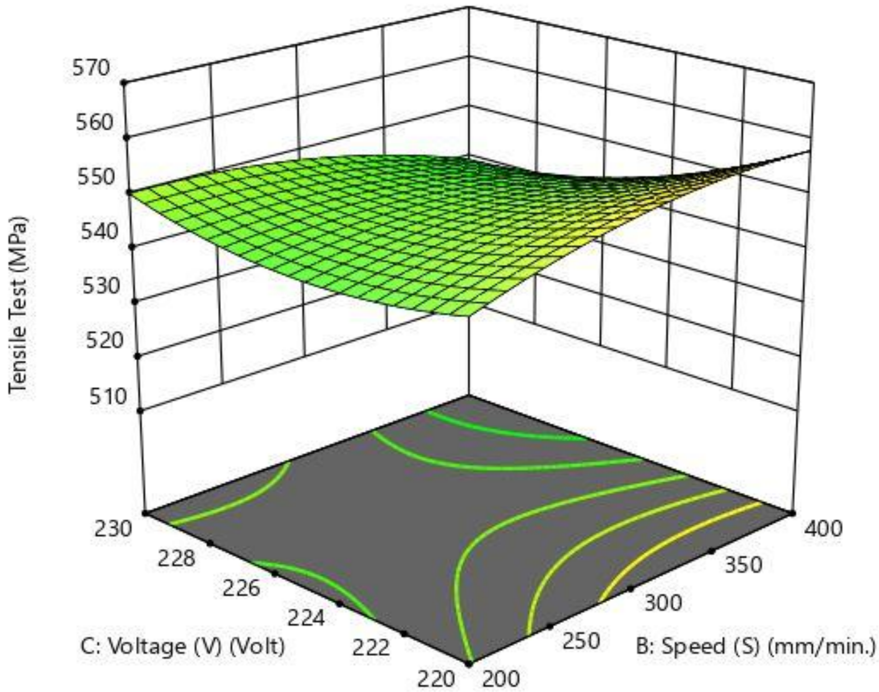

Figure 2c:3D plot of the influence of speed and voltage on tensile

The impact of current and speed on the tensile test is shown in Figure 2a. Tensile decreases with increasing speed and current; a maximum of 551 MPa was obtained at 92.5383 A current and 319.839 mm/min speed, whereas Figure 2b shows that tensile decreases with increasing voltage; a maximum of 539 MPa was obtained at 92.5383 A current and 227.545 V voltage. Maximum tensile strength of 550 MPa was attained at a speed and voltage of 319.839 mm/min and 227.545 volts, respectively, as shown in Figure 2c as well.

3.1.3 Effect of factors on Impact test

Table 8 obtained from the RSM model shows the analysis of variance for the quadratic impact strength model shown in Equation 7.

$$I = -46.0169 + 0.04841X_2 + 0.351772X_3 - 0.5X_1X_2 - 0.0001225X_1X_2 - 0.00018025X_2X_3 + 0.000181116X_1^2 - 0.000647324X_3^2 \quad (7)$$

Where I represent impact strength, X_1 denotes current, X_2 signifies speed, and X_3 indicates voltage. Equation 7 illustrates that impact strength is a function of current, speed, and voltage.
The analysis of variance for the quadratic impact model is presented in Table 8.

Table 8: Analysis of variance summary for Quadratic model of Impact

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.1357	9	0.0151	292.52	< 0.0001	Significant
X_1-Current	0.0002	1	0.0002	4.49	0.0601	Not significant
X_2-Speed	0.0045	1	0.0045	87.78	< 0.0001	Significant
X_3-Voltage	0.0117	1	0.0117	226.69	< 0.0001	Significant
X1X2	0.0443	1	0.0443	858.81	< 0.0001	Significant
X1X3	0.0003	1	0.0003	5.82	0.0365	Significant
X2X3	0.0650	1	0.0650	1261.06	< 0.0001	Significant
X_1^2	0.0047	1	0.0047	91.74	< 0.0001	Significant
X_2^2	0.0002	1	0.0002	4.44	0.0613	Not significant
X_3^2	0.0038	1	0.0038	73.25	< 0.0001	Significant
Residual	0.0005	10	0.0001			
Lack of Fit	0.0004	5	0.0001	2.15	0.2097	Not significant
Pure Error	0.0002	5	0.0000			
Cor Total	0.1362	19				

The model F-value of 292.52 indicates that the model is highly significant, with less than a 0.01% chance that such a large F-value could occur due to noise. P-values below 0.05 signify that the model terms are significant.
Table 9 presents the fit statistics for the tensile test, showing that the predicted R^2 value of 0.9787 and the adjusted R^2 value of 0.9928 are in close agreement. The high correlation coefficient of 0.9962 demonstrates that the generated model can accurately predict the impact strength of the welded mild steel.

Table 9: Fit Statistics Summary of Impact Test

Std. Dev.	0.0072	R^2	0.9962
Mean	0.9113	Adjusted R^2	0.9928
C.V. %	0.7877	Predicted R^2	0.9787
		Adeq Precision	74.7181

The 3D surface plots for tensile tests are presented in Figure 3 (a-c). The impact of current and speed on impact results is shown in Figure 3a. Figure 3b shows that impact decreases with increasing current and voltage, with a maximum of 0.9083 J/mm^{2}obtained at 92.5383A current and 227.545V voltage. It shows that impact decreases with increasing current and speed, with a maximum of 0.9083 J/mm^2 obtained at 92.5383A current and 319.839mm/min speed. Maximum impact strength of 0.9083 J/mm^2 was attained at a speed and voltage of 319.839 mm/min and 227.545 volts, respectively, as shown in Figure 3c.

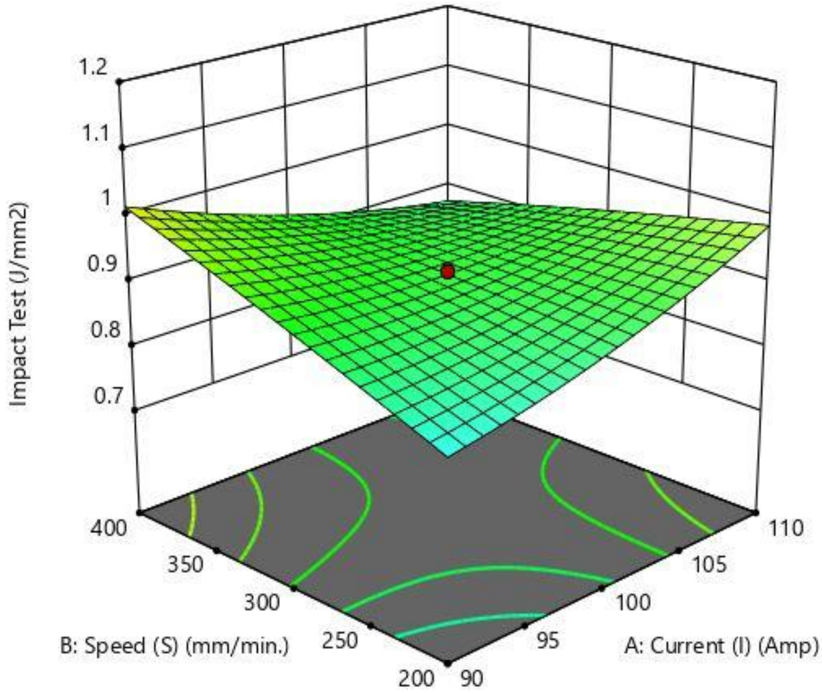

Figure 3a: 3D plots of the influence of current and speed on impact

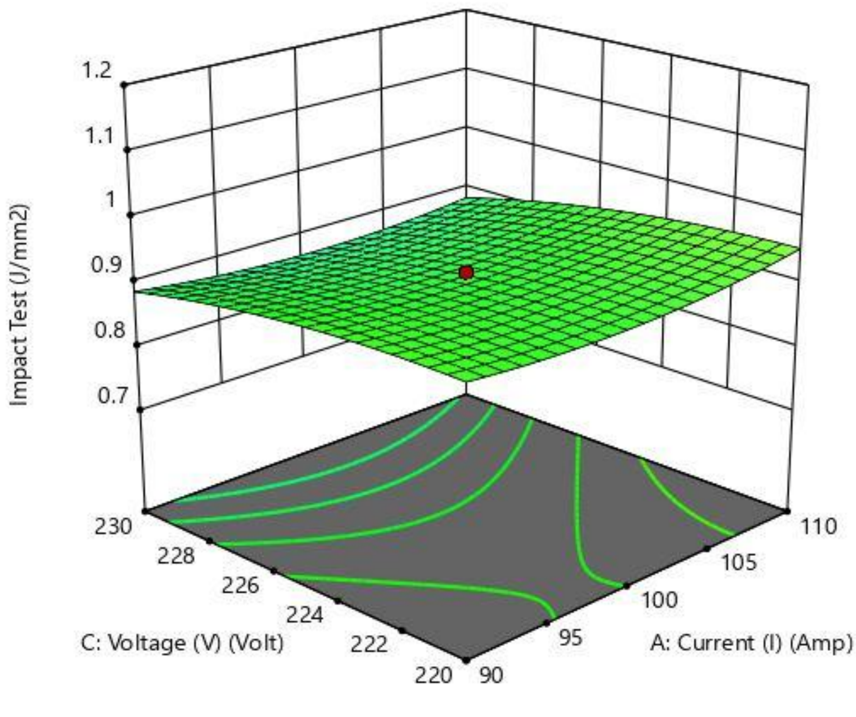

Figure 3b: 3D plots of influence of current and voltage on impact

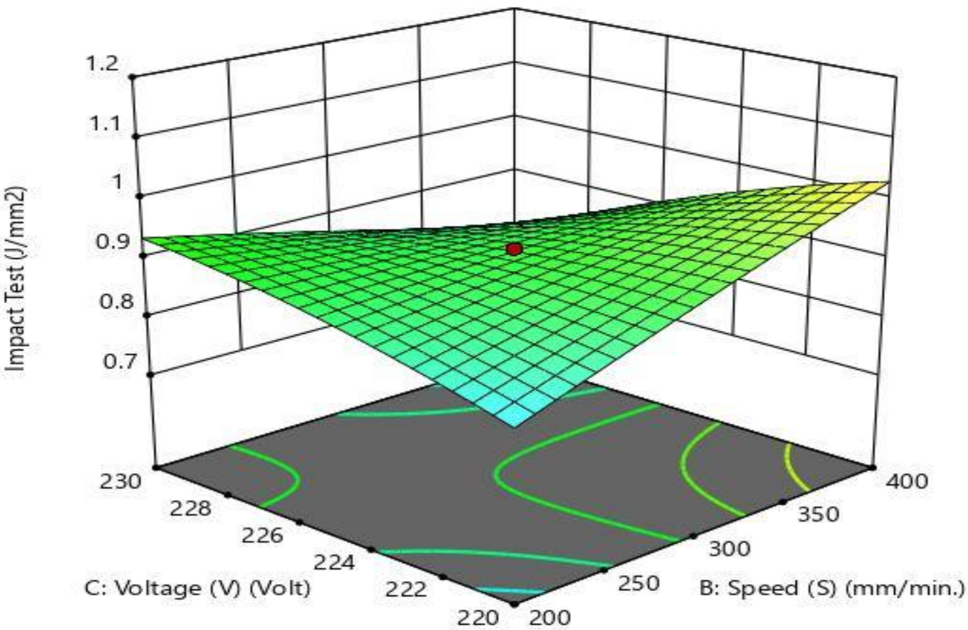

Figure 3c: 3D plots of the influence of speed and voltage on impact

3.2 Optimization

The optimization of the welding processes and parameters for the welded joint was performed using the optimization tool in the Design Expert software. All independent variables were set within the ranges examined during the experimental process. The dependent variables, including tensile strength, hardness, and impact strength, were optimized to achieve their maximum values. Table 10 shows the optimization solutions for the welding process parameters.

Table 10: Optimization Solutions

Number	Current (I)	Speed (S)	Voltage (V)	Hardness Test	Tensile Test	Impact Test	Desirability	
1	*103.396*	*246.019*	*221.696*	165.628	551.090	0.900	1.000	Selected
2	*90.000*	*200.000*	*230.000*	166.259	526.517	0.881	1.000	
3	*110.000*	*400.000*	*220.000*	167.923	531.909	0.984	1.000	
4	*110.000*	*200.000*	*230.000*	167.091	557.753	1.026	1.000	
5	*90.000*	*200.000*	*220.000*	167.298	528.897	0.747	1.000	
6	*90.000*	*400.000*	*230.000*	164.052	545.291	0.886	1.000	
7	*110.000*	*400.000*	*230.000*	167.884	517.528	0.733	1.000	
8	*110.000*	*200.000*	*220.000*	165.130	552.134	0.916	1.000	
9	*90.000*	*400.000*	*220.000*	167.091	567.672	1.112	1.000	
10	*97.651*	*373.102*	*220.195*	166.632	560.398	1.012	1.000	
11	*103.031*	*305.621*	*223.144*	165.937	548.663	0.927	1.000	
12	*100.388*	*263.678*	*220.389*	165.901	553.670	0.890	1.000	
13	*96.870*	*282.623*	*226.501*	165.517	545.933	0.901	1.000	
14	*107.246*	*253.180*	*223.361*	165.843	547.953	0.936	1.000	
15	*102.715*	*360.807*	*222.448*	166.323	547.829	0.952	1.000	
16	*96.639*	*307.800*	*227.128*	165.400	546.350	0.899	1.000	
17	*93.950*	*335.756*	*220.964*	166.430	556.955	0.975	1.000	
18	*94.533*	*257.025*	*227.574*	165.578	541.814	0.892	1.000	
19	*102.250*	*276.378*	*220.569*	165.906	553.691	0.909	1.000	
20	*91.674*	*331.436*	*222.070*	166.301	552.514	0.972	1.000	

The optimization tool yielded a set of solutions, among which one with a desirability of 1.0 and corresponding to a hardness of 165.628 BHN, tensile strength of 551.090 N/mm², and impact strength of 0.9 J/mm² was chosen. This selection prioritized high values for all three responses, aligning with desired outcomes. The findings, summarized in Table 11, underscore the accuracy of the predictive models for welded hardness, tensile, and impact strengths at optimal levels of independent variables. Among the twenty solutions proposed by the optimization tool, the software identified optimal values of 103.396 A for current, 246.019 mm/min for speed, and 221.696 V for voltage while adhering to specified constraints. These values represent the ideal welding compositions and parameters for mild steel welding. Consequently, employing a current of 103.396 A, a speed of 246.019 mm/min, and a voltage of 221.696 V ensures the mechanical properties of the weldment, achieving a hardness of 165.628 BHN, tensile strength of 551.090 N/mm², and impact strength of 0.90 J/mm². The resulting weldment exhibits high tensile, hardness, and impact values, indicative of its robustness and suitability for applications requiring resilience.

4. Conclusion

The process optimization of welding parameters for mild steel SAE10XX joints has been successfully implemented. The analysis of the welded joints revealed that the optimized weldments exhibit superior mechanical properties, making them suitable for demanding structural applications. In order to ensure the production of high-quality welded joints, proper control of welding parameters is essential. The combined influence of three process variables—welding current, welding speed, and arc voltage—on tensile strength, impact strength, and hardness was investigated. At a welding current of 103.396 A, a welding speed of 246.019 mm/min, and an arc voltage of 221.696 V, the optimum hardness, tensile strength, and impact strength obtained were 165.628 BHN, 551.090 N/mm², and 0.90 J/mm², respectively. The optimum conditions of these key process variables can be applied to design a robust welding procedure for producing high-quality mild steel joints. This will help improve the mechanical integrity of welded structures and minimize frequent failures, thereby enhancing their durability and performance.

Conflict of Interest

The authors don't have any competing interest

Reference

[1] Sada S.O, Achebo J., Obahiagbon K. (2021). Evaluation of the optimal strength and ductility of a mild steel arc welded plate based on the weld design. Welding International, 35(7-9), 261-268.

[2] Kartsonakis, I.A., Charitidis, C.A. (2020). Corrosion Protection Evaluation of Mild Steel: The Role of Hybrid Materials Loaded with Inhibitors. Applied Science, 10, 6594. https://doi.org/10.3390/app10186594.

[3] Medupin, R.O., Ukoba, K.O., Yoro, K.O., Jen, T-C. (2023). Sustainable approach for corrosion control in mild steel using plant-based inhibitors: a review. Materials Today Sustainability, 22, 100373. https://doi.org/10.1016/j.mtsust.2023.100373.

[4] Kumar, S. S., Balaji, V. N., & Prrithvi, P. M. (2014). Influence of Residual Stress on Stress Intensity Factor Estimation of Multiple Cracks in a Dissimilar Welded Joint. Procedia Engineering, 86, 234–241. doi:10.1016/j.proeng.2014.11.033

[5] Tang, L., Qian, C., Ince, A,.Zheng, J., Li, H., Han, Z. (2018). Fatigue Crack Growth Behavior of the MIG Welded Joint of 06Cr19Ni10 Stainless Steel. Materials (Basel), 11(8), 1336.

[6] Le, L., Sofi, M., Lumantarna, E. (2021). The combined effect of stress and corrosion on mild steel. Journal of Constructional Steel Research, 185,106805. https://doi.org/10.1016/j.jcsr.2021.106805.

[7] Al-Assadi, A.H., Asker, A., Samad, A.A and Samuel, M. (2020). Study of mechanical and corrosion properties for seamless gas pipelines. Global Scientific Journal, 8(8), 2565-2575.

[8] Afolabi, A.S. (2008). Effect of Electric Arc Welding Parameters on Corrosion Behaviour ofAustenitic Stainless Steel in Chloride Medium. Assumption University Journal of Technology, 3, 171-180.

[9] Chuka, C.E., Odior, B.O.,Chukwuneke, J. L., Sineb, J. (2014). Investigation Of The Effect Of Corrosion On Mild Steel In Five Different Environments.International Journal of Scientific & Technology Research, 3(7), 306-310

[10] Omiogbemi, I.M.B., Yawas, D.S., Dagwa, I.M., Okibe, F.G. (2017). Effects of metal inert gas welding parameters on some mechanical properties of Austenitic stainless steel in acidic environment. National Journal of Technology, 36(3), 835-843.

[11] Li, M., Wu, H., Sun, Y. (2023). Corrosion Performance of Welded Joints for E40 Marine Steel. Metals, 13, 1528. https://doi.org/10.3390/met13091528.

[12] Senthilkumar, S., Manivannan, S., Venkatesh, R., Karthikeyan, M. (2023). Influence of heat input on the mechanical characteristics, corrosion and microstructure of ASTM A36 steel welded by GTAW technique. Heliyon, 9(9):e19708. doi: 10.1016/j.heliyon.2023.e19708.

[13] Lofinmakin OO, Sada SO, Emovon I, Samuel OD, Oke SA (2024) Prediction of optimal mild steel weld parameters using Adaptive Neuro-Fuzzy Inference System (ANFIS) techniques. The International Journal of Advanced Manufacturing Technology, 131(3-4), 1-8

[14] Hutsaylyuk, V., Student, O., Maruschak, P., Krechkovska, H., Zvirko, O., Svirska, L., Tsybailo, I. (2023). Analysis of Mechanical Properties of Welded Joint Metal from TPP Steam Piping after Its Operational Degradation and Hydrogenation. Materials (Basel0, 16(24), 7520.

[15] Sada S.O., Achebo J. (2022). Optimization and prediction of the weld bead geometry of a mild steel metal inert gas weld. Advances in Materials and Processing Technologies, 8(2), 1625 – 1634.

[16] Szusta, J., Derpeński, Ł., Karakaş,Ö.,Tüzün, N., Dobrzański, S. (2023). Effect of Welding Process Parameters on the Strength of Dissimilar Joints of S355 and Strenx 700 Steels Used in the Manufacture of Agricultural Machinery. *Materials* (Basel), 16(21), 6963. doi: 10.3390/ma16216963.

[17] Prabhakar, D.A.P., Korgal, A., Shettigar, A.K., Herbert, M.A., Chandrashekharappa, M.P.G., Pimenov, D.Y., Giasin, K. (2023). A Review of Optimization and MeasurementTechniques of the Friction Stir Welding (FSW) Process. Journal of Manufacturing and Materials Processing, 7, 181.

[18] Orugba, H.O., Onukwuli, O.D., Babayemi, A.K., Umezuegbu, J.C. (2020). Five-factor response surface optimization of Hydrochloric acid dissolution of alumna from a Nigerian clay. Arid Zone Journal of Engineering, Technology and Environment, 16 (4), 821–832.

[19] Tsai, C.-H., Tsai, W.-T. (2023). Optimization of Physical Activation Process by CO2 for Activated Carbon Preparation from Honduras Mahogany Pod Husk. Materials, 16(19), 6558. https://doi.org/10.3390/ma16196558

[20] Prilutskyi, V. P., &Yeroshenko, L. Ye. (2021). Influence of the conditions of weld pool protection by argon on the properties of welds in tig welding of titanium. The Paton Welding Journal, 6, 36–40.

[21] Chukwuneke, J. L., Ndefo, M. I., Sinebe, J. E., &Ofochebe, S. M. (2022). Numerical and thermal analysis of mechanical properties degradations and distortions in steel weld joint. Cleaner Materials, 6, 100150.

[22] Wu, T., & Yang, C. (2022). Influence of pulse TIG welding thermal cycling on the microstructure and mechanical properties of explosively weld titanium/steel joint. *Vacuum*, 197, 110817.

[23] Ezenwa, O. N., Obika, E. N., Azaka, O. A., & Nwadike, E. C. (2021). Effect of filler carbonization on agro-waste based ceiling board. Advances in Mechanical Engineering, 13(2), 168781402199440.

[24] Pintaude, G. (2022). Hardness as an indicator of material strength: a critical review. Critical Reviews in Solid State and Materials Sciences, *48*(5), 623–641. https://doi.org/10.1080/10408436.2022.2085659