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Integrated Assessment of MIG Welding Parameters on Carbon Steel using RSM Optimisation

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ABSTRACT

This study explores the effects of parameter optimisation in MIG welding on material properties, weld quality, and bead geometry using an experimental design. The goal is to minimise weld defects and enhance material strength in welded parts. A quadratic second-order regression model predicts optimal process parameters for JIS G3131 hot-rolled carbon steel in MIG buttwelding. Tests include a 3-by-3 orthogonal array for welding current, arc voltage, and welding speed, measuring responses like bead height, bead width, penetration, and flexural strength. NDT X-ray radiography identifies flaws, and durability is assessed through a three-point bending test. The study utilises an experimental design, ANOVA, and regression analysis, predicting flexural strength with a 0.66% error. Additionally, the errors for weld penetration, bead width, and bead height are 1.29%, 2.32%, and 2.45%, respectively. The results highlight improved weld geometry and flexural strength through optimised process parameters, offering valuable insights for metal fabrication.

1. Introduction

Metal inert gas welding, commonly referred to as MIG welding, is extensively employed across diverse industries, including manufacturing, oil and gas, and construction [1, 2] The primary factor contributing to its extensive implementation is its high level of efficiency and minimal depletion of alloying elements. MIG welding is a highly adaptable choice for various production environments, as it possesses the capability to accommodate both semi-automatic and fully automatic operations [3]. The process of MIG welding entails the controlled application of heat to fuse filler and parent metals, thereby generating a localised fusion zone [4, 5]. MIG welding in the automotive industry often relies on the utilisation of carbon steel, primarily owing to its robust mechanical characteristics [6]. MIG welding offers numerous benefits, such as the generation of welds of superior quality and the reduction of post-weld cleaning requirements [7]. However, the attainment of the desired welding quality is contingent upon the precise management of various welding parameters. Previous research

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encompasses a range of studies, including optimisation methods like Taguchi and Response Surface Methodology, integration of artificial intelligence, and a multi-objective approach, providing insights into selecting welding process parameters for enhanced efficiency, sustainability, and weld quality [8].

The attainment of the desired welding quality is contingent upon the meticulous evaluation of multiple welding parameters [9]. The various parameters, including arc voltage, welding current, travel speed, wire feed rate, and torch angle, exert a substantial influence on the outcome of the welding process and the overall quality of the weld [10]. Defects in welded joints, specifically within the heat-affected zone (HAZ), can arise due to thermal fluctuations occurring throughout the welding procedure [11]. Defects in the welding process can jeopardize a welded component's structural integrity, emphasizing the importance of optimizing welding parameters to ensure quality assurance [1]. The welded joint is often thought to be the weakest part of a structure because it is a localised fusion of materials, which can give it different properties than the base metal [12].

The utilisation of the Design of Experiment (DOE) in conjunction with the Response Surface Method (RSM) is widely acknowledged as a prevalent methodology for the optimisation of this particular process [13, 14]. This methodology facilitates the identification of optimal welding input parameters through the establishment of mathematical relationships between these parameters and the output variables that characterise the weld joint. The primary aim is to enhance key attributes such as tensile strength, microstructure, and mechanical properties of the welded material while simultaneously reducing the need for extensive experimentation. This methodology facilitates cost reduction and resource conservation [15].

Notwithstanding the implementation of sophisticated methodologies, the existence of welding imperfections continues to pose a substantial obstacle. Imperfections in the weld pool and heat-affected zone can have a significant impact on the structural integrity of the welded component [16]. The task of detecting and predicting defects can pose significant challenges and consume a substantial amount of time. The pursuit of optimal MIG welding parameters holds significant importance as it has the potential to enhance the quality of welds, boost productivity, and streamline the processes involved in detecting defects [17].

However, the process of optimising parameters, specifically for multi-objectives that include weld bead size, mechanical properties, and defect reduction, remains a difficult and time-consuming task [18]. To achieve the desired outcomes, it is imperative to possess a thorough comprehension of the intricate correlations existing among various welding parameters. The present study seeks to comprehensively tackle the challenges mentioned earlier.

The objective of this study is to conduct an analysis of the flaws present in MIG welding. Additionally, it aims to optimise the essential welding parameters, namely current, speed, and voltage, utilising the Response Surface Methodology (RSM) [15]. Furthermore, the study intends to comprehensively investigate the impacts of these parameters on both the geometry of the weld bead and its flexural strength. Flexural strength is crucial in the automotive sector, ensuring materials' resistance to bending and deformation, vital for safety, structural integrity, and performance in dynamic and static loads. In order to accomplish this objective, we will employ sophisticated statistical methodologies such as analysis of variance (ANOVA) and visual aids such as surface and contour plots [19]. The primary objective of this study is to offer significant contributions towards enhancing the calibre and dependability of MIG welding procedures.

2. Methodology

2.1 Flow Chart

The methodology flowchart used in the study is shown in Figure 1. Planning Experiment: In the first phase, the MIG weld process parameters are selected carefully, considering their potential influence on the response variables. DOE is used to design the experiment [20] and ANOVA is employed to evaluate the significance of parameters [21]. The response surface method optimises process parameters to achieve desired outcomes. In the second phase, both destructive and non-destructive tests are conducted to evaluate welding defects on the surface of the samples. This step provides important information about weld quality.

Experimental Design Optimisation: Phase three involves developing an experimental design using the identified welding process parameters. The goal is to find the best MIG weld process parameters for the desired weld quality. This involves experimenting and analysing data to find the best parameter settings. In the fourth phase, data is analysed and mathematical models are developed to establish quantitative relationships between process parameters and the desired response. Analyse the collected data and use statistical techniques to derive mathematical models describing the relationship between process parameters and weld quality. This methodology allows for systematic exploration and optimisation of MIG weld process parameters, establishing quantitative relationships with the desired response. It optimises the welding process to achieve the desired outcomes. The flowchart shows the steps in the research process.

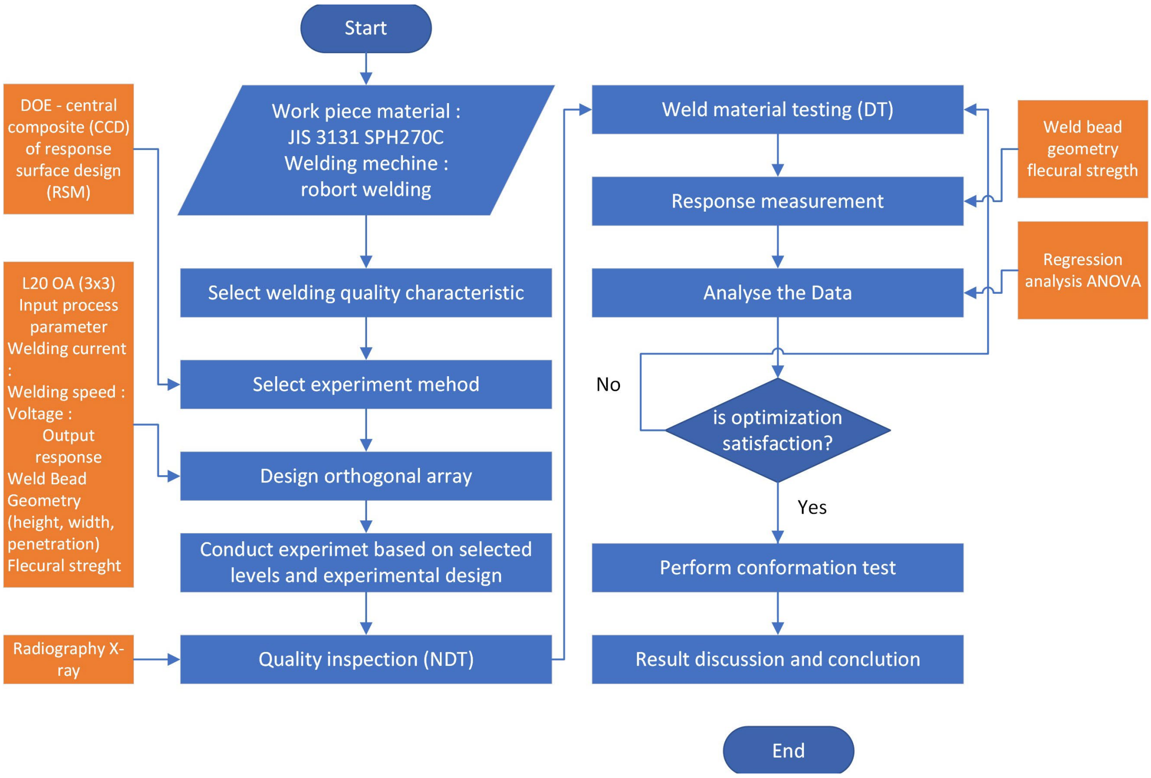


Fig. 1. Flow chart of methodology

2.2 Material and Welding Equipment

The primary consideration during the welding process was selecting the appropriate welding material [22]. As a result, hot-rolled carbon steel sheets of standard serial number JIS G3131 SPH270C were utilised in this experiment. This JIS G3131 steel sheets, despite its low tensile strength, fulfils the automotive industry's demand for weight reduction and safety through contributions to lighter structures without compromising safety standards. These sheets have a yield strength of 340 MPa and a tensile strength of 410 MPa. This particular material is commonly employed in the automotive industry. Carbon dioxide (CO_2) was chosen as the inert gas [23], and the ER70S-6 electrode wire was selected based on its filler properties, compatibility with the base material, weld dimension requirements, and availability of cored wire inventory [24]. To examine the chemical compositions of the materials in this experimental study, an Arc Spark Emission Spectrometer was utilised along with the Spark Analyzer MX software. Figure 2a presents the results of these tests, highlighting the composition of the material and solder as described in Table 1.

Table 1
Nominal composition of carbon steel G3131 and filler wire ER70S-6 (Weight In %)

Elements	Nominal Carbon Steel G3131	ER70S-6
C	0.13	0.06-0.15
Si	0.05	0.80-1.15
Mn	0.5	1.40-1.85
P	0.035	0.025 max
S	0.035	0.025 max
Cu	…	0.50
Alt	0.010	…

Fig. 2. Material Composition Tested Machine (left) and Arc Welding Robot (right)

Metal inert gas (MIG) welding machines of the Daiken Arc Welding Robot Alpha AII Series are used and available at the Universiti Kuala Lumpur Malaysia France Institute. The apparatus primitive is shown in Figure 2b. MIG (metal inert gas) welding is an arc welding process that utilises a continuous electrode wire, which serves as both the filler metal and the electrode. The welding process involves the continuous feeding of the wire into the weld pool using powered feed rollers. At the same time, an electric arc is generated between the tip of the wire and the base metal. Throughout the welding process, a shielding gas is utilised to safeguard the arc and the weld pool against reactive gases such as oxygen and nitrogen that may be present in the surrounding atmosphere. The shielding gas acts as a barrier, preventing the reactive gases from interfering with the welding process and ensuring the integrity of the weld.

3. Results

3.1 Radiography Testing (RT)

In this research, non-destructive testing (NDT) was performed using radiographic testing (RT). Figure 3 illustrate the impact of errors on the test samples. Test samples 2 and 6 exhibited a lack of penetration accompanied by porosity, while test samples 3, 7, and 9 displayed a lack of penetration along the weld. Furthermore, it was observed that test samples 8 and 11 had incomplete fillings and undercuts.

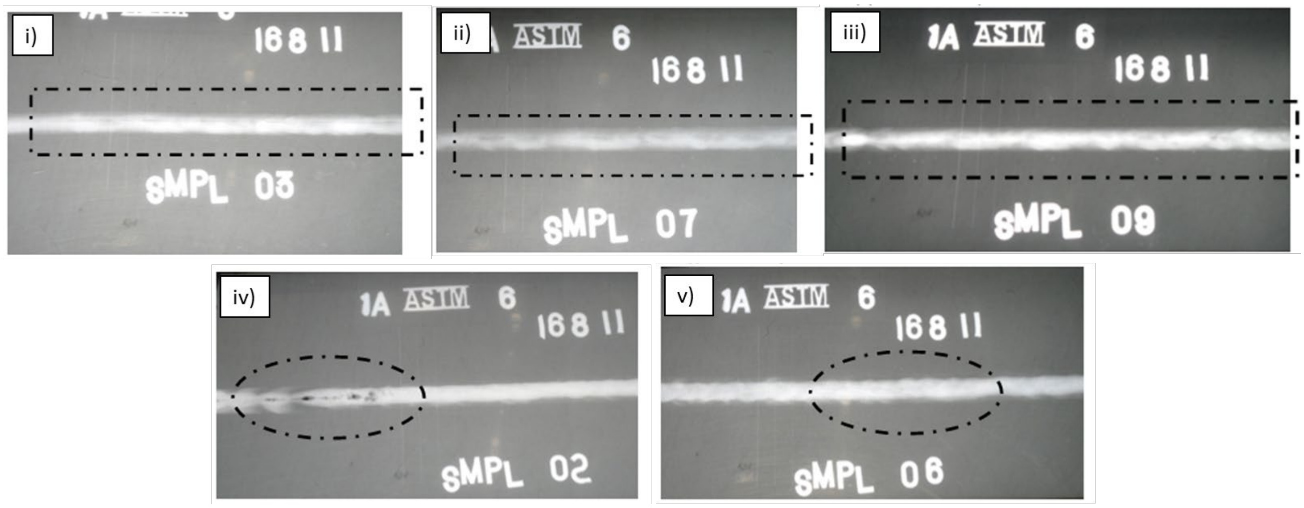


Fig. 3. LOP defects along the weld in test samples (i) no. 3 (ii) no. 7 (iii) no. 9 and LOP defects associated with porosity in test samples (iv) no. 2 (v) no. 6

The analysis of the results reveals that porosity and lack of fusion or penetration (LOP) are more prominent compared to other types of weld defects. Porosity refers to the presence of voids or pores resulting from ambient gases and the entrapment of non-metallic materials during the solidification phase of the weld [25]. Porosity can be categorised into two types: internal porosity and surface porosity [26]. Incomplete penetration of the joint is another prevalent condition where the weld metal fails to fully penetrate through the thickness of the plate. Areas with incomplete penetration and a lack of connection are referred to as incomplete joint penetration. Several factors can contribute to incomplete weld penetration, including insufficient weld heat, improper weld design, or inadequate control of weld parameters [27].

Undercutting is another common welding defect characterised by an unfilled groove along the weld's edge. It is often attributed to factors such as incorrect electrode angles, improper weaving technique, excessive current, and high movement speed [28]. However, welding speed and wire feed speed are particularly susceptible to these welding errors. When the processing speed is too high, the weld bead tends to have a sharp profile due to rapid solidification. Surface tension forces cause the molten metal to be pulled along the edges of the weld, resulting in a build-up of metal in the centre. The molten base material is also affected in a similar manner. It is drawn into the undercut groove within the weld and fails to be sufficiently rewetted due to the rapid solidification. By reducing the arc travel speed, the size of the undercut can be gradually diminished and eventually eliminated.

3.2 Experimental Design Response

The test results of measured responses to material properties based on weld geometry and flexural strength are shown in Tables 2 and 3. This is the complete result of twenty experiments conducted according to the experimental design.

Table 2
Independent process variables and experimental design levels of weld bead geometry

Exp. no	Factor			Responses		
	Current (amps)	Speed (mm/min)	Voltage (Volts)	Weld bead geometry		
				Weld width (mm)	Weld height (mm)	Penetration (mm)
1	100	20	19	8.82	1.96	3.23
2	120	20	19	9.12	1.04	3.73
3	100	30	19	7.56	2.01	2.93
4	110	25	19	8.6	0.82	4.47
5	110	25	18	8.56	1.51	3.46
6	100	25	18	8.1	1.74	3.28
7	120	20	17	9.21	1.75	3.22
8	110	25	18	8.81	2.2	2.75
9	110	25	17	7.5	1.85	3.55
10	120	30	17	7.81	1.68	3.5
11	110	30	18	8.59	2.56	3.42
12	100	30	17	7.04	1.47	2.93
13	110	25	18	8.05	1.78	3.81
14	110	25	18	8.23	1.95	3.33
15	110	25	18	8.23	1.66	3.2
16	100	20	17	8.82	1.96	3.32
17	120	30	19	8.48	1.22	4.25
18	110	20	18	9.26	1.91	4.2
19	120	25	18	7.57	1.77	4.15
20	110	25	18	7.92	3.67	3.67

This collected experimental data was fed into MINITAB for the analysis process using the RSM Response Surface Design method to determine the importance of the regression models for each model coefficient to predict the impact of various process parameters on the performance measurement. In this study, some data that appears to be an outlier is considered to understand the limits or extreme values of the dataset. Outliers can provide valuable insights into the variability and distribution of the data, helping identify boundaries and extreme points. This is particularly relevant in situations where understanding the range and potential outliers is crucial for making informed decisions or drawing accurate conclusions [29].

The experiment data collected for flexural strength shown in Table 3 indicated that test sample no. 5 had the highest value of strength as compared to the other 19 test samples. From the results tabulated, test samples affected by defects showed different values of strength among them. Test samples #3, #7, and #9, with penetration defects, show different strength results due to different parameters applied during the welding process. Test sample no. 3 has the lowest strength, 377 MPa, followed by test sample no. 7, 561.5 MPa, as compared to test sample no. 9, 846.43 MPa. In addition, sample #8 indicated good strength even though it had incomplete filling on the joint. From observation, the combination of welding parameters (current, speed, and voltage) will influence the strength of the material.

Table 3
Independent process variables and experimental design levels of flexural strength

Exp no	Factor			Responses	
	Current (amps)	Speed (mm/min)	Volt (Volts)	Flexural strength (N/mm^2)	Flexural strain
1	100	20	19	567.991	4.149
2	120	20	19	585.516	4.537
3	100	30	19	376.928	3.959
4	110	25	19	784.444	9.778
5	110	25	18	948.489	10.407
6	100	25	18	932.828	10.307
7	120	20	17	561.46	8.595
8	110	25	18	944.469	12.393
9	110	25	17	846.432	12.106
10	120	30	17	939.399	11.204
11	110	30	18	862.711	11.626
12	100	30	17	907.547	12.446
13	110	25	18	861.102	12.813
14	110	25	18	872.635	12.391
15	110	25	18	761.918	12.001
16	100	20	17	914.303	12.501
17	120	30	19	936.398	12.063
18	110	20	18	812.952	11.594
19	120	25	18	947.656	13.196
20	110	25	18	859.857	11.673

3.3 Statistical Analysis

The analysis of variance (ANOVA) technique was used to identify significant factors in optimising flexural strength (FS) and weld geometry on weld bead width (WW), weld penetration (WP), and weld bead height (WH). The ANOVA results for these material properties are presented in Table 4 to Table 7. The significance level of the quadratic model was set at 95% of the standard confidence level and measured by p-value when the p-value of the developed model does not exceed the standard confidence level given there, with p-values of < 0.05: If there is insufficient evidence to reject the null hypothesis, the model is considered satisfactory. The evaluated null hypothesis showed that the models are suitable

In addition, the determination coefficient is used to check the goodness of the model and to determine the gap value between predicted and experimental values. The table shows that the flexural strength model is substantial because the fitted R^2 value shows that the coefficient value is greater than 80%. While the weld geometry models, weld width (WW), penetration depth (WP), and weld height (WH), are satisfactory because they are over 60%, Relationship between actual and predicted measured response, suggesting that the model is appropriate for the welding process parameter as a predictor [30]. The residuals of each response are at the minimum, indicating that the model is reasonable.

Table 4
Analysis of variance (ANOVA) level of significance for flexural strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Significance
Regression	9	455616	50624	11.24	0.001	Significance
Linear	3	244750	81583	18.11	0.000	Significance
C (Current)	1	78386	78386	17.40	0.002	Significance
S (Speed)	1	10413	10413	2.31		
V (Voltage)	1	155952	155952	34.63	0.000	Significance
Square	3	125966	41989	9.32	0.004	Significance
C^2	1	78386	78386	17.40	0.002	Significance
S^2	1	38	38	0.01		
V^2	1	47434	47434	10.53	0.010	Significance
2-Way Interaction	3	96525	32175	7.14	0.009	Significance
CS	1	77748	77748	17.26	0.002	Significance
CV	1	416	416	0.09		
SV	1	18360	18360	4.08		
Error	9	40533	4504			
Lack-of-Fit	4	13121	3280	0.60	0.681	
Pure Error	5	27412	5482			
Total	18	496150				

R^2=91.83%; Adjusted R^2=83.66%; Predicted R^2=68.81%

Table 5
Analysis of variance (ANOVA) level of significant for Weld Bead Width (WW)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Significance
Regression	9	5.81449	0.64605	4.35	0.016	Significance
Linear	3	4.13250	1.37750	9.28	0.003	Significance
C (Current)	1	0.34225	0.34225	2.31	0.160	
S (Speed)	1	3.30625	3.30625	22.29	0.001	Significance
V (Voltage)	1	0.48400	0.48400	3.26	0.101	
Square	3	1.35174	0.45058	3.04	0.080	
C^2	1	0.46536	0.46536	3.14	0.107	
S^2	1	1.26651	1.26651	8.54	0.015	Significance
V^2	1	0.10604	0.10604	0.71	0.418	
2-Way Interaction	3	0.33025	0.11008	0.74	0.551	
CS	1	0.12500	0.12500	0.84	0.380	
CV	1	0.00045	0.00045	0.00	0.957	
SV	1	0.20480	0.20480	1.38	0.267	
Error	10	1.48359	0.14836			
Lack-of-Fit	5	0.93919	0.18784	1.73	0.282	
Pure Error	5	0.54440	0.10888			
Total	19	7.29808				

R^2=79.67%; Adjusted R^2=61.38%; Predicted R^2=0.0%

Table 6
Analysis of variance (ANOVA) level of significant for Weld Bead Height (WH)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Significance
Regression	9	1.97758	0.21973	2.43	0.091	
Linear	3	0.56804	0.18935	2.09	0.165	
C (Current)	1	0.28224	0.28224	3.12	0.108	
S (Speed)	1	0.01024	0.01024	0.11	0.743	
V (Voltage)	1	0.27556	0.27556	3.05	0.111	
Square	3	0.92821	0.30940	3.42	0.061	
C^2	1	0.01740	0.01740	0.19	0.670	
S^2	1	0.44100	0.44100	4.88	0.052	Significance
V^2	1	0.68625	0.68625	7.59	0.020	Significance
2-Way Interaction	3	0.48134	0.16045	1.77	0.215	
CS	1	0.03781	0.03781	0.42	0.532	
CV	1	0.36551	0.36551	4.04	0.072	
SV	1	0.07801	0.07801	0.86	0.375	
Error	10	0.90431	0.09043			
Lack-of-Fit	5	0.61563	0.12313	2.13	0.213	
Pure Error	5	0.28868	0.05774			
Total	19	2.88190				

R^2=68.62%; Adjusted R^2=40.38%; Predicted R^2=0%

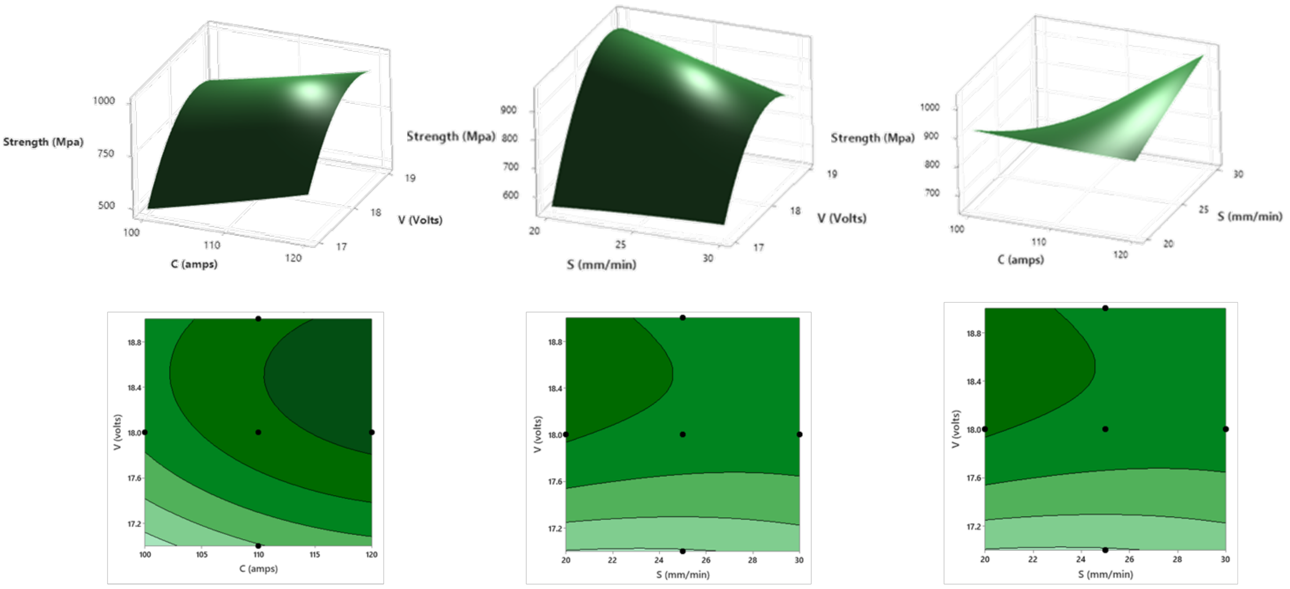
Table 7
Analysis of variance (ANOVA) level of significant for Weld Bead Panetration (WP)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Significance
Regression	9	2.23093	0.247881	3.47	0.047	Significance
Linear	3	1.44501	0.481669	6.74	0.014	Significance
C (Current)	1	0.78961	0.789610	11.04	0.010	Significance
S (Speed)	1	0.06004	0.060038	0.84	0.386	
V (Voltage)	1	0.59536	0.595360	8.33	0.020	Significance
Square	3	0.48812	0.162707	2.28	0.157	
C^2	1	0.00135	0.001346	0.02	0.894	
S^2	1	0.38440	0.384400	5.38	0.049	Significance
V^2	1	0.23451	0.234507	3.28	0.108	
2-Way Interaction	3	0.34525	0.115083	1.61	0.262	
CS	1	0.16245	0.162450	2.27	0.170	
CV	1	0.12500	0.125000	1.75	0.223	
SV	1	0.05780	0.057800	0.81	0.395	
Error	8	0.57212	0.071514			
Lack-of-Fit	4	0.32680	0.081699	1.33	0.394	
Pure Error	4	0.24532	0.061330			
Total	17	2.80304				

R^2=79.59%; Adjusted R^2=56.63%; Predicted R^2=0%

3.4 Interaction Effect and Response Surface Analysis of MIG Welding Process Parameters

A two-dimensional contour plot and a three-dimensional surface plot were used to study the effects of welding parameters on the responses (weld geometry and flexural strength) [31]. Figure 4 shows how the developed model's surface and contour plots were used to make the response graph. The response contours would help predict the best parameters for the MIG welding process of JIS G3131 SPH270C hot-rolled carbon steel sheet. show the surface and contour plots of flexural strength and illustrate the interaction effect of the welding parameter on flexural strength versus two of the operating parameters. Figure 4a illustrates that as the welding current and voltage increase, the material strength also increases. Figures 4b and 4c show that when the arc voltage and welding current go up but the welding speed stays the same, there can be big changes in flexural strength due to changes in the amount of heat input.



a b c

Fig. 4. The development of the response graph using the surface and contour plot of the developed model

3.5 Optimizing Result

The MIG welding process of JIS G3131 SPH270C hot-rolled carbon steel plate has been effectively optimised and analysed using statistical methods. An analysis of variance (ANOVA) was conducted to assess the influence of different factors on the welding process. The findings from the ANOVA analysis enabled the development of a predictive model. This model allows for precise prediction of the responses or outcomes of the welding process within the defined range of factors. By utilising this developed model, it becomes feasible to identify the optimal welding parameters necessary to achieve the desired results. By optimising the MIG welding process, the selection and adjustment of welding parameters are carefully done to attain the desired level of weld quality and performance [32]. This approach enables efficient and effective utilisation of welding resources, leading to improved productivity and reduced costs.

Overall, the successful optimisation and statistical analysis of the MIG welding process for JIS G3131 SPH270C hot-rolled carbon steel plate provide valuable insights and guidance for achieving high-quality welds with optimal parameters. By employing the response optimisation feature in MINITAB, the parameter levels for each response were assessed. This tool enabled the identification of the optimal combination of input variable settings that resulted in the optimisation of a single response or a set of responses. The optimisation plot provided a visual representation of the optimal solution, indicating the specific combination of input variables that yielded the desired results.

In Figure 5, the target values for each response were set according to the optimisation diagram. The figures below demonstrate that the desired desirability was achieved, with a minimum response value of y = 903.1 for flexural strength and 9.45 for WW, 2.049 for WH, and 3.11 for WP, respectively. This indicates 100% acceptance of the optimal values. The optimisation process facilitated the identification of the optimal parameter levels that led to the desired outcomes in terms of responses.

Based on the attainment of the desired desirability, it can be inferred that the manufacturing proposals were effectively optimised and aligned with the specified target values.

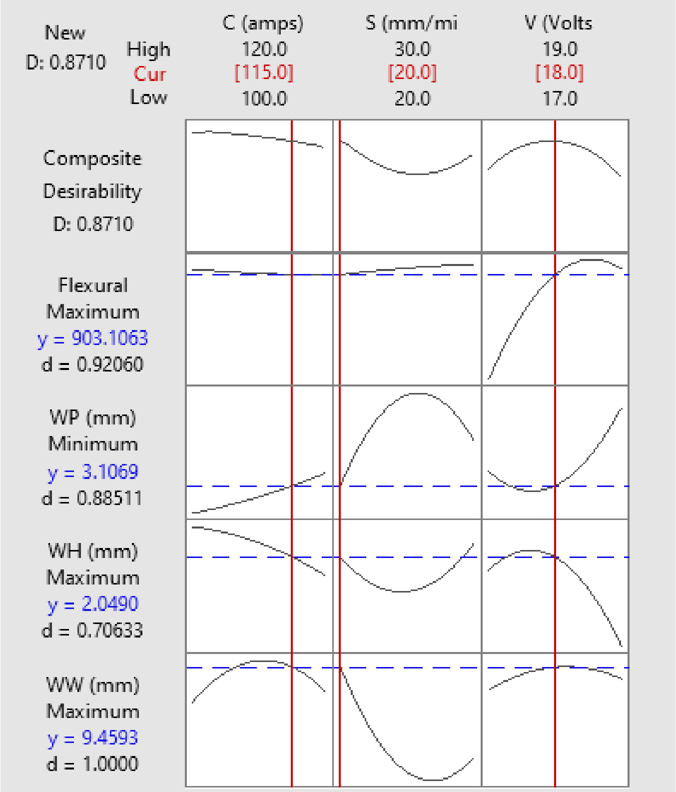


Fig. 5. Result of response optimizer for experimental responses of Flexural Strength and weld bead geometry

3.6 Conformation Test Result

To validate the optimal parameter settings suggested by the matrix and confirm the predicted improvements, three confirmation experiments were conducted at the optimised settings. The objective of these experiments was to evaluate the accuracy and reliability of the developed models and validate the optimal parameters. The test conditions in the confirmation experiments were carried out using the predicted values obtained from the optimisation process. A comprehensive list of the collected parameters and corresponding response values from these experiments is presented in Table 8. Through the comparison of the results obtained from the confirmation experiments with the predicted values, it becomes possible to evaluate the accuracy and reliability of the developed models. This comparison facilitates an assessment of whether the optimal parameter settings have indeed generated the predicted improvements in the desired responses.

Table 8
Conformation, experimental, and validation of optimised welding conditions

	Optimum parameter			Weld bead geometry			
	C (amp)	S (cm/min)	V (volts)	WP (mm)	WW (mm)	WH (mm)	Flexural strength
Predicted	-	-	-	3.1	9.45	2.04	903
Exp 1	115	20	18	3.05	9.40	1.94	901.2
Exp 2				3.06	9.14	1.95	894.5
Exp 3				3.08	9.16	2.07	895
Average	-	-	-	3.06	9.23	1.99	897
Error (%)	-	-	-	1.29	2.32	2.45	0.66

Examining the consistency between the experimental results and the predicted values serves to validate the effectiveness of the developed models and install greater confidence in the optimised parameter settings. The favourable outcomes observed in the confirmation experiments demonstrate a close agreement between the predicted values from the model and the actual experimental values. The deviation between the predicted and experimental values, which falls within the range of less than 5%, indicates the validity and reliability of the developed model for this study. This discovery enhances the certainty of the optimised parameter settings derived from the model. It signifies that the model effectively captures the correlation between the welding parameters and the desired responses, facilitating dependable predictions and optimization. Furthermore, the RT test conducted on the specimens revealed that there were no defects in the weld geometry. Figure 6 demonstrates the absence of any visible defects, reinforcing the quality and integrity of the welding process carried out using the optimal parameter settings.

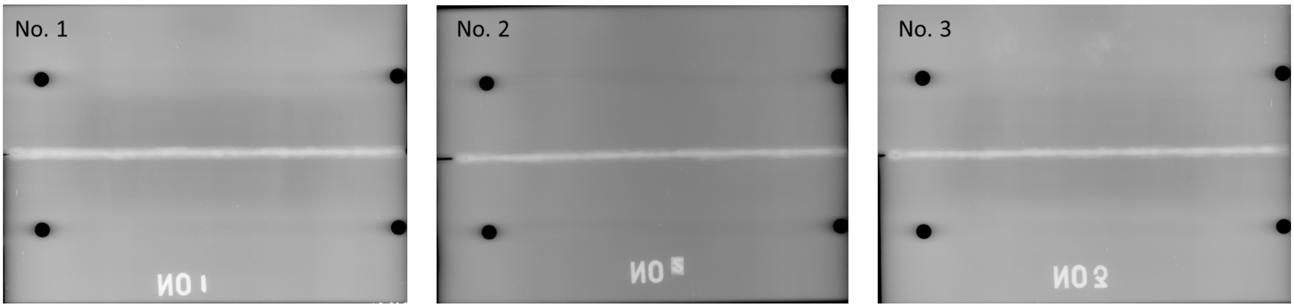


Fig. 6. RT results of conformation test sample shows no defect

When the results of the confirmation experiments are good and there are no flaws in the shape of the weld, this proves that the model is correct and useful. These findings provide a solid basis for further analysis and application of the optimised parameters in practical welding operations.

4. Conclusions

The study aimed to optimise MIG welding parameters for carbon steel material (JIS 3131 SPH270C) to improve weld bead quality and material strength. Factors investigated and controlled during the welding process were welding current, speed, and voltage. The researchers analysed the effects of different combinations of these parameters on the welding process. To investigate MIG welding flaws brought on by incorrect parameter selection, researchers used the Response Surface Method (RSM). The study found that welding speed, voltage, and current were the most influential parameters for MIG bead welding. The RSM optimisation technique achieved an optimal value by combining parameters in the experiment, resulting in better weld quality and material properties.

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