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ANALYSIS OF DISSIMILAR JOINING OF STAINLESS STEEL AND MILD STEEL USING MIG WELDING

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Abstract-This paper investigates the effectiveness of Metal Inert Gas (MIG) welding in joining dissimilar metals, specifically stainless steel and mild steel. The study explores the challenges associated with welding two different metals and the effect of welding parameters on the quality of the joint. The experiments were conducted by varying welding parameters such as welding current, voltage, and welding speed. The weld quality was evaluated by examining the hardness and weld width of the joint. The results indicated that the welding parameters significantly influenced the quality of the joint. It was observed that the welding current and voltage had a significant impact on the joint hardness. Overall, the study provides valuable insights into the welding of dissimilar metals and offers a guideline for selecting appropriate welding parameters to achieve a high-quality joint.

Keywords: **Metal inert gas welding; Weld width; Response surface methodology; Optimization.**

1. INTRODUCTION

Dissimilar metal welding is a process that involves joining two metals with different chemical compositions and properties. One of the most common dissimilar metal combinations is stainless steel and mild steel. This combination is widely used in the manufacturing of various products, such as pipes, tanks, and automotive parts. MIG welding is a widely used welding process for joining dissimilar metals due to its high welding speed, ease of use, and low cost. However, MIG welding of dissimilar metals can be challenging due to the difference in their properties, which can lead to the formation of brittle intermetallic compounds and poor weld quality. The MIG welding of dissimilar metals, specifically stainless steel and mild steel, with the aim of identifying the optimal welding conditions for producing sound welds with adequate mechanical properties. The study focused on the effects of process parameters, such as welding current, voltage, and travel speed, on the weld quality and microstructure. The experiment needed a commercial MIG welding machine and a range of filler wires with varying compositions and also a MIG welding machine and mild steel has been used as filler wire. The outcome can be useful for selecting the appropriate welding parameters for MIG welding of dissimilar metals, specifically stainless steel and mild steel. The findings can also help to improve the understanding of the mechanisms of formation of intermetallic compounds and their effects on the properties of the weld.

Literature Review -Rajendra singh & Dr. SS Dhami [1] - discussed the parametric optimization of Metal Inert Gas (MIG) welding of stainless steel (316) and mild steel using the Taguchi technique. The study focuses on identifying key process parameters that influence the quality of the weld joint and developing an optimal combination of these parameters for enhanced weld quality. The study highlights the potential of the Taguchi technique as an effective method for process optimization in MIG welding of dissimilar metals. J. P. Ganjigattiet al. [2] – focussed on regression analysis to establish input-output relationships of the MIG welding process. Both linear and nonlinear regression techniques are employed to analyse the effects of welding parameters. Results are compared and some concluding remarks made, adding to the literature on statistical methods for modelling MIG welding. Kumar Rahul Anand & Vijay Mittal [3]- Carried out the optimization of TIG welding parameters for a joint of AISI 316 stainless steel and mild steel using the Taguchi method. He carried out the experiment on parametric optimization of CO2 welding. The study found that arc current, voltage, and gas flow ratio significantly influenced the joint's mechanical properties. The optimized parameters for maximum tensile strength and hardness were identified. Vishal Chaudhari et al. [4] - investigated the use of TIG welding to join stainless steel 304 and mild steel materials. The Taguchi method was employed to optimize the welding parameters, including current, voltage, and gas flow rate, which significantly influenced the joint's tensile strength and hardness. The study also used Taguchi's orthogonal array and analysis of variance to investigate welding characteristics. Abhishek Prakash et al. [5] - investigated the Tungsten inert gas welding process on ASTM A29, with welding current having the greatest influence on tensile strength and hardness. Optimal conditions were determined for both properties using welding current, voltage, and wire speed. Mrugesh Solanki & Ketan Shah [6] - aimed to optimize the Tungsten Inert Gas (TIG) welding process for dissimilar metals by using the Response Surface Methodology (RSM). The results showed that welding current had the greatest impact on ultimate tensile strength and microhardness. The formation of steel and copper globules in the fusion zone was also observed. N. Murugan & R.S. Parmar [7] – found that voltage affects with weld width. Compared to other parameters, voltage has a stronger influence on the width, as the width remains constant at 31 and 34 volts regardless of the speed and wire feed rate values. Ravinder & S. K. Jarial [8] - had carried out the experiment using Taguchi method and found that voltage had a great impact on the welded joint and the tensile strength. Dr. S V Anil Kumar & Dr. R Gandhinathan [9] – carried out the experiment and concluded that as the welding current, voltage, and gas flow rate increases, the tensile strength and elongation starts to decrease, while when the welding speed is increased it improves tensile strength. L9 orthogonal arrays and S/N ratio analysis of variance were used to optimize the process, with controllable parameters of voltage, current, and gas flow rate for the response variables of tensile strength. Nizar Ramadan & Abduladim Boghdadi [10] –utilized theoretical and experimental methods, including Taguchi analysis to optimize the process. The results showed that the gas flow rate had a greater effect on the tensile strength compared to the current. D. Bahar [11] - concluded that higher levels of welding current result in better bending strength, but there is an upper limit beyond which further increases may lead to defects that decrease the bending strength. Similarly, increasing welding speed improves bending strength up to a certain limit, beyond which there is a risk of lack of reinforcement and decreased strength. Finally, the bending strength of joints improves with higher gas flow rates due to more effective shielding. Based on the results, the optimal conditions for welding include higher levels of welding current, welding speed, and gas flow rate, under the given circumstances and welding conditions. Nabendu Ghosh et al. [12] – experimented on austenitic stainless steel using Mig welding and found that current had a greater influence on joint strength than gas flow rate and nozzle to plate distance.

2. EXPERIMENTAL PROCEDURE

The materials used in this study are Stainless steel 304 and Mild steel (low carbon). The dimensions of both Stainless steel plate and Mild steel plate are 50mm x 50mm x 5mm. Mild steel filler material having a diameter of 1.2mm is selected as the filler material. Gas selected for shielding gas is Carbon dioxide. The chemical composition of mild steel is shown in Table 1. The mechanical properties of mild steel (low carbon) are –It has a tensile strength of 400-550 MPa. Mild steel (low carbon) has yield strength of 250 MPa. It has an elongation of 20-25%, modulus of elasticity of 200 GPa and Poisson's ratio of 0.3. It has a hardness of 140-160 Brinell Harndess. The chemical composition of Stainless Steel 304 is shown in Table 2. The mechanical properties of stainless steel are –It has a maximum tensile strength of 621 MPa (90 ksi). It has a yield strength of 207 MPa (30 ksi). It has a minimum elongation of 40%, which means it can be stretched without breaking. Its Brinell hardness is 201. It has good ductility and can be easily welded.

Table 1 – Chemical composition of Mild steel

Element	C	Si	Mn	P	S
Percentage	0.28%	0.55%	0.85%	0.08%	0.06%

Table 2 – Chemical composition of Stainless Steel

Element	P	Cr	N	C	S	Si	Ni	Mn
Percentage	0.055%	22%	0.15%	0.10%	0.035%	1.05%	12%	2.50%

The software Minitab is used to develop the experimental plan. The necessary work-piece materials, including mild steel and stainless steel 304, have been cut to the required dimensions (50x50x5mm). We have adopted the response surface methodology to optimize our welding process parameters - current, voltage, and welding speed. Selected welding Parameters and their levels are shown in Table-3. Response surface methodology (RSM) is an effective approach that combines statistical and mathematical techniques to analyse models and optimize operations. It can be applied to various fields of engineering to establish the correlation between independent process parameters (input factors) and the desired response, making it a valuable tool for determining this relationship. In addition, statistical ANOVA has been conducted to determine which process parameters are significant. To achieve the desired outcome, welds are produced under different welding conditions as outlined in the L15 orthogonal array of the Response Surface Methodology.

Table 3 - MIG welding Parameters and their levels.

Parameters	Notation	Levels		
		Level 1	Level 2	Level 3
Current (amp)	A	100	150	200
Voltage (volt)	B	20	30	40
Welding Speed (cm/m)	C	10	12	14

In this experiment ESAB AUTO K-400 MIG welding machine is used for the welding procedure. The current, speed, and welding speed are manually controlled for each run. Fig.1 shows the workpiece before welding and the welded product is shown in the Fig.2. This gives a clear pictorial representation of before and after the MIG welding procedure. The hardness is tested on Rockwell hardness testing machine and the weld width is is measured with the help of a Vernier caliper scale. The obtained results are shown in Table-4.


Fig. 1 Workpiece before welding


Fig.2 MIG Welded sample

Table 4 Output responses

Run	Box-Behnken design table			Output Responses	
	Current	Voltage	Welding speed	Hardness	Weld Width
1	150	40	10	79.14	11.63
2	200	20	12	75.31	12.49
3	200	30	10	77.23	12.71
4	100	40	12	85.37	9.10
5	200	30	14	71.25	10.40
6	150	30	12	84.12	12.35
7	150	30	12	82.69	12.20
8	150	30	12	83.16	11.90
9	150	40	14	83.25	10.50
10	200	40	12	75.33	11.26
11	150	20	10	84.12	12.29
12	100	20	12	80.18	10.53
13	150	20	14	71.25	11.14
14	100	30	14	80.39	9.20
15	100	30	10	82.45	9.80

3. RESULT AND DISCUSSION

3.1 Hardness Test

Hardness is commonly defined as a metal's resistance to plastic deformation, typically through indentation. The term "hardness" can also refer to stiffness, abrasion resistance, cutting ability, and scratch resistance, among other properties. In order to determine the hardness, measurements were conducted using the Rockwell hardness test, which is defined in ASTM E-18, is the most widely utilized method for testing hardness. The samples were prepared accordingly, and hardness testing was conducted on all 15 samples. Table 5 shows the ANOVA (Analysis of variance) test results of hardness.

Table 5- ANOVA test results for Hardness test.

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Model	9	299.014	33.224	105.50	0.000
Linear	3	161.068	53.689	170.49	0.000
Current	1	107.092	107.092	340.06	0.000
voltage	1	18.697	18.697	59.37	0.001
welding speed	1	35.280	35.280	112.03	0.000
Square	3	55.342	18.447	58.58	0.000
Current*Current	1	31.978	31.978	101.54	0.000
voltage*voltage	1	6.560	6.560	20.83	0.006
welding speed*welding speed	1	24.017	24.017	76.26	0.000
2-Way Interaction	3	82.604	27.535	87.43	0.000
Current*voltage	1	6.682	6.682	21.22	0.006
Current*welding speed	1	3.842	3.842	12.20	0.017
voltage*welding speed	1	72.080	72.080	228.89	0.000
Error	5	1.575	0.315		
Lack-of-Fit	3	0.512	0.171	0.32	0.815
Pure Error	2	1.062	0.531		
Total	14	300.589			

3.2 Regression Analysis for Hardness

To derive the quadratic mathematical equations for hardness in the current inquiry, experimental data were fed into the Minitab software. This regression equation is used to predict the responses of hardness in terms of current, voltage and welding speed. Regression analysis as per notation.

$$\text{Hardness} = 27.82 + 0.4551A - 1.307B + 8.35C - 0.001110A*A - 0.01166B*B$$
$$- 0.5959C*C - 0.002585A*B - 0.00980A*C + 0.21225B*C$$

Fig. 3 shows the Normal Probability Plot for Hardness. The graph shows that the model developed is adequate. The developed model has been inspected by the normal probability plot and it is seen that the residuals are on the straight line which shows that the errors are normally distributed.

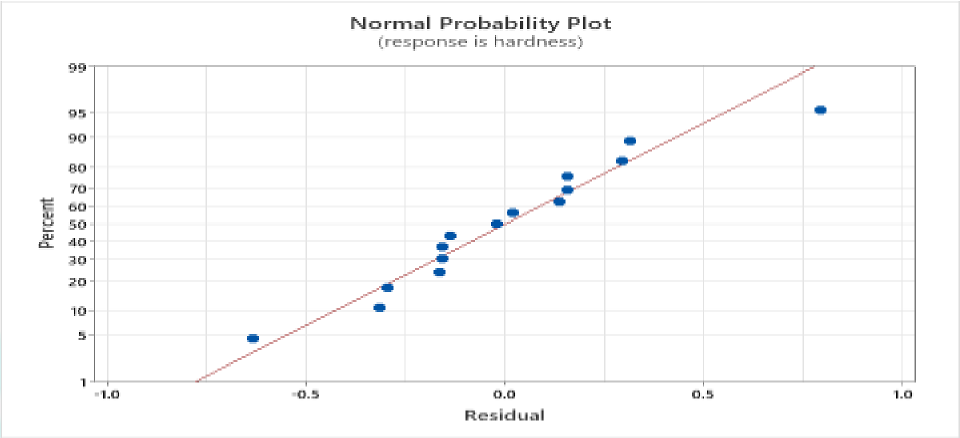
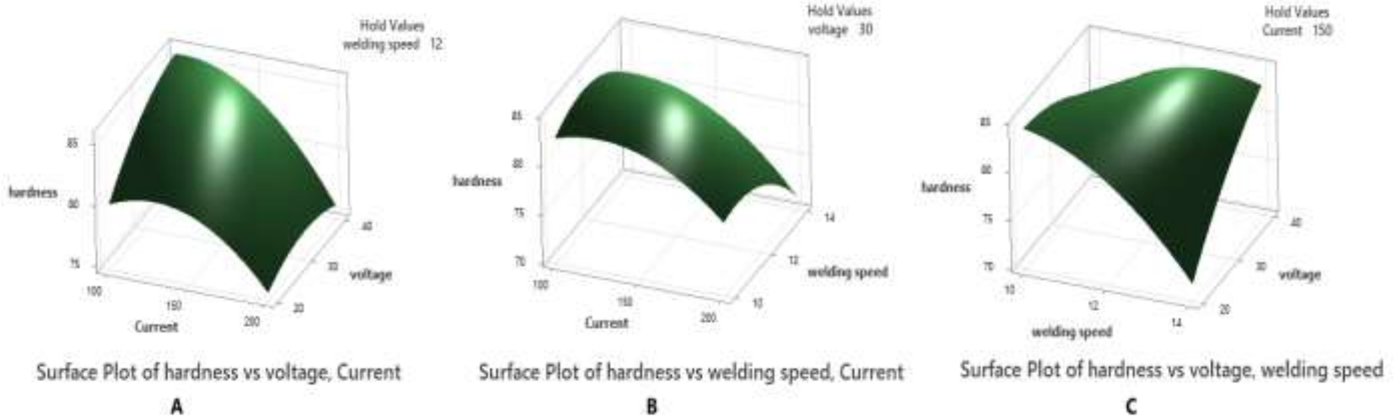


Fig. 3- Normal Probability Plot for Residuals.

Fig.4 shows the Surface Plot and Fig.5 shows the Contour Plot hardness interacting with the process parameters. It shows that the hardness varies with the parameters and gets maximize at low welding current and high welding voltage. The hardness is found to be maximum at high welding speed.



Surface Plot of hardness vs voltage, Current
A

Surface Plot of hardness vs welding speed, Current
B

Surface Plot of hardness vs voltage, welding speed
C

Fig.4- Surface Plot of Hardness

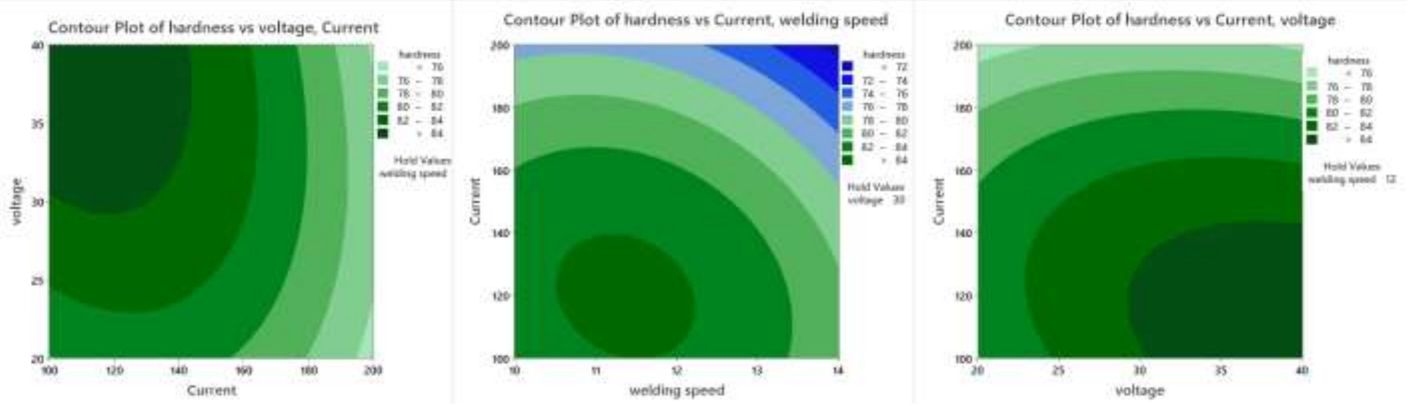


Fig.5- Contour Plot of hardness

3.3 Weld Width Test

The weld width is measured by vernier caliper scale. It is measured in multiple points to get the specific measurement of the weld width. It is seen that the weld width noticeably varies with the process parameters. Table 6 shows the ANOVA test results for weld width on all 15 samples.

Table 6- ANOVA test results for weld width.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	19.6833	2.18703	28.34	0.001
Linear	3	13.7938	4.59794	59.59	0.000
Current	1	8.4666	8.46661	109.72	0.000
voltage	1	1.9602	1.96020	25.40	0.004
welding speed	1	3.3670	3.36701	43.63	0.001
Square	3	5.1484	1.71612	22.24	0.003
Current*Current	1	4.3367	4.33667	56.20	0.001
voltage*voltage	1	0.1807	0.18074	2.34	0.186
welding speed*welding speed	1	1.0717	1.07170	13.89	0.014
2-Way Interaction	3	0.7411	0.24704	3.20	0.121
Current*voltage	1	0.0100	0.01000	0.13	0.734
Current*welding speed	1	0.7310	0.73102	9.47	0.028
voltage*welding speed	1	0.0001	0.00010	0.00	0.973
Error	5	0.3858	0.07717		
Lack-of-Fit	3	0.2808	0.09361	1.78	0.379
Pure Error	2	0.1050	0.05250		
Total	14	20.0691			

3.4 Regression Analysis for Weld Width

Minitab software has been used to develop the regression equation for weld width. It is used for predicting the responses of weld width in effect of the welding parameters. Regression analysis as per notation.

$$\text{Weld width} = -23.85 + 0.1989A + 0.065B + 3.542C - 0.000434A*A - 0.00221B*B \\ - 0.1347C*C + 0.000100A*B - 0.00427A*C + 0.00025B*C$$

Fig. 6 shows the Normal Probability Plot for weld width. The graph shows that the weld width varies with current, voltage and welding speed. The residuals are on the straight line in the Normal Probability Plot which shows that the errors are normally distributed.

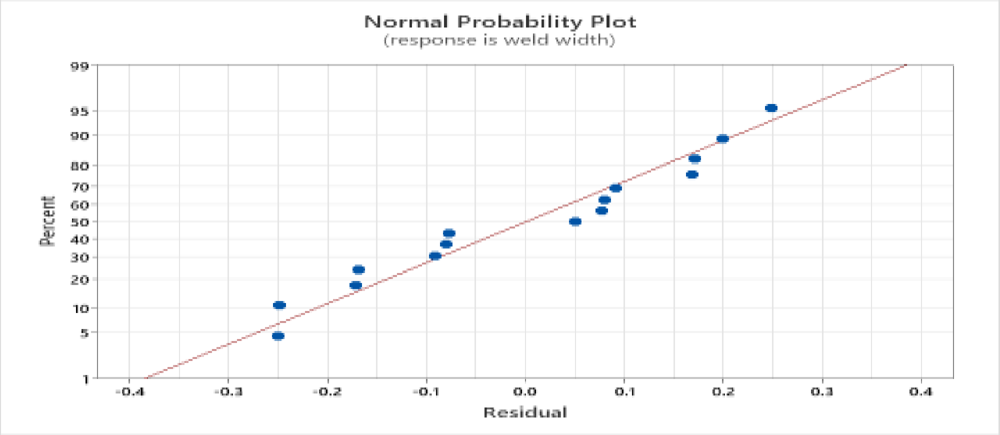


Fig.6- Normal Probability Plot for weld width.

Fig.7 shows the Surface Plot and Fig.8 shows the Contour plot of weld width interacting with welding current, welding voltage and welding speed. The graph indicates the gradual increase of weld width when the welding speed in low. Low welding current stipulates better welding width. Fig.7 and fig.8 presents the combine effect on welding current, welding voltage and welding speed on weld width of the project model. It is observed that current has a significant factor on weld width and it is followed by welding voltage and welding speed.

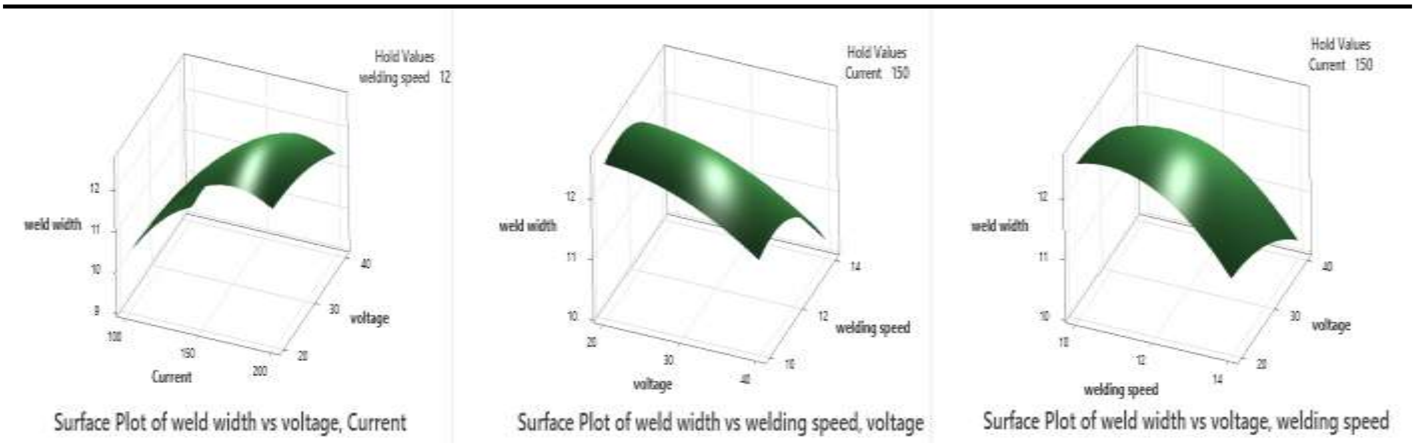


Fig.7- surface plot of weld width

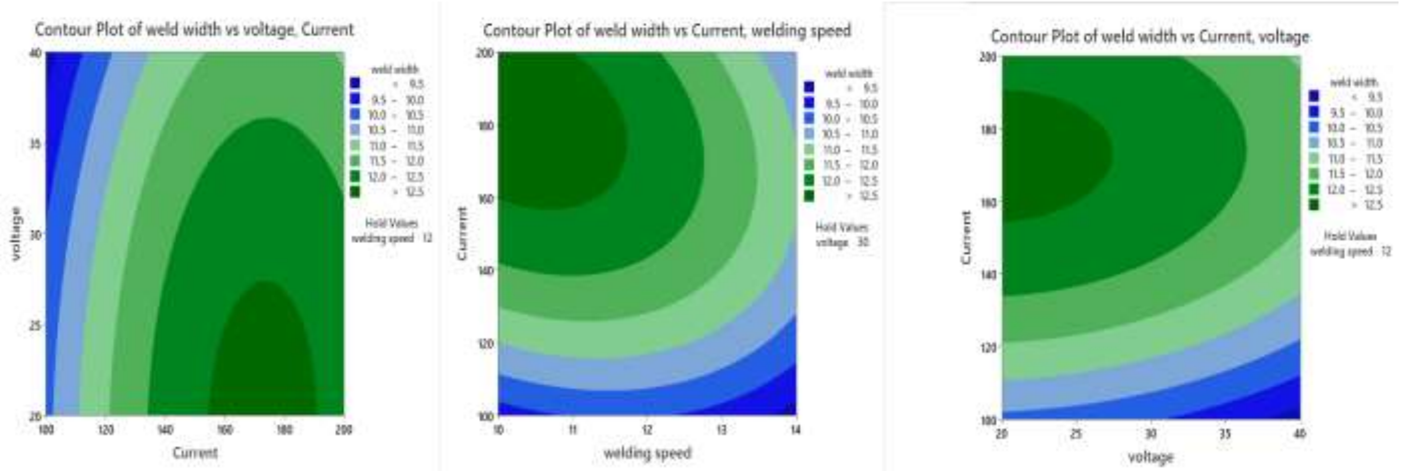


Fig.8- Contour Plot of weld width

4. NUMERICAL OPTIMIZATION

The ultimate aim for this project is to optimize the parametric setting to attain the maximum hardness and to minimize the weld width of the model. Minitab software is used to analyze the optimum setting for the MIG welding. The results of the optimization for hardness and weld width is shown in the Fig.9. The optimum hardness: 86.3 and weld width: 8.52 is obtained at current of 100A, voltage of 40V and welding speed of 14cm/min.

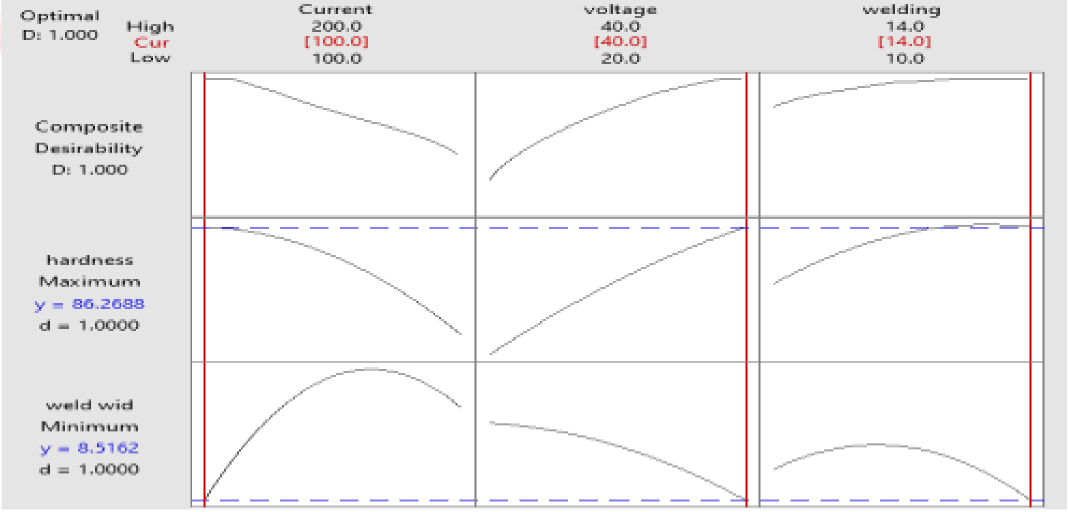


Fig.9- Optimization results of Hardness and Weld Width.

5. CONFIRMATION TEST

To validate the results of optimization, confirmatory experiments were conducted and the findings are presented in Table-7. The results demonstrate that the predicted values closely match the experimental data, with an error percentage of less than 2%. This stipulates that the optimized MIG welding parameters can be considered to maximize the hardness and minimize the weld width to get the optimum result.

Table 7- Optimization Results

Optimum condition				Responses	
Current(A)	Voltage(V)	Welding Speed (cm/min)		Hardness	Weld width
100	40	14	Avg. actual	87.2	8.65
			Predicted	86.3	8.52
			Error%	1	1..5

CONCLUSION

In this research, the aim was to optimize the welding process parameters and determine their optimized values by conducting Hardness and Weld Width testing on welding samples. The study revealed the maximum hardness values and minimum weld width values and identified the varying effects of control parameters on the hardness and weld width. The L15 orthogonal array with three control parameters was employed, allowing the study to be conducted on fifteen work pieces. Among the control factors, current and voltage had the highest impact. The optimum hardness of 86.3 and weld width of 8.52 are acquired under the welding conditions of current at 100A, voltage of 40V and welding speed at 14 cm/min. The optimization method used was validated by comparing the predicted results with the results of the confirmatory test, and it was found that the percentage error was less than 2%, indicating the effectiveness of the applied optimization method.

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