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Research paper

Modeling And Prediction of Mechanical Strength in Electron Beam Welded Dissimilar Metal Joints of Stainless Steel 304 and Copper Using Grey Relation Analysis

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Abstract

Aircraft industries witness an extensive variety of utilizations in unique welded joints thinking about the benefit of quality and high corrosion protection. In any case, joining of dissimilar materials is more mind boggling because of the distinction in material properties. In this investigation dissimilar metal joints of pure Copper plates and Stainless Steel 304 plates of 3mm thickness were welded with Electron Beam Welding. The welding input parameters like Welding speed, Beam current and Work distance liable to quality of weld are considered. Plan of analysis has been made utilizing Taguchi strategy with three levels of input values. Ultimate tensile strength and hardness number were found to decide the mechanical quality. Both the yield esteems are consolidated for expectation and optimized using Gray Relation Analysis (GRA). The impacts of the input parameters towards weld quality were analyzed using ANOVA.

Keywords: *Dissimilar metal joints, electron beam welding, mechanical strength, grey relation analysis*.

1. Introduction

The use of Electron beam for dissimilar metal joints in aircraft industry has amplified in the present days due to its fastest rate constricted with the quality standards. In electron beam welding the fusion zone and the heat affected zone are very narrow when compared with other conventional welding methods. The heat energy produced is a function of beam current, beam Voltage, welding time and Work distance. Taguchi method was adopted in this research and nine sets of input values of beam current, welding speed and Work distance were considered. Grey Relation Analysis has been carried out for the Prediction of Mechanical strength in Electron Beam Welded dissimilar metal joints of Stainless Steel 304 and Copper.

2. Literature Review

Welding is a procedure with various troublesome normal wonders, the greater part of which can't be completely comprehended. It isn't conceivable to build up a differential condition of some confused procedure. In such circumstances, models are produced using the tests and afterward examined by relapse techniques and yield can be anticipated. Yang et al., [1] performed grey relation examination for submerged arc welding process. Their outcomes demonstrate a few deviations in expectation at the middle of the road focuses. To beat this issue, Ganjigatti et al., [2] built up another approach to demonstrate the input yield connections via doing regression investigation. A neural system of model with back propagation was utilized by Nagesh and Datta. [3] Using this they have anticipated the spot geometries of the steel and iron plates. De et al., [4] used an ANN strategy to anticipate the welding impacts of Gas Metal Arc Welding technique. Kim et al., [5] displayed that neural structure based model gives the best results than the precisely influenced conditions can settle. This perception was affirmed by Lee and Um [6] with his exploration in neural system and inferred that this strategy will give great outcomes when compared with other existing models.
Tay and Butler [7] utilized a spiral premise capacity to surmised non-direct flow of the welding procedure to improve the essential welding parameters. Benyounis et al., [8] developed Response Surface Methodology (RSM) to anticipate weld geometries in medium carbon steel welded by laser welding. Gunaraj and Murugan [9] accomplished experiments using submerged arc welding for funnels made of stainless steel in light of CCD with four elements, at five levels to anticipate dab geometry parameters.
Taguchi [10] created technique for directing analyses in light of orthogonal beam, which gave a much diminished change to try different things with ideal setting of control parameters responsible to produce quality welds. This strategy demonstrated the plan of examinations with advancement of control parameters to acquire the best outcomes. Taguchi strategy was adjusted by Tarng and Yang [11] to examine the impact of each welding procedure parameter on the weld-globule geometry. Tarng et al., [12] utilized Gray social examination to research numerous execution attributes in the Taguchi technique for the advancement of submerged bend welding process. By utilizing this approach they enormously improve the advancement technique for deciding the ideal welding parameters with different execution qualities in the submerged bend welding process. R. Ajith Raj et al., [8]

anticipated the mechanical quality of TIG welded Stainless steel 304 utilizing Gray RSM. Mechanical properties like UTS and hardness number were considered as output values in this research and joined through Gray Relation Analysis (GRA) and anticipated the review utilizing Response Surface Methodology (RSM). G. Metzger et al. [14] contemplated the weld ability of different metal joints with metallographic examination and elastic tests in the welded example. R. Rai et al., [15] built up a numerical model for 3Dheat exchange and liquid stream in electron beam welding for 304L stainless steel. In this exploration welds made at various power densities. MiroslavSahul et al. [16] considered dissimilar metal joints of Copper and Stainless Steel plates with laser welding. K. Kanaujia et al., [17] enhanced the elasticity of AISI304 Stainless Steel and Copper utilizing Laser Welding. Info welding parameters, for example, laser control, welding speed and welding length were considered in this investigation. Taguchi approach was utilized for the plan of investigations and the Joint quality was resolved utilizing the universal testing machine. T.A. Mai and A.C. Spowage [18] dissected the dissimilar joints of copper/steel plates, steel/kovar plates, and copper/aluminum plates utilizing laser welding. Rakesh Chaudhari et al., [19] made research to locate the distinctive strategies to join different metals and inferred that MIG does not agree copper to liquefy with press, which prompts absence of entrance. P. Lacki et al., [20] examined the thermo-mechanical examination of In conel 706 tube utilizing electron beam welding.

3. Experimentation

Stainless Steel 304 and Copper both of size 100mm X 60mm X 6mm has been taken for this research. A design of experiment for the three input parameters with three levels of value is made by adopting Taguchi method. To analyze the weld quality mechanical testing has been carried out to find the Ultimate Tensile strength and Micro hardness using UTM and Vickers Hardness. The different process parameters and obtained output values are tabulated in Table 1.

Table 1: Input and Output Parameters of EBW Welding

Sample Number	Input Values			Output Values	
	Beam Current mA	Welding Speed mm/s	Work Distance mm	Tensile Strength Mpa	Hardness Number HV
1	10	8	100	34.92	108
2	10	24	260	32.01	102
3	10	40	425	29.10	98
4	30	8	260	280.24	182
5	30	24	425	90.22	114
6	30	40	100	81.49	143
7	50	8	425	262.01	162
8	50	24	100	219.24	146
9	50	40	260	242.75	150

4. Grey relation Analysis

In Grey Relation examination both the output parameters were changed over in to a solitary Grey relation grade. Utilizing this response grade prediction and optimization has been completed. The different advances took after to determine the grey relation grade has been portrayed beneath.

1. Normalization

The first step in grey relation analysis is the normalization or pre processing of the two output data. Here the values of tensile strength and hardness number have been normalized. The formula used for this purpose is given below.

$$Y_i = \frac{(\text{Xi} - \text{Xi Minimum})}{(\text{Xi Maximum} - \text{Xi Minimum})}$$

Where

Y_i - Normalized value

X_i - Output values

i = 1, 2, 3, 4,…n.

The normalized values of tensile strength and Hardness number are tabulated in Table 2.

Table 2: Normalized Output Values of EBW Welding

Sample Number	Input Values			Output Values	
	Beam Current mA	Welding Speed mm/s	Work Distance mm	Normalized Tensile Strength Mpa	Normalized Hardness Number HV
1	10	8	100	0.023174	0.119048
2	10	24	260	0.011587	0.047619
3	10	40	425	0	0
4	30	8	260	1	1
5	30	24	425	0.24337	0.190476
6	30	40	100	0.208609	0.535714
7	50	8	425	0.927411	0.761905
8	50	24	100	0.757108	0.571429
9	50	40	260	0.850721	0.619048

2. Grey Relation Coefficient

The next step in this process is to find the coefficient value of the normalized responses. The formula used to find the coefficient value is given below.

$$C = \frac{(\text{YiMinimum} + \text{D YiMaximum})}{(\text{Yi} + \text{D YiMaximum})}$$

Where,

C is the grey relation coefficient

D is the distinguishing coefficient ranges ($0 \leq D \leq 1$)

The calculated coefficient values of the normalized responses are tabulated in Table 3.

Table 3: Grey Relation Coefficient Values of Normalized Responses

Sample Number	Input Values			Output Values	
	Beam Current mA	Welding Speed mm/s	Work Distance mm	Grey Relation Coefficient (Tensile Strength Mpa)	Grey Relation Coefficient (Hardness Number HV)
1	10	8	100	0.338564	0.362069
2	10	24	260	0.335928	0.344262
3	10	40	425	0.333333	0.333333
4	30	8	260	1	1
5	30	24	425	0.39789	0.381818
6	30	40	100	0.387179	0.518519
7	50	8	425	0.873227	0.677419
8	50	24	100	0.673045	0.538462
9	50	40	260	0.770085	0.567568

3. Grey Relation Grade

Grey Relation Grade for the tensile strength and micro hardness has been found out by averaging the grey relation coefficient values. This calculated grade values can be utilized for optimization and prediction of mechanical strength of the welded joint with numerous performance features. The grade values thus found from the grey relation coefficient values are tabulated in Table 4.

Table 4: Grey Relation Grade Values

Sample Number	Beam Current mA I	Welding Speed mm/s S	Work Distance mm D	Grey Relation Grade GRG
1	10	8	100	0.350316
2	10	24	260	0.340095

3	10	40	425	0.333333
4	30	8	260	1
5	30	24	425	0.389854
6	30	40	100	0.452849
7	50	8	425	0.775323
8	50	24	100	0.605753
9	50	40	260	0.668826

The values of grey relation grade have been plotted in a time series plot as shown in Figure 1.

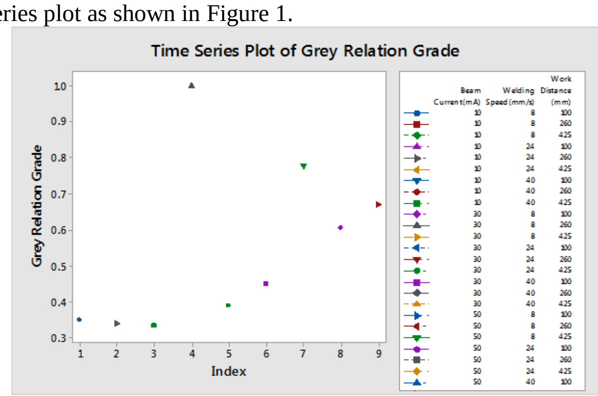

Figure 1: Time series strategy of grey relation grade values

Utilizing the estimations of Gray Relation Grade, fundamental impact plot for current, welding speed and work distance has been made utilizing ANOVA in MINI TAB programming as appeared in figure 2.

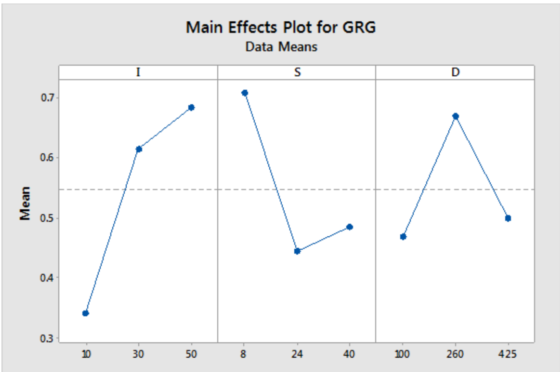

Figure 2: Main effects strategy of grey relation grade values

From the above plot it was found that the optimum input values of beam current, welding speed and Working distance are 50 mA, 8 mm/s and 260 mm.

Factor Information

Factor	Type	Levels	Values		
I	Fixed	3	10,	30,	50
S	Fixed	3	8,	24,	40
D	Fixed	3	100,	260,	425

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
I	2	0.19629	0.09815	3.98	0.201
S	2	0.12089	0.06044	2.45	0.290
D	2	0.06984	0.03492	1.42	0.414
Error	2	0.04932	0.02466		
Total	8	0.43634			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.157033	88.70%	54.79%	0.00%

Coefficients

Term	Coef	SECoef	T-Value	P-Value	VIF
Constant	0.5463	0.0523	10.44	0.009	
I					
10	-0.2050	0.0740	-2.77	0.109	1.33
30	0.0680	0.0740	0.92	0.455	1.33
S					
8	0.1623	0.0740	2.19	0.160	1.33
24	-0.1010	0.0740	-1.36	0.306	1.33
D					
100	-0.0766	0.0740	-1.04	0.409	1.33
260	0.1234	0.0740	1.67	0.238	1.33

Regression Equation

GRG = 0.5463 - 0.2050 I_10 + 0.0680 I_30 + 0.1370 I_50
+ 0.1623 S_8 - 0.1010 S_24
- 0.0613 S_40 - 0.0766 D_100 + 0.1234 D_260 - 0.0468 D_425

From the above regression equation the predicted output grade shows that the average error obtained is 0.04932

Influence of Input Parameters Towards Weld Quality

From the analysis of variance the percentage of influence of the three input parameters towards weld quality are found out. The formula used to find the percentage of influence is given below

$$\% \text{ of Influence} = \frac{\text{Adj SS}}{Total} X\ 100$$

Using this formula the proportion of effect of all the three welding machine input parameters has been calculated as mentioned in table 5.

Table 5: Percentage of Influence of Input Parameters

Source	Adj SS	Total	% of Influence
Beam Current	0.19629	0.43634	44
Welding Speed	0.12089	0.43634	27.7
Work Distance	0.06984	0.43634	16

From the above Table 5 it was found that the percentage of error is 11.3.
The percentage of influence of Beam current, Welding speed and Work distance is also represented in the bar chart as shown in Figure 3.

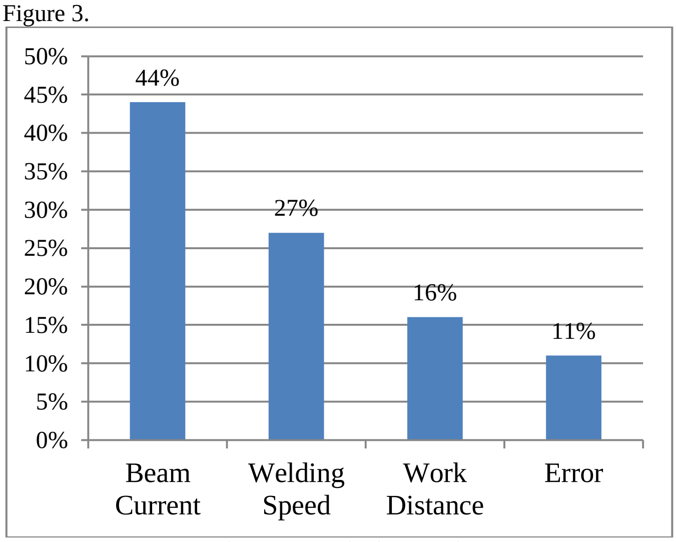

Figure 3: Bar chart of percentage of influence of input parameters

Effect of Current and Speed on Grey Relation Grade

The estimations of Tensile strength and hardness number were changed over to a solitary goal as grade value. A contour plot has been made for the grade value as an incentive regarding beam current and welding speed as appeared in Figure 4.

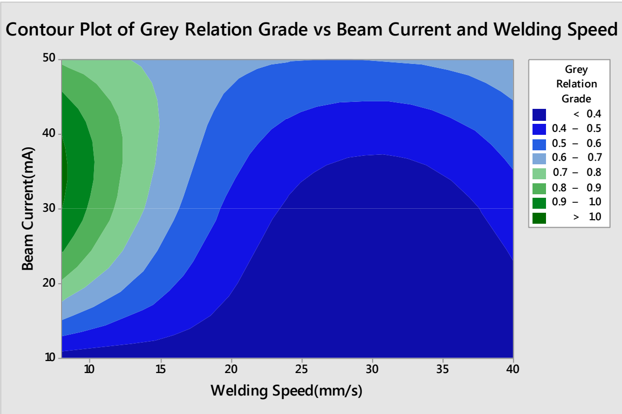

Figure 4: Contour plot of grey relation grade Vs beam current and welding speed

By analysing this contour the impact of these input parameter values on the grade value can be assumed. It was found that the grade value is maximum when the speed is less and Beam current is maximum.

Effect of Beam Current and Work Distance on Grey Relation Grade

A contour has been created for the grade value with respect to Beam current and work distance as shown in Figure 5.

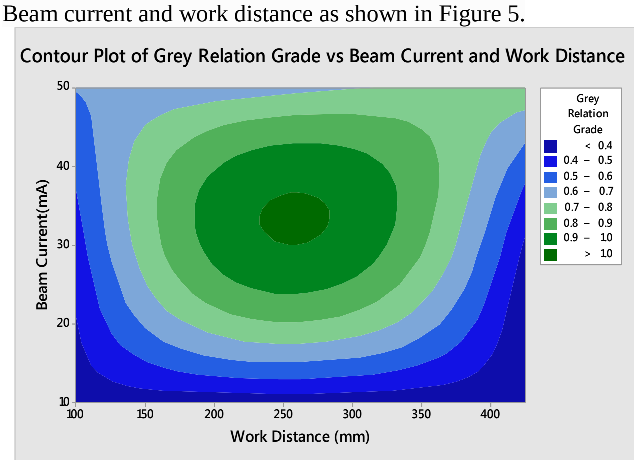

Figure 5: Contour plot of grey relation grade Vs beam current and work distance

By analysing this contour the impact of the input parameter values on the grade value can be assumed. It was found that the grade value is found to be maximum when the Beam current is 30mA and work distance is 260 mm.

Effect of Welding Speed and Work Distance on Grey Relation Grade

A contour has been created for the grade value with respect to welding speed and work distance as shown in Figure 6.

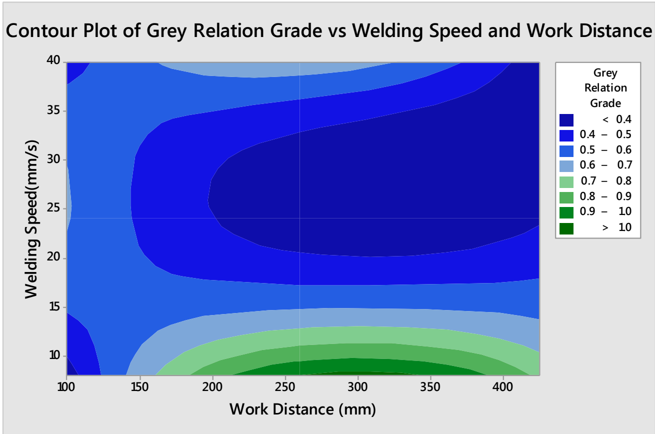

Figure 6: Contour plot of grey relation grade Vs welding speed and work distance

By analysing this contour the impact of the input parameter values on the grade value can be found out. It was found that the grade value is maximum when the welding speed is less and work distance is medium. It was found that the grade value is less when the work distance is too less and if it is too high.

5. Conclusion

The values of two output parameters Tensile strength and hardness number were converted to a single objective as grade value for prediction and optimized using Grey Relation Analysis (GRA). The impacts of the input parameters towards weld quality were additionally analyzed. The got result shows that the mistake acquired in the predicted output response grade is 0.04932.

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