Parametric Optimization for Hardness of Tungsten Inert gas Welding on Copper Reinforced Mild Steel Composite

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Abstract:-**This paper presents the parametric optimization for hardness of tungsten inert gas welding on copper reinforced mild steel composite joint. The process variables are current, voltage and gas flow rate. The investigation is based on Response surface method using the Box-behnhen design to determine the influence of parameters with the optimal condition on Hardness response. Analysis of variance indicated that the proposed quadratic model successfully interpreted the experimental data with adequacy measure values of R^2= O.9959 , R-adjusted= 0.9806 and Adequate Precision =47.131. The predicted hardness from RSM under the optimal conditions was 70 BHN. A confirmation test was conducted to verify the validity of the model, resulting in a hardness of 68 BHN**

I. INTRODUCTION

In manufacturing, welding is one of the important processes. It is used widely to join metals using metals or fillers [1]. There are many types of welding such as arc welding, Metal inert gas welding, plasma arc welding, laser welding, friction, and tungsten inert gas welding (TIG) etc.

[1]Tungsten inert gas welding is an arc welding process that uses a non consumable tungsten electrode and an inert gas for arc shielding. The term TIG welding (tungsten inert gas welding) is often applied to this process. TIG can be implemented with or without a filler metal. Tungsten inert gas welding is high quality and precision welding process which are suitable for welding metals. Inert gas such as argon and helium are used in shielding gas to prevent the weld from contamination that is detrimental to the properties of the material. [2]Important process parameter which may affect the weld quality are welding current, arc voltage, welding speed, gas flow rate, heat input, gun angle and specimen thickness. The properties of welded joints such as hardness, toughness and tensile strength are affected by a great number of welding parameter.

[1] A “composite” is when two or more different materials are combines to create a superior and unique material. Metal matrix composite (MMC) are metals reinforced with other metals, ceramics, or organic compounds. They are made by dispersing the reinforcement in the metal matrix. reinforcement are usually done to improve the properties of the base metal like strength stiffness, conductivity etc.

Metal matrix composite materials are increasingly replacing traditional materials used in building engineering, aeronautics, mechanical engineering and many other domains. It is related to a possibility of obtaining practically any combination of beneficial properties of the material [3].

Metal matrix composites constitute a metallic matrix that is reinforced with another material, usually in the form of a fiber, particulates, whiskers etc. according to [4], the reinforcing material carries most of the load and the matrix material, holding them together, enables load transfer. The advantages of using metal materials as matrix includes, high tensile and shear moduli, good fatigue and fracture properties, high thermal and electrical conductivities and moisture resistance

Tungsten inert gas TIG inert gas parametric effect has be studied on several materials which includes, aluminum composite, AZ31B, magnesium alloy, dissimilar pipe joints etc. [5] The dissimilar joining of copper to 304 stainless steel was performed by TIG process using different filler materials. The results indicated the formation of defect free joint by using copper filler material. But, the presence of some defects like solidification crack and lack of fusion caused decreasing tensile strength on other joints. In the optimal conditions, the tensile strength of the joint was 96% of the weaker material. Also the joint was bent till to 180 degrees without any microscopic defects.

[6] Copper matrix composites have been found to be the most competent of metallic matrices in applications were a good combination of properties such as excellent thermal and electrical conductivity, good toughness; formability, high wear and oxidation resistance are required. Based on these property advantages they are used in many applications, such as radiators, electronic contact devices, casing in jet engines and in recent years as substitute materials for cylinder heads, liners and brake disc in automotive industry. There has been an improvement on the mechanical, electrical, thermal

properties as well as interfacial strength and wettability of copper matrix composites, though the use of ceramic materials to reinforce copper still has challenges which have prompted many studies on copper matrix composites [7].

II. EXPERIMENTAL PROCEDURE

2.1 Material

The materials used for this research work are steel machining chips, and commercial pure grade copper which were all sourced locally within delta state. The steel chips utilized were chippings from milling of mild steel and were sourced locally from a machine shop from Delta State Polytechnic Ogwashi-uku.

2.2 Method

[8] Copper reinforced with steel chip in the proportion of (92.5: 7.5) % by mass, was produced using the stir cast method. Being a cast composite, it was subjected to liquid reentrant test and microstructure test to confirm the integrity of the composite.

2.3 Experimental Design Using a Box-Behnken Design on Response Surface Method

Engineers often wish to determine the values of the process input parameters at which the responses reach their optimal. The optimum could be either minimum or a maximum of a particular function in terms of the process input parameters. RSM is one of the optimization techniques currently in wild spread rise in describing the performance of the welding process and finding the optimum of the responses of interest.

RSM is a set of mathematical and statistical techniques that are useful for modeling and predicting response of interest affected by a number of input variables with the aim of optimizing the response.[9]

RSM also specifies the relationship among one or more measured responses and the essential controllable input factors when all independent variables are measureable, controllable and continuous in the experiments, with negligible error, the response surface can be expressed by

$$y = f(x_1, x_2, x_3 \ldots. x_k) \quad \text{equ. 1}$$

Where: k is the independent variable

[9] To optimize the response "y", it is necessary to find an appropriate approximation for the true functional relationship between the independent variables and the response surface. Usually a second order polynomial is used on RSM

$$Y = b_o + \sum b_i x_i + \sum b_{ii} x_{ii}^2 + \sum b_{ij} x_i x_j + \varepsilon \quad \text{equ.2}$$

After screening of favorable factors from welding procedure qualification, the Box Behnken statistical design as one kind of the most effective response surface method was applied. To find the optimal concentration of three process independent variables (Current, Voltage, and Gas flow rate), the table below show the details of the design matrix on the variables in the actual units employed in the Response surface method along with the observed responses for hardness, Toughness and Tensile Strength.

III. RESULT AND DISCUSSION

Table:1 Design matrix with experimental results

Run	Factor1 Current	Factor2 Voltage	Factor3 Gas flow rate	Response Hardness (BHN)
1	105	22	12	77
2	105	26	14	83
3	105	18	14	76
4	105	22	12	77
5	120	18	12	74
6	105	22	12	76
7	90	22	14	76
8	120	22	10	75
9	105	26	10	76
10	105	22	12	77
11	105	18	10	69
12	90	18	12	69
13	120	22	14	81
14	120	26	12	81
15	90	22	10	69
16	105	22	12	77
17	90	26	12	76

Table 2.Independent variables and experimental designs level

			Level		
variable	Notable	Unit	1	2	3
Current	A	Amperes	90	105	120
Voltage	B	Volts	18	22	26
Gas flow rate	C	Lit/mins	10	12	14

Table3 ANOVA analysis for hardness model

Source	Sum of Square	Mean Square	F value	P-value Prob>F	
Model	253.42	28.16	187.72	< 0.0001	Significant
A-Current	*55.13*	*55.13*	*367.50*	*< 0.0001*	

B-Voltage	*98.00*	*98.00*	*653.33*	*< 0.0001*	
C-GAs flow rate	*91.12*	*91.12*	*607.50*	*< 0.0001*	
AB	*0.000*	*0.000*	*0.000*	*1.0000*	
AC	*0.25*	*0.25*	*1.67*	*0.2377*	
BC	*0.000*	*0.000*	*0.000*	*1.0000*	
A^2	*6.84*	*6.84*	*45.63*	*0.0003*	
B^2	*1.16*	*1.16*	*7.74*	*0.0272*	
C^2	*0.32*	*0.32*	*2.12*	*0.1885*	
Residual	1.05	0.15			
Lack of Fit	*0.25*	*0.083*	0.42	0.7510	Not significant
Pure Error	*0.80*	*0.20*			
Cor Total	254.47				
R-Squared = O.9959			Adj R-Squared = 0.9806		
Predicted R-Squared = 0.9594			Adequate Precision = 47.131		

The tables above shows the ANOVA result for the required model. ANOVA is an analytical technique that is used to identify the importance of a model and its parameters using fishers F test and student t test [10]. Student's t test was used to determine the significance of the regression coefficient using a p value standard. In general, larger F values and smaller p value indicate more significant coefficient terms.

Table 3 shows the ANOVA for hardness response. The same table shows also the other adequacy measures which are the R^2, adjusted R^2 and predicted R^2. All the adequacy measures are in logical agreement and indicate significant relationships. The tables also show the statistical summary for each model that was output by Design Expert 10. A quadratic model was suggested, even though it has lower R^2 and adjusted-R^2 (Adj-R^2) values than the cubic model. This is because the cubic model is aliased, which means that the effects of each variable that cause different signals become indistinguishable. [10]

The coefficient of determination R^2 is defined as the ratio of the explained variation to the total variation, and is a measure of the degree of fit. (11) Suggested that a good model fit should yield an R^2 of at least 0.8. The adequate precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The three models have adequate precision of greater than 4 which indicates an adequate signal. The models can be used to navigate the design space

The ANOVA analysis for hardness response model with main effects of the process with interactive effects being significant in this case, A,B,C A^2 and B. The model F value is 187.72 which imply significance of model. Gas flow rate with an F value of 98 indicates this factor as the most significant with least factor as current with an F value of 55.13 estimate hardness. According to the obtained results the developed models are statistically accurate and can be used for further analysis. The final models in terms of coded factors are shown in equations 1. The equation in terms of coded factors can be used to make predictions about the response for given levels of each factors. The coded equation is useful for identifying the relative impact of the factors by comparing the coefficients.

$$Hardness = 76.80 + 2.63A + 3.50B + 3.38C - 0.25AC - 1.28A^2 - 0.53B^2 - 0.27C^2$$

Effect of Process Parameters on Hardness

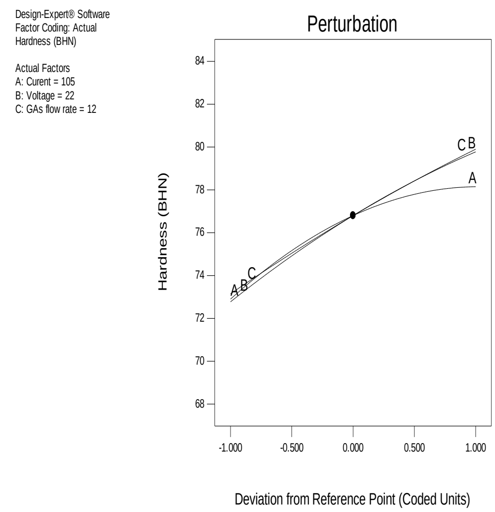

Fig.1. Perturbation plot with reference On hardness response

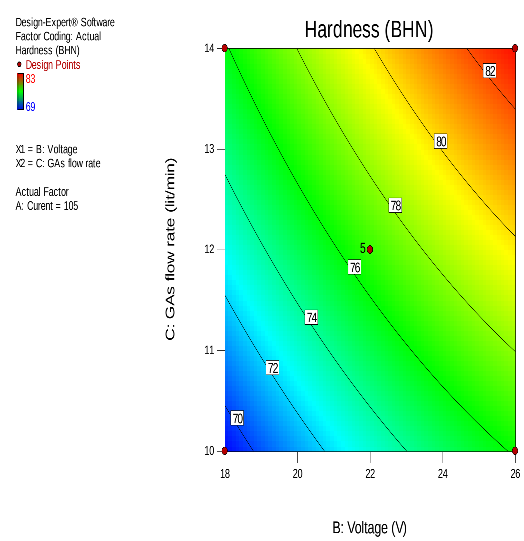

Fig.2. Contour plot of voltage and gas flow rate on hardness

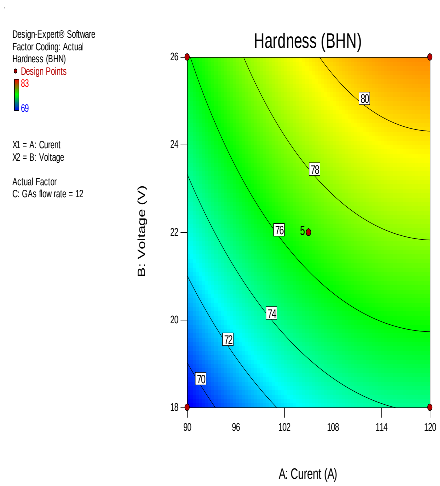

Fig.4 Contour plot of voltage and current on hardness

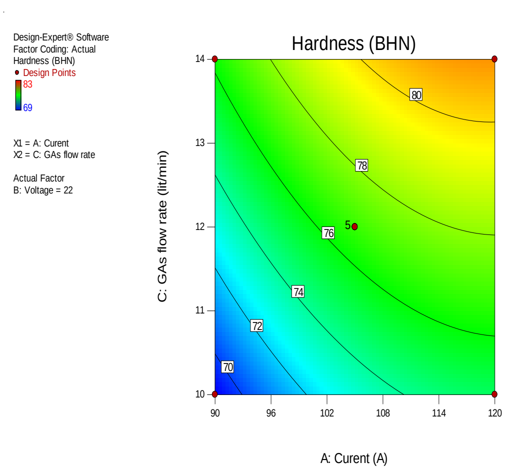

Fig.3 Contour plot of current and gas flow rate on hardness

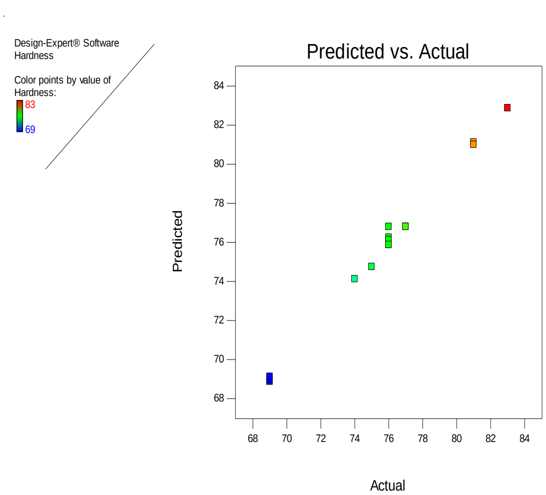

Fig.5. Actual vs Predicted plot for hardness

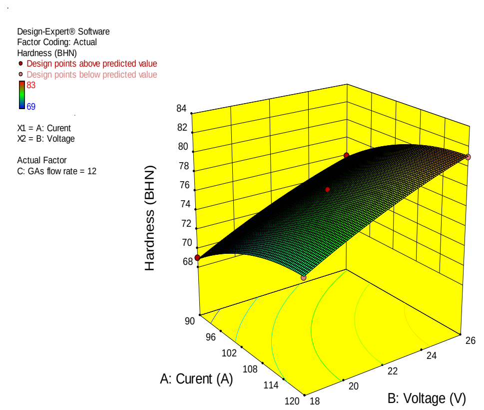

Fig.6 3D graph plot voltage and current on hardness

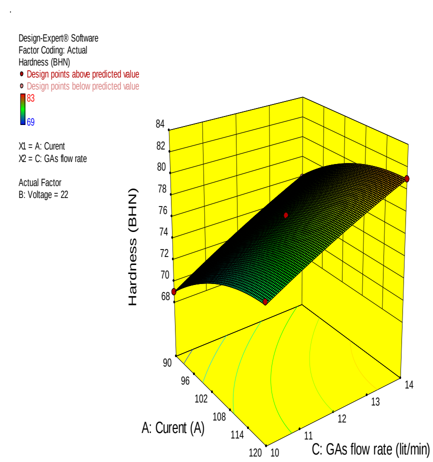

Fig.7. 3D graph plot current and gas flow rate on hardness

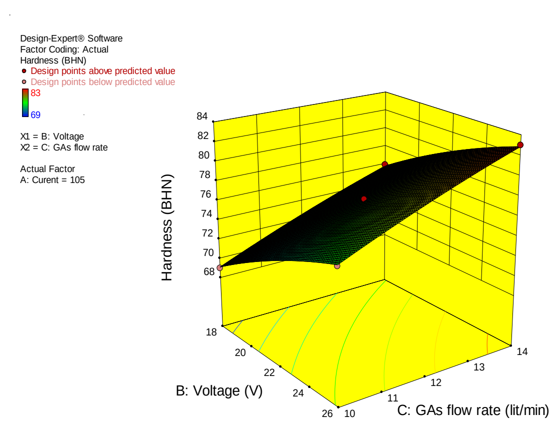

Fig.8 .3D graph plot voltage and gas flow rate on hardness

From the perturbation plot in figure 1, the factors of current, voltage and gas flow rate show increasing hardness effect on the composite with gas flow rate having the most effect. From the plot, it shows that gas flow rate and voltage increase causes increase in hardness beyond the central reference point.

It did not record any decline within the design space. This is because increasing arc voltage lengthens the arc which results in increase in, penetration, flux consumption and reinforcement with a risk of arc blow which is detrimental to quality weld. [12]. With the combination of increased gas flow rate and voltage resulting in steady increase in hardness, it becomes an indication that the design ranges for the two factors have increase influence on the hardness though it isn't a good result for achieving good tensile and toughness response. Because of this, optimization for hardness would be set at a goal of minimizing hardness in order to maintain optimal toughness and tensile strength.

The relationships between the hardness and the three factors are shown in figure 2-8.Each plot shows the effect of two variables within their study ranges with the other variables fixed at the central point. The response surfaces better visualizes the tendency of each factor to influence the hardness. An elliptical contour plot indicates a prominent interaction, whereas a negligible effect appears as a circular contour plot [13]

Perturbation plot is an important diagrammatic representation to compare effects of all factors at a particular point in design space. The response is plotted by changing only one factor over its range while holding of other factors constant. A steep slope or curvature in a factor shows that the response is sensitive to other factor. A relatively flat line shows insensitivity to change in that particular factor. If there are more than two factors, perturbation plot could be used to find factors that most affect the response

Condition for Optimization and Confirmation Tests

Optimal conditions for hardness was output using Design Expert software with optimization goal set at minimize because of the detrimental effect of hardness property on toughness and tensile strength properties

Table 4 Optimization criteria used in this study

Factor and Response	Limits		Criterion	Goal
	Lower	Upper		
Current	90	120	In range	In range
Voltage	18	26	In range	In range
Ss	10	14	In range	In range
Hardness	69	83	In range	Minimize

Table 5 Optimal solution as obtained by Design Expert based on the criterion and Goal on Hardness

s/n	Current	Voltage	Gas flow rate	Hardness
1	104	21	13	71
2	104.	21	11.5	70
3	104	21	12	69

Validation of Test

Table 6. Optimized solution from table 5 was averaged and result used in validatation

s/n	current	voltage	GFR		Hardness
1	104	21	12	Actual	68
				`Predicted	70

Microstructure

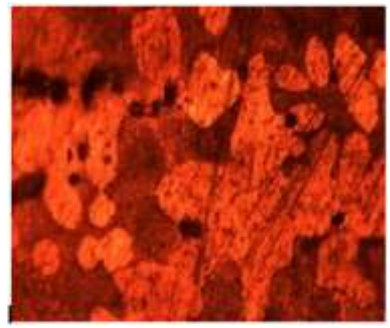

Fig. 9.Micrograph of validated hardness sample

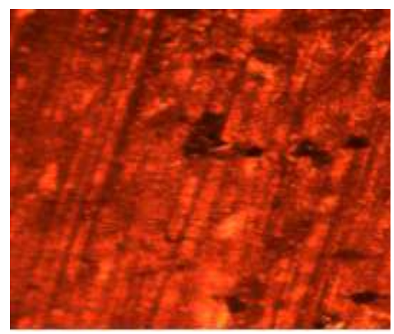

Fig. 10 Micrograph of as composite

The microstructures showed varied phase contrast of the copper matrix with evidence of visible dispersion of the reinforcing particulates. Similar phase contrast and dispersion of particulates in Cu matrix composites produced by double stir casting have been reported by [14]. In order to achieve the optimum mechanical properties, it is essential to achieve the uniform distribution of reinforcement within the matrix.

IV. CONCLUSION

RSM is an accurate technique to optimize the TIG welding process in order to obtain the best hardness properties of the welded component Parameters set at (current 104A voltage 21V and gas flow rate of 11 lit/mins) with the goal of minimizing the hardness so that toughness should not be compromised gave the least hardness value of 68 BHN

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