EFFECT OF WELDING VARIABLES ON TENSILE STRENGTH OF CU-STEEL WELDMENTS THROUGH DESIGN OF EXPERIMENTS AND REGRESSION MODEL

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ABSTRACT

In this paper, Response Surface Methodology (RSM) is used to investigate the effect of twoprocess variables viz. Welding Speed and Current forTensile Strength of the weld of Copper and Steel. A Central Composite Design (CCD) is used to study the proposed model for Tensile Strength and to estimate the model coefficients of the two factors, which are supposed to influence the Tensile Strengthof the weld.Experiments were conducted on Copper and Steel. The RSM technique is used to model the response on experimental data. The significant coefficients are obtained by performing Analysis of Variance (ANOVA) at 5% level of significance.

Keywords: Tensile Strength, RSM, Welding, Dissimilar Metals, Modelling

I. INTRODUCTION AND LITERATURE REVIEW

Out of the various types of welding methods available in the weld industry Gas metal arc welding (GMAW) is one of the most important one, due to its flexibility, possibility of welding in different thicknesses, possibility of automatic implementation and high production capability [Moore et al. (2003), Tzafestas et al. (2000)].Industries have an increasing demand of dissimilar metal joints for various applications, viz. reduction in weight, concern regarding environment, high performance, cost saving and energy saving [Dong et al. (2012), Uzun et al. (2005)]. The transportation industry widely uses aluminium alloys for the purpose of reduction in weight [Chen et al. (2013), Zhang et al. (2007)]. [Korenyuk (1975)] tried to weld Aluminium to Titanium, this combination was not accomplished successfully by conventional arc welding processes. [Gorin (1964), Lv et al. (2012)] welded Titanium to nickel, an attempt to weld Ti and Ni using TIG was not successful. However, they used copper alloy as an insert which, led to a joint without harmful intermetallic compounds. [Mikhailov et al. (1965)] successfully welded Titanium to Copper, their produced joints were with the highest tensile strength and ductility with Ti-30Cb and Ti-

3Al-6.5Mo-11Cr. [O'Brien (2011)] welded Copper alloys to Nickel, and found that, the Copper and nickel are mutually soluble in each other. [Shao et al. (2015)] welded Aluminium and Galvanized Steel. Their thermodynamic calculations predicted that the Fe_2Al_5 intermetallic compound layer was formed first in the steel side, when temperature gradually reduced. The joining of steel and copperhas become an essential research and application focus [Chen (2015)]. It is nevertheless difficult to join them together due to the differences in physical characteristics such as the melting temperature, the poor metallurgical compatibility and thermal expansion, of these two metals.In this paper, gas metal arc welding (GMAW) method was used to join steel and copper.

II. EXPERIMENTAL SET-UP

The experiments were conducted to study the effects of various parameters of welding onjoining Copper and Steel with GMAW. These studies were undertaken to investigate the effects of Welding Speed and CurrentforTensile Strength. The workpiece material selected for the research work was Copper (100%) and steel (composition shown in Table 1). Due to its emergent range of applications in the field of manufacturing tools in mould industries, we selected Steel. Workpiece materials used were steel square plates of dimensions 100×80 mm and of thickness 6 mm. the welding process is shown in Figure 2 (b) and the Tensile Strength Specimens are shown in figure 2 (a).The test conditions are depicted in Table II.

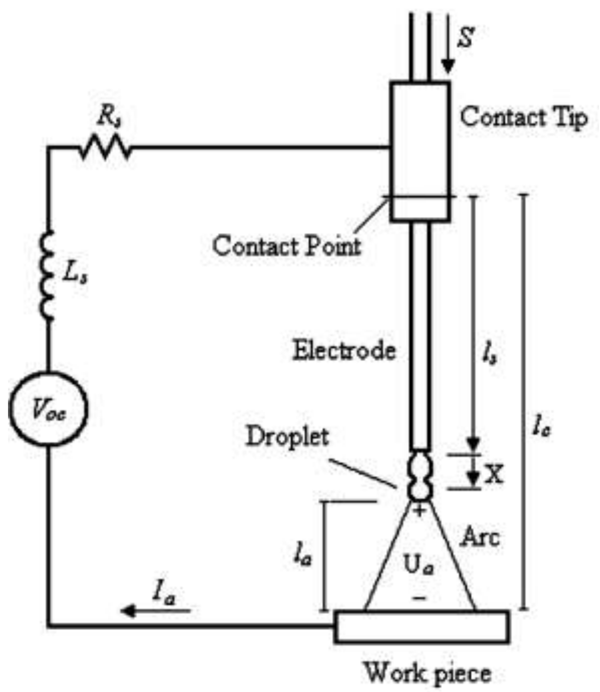

Figure 1: **Model of GMAW Process [Shao et al. (2015)]**

Table I: Composition of Steel Welded with copper

Carbon	Silicon	Manganese	Phosphorus	Sulphur	Chromium	Molybdenum	Nickel	Copper	Titanium	Cobalt	Vanadium
.352	.178	.61	.035	.037	.243	.033	.080	.089	.007	.003	.003

(a) (b)

Figure 2: Welded Process being conducted

III. RESPONSE SURFACE METHODOLOGY

The collection of statistical and mathematical techniques named Response Surface Methodology (RSM) is useful for modelling and analysis of the problems in several input variables influences the responses. RSM objective is to find the correlation between the variables investigated and the response [Rana et al. (2014), Montgomery (2001)]. Design of Experiments (DOE) was used to estimate an unknown function for which only a few values were computed. Least square error fitting was used to model the generated relations of the response surface.A Central Composite Design (CCD) gives a comparatively accurate prediction of all response variable averages related to quantities measured during experimentation, hence it was used [Mason et al. (2003)]. Central Composite Design (CCD) offers the advantage that certain level adjustments are acceptable and can be applied in the two-step chronological RSM. In these methods, there is a possibility that the experiments will stop with few runs and decide that the prediction model is satisfactory.

Table I: DIFFERENT VARIABLES USED IN THE EXPERIMENT AND THEIR LEVEL

Variable	CODE	LEVELS	
		1	2
Current (A)	A	200	240
Welding Speed (mm/s)	B	1.11	1.44

The Current, and Welding Speedwere the variables selected for this investigation. The different levels taken for this study are shown in Table I. Three replications of Tensile Strength were taken, and the average value of Tensile Strengthused in the design matrix, is shown in Table II.

Table II: PLANNING MATRIX OF THE EXPERIMENTS WITH THE OPTIMAL MODEL DATA.

Current(A)	Welding speed(mm/s)	Tensile Strength(N/mm^2)
240	1.11	133
240	1.44	86
200	1.44	114
200	1.11	108

The experimental values were analysed and then a mathematical model was developed which, illustrated the relationship between the process response and the variables. The model in equation 1 explains the behaviour of the system.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \epsilon \qquad \ldots 1$$

Where y = Hardness, x_1 = Current (A), x_2 = Welding speed (mm/s) and β_1, β_2= Partial Regressors.

IV. RESULT AND DISCUSSION

Based on the experimental data gathered, statistical regression analysis enabled to study the correlation of process parameters with the Tensile Strength. In this study, a polynomial regression was modelled for two variables under consideration. For simplicity, a quadratic model of Tensile Strengthwas proposed.

The coefficients of regression model was estimated from the experimental results. The effects of these variables and the interaction between them were included in this analyses and the developed model is expressed as interaction equation:

Tensile Strength (N/mm^2) = 198 - 0.037 Current (A) - 62.1 Welding speed (mm/s) …2

TABLE III: ANOVA TABLE FOR TENSILE STRENGTH

Term	**Coef SE**	**Coef**	**T-Value**	**P-Value**
Constant	198	179	1.11	0.468
Current (A)	-0.037	0.663	-0.06	0.964
Welding Speed (mm/s)	-62.1	80.3	-0.77	0.581

The unknown coefficients were determined from the experimental data as presented in Table III. The standard errors on estimation of the coefficients were tabulated in the column 'SE coef'.

It was important to check the adequateness of the model, because under-specified or an incorrect model could have lead us to misleading conclusion. The model adequateness checking included the test for significance of the model coefficients, lack of fit and regression model, which were carried out subsequently using ANOVA on the curtailed model (Table. IV).

Table IV: ANALYSIS OF VARIANCE TABLE FOR THE FITTED MODELS:

Source	DOF	Adj. SS	Adj. MS	F-Value	P-Value
Regression	2	422.50	211.250	0.30	0.790
Current(A)	1	2.25	2.250	0.0	0.964
Welding speed(mm/s)	1	420.25	420.250	0.60	0.581
Error	1	702.25	702.250	*	*
Total	3	1124.75	*	*	*

Current decreases the Tensile Strength with the increase in its value, as that is depicted in the figure 3. From figure 3 it is also vindicated that lower value of Welding Speed produces welds of high Tensile Strength. The figure 4 depicts that, the optimum value of Tensile Strength can be achieved with both the Current and Welding Speed. The surface plot of the Tensile Strength vs Welding Speed (mm/s) and Current (A) is plotted in figure 5.

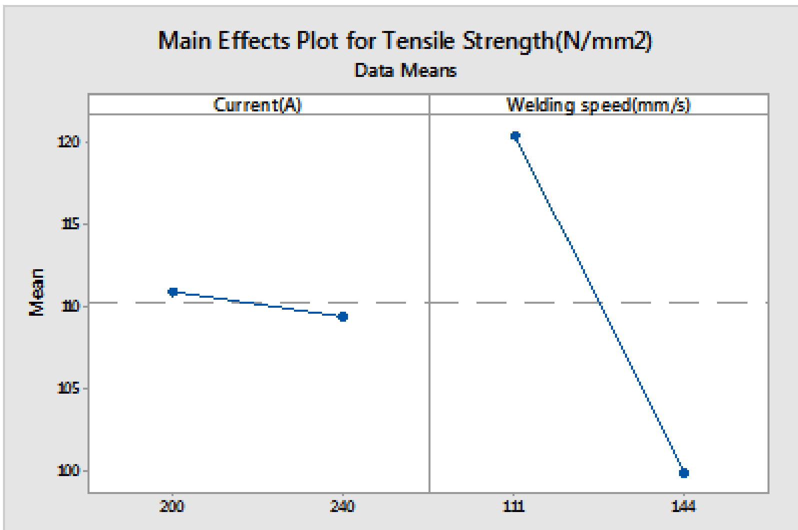

Figure 3: Effect of Current and Welding Speed on Tensile Strength

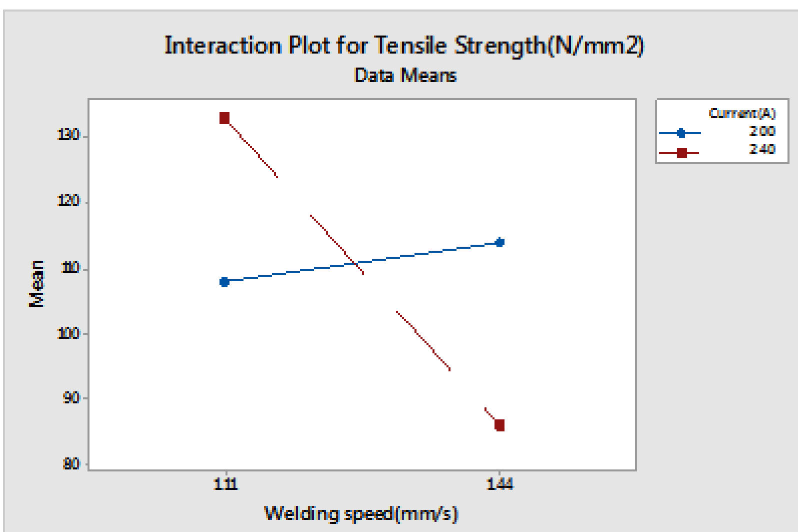

Figure 4: interaction plot of Current vs Welding Speed

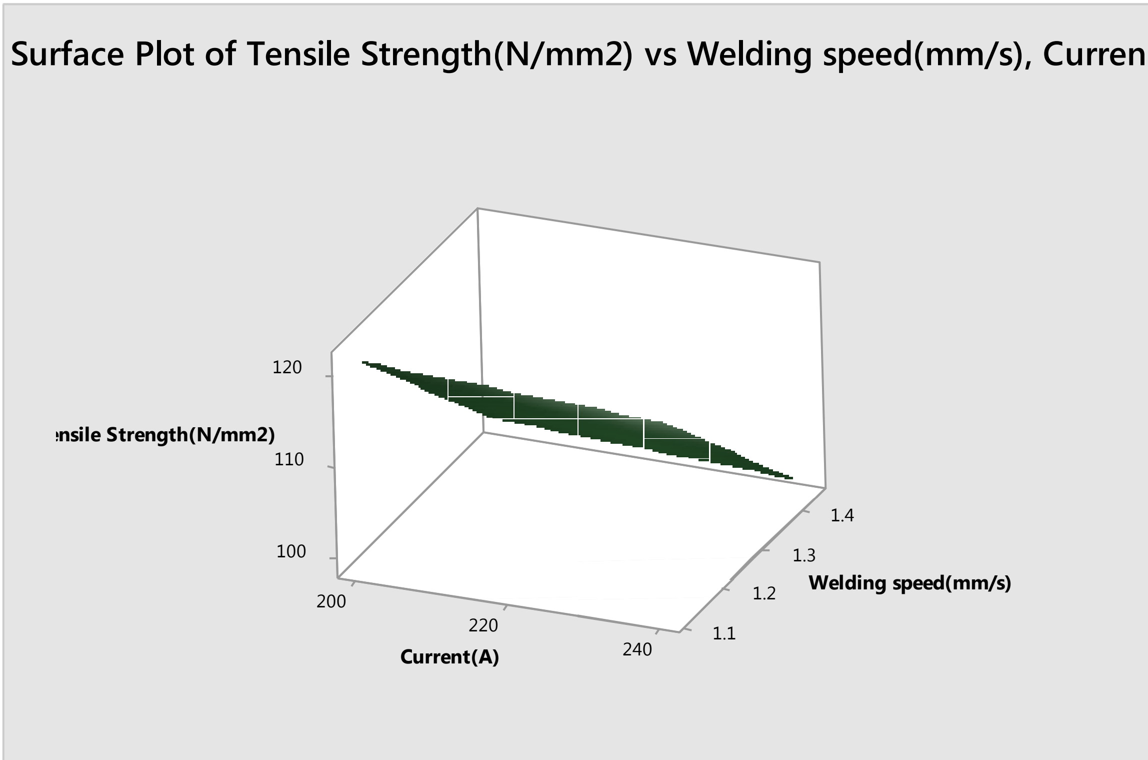

Figure 5: Surface plot of the Tensile Strength vs Welding Speed (mm/s) and Current (A)

V CONCLUSION

In thispaper, the process parameters with significant influence on Tensile Strengthwas determined by using RSM. A response model of these parameters were developed and it was found that the Current, Welding Speed, and interaction term of Current with Welding Speed significantly affect the Tensile Strength. Tensile Strength is inversely proportional to the linear effect of Welding Speed and Current. The higher value of Tensile Strength is achieved with I = 200 A, and Welding Speed = 1.11 mm/s within the experimental domain. The research findings of the present study is based on RSM models, and can be used effectively in joining of Steel with Copper, in order to obtain best possible strength of weld. This research can also help researches and industries for developing a reliable and robust knowledge base along with early prediction of Tensile Strength without experimenting with joining of materials.

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