OPTIMIZING THE PARAMETER OF FRICTION WELDING IN DISSIMILAR MATERIAL USING RESPONSE SURFACE METHOD

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Abstract

Friction welding is widely used in determining the mass production process for joining dissimilar materials due to its environment friendliness, production efficiency and low heat input. The process parameters of friction pressure, upset pressure, rotational speed and burn-off length shows the major role in deciding the strength of friction welded joint to predict the response of tensile strength. In this experimental study, the dissimilar joints of austenitic stainless steel and copper are evaluated by response surface methodology (RSM) using central composite design to develop the mathematical relationship. The correlation coefficient of the regression model was tested by analysis of variance method to check their adequacy of the tensile strength of friction welded joint. Friction pressure has high significance on tensile strength followed by speed and burn off length. A good agreement is shown by comparing between the measured and calculated results of tensile strength.

Key words: *Friction welding, RSM, Austenitic Stainless Steel, Copper, ANOVA*

I. INTRODUCTION

Friction welding is extensively used for joining dissimilar materials mainly due to solid state welding process. Friction welding is used in number of industrial applications such as aerospace, automobile, defence and other industries. The dissimilar metal combinations employed in different applications for a combination of properties to save cost towards costly materials. Dissimilar materials offer the combination of good mechanical properties developed under shipbuilding, automotive and particularly in aerospace industries due to the drastic weight reduction in components.

Faseeulla et al studied the influence of process parameters of weld-bonding on tensile shear strength of aluminium alloy 6061 T651 sheets with significant and controllable process parameters by using RSM and the optimal combination of process parameters are evaluated by maximizing the tensile shear strength of the weld bond (1). Rajakumar et al conducted an FSW experiment by using six different grades of aluminium alloys using different levels of process parameters and the optimal welding conditions were identified using RSM to attain maximum tensile strength (2). Benyounis et al developed mathematical models to predict the process factors to reach the desirable weld bead quality of medium carbon steel using laser butt-welding of medium carbon steel (3). Paventhan et al developed an empirical relationship to predict the tensile strength of the friction welded AA 6082 aluminium alloy and AISI 304 austenitic stainless steel joints to attain the maximum tensile strength using response surface method (RSM) (4). Huixia et al investigated by developing mathematical model between the process parameters and the response using central composite design in order to determine bond strength (5). Satheeshkumar et al undergone the experiment to determine the optimal factors of heat treatment process of ZE41A magnesium alloy by response surface methodology using a central composite design. The process variables used in the study of optimization of tensile strength and acoustic emission counts describes the performance within the limits and these models can be used effectively for the desired values of response parameters (6). Acherjee et al established the design matrix to develop mathematical relationships between the welding process parameters to determine the welding input parameters and the calculated results are in good agreement within the limits of welding parameter (7). Heidarzadeh et al investigated the response surface method to develop a mathematical model for predicting the tensile strength of friction stir welded AA6061-T4 aluminium alloy joints at 95% confidence level (8). Elangovan et al has been developed an mathematical model to predict the tensile strength of friction stir welded AA6061 aluminium alloy joints using design of experiments and the joints exhibit superior tensile properties at 95% confidence level (9). Vettivel et al research focused on dry sliding wear test at room condition by using central composite design approach. The mathematical model developed based on experimental conditions between the process parameters shows 99% confidence level (10). Shanmuga et al conducted the experiment using Central composite design with four parameters, five levels to develop mathematical model to predict the tensile strength and elongation of the dissimilar friction stir welded joints of aluminium alloys (11). Joseph et al investigated to maximize the strength of AA6061 aluminium and AZ31B magnesium alloy by developing an empirical relationship using response surface method (12). Sathiya et al undergone the experiment on AISI 304 austenitic stainless steel with the effects of joining process parameters on metallurgical and mechanical properties of friction-welded joints (13). Khodaverdizadeh et al studied the effect of tool pin profile on microstructure and mechanical properties of friction stir welded pure copper to perform the welded joints (14).

Fig. 1. Friction welding machine

From the literature review, it shows that most of the published information on friction welding of dissimilar materials focused on the mechanical characteristics of steel to other combination of materials. But the combination of austenitic stainless steel (304L) and copper joints is very limited. Hence in this investigation, an attempt was made to optimize friction welding process parameters for tensile strength in copper and AISI 304L austenitic stainless steel dissimilar joints using response surface methodology.

II. EXPERIMENTAL DETAILS

The materials used for experimental investigation are dissimilar materials of austenitic stainless steel (304L) and copper. The materials used for friction welding with the cylindrical rods of 24mm diameter and 75 mm in length. The chemical composition and mechanical properties of the base materials are presented in Table 1and Table 2, respectively. The friction welding samples were well polished using emery paper and cleaned using acetone. The machine has a stroke of 300mm and upset force of 200kN. Friction and upset forces are read by a load cell and operating speed can be varied from 1 to 2500 rpm. The friction welding machine used for this study is shown in Fig 1.

Table 1. Chemical composition of Austenitic stainless steel

Element	C	Si	Mn	P	S	Ni	Cr
%	0.03	0.39	1.63	0.042	0.027	8.99	19.05

Table 2. Chemical composition of Copper

Element	Cu	Fe
%	99.99	<0.01

The experiments were conducted with three levels and four parameters which are used as friction pressure, upset pressure, rotational speed and burn-off length are presented in Table 3.

Table 3. Experimental levels and factors

No.	Factors	Unit	Notation	Levels		
				-1	0	1
1	Friction pressure	MPa	A	22	33	43
2	Upset pressure	MPa	B	65	87	108
3	Burn-off length	mm	C	1	2	3
4	Speed	rpm	D	500	1000	1500

A central composite rotatable four-factor, three level design matrix was selected. The experimental design matrix (Table 4), consisting of 30 sets of coded conditions and comprising a full replication four-factor factorial design of 16 points, 8 star points, and 6 center points, was used. The upper and lower limits of the parameters were coded as +1 and −1, respectively.

Table 4: Design matrix and Experimental Results

Experiment No.	Std order	Run order	Coded Value				Actual Value				Tensile Strength (MPa)
			A	B	C	D	A	B	C	D	
1	1	13	-1	-1	-1	-1	22	65	1	500	193
2	2	17	1	-1	-1	-1	43	65	1	500	185
3	3	25	-1	1	-1	-1	22	108	1	500	194
4	4	18	1	1	-1	-1	43	108	1	500	200
5	5	27	-1	-1	1	-1	22	65	3	500	216
6	6	11	1	-1	1	-1	43	65	3	500	200
7	7	24	-1	1	1	-1	22	108	3	500	200
8	8	7	1	1	1	-1	43	108	3	500	203
9	9	14	-1	-1	-1	1	22	65	1	1500	202
10	10	15	1	-1	-1	1	43	65	1	1500	204
11	11	5	-1	1	-1	1	22	108	1	1500	187
12	12	22	1	1	-1	1	43	108	1	1500	178
13	13	8	-1	-1	1	1	22	65	3	1500	221
14	14	2	1	-1	1	1	43	65	3	1500	194
15	15	9	-1	1	1	1	22	108	3	1500	223
16	16	30	1	1	1	1	43	108	3	1500	197
17	17	26	-1	0	0	0	22	87	2	1000	197
18	18	3	1	0	0	0	43	87	2	1000	186
19	19	19	0	-1	0	0	33	65	2	1000	192
20	20	6	0	1	0	0	33	108	2	1000	181
21	21	16	0	0	-1	0	33	87	1	1000	182
22	22	28	0	0	1	0	33	87	3	1000	169
23	23	10	0	0	0	-1	33	87	2	500	178
24	24	4	0	0	0	1	33	87	2	1500	240
25	25	1	0	0	0	0	33	87	2	1000	197
26	26	20	0	0	0	0	33	87	2	1000	194
27	27	29	0	0	0	0	33	87	2	1000	187
28	28	12	0	0	0	0	33	87	2	1000	192
29	29	21	0	0	0	0	33	87	2	1000	199
30	30	23	0	0	0	0	33	87	2	1000	198

III . DEVELOPING EMPIRICAL RELATIONSHIPS

The relationship between tensile strength (σ) of the friction welded austenitic stainless steel and copper joint is a function of the friction welding parameters such as a friction pressure (*A*), upset pressure (*B*), burn off length (*C*) and rotational speed (*D*) which can be expressed as:

$$TS = f\{A, B, C, D\} \quad [1]$$

A second order polynomial regression model is used for establishing a mathematical relationship between the friction welding parameters and the interaction effects of all parameters were developed based on the tensile strength of welds. For the four factors, the second degree response surface is expressed as follows:

$$TS = b_0 + b_1(A) + b_2(B) + b_3(C) + b_4(D) + b_{11}(A^2) + b_{22}(B^2) + b_{33}(C^2) + b_{44}(D^2) + b_{12}(AB) + b_{13}(AC) + b_{14}(AD) + b_{23}(BC) + b_{24}(BD) + b_{34}(CD) \quad [2]$$

where b_0 is the average of the responses, and b_1, b_2, b_3, …, b_{44} are regression coefficients which was calculated using Design Expert Software. The significance of each coefficient was determined by Student's *t* test, *p* values and the significance of model terms at 95% confidence level. The model were developed using the coefficients and the final empirical relationship developed to estimate the tensile strength are given below:

Coded factors:

$$\text{Tensile Strength} = +193.08 - 3.60\,A - 1.44\,B + 5.63\,C + 0.27\,D + 2.74\,AB - 3.27\,AC - 2.83\,AD + 1.15\,BC - 3.00\,BD + 1.52\,CD - 0.33A^2 - 4.16\,B^2 - 8.16\,C^2 + 17.84\,D^2 \quad [3]$$

Actual factors:

$$TS = +154.58 - 0.73\,A + 27.30\,B + 40.45\,C - 0.107\,D + 5.49\,AB - 6.55AC - 0.01\,AD + 1.15\,BC - 0.006\,E - 0.03CD + 3.03E\text{-}003\,CD - 1.34\,A^2 - 4.16\,B^2 - 8.16\,C^2 + 7.14E\text{-}005\,D^2 \quad [4]$$

The significance of each coefficient was determined by Student's *t* test and *p* values, which are listed in Table 5. The values of "Prob>*F*" less than 0.05 indicate that the model terms are significant. In this case, *A*, *B*, *C*, AB, *AC*, AD, B^2, C^2 and D^2 are significant model terms. The values greater than 0.10 indicate that the model terms are not significant are found as D and A^2. The results of multiple linear regression coefficients for the second- order response surface model are given in Table 6. Analysis of variance (ANOVA) technique was used to check the adequacy of the developed empirical relationship. In this investigation, the desired level of confidence was considered to be 95%. It is found that the above model is adequate. The predicted values are well matched with its experimental value, as shown in Figure. 2.

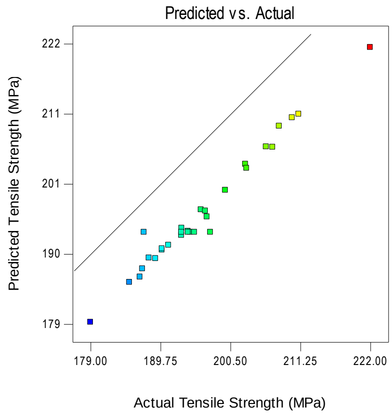

Fig. 2. Correlation graph

IV . RESULTS AND DISCUSSION

RSM is a collection of mathematical and statistical techniques by developing a mathematical model, analyzing the optimum combination of input parameters, and expressing the values graphically (17,18). Based on the proposed empirical relationship, the contour plots are used to obtain the influencing nature by considering two parameters in the (X axis) and one parameter in Y axis as shown in Fig. 3.

The RSM models constructed out of the experimental data correlated fairly well with $R^2 = 0.97$ for tensile strength. It is clear from Fig. 3 that the tensile strength increases with the friction pressure, upset pressure and burn-off length to a certain value and then decreases. By analyzing the response surfaces and contour plots (Fig. 3), the maximum achievable tensile strength value is found to be 240 MPa. The corresponding parameters that yielded this maximum value are friction pressure of 33 MPa, upset pressure of 87 MPa, burn-off length of 2 mm and rotational speed of 1500 rpm. The higher f value denotes the term is more significant and from the F values, it can be shown that friction pressure contributes more to tensile strength, followed by burn-off length, upset pressure and speed in this investigation. The predicted values are in good agreement with the observed values for developed model.

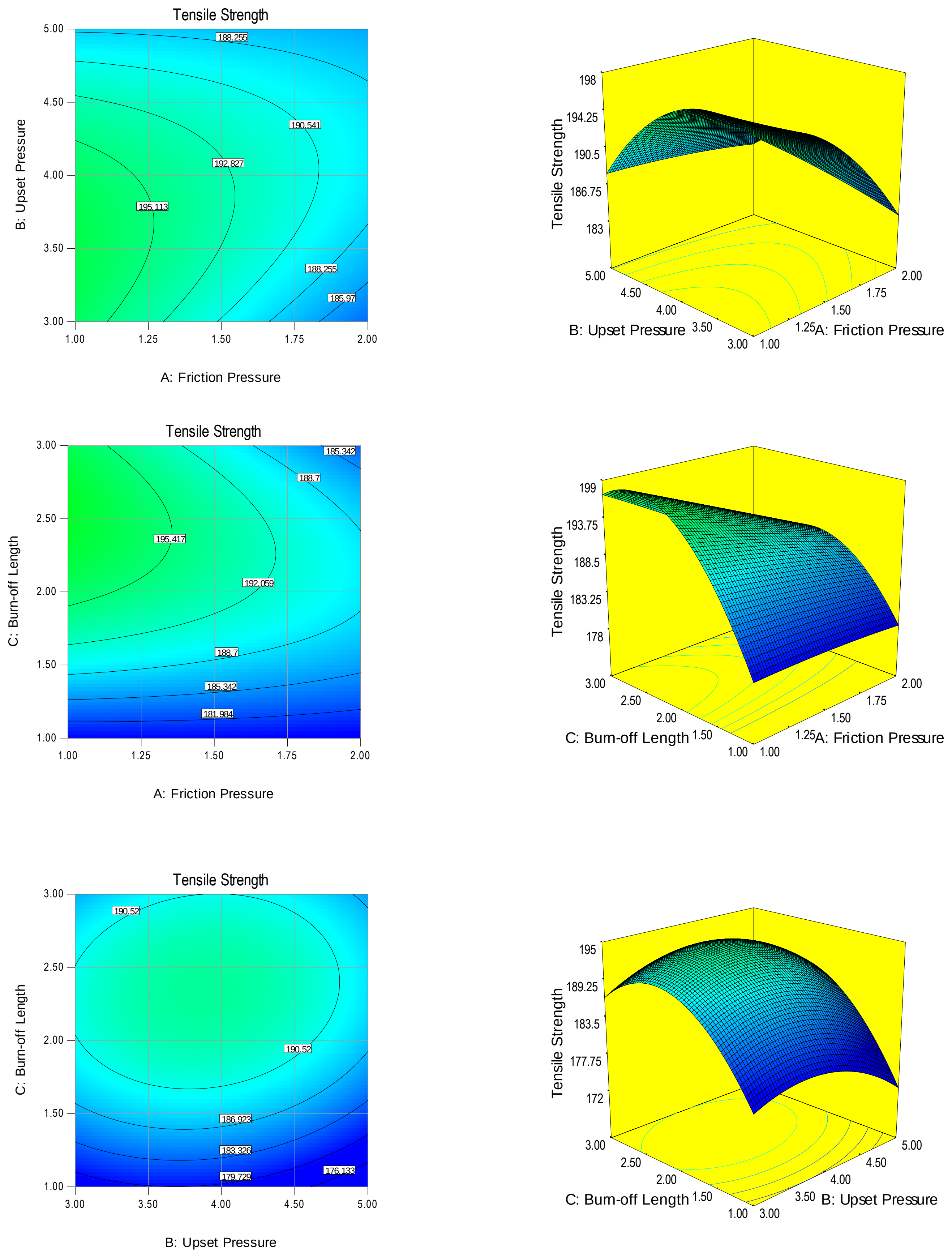

Fig. 3. Contour plots

Table 5. Analysis of Variance

Source	Sum of Squares	f	Mean Square	F Value	p-value
Model	2408.90	14	172.06	37.24	< 0.0001
A-A	233.49	1	233.49	50.54	< 0.0001
B-B	37.44	1	37.44	8.10	0.0122
C-C	570.76	1	570.76	123.54	< 0.0001
D-D	1.35	1	1.35	0.29	0.5960
AB	120.34	1	120.34	26.04	0.0001
AC	171.34	1	171.34	37.08	< 0.0001
AD	127.80	1	127.80	27.66	< 0.0001
BC	21.20	1	21.20	4.59	0.0490
BD	144	1	144	31.16	< 0.0001
CD	36.72	1	36.72	7.94	0.0129
A^2	0.29	1	0.29	0.06	0.8055
B^2	44.82	1	44.82	9.70	0.0071
C^2	172.50	1	172.50	37.33	< 0.0001
D^2	824.62	1	824.62	178.49	< 0.0001
Residual	69.29	15	4.61		
Lack of Fit	11.16	10	1.11	0.09	0.9990
Pure Error	58.13	5	11.62		
Cor Total	2478.2	29			
Std. Dev.	**2.15**		**R-Squared**		**0.9720**
Mean	196.19		Adj R-Squared		0.9459
C.V. %	1.10		Pred R-Squared		0.9408
PRESS	146.73		Adeq Precision		27.721

V . CONCLUSIONS

1) An empirical relationship was developed to predict the tensile strength of friction welded copper and AISI 304L austenitic stainless steel dissimilar joints, incorporating process parameters. The developed empirical relationship can be effectively used to predict the tensile strength of friction welded joints at 95% confidence level.
2) The maximum tensile strength of 240 MPa could be attained under the welding conditions of 33 MPa friction pressure, 87 MPa of upset pressure, 2 mm burn-off length and 1500 rpm rotational speed.
3) Friction pressure was found to have greater influence on tensile strength of the joints, followed by burn-off length, upset pressure and rotational speed.

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