Friction Stir Spot Welding (FSSW) of AA1100 Aluminum Alloy – Parameters Optimization and Sensitivity

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ABSTRACT

Friction stir spot welding (FSSW) is a single spot solid state joining process and has widely been employed in transportation industries especially for joining lightweight materials such as aluminum, copper and magnesium alloys. FSSW process parameters such as tool rotational speed, plunge rate, plunge depth, dwell time play major role in determining the strength of the joints. A central composite rotatable design with four factors and five levels has been chosen to minimize the number of experimental conditions. An empirical relationship is established to predict the tensile shear fracture load (TSFL) of friction stir spot-welded commercial grade (AA1100) aluminum alloy by incorporating independently controllable above said process parameters. Response Surface Methodology (RSM) is applied to optimize the process parameters to attain maximum shear strength in the spot welded lap joints. Sensitivity analysis also carried out to study the impact of process parameters on output.

Keywords: Friction stir spot welding; Aluminum alloy; Response Surface Methodology; Optimization; Sensitivity analysis.

INTRODUCTION

The constantly increasing demands in weight reduction of vehicles for fuel economy and emission regulations have led to wider application of aluminum sheets in transportation industries. But welding of aluminum with the conventional electrical resistance spot welding is highly difficult because aluminum has higher electrical and thermal conductivity. Moreover aluminum has a higher chemical affinity for copper, which limits the electrode life. Friction stir spot welding (FSSW) is a derivative process of friction stir welding process. FSSW is a single spot joining process, in which a solid state joining is made between adjacent materials at overlap configuration. This process also eradicates the problems associated with conventionally used non-welding joining processes such as mechanical riveting and toggle lock [1-4]. It is well known that the welding process parameters play a major role in determining the weld quality. However, the process parameters that provide welds of acceptable quality are not readily available in open literature and hence, the selection of input parameters to join aluminum alloy is very difficult. This is all the more relevant for a new process such as FSSW.

Pan, et al., [5] studied the effect of tool penetration depth at a constant tool rotational speed and reported that the test samples showed a failure mode of interfacial separation at shallow insertion depths, to a nugget-pull mode at highest strength and intermediate insertion depth and then changing to a perimeter failure when the insertion was deepest. Arul et al. [6] investigated the micro-structures and failure mechanisms of FSSW AA5754 aluminum alloy and reported that the failure mechanism is necking and shearing. Mitlin et al., [7] reported that the tool pin penetration depth has a strong effect on the failure mode of the joints and a lesser effect on the joint shear strength. Yasunari et al [8] studied the effect of various FSSW parameters on bonding strength and reported that plunge depth was an important variable affecting bonding area and strength. Wang et al., [9] reported that fatigue lives of friction stir spot welds of aluminum alloys. The effect of pin geometry on the hook formation was analyzed by Badarinarayanan et al [10].

From the literature review, it is understood that the FSSW process is gaining importance to join aluminum alloys, but the published information on the effect of all the process parameters on mechanical characteristics of FSSW aluminum joints is not available. Hence, the present investigation was carried out to find the optimized process parameters, namely, tool rotational speed, plunge rate, plunge depth and dwell time to attain maximum lap shear strength in friction stir spot welded commercial grade (AA1100) aluminum alloy joints.

EXPERIMENTAL WORK

In this investigation, rolled sheets of AA1100 grade aluminum alloy of thickness 3 mm, were used to make the joints. The sheets were cut to required size (150 X 75 mm) by power hacksaw cutting followed by grinding to remove the burr. Chemical composition and mechanical properties of the base metal are presented in **Table1 (a) and (b)** respectively. Lap joint configuration was used to fabricate the spot welds. The joint was initially obtained by securing the plates in position using mechanical clamps. A non-consumable, threaded straight cylindrical tool made of high-carbon steel was used to fabricate the joints. An indigenously designed and developed computer numerical controlled friction stir spot welding machine (4000 rpm, 22kW, 6 ton) was used. Lap shear tensile specimens were prepared as per the dimensions shown in **Fig.1.**

The process parameters that were investigated are i) tool rotational speed, ii) plunge rate, iii) plunge depth and iv) dwell time. A large number of trial experiments were conducted to determine the working range for these parameters by varying one of the them while keeping the rest at constant value. The parameters that produce defect free welds with adequate TSFL were chosen for the working range. The chosen welding parameters and their levels are presented in **Table 2.**

As the range of individual factor is wide, four-factor; five level central composite rotatable design matrix was selected to optimize experimental conditions. The design matrix is consisting 31 sets of coded condition and comprising a full replication four factors factorial design of 16 points, eight star points and seven center points. Since the design matrix is five levels, the upper and lower limits are coded as +2 and -2 respectively and other three are equal intervals of upper and lower values. The coded values for intermediate levels can be calculated from the relationship.

$X_i = 2\ [2X-(X_{max} + X_{min})]\ /\ [X_{max}-X_{min}]$ (1)

where, X_i is the required coded value of a variable X and X is any value of the variable from X_{min} to X_{max}.

The experimental design matrix and corresponding lap shear tensile fracture load are presented in **Table 3**. The spot welds were made as per the conditions dictated by the design matrix at random fashion so as to avoid noise. Some of the fabricated FSSW lap joints are displayed in **Fig.2**. Lap shear test was carried out in 100 kN, electro-mechanical controlled Universal Testing Machine (Make : FIE-Bluestar, India; Model: UNITEK-94100). The specimen was loaded at the rate of 1.5 kN/min as per ASTM specifications until the faying surfaces of specimen were sheared off and the values were recorded.

DEVELOPING AN EMPIRICAL RELATIONSHIP

Tensile shear fracture load (TSFL) of friction stir spot welded AA1100 aluminum alloy is a function of the welding parameters such as tool rotational speed (N), plunge rate (R), plunge depth (D) and dwell time (T) and it can be expressed as TSFL = f(N,R,D,T) (2)

The second order polynomial (regression) equation used to represent the response surface "Y" is given by

$Y = b_0+\Sigma b_i x_i+\Sigma b_i x_i^2+\Sigma b_{ij} x_i x_j$ (3)

The significance of each coefficient was determined by Student's t-test and p-values, which are listed in **Table 4.** Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case N, R, D, T, N^2, R^2, T^2 are significant model terms. Values greater than 0.10 indicate the model terms are not significant. The constructed final empirical relationship from the results of multiple linear regression coefficients for the second order response surface model is given below:

TSFL={4.78+0.105*N+ 0.125* R+0.154* D+0.106* T+0.037* N* R - 0.051* N* D - 0.038* N* T-0.027* R* D +0.011*R* T-0.052* D* T-0.359* N2-0.213* R2-0.044* D2-0.358* T2} kN (4)

Analysis of variance (ANOVA) technique was used to check the adequacy of the developed empirical relationship. In this investigation the desired level of confidence is considered to be 95%. The relationship may be considered to be adequate provided (i) the calculated value of the F ratio of the model developed should not exceed the standard tabulated value of F ratio and (ii) the calculated value of the R ratio of the developed relationship should exceed the standard tabulated value of R ratio for a desired level of confidence. It is found that the model is adequate.

The Model F-value of 28.85 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. The Lack of Fit F- value of 0.66 implies the Lack of Fit is insignificant, as it is desired. Each predicted value matches its experimental value well as shown in **Fig. 3.**

The Fisher F-test with a very low probability value (Pmodel > F = 0.0001) demonstrates a very high significance for the regression model. The goodness of fit of the model was checked by the determination coefficient (R^2). The coefficient of determination (R^2) was calculated to be 0.9641 for response. This implies that 96.41% of experimental data confirms the compatibility with the data predicted by the model and the model does not explain only 3.59% of the total variations. The R^2 value is always between 0 and 1, and its value indicates aptness of the model. For a good statistical model, R^2 value should be close to 1.0. The adjusted R^2 value reconstructs the expression with the significant terms. The value of the adjusted determination coefficient (Adj R^2 = 0.9307) is also high to advocate for a high significance of the model. The Pred R^2 is 0.8548 that implies that the model could explain 85 percent of the variability in predicting new observations. This is in reasonable agreement with the Adj R^2 of 0.9307. The value of CV is also low as 3.59 %. It indicates that the deviations between experimental and predicted values are low. For adequate precision, signal to noise ratio was mesued. A ratio greater than 4 is desirable. In this investigation the ratio is 17.49, which indicates an adequate signal. This model can be used to navigate the design space.

OPTIMIZING THE WELDING PARAMETERS

The response surface methodology (RSM) was used to optimize the parameters in this study. RSM is a collection of mathematical and statistical techniques that are useful for designing a set of experiments, developing a mathematical model, analyzing for the optimum combination of input parameters and expressing the values graphically [12,13]. To obtain the influencing nature and optimized condition of the process on TSFL, the surface plots and contour plots which are the indicative of possible independence of factors have been developed for the proposed empirical relation by considering two parameters in the middle level and two parameters in the X and Y axes as shown in **Fig. 4**. These response contours can help in the prediction of the response (TSFL) for any zone of the experimental domain [14]. The apex of the response plot shows the maximum achievable TSFL. A contour plot is produced to display the region of the optimal factor settings visually. For second order responses, such a plot can be more complex compared to the simple series of parallel lines that can occur with first order models. Once the stationary point is found, it is usually necessary to characterize the response surface in the immediate vicinity of the point. Characterization involves identifying the whether the stationary point is a minimum response or maximum response or a saddle point. To classify this, it is most straightforward to examine it through a contour plot. Contour plots play a very important role in the study of a response surface. It is clear from the Fig.4 that the TSFL increases with the increase of tool rotational speed, plunge rate and dwell time to a certain value and then decreases. It is also observed that the initial increase of plunge depth increases the TSFL to certain value and further increase of plunge depth makes the TSFL to remain constant.

By analyzing the response surfaces and their corresponding contour plots, the maximum value of TSFL is 4.9 kN. Of the four factors, the plunge depth is the most significant factor influencing TSFL, which is then followed by plunge rate, tool rotational speed, and dwell time respectively. The maximum value of TSFL 4.9 kN was exhibited by a joint fabricated at tool rotational speed, plunge rate, plunge depth and dwell time of 604 rpm, 12.38 mm/min, 5.43 mm and 5.03 sec respectively.

SENSITIVITY ANALYSIS

Sensitivity analysis yields the information about the increment or decrement tendency of the objective function with respect to the design parameter and ranks the process parameters by their order of importance. This type of analysis can be used to control the input parameters during welding as if they were more sensitive that influence upon output [15]. Mathematically, sensitivity of an objective function with respect to a design variable is the partial derivative of that function with respect to its variables. The sensitivity equations (5), (6), (7), and (8) represent the sensitivity on TSFL for tool rotational speed, plunge rate, plunge depth and dwell time respectively.

$$\partial(TSFL)/\partial N=0.105+0.037*R-0.051*D-0.038*T-0.719*N \text{ kN} \quad (5)$$

$$\partial(TSFL)/\partial R=0.125+0.039*N-0.027*D+0.011*T-0.426*R \text{ kN} \quad (6)$$

$$\partial(TSFL)/\partial D=0.154-.051*N-0.027*R-0.052*T-0.089*D \text{ kN} \quad (7)$$

$$\partial(TSFL)/\partial T = 0.106 - 0.038*N + 0.0106*R - 0.052*D - 0.716*T \text{ kN} \quad (8)$$

In this investigation, the aim is to rank the process parameters through their impact on TSFL due to a small change in process parameters of FSSW process. Sensitivity is here analyzed using the partial derivatives of (5) through (8). Namely, positive sensitivity values imply an increment in the objective function by a small change in design parameter, whereas negative values state the opposite [16]. Sensitivities of process parameters on TSFL are presented in **Table 5. Fig. 5 (a-d)** shows the sensitivity of tool rotational speed, plunge rate, plunge depth and dwell time respectively on TSFL for changes of tool rotational speed, plunge rate and dwell time when plunge depth is kept constant at D = 5.45 mm. **Table 6** shows the sensitivity range and rank of each process parameter. From this table 6 it can be ranked that the dwell time is more sensitive on TSFL and it is followed by tool rotational speed, plunge rate and plunge depth (ie. T > N > R > D).

Sensitivity can also be inferred that by simply examining the **Figs. 4 (b) and (d)**, the change in tool rotational speed is more sensitive to changes in TSFL than that of plunge rate and plunge depth respectively (N > R, D). When dwell time is compared with tool rotation speed at a plunge rate of 12.38 mm/min and a plunge depth of 5.43 mm, the dwell time is slightly more sensitive (T > N) to changes in TSFL as illustrated in **Fig. 4 (f)**. At a tool rotational speed of 604 rpm and dwell time of 5.03 sec the TSFL is more sensitive to changes in plunge rate than to changes in plunge depth(R>D), as the total combined sheets thickness imposes a limit on plunge depth. An interaction effect between the factors of plunge rate and plunge depth on TSFL is evidenced in the **Fig. 4 (h)**. From the **Figs. 4 (j) and (l)**, it is inferred that the TSFL is more sensitive to changes in dwell time than changes in plunge rate and plunge depth (T > R, D), when tool rotational speed and plunge rate is 604 rpm and 12.38 mm/min respectively.

CONCLUSIONS

1. An empirical relationship was developed to predict the tensile shear fracture load of friction stir spot welded AA1100 aluminum alloy joints incorporating friction stir spot welding parameters at 95 % confidence level.
2. A maximum tensile shear fracture load of 4.9 kN could be attained for friction stir spot welded AA1100 aluminum alloy under the welding conditions of 604 rpm of tool rotational speed, 12.38 mm/min of plunge rate, 5.43 mm of plunge depth and 5.03 seconds of dwell time.
3. From the sensitivity analysis, it is found that the dwell time is the most sensitive process parameter, followed by tool rotational speed, plunge rate and plunge depth.

REFERENCES

1. Iwashita T, Method and apparatus for joining, US Patent 6,601,751 B2 (August 5, 2003).
2. Sakano R, Murakami K, Yamashita K, Hyoe T, Fujimoto M, Inuzuka M, Nagao U, Kashiki H, Development of spot FSW robot system for automobile body members, in: Proceedings of the Third International Symposium of Friction Stir Welding, Kobe, Japan, 2001.
3. Sakaguchi S. Resistant spot welding of aluminum alloy. J Light Metal Weld Construct 1979; 17(3): 126 - 134 (in Japanese).
4. Wang D, Liu S, Cao Z., Study of friction stir welding of aluminum, J. Mater. Sci. 39 (2004) 1689-1693.
5. Tsung-Y Pan, Armando Joaquin, Daniel E. Wilkosz, Larry Reatherford, John M. Nicholson Zhili Feng, Michael L. Santella, (2004), "Spot Friction Welding for Sheet Aluminum Joining", 5th International Symposium on Friction Stir Welding, The Welding Institute, Metz, France. Paper No.11A-1
6. Arul S. G, Pan T, Lin P-C, Pan J, Feng Z, Santella M. L. Micro-structures and Failure Mechanisms of Spot Friction Welds in Lap-Shear Specimens of Aluminum 5754 Sheets, SAE International, 2005-01-1256
7. Mitlin D, Radmilovic V, Pan T, Chen J, Feng Z, Santella M.L, (2006), Structure-properties relations in spot friction welded (also known as friction stir spot welded) 6111 aluminum, Materials Science and Engineering A.
8. Yasunari Tozaki, Yoshihiko Uematsu, Keiro Tokaji, (2007), Effect of tool geometry on microstructure and static strength in friction stir spot welded aluminum alloys
9. Wang D.-A, Chen C.-H., (2008), Fatigue lives of friction stir spot welds in aluminum 6061-T6 sheets.
10. Badarinarayanan H, Yang Q, Zhu S,(2008) Effect of tool geometry

on static strength of friction stir spot-welded aluminum alloy.

11. Box GEP, Hunter WH, Hunter J.S, Statistics for experiment. New York: John Wiley Publications: 1978.

12. Khuri A.I, Cornell J, Response Surfaces; Design and Analysis, Marcel Dekker, New York, 1996.

13. Gunaraj V, Murugan N, Application of Response Surface methodology for predicting weld bead quality in submerged arc welding of pipes, J. Material. Process. Technol. 88(1999) 266-275.

14. Tien C.L and Lin S.W, Optics Communications 266, 574 (2006).

15. Kim IS, Son KJ, Yang YS, Yaragada PKDV (2003) Sensitivity analysis for process parameters in GMA welding processes using a factorial design method. Int J Mac Tools Manuf, 43: 763-769.

16. Serdar Karaoglu, Abdullah Secgin (in press) Sensitivity analysis of submerged arc welding process parameters. J Mater Process Technol, doi: 10.1016/j. jmatprotec 2007.10.035.

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TABLES

Table 1(a) Chemical composition (wt %) of base metal AA1100

Cu	Mn	Si	Fe	Zn	Al.
0.15	0.05	0.40	0.35	0.10	Bal.

Table 1(b) Mechanical Properties of base metal

Tensile Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Shear Strength (MPa)	Elongation (%)	Hardness (Hv)
33	89	62	35	40

Table 2 Important factors and their levels

S.No	Factor	Unit	Notation	Levels				
				-2	-1	0	1	2
1	Tool rotational speed	rpm	N	400	500	600	700	800
2	Plunge rate	mm/min	R	8	10	12	14	16
3	Plunge depth	mm	D	5.25	5.30	5.35	5.40	5.45
4	Dwell time	sec	T	3	4	5	6	7

Table 3 Design matrix and experimental results									
Expt. No	Coded value				Original value				Tensile shear fracture load [TSFL] (kN)
	N	R	D	T	N	R	D	T	
1	-1	-1	-1	-1	500	10	5.30	4	3.21
2	+1	-1	-1	-1	700	10	5.30	4	3.42
3	-1	+1	-1	-1	500	14	5.30	4	3.48
4	+1	+1	-1	-1	700	14	5.30	4	3.93
5	-1	-1	+1	-1	500	10	5.40	4	3.68
6	+1	-1	+1	-1	700	10	5.40	4	3.91
7	-1	+1	+1	-1	500	14	5.40	4	3.92
8	+1	+1	+1	-1	700	14	5.40	4	4.19
9	-1	-1	-1	+1	500	10	5.30	6	3.53
10	+1	-1	-1	+1	700	10	5.30	6	3.76
11	-1	+1	-1	+1	500	14	5.30	6	3.87
12	+1	+1	-1	+1	700	14	5.30	6	4.24
13	-1	-1	+1	+1	500	10	5.40	6	3.95
14	+1	-1	+1	+1	700	10	5.40	6	3.84
15	-1	+1	+1	+1	500	14	5.40	6	4.19
16	+1	+1	+1	+1	700	14	5.40	6	4.25
17	-2	0	0	0	400	12	5.35	5	3.08
18	+2	0	0	0	800	12	5.35	5	3.48
19	0	-2	0	0	600	8	5.35	5	3.81
20	0	+2	0	0	600	16	5.35	5	3.92
21	0	0	-2	0	600	12	5.25	5	4.24
22	0	0	+2	0	600	12	5.45	5	4.84
23	0	0	0	-2	600	12	5.35	3	3.12
24	0	0	0	+2	600	12	5.35	7	3.45
25	0	0	0	0	600	12	5.35	5	4.93
26	0	0	0	0	600	12	5.35	5	4.59
27	0	0	0	0	600	12	5.35	5	4.73
28	0	0	0	0	600	12	5.35	5	4.63
29	0	0	0	0	600	12	5.35	5	4.97
30	0	0	0	0	600	12	5.35	5	4.83
31	0	0	0	0	600	12	5.35	5	4.87

Table 4 ANOVA Test Results						
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	8.331072	14	0.595077	28.84753	< 0.0001	significant
N-N*	0.262504	1	0.262504	12.72542	0.0028	
R-R*	0.372504	1	0.372504	18.05789	0.0007	
D-D*	0.567338	1	0.567338	27.50283	< 0.0001	
T-T*	0.270938	1	0.270938	13.13424	0.0025	
NR	0.021756	1	0.021756	1.054678	0.3207	
ND	0.041006	1	0.041006	1.987861	0.1790	
NT	0.023256	1	0.023256	1.127394	0.3051	
RD	0.011556	1	0.011556	0.560212	0.4657	
RT	0.001806	1	0.001806	0.087562	0.7714	
DT	0.043056	1	0.043056	2.087238	0.1691	
N2*	3.544465	1	3.544465	171.8251	< 0.0001	
R2*	1.247086	1	1.247086	60.45501	< 0.0001	
D2	0.054265	1	0.054265	2.630585	0.1256	
T2*	3.519857	1	3.519857	170.6322	< 0.0001	
Residual	0.309425	15	0.020628			
Lack of Fit	0.187225	10	0.018723	0.76606	0.6643	not significant
Pure Error	0.1222	5	0.02444			
Cor Total	8.640497	29				
Std. Dev.	0.143626		R-Squared		0.964189	
Mean	3.999667		Adj R-Squared		0.930765	
C.V. %	3.590941		Pred R-Squared		0.854825	
PRESS	1.254384		Adeq Precision		17.49399	
df: degrees of freedom; CV: co-efficient of variation; F: Fisher ratio; p: probability * significant factor						

Table 5 Sensitivities of process parameters on TSFL (D=5.45 mm)							
Dwell time T (Sec.)	Rotational speed N (rpm)	Plunge rate R (mm/min)	TFSL (kN)	∂(TFSL) ∂N	∂(TFSL) ∂R	∂(TFSL) ∂D	∂(TFSL) ∂T
3	400	8	2.94	1.44	0.83	0.24	1.49
	500	10	4.67	0.76	0.44	0.16	1.46
	600	12	5.34	0.08	0.05	0.08	1.44
	700	14	4.93	-0.60	-0.34	0.00	1.41
	800	16	3.45	-1.28	-0.73	-0.08	1.38
4	400	8	3.14	1.41	0.84	0.18	0.77
	500	10	4.85	0.72	0.45	0.11	0.75
	600	12	5.48	0.04	0.06	0.03	0.72
	700	14	5.05	-0.64	-0.33	-0.05	0.69
	800	16	3.54	1.32	-0.72	-0.13	0.66
5	400	8	2.62	1.37	0.85	-0.07	0.06
	500	10	4.85	0.69	0.46	0.05	0.03
	600	12	3.64	0.01	0.07	-0.02	0.00
	700	14	3.95	-0.68	-0.32	-0.10	-0.03
	800	16	2.74	-1.36	-0.71	-0.18	-0.05
6	400	8	1.56	1.33	0.86	0.08	-0.66
	500	10	2.50	0.65	0.47	0.00	-0.69
	600	12	3.74	-0.03	0.08	-0.08	-0.71
	700	14	3.48	-0.72	-0.31	-0.15	-0.74
	800	16	1.71	-1.40	-0.69	-0.23	-0.77
7	400	8	2.55	1.29	0.87	0.31	-1.38
	500	10	3.08	0.61	0.48	-0.05	-1.40
	600	12	3.76	-0.07	0.09	-0.13	-1.43
	700	14	2.93	-0.76	-0.30	-0.21	-1.46
	800	16	0.59	-1.43	-0.69	-0.28	-1.48

Table 6 Sensitivity range and rank				
Process parameters	Peak value on	Peak value on	Sensitivity positive side	Rank negative siderange
Tool rotational speed (N)	1.44	-1.43	2.87	II
Plunge rate (R)	0.87	-0.72	1.59	III
Plunge depth (D)	0.31	-0.28	0.59	IV
Dwell time (T)	1.49	-1.48	2.97	I
Inference		T > N > R > D		

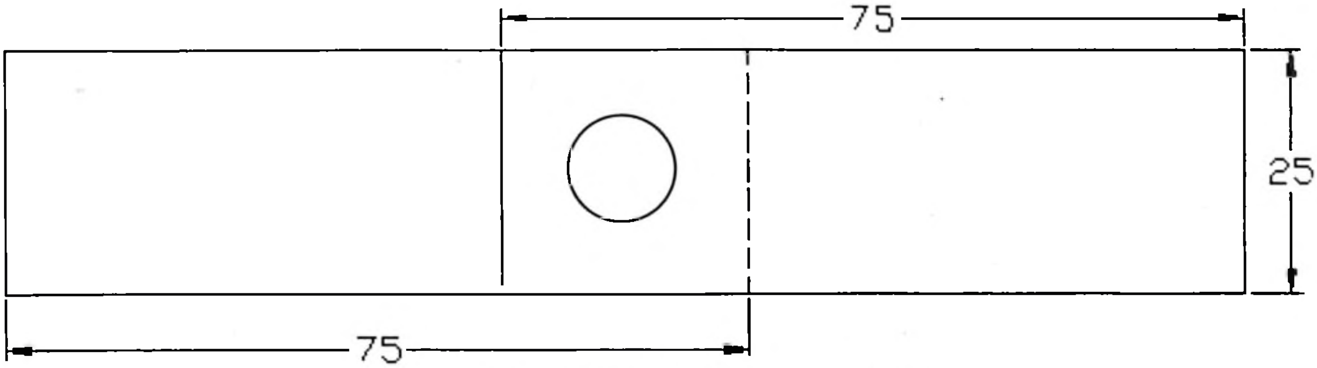


Fig. 1 : Configuration of a lap-shear test specimen

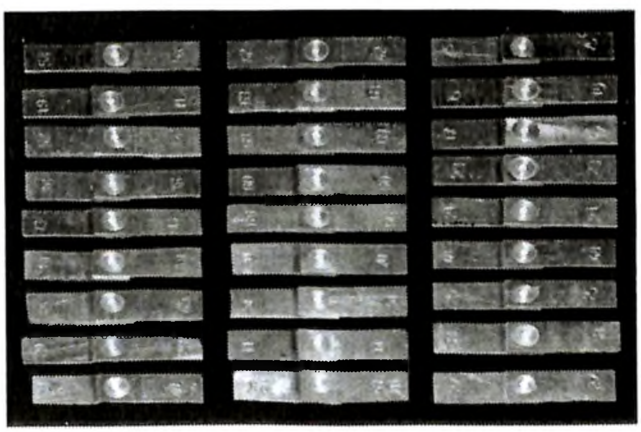


Fig. 2 : A photograph of AA1100 friction stir spot welded lap shear specimens before testing

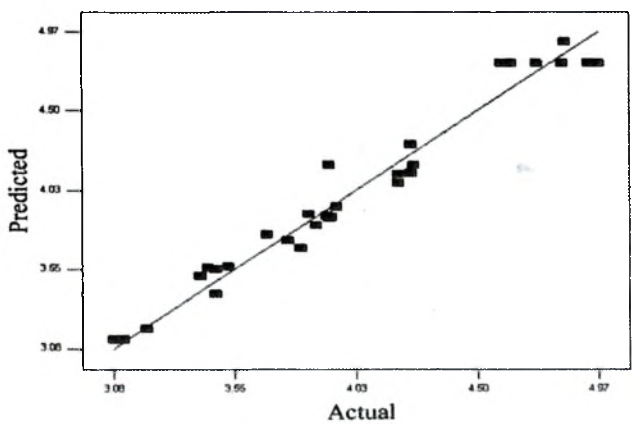


Fig. 3 : Correlation graph

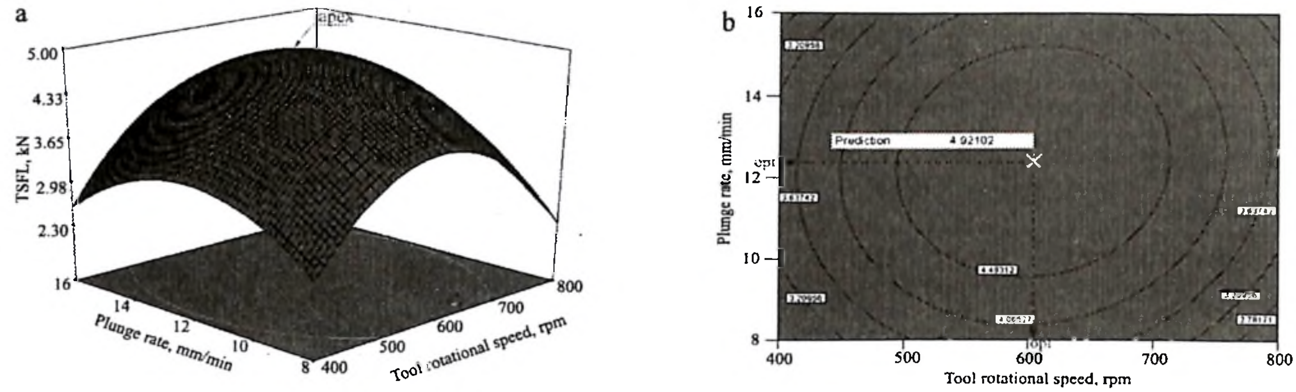
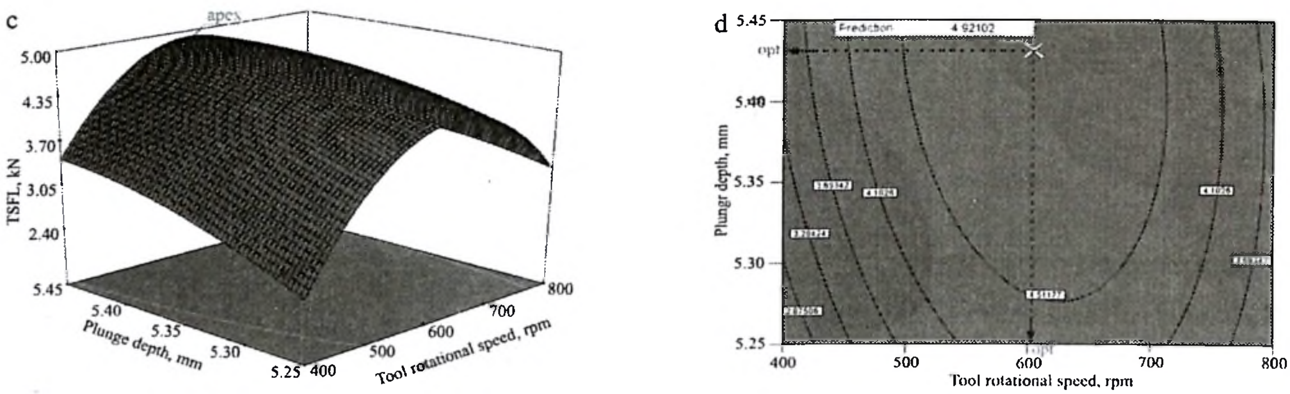
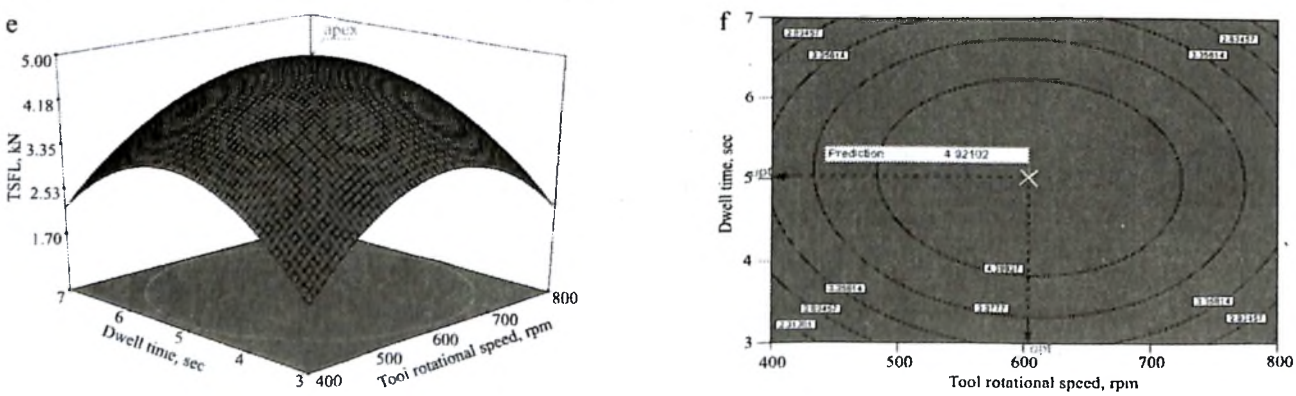


Fig. 4 : Response Graphs and Contour Plots

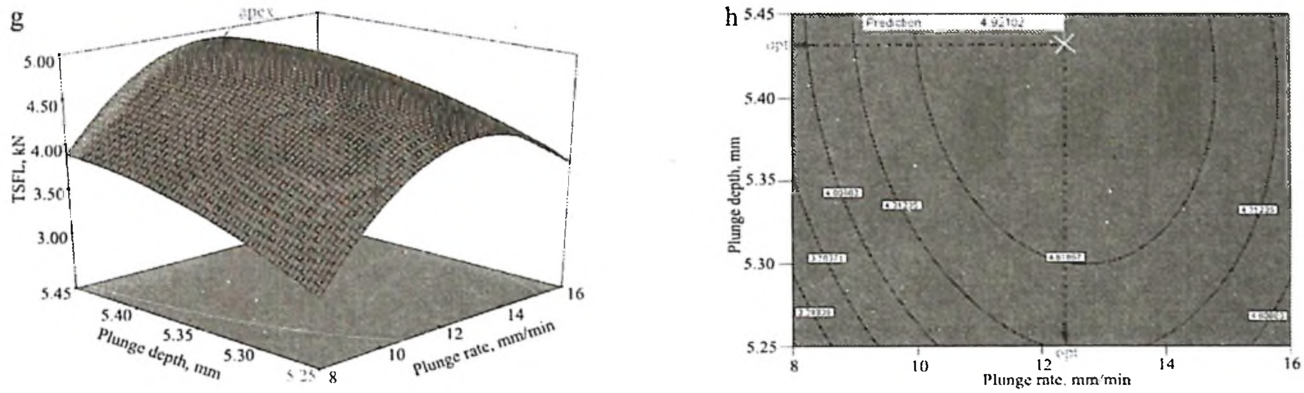
(a) & (b) Interaction effect of tool rotational speed and plunge rate



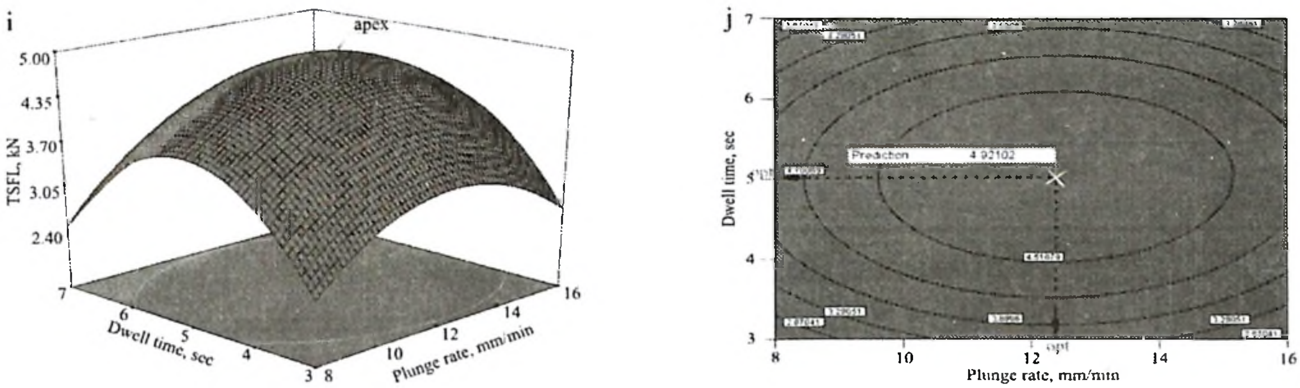
(c) & (d) Interaction effect of tool rotational speed and plunge depth



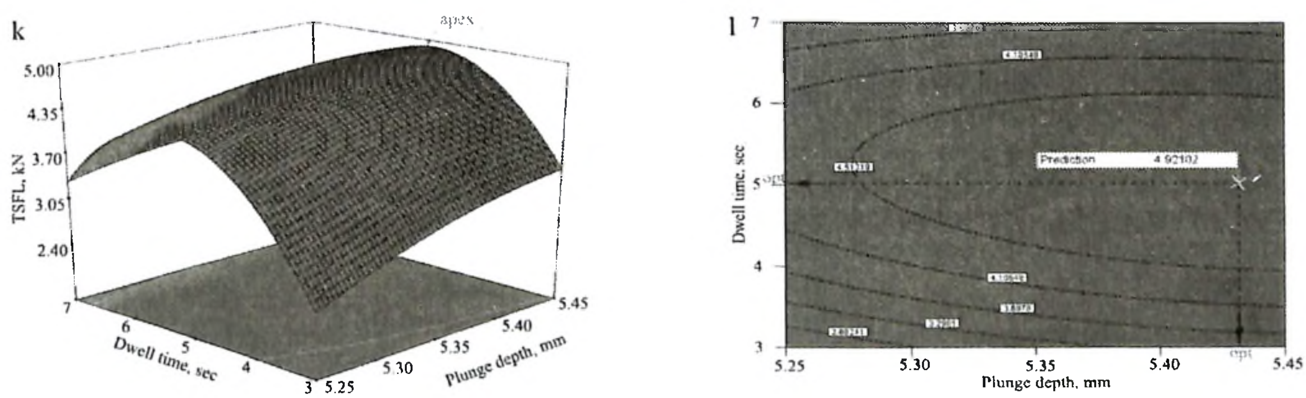
(e) & (f) Interaction effect of tool rotational speed and dwell time



(g) & (h) Interaction effect of plunge rate and plunge depth



(i) & (j) Interaction effect of plunge rate and dwell time



(k) & (l) Interaction effect of plunge depth and dwell time

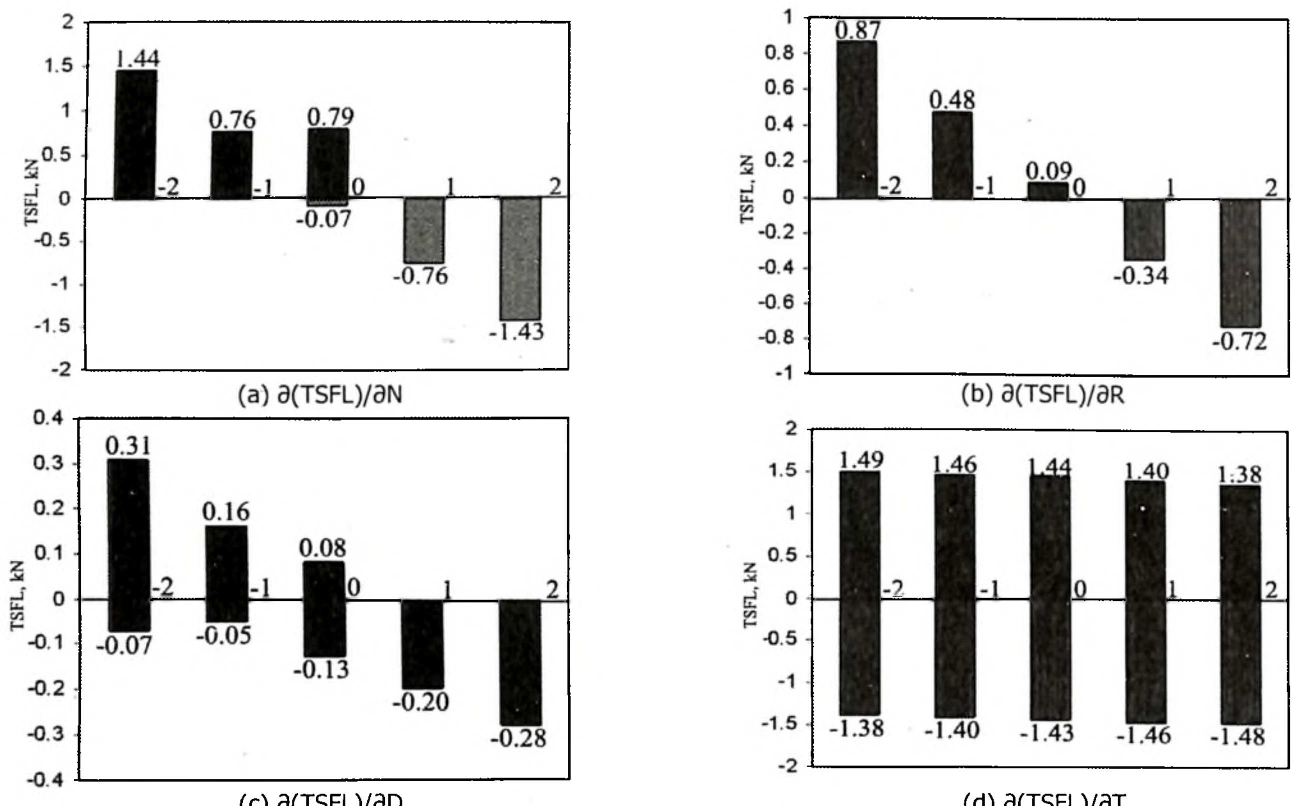


Fig. 5 : Sensitivity analysis

Guidelines for acceptance & publication of Technical Papers in the Indian Welding Journal

TYPES OF CONTRIBUTION

Original Papers

Dealing with research, technology & industrial application should be typically around 3500 words, plus figures & tables. Authors are requested to give an understanding that the matter is original.

Conference Papers

Materials submitted to conferences may be accepted, particularly if it is expanded or modified and provided that the Editor considers that the paper would be of interest to the wider readership of the Indian Welding Journal. The authors are responsible for obtaining the consent of the editor / sponsor of the conference proceedings to publish the materials in the IWJ.

Critical assessment / Reviews

Dealing with welding of joining subject in a critical, comprehensive and well referenced manner typically around 3500-4000 words plus figures and table. The reference of the conclusions of the research work review to industrial practice should be emphasized.

SUBMISSION OF THE PAPERS

All the papers should be sent to the Editor at the Head Quarter of the Indian Institute of Welding. Normally an acknowledgement of receipt will be sent within one week by E-mail. Papers should be printed in 3 columns (please refer January / April 2005 issue of the IWJ) and sent in a CD over and above the hard print. Figures, Diagrams & sketches should be neat and clear and the papers after preliminary screening by the Editor will be sent to one or more of Review Panel Members (see list below).

Based on the feedback, the Editor will decide about publication subject to space availability in a particular issue. A final communication about acceptance / modification / non-acceptance of the papers would then be sent to the authors in due course. Normally, the authors expecting their papers to be published in a particular issue should send the manuscript at least 2 months before the issue date.

REVIEW PANEL MEMBERS

Prof. G. L. Datta, Prof. T. K. Pal, Prof. P. K. Ghosh, Mr. R. Banerjee, Mr. R. Ravi & Dr. A. K. Bhaduri.