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APPLICATION OF TAGUCHI METHOD FOR OPTIMIZATION OF CONTINUOUS DRIVE FRICTION WELDING PROCESS PARAMETERS

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Abstract. The objective of present study was to determine optimal conditions to achieve satisfactory friction welds between two dissimilar metals namely copper and carbon steel bars of same diameter. Three process parameters namely speed of rotation, axial pressure, and forge pressure were considered for the present study. Two multiple performance characteristics, considered were breaking load strength and upset. The optimization of the process parameters was done using ANOVA. The obtained results indicated that the most significant process parameters are axial pressure and rotational speed that affect the optimization of multiple performance characteristics.

Introduction

With development of new materials and modification of existing materials, various methods of joining dissimilar materials have been introduced. Joining of dissimilar metals by fusion welding, such as TIG, MIG and Brazing, is difficult because of diverse characteristics of each material [1]. Metals with different thermal and mechanical properties can be joined by Friction welding.

The pressure and relative motion between the components to be joined are applied simultaneously during Friction welding. The interface temperature of the components rises to a value close to their melting points because of heat generated during friction welding. The components to be joined are brought into contact because of the flow of the heated material from the interface, by the axial pressure applied. Sound metallurgical bond between the components can be produced by maintaining or increasing the axial pressure during termination of relative motion.

Chudikov introduced the use of Friction welding to commercial use in Russia around 1956–57 [2] and Vill in 1962 introduced the process to west in 1959 [3]. Vill in 1959 reported the results of research on low carbon steel bar 0.79 inch diameter [4] and he has investigated the torque-time, and speed-time curves. Vill also found that power required was proportional to the axial pressure. Cheng studied the heat distribution in the stationary component during friction welding and confirmed that the coefficient of friction does not remain constant over the cycle but varies with the speed, pressure, surface temperature, hardness and surface conditions [5]. Sahin and Akata in 2003 did experimental work on friction welding of plastically deformed steel bars [6]. Sahin joined plastically deformed Austenitic-Stainless steel by Friction Welding and investigated their properties under different process parameters. Strength of the welded joint was determined by using Statistical approach [7].

The objective of this study was to determine the optimal welding conditions with various process parametric combinations, i.e., Rotational speed (N), Axial pressure (P_a) and Forge pressure (P_f) for friction welded joints of copper to low carbon steel employing Taguchi experimental design methodology.

Experimental procedure

Material specifications

Materials taken up for the study of friction welding were pure Copper and Low carbon steel in the form of rod having 16 mm diameter and 116 mm length with following specification and composition (as shown in Table 1 & 2).

Table 1

Percentage Composition of Copper rod

Cu	Zn	Sn	Al	Ni	Pb	Si	Fe
99.99	0.003	0.010	< 0.005	< 0.00	< 0.01	< 0.005	< 0.003

Table 2

Percentage Composition of Carbon steel rod

C	Si	Mn	Ni	Cr	Cu	Fe
0.175	0.118	0.394	0.016	0.02	0.022	99.1

Experimental set-up

Modified lathe machine friction welding setup similar to conventional friction welding machine was developed by fitting the additional components as shown in Fig. 1, to study the effect of rotational speed (N), axial pressure (P_a) and forge pressure (P_f) on the breaking strength and upset of the welding joints. Additional equipment was fitted to the lathe machine for applying axial pressure and for holding the workpieces firmly.

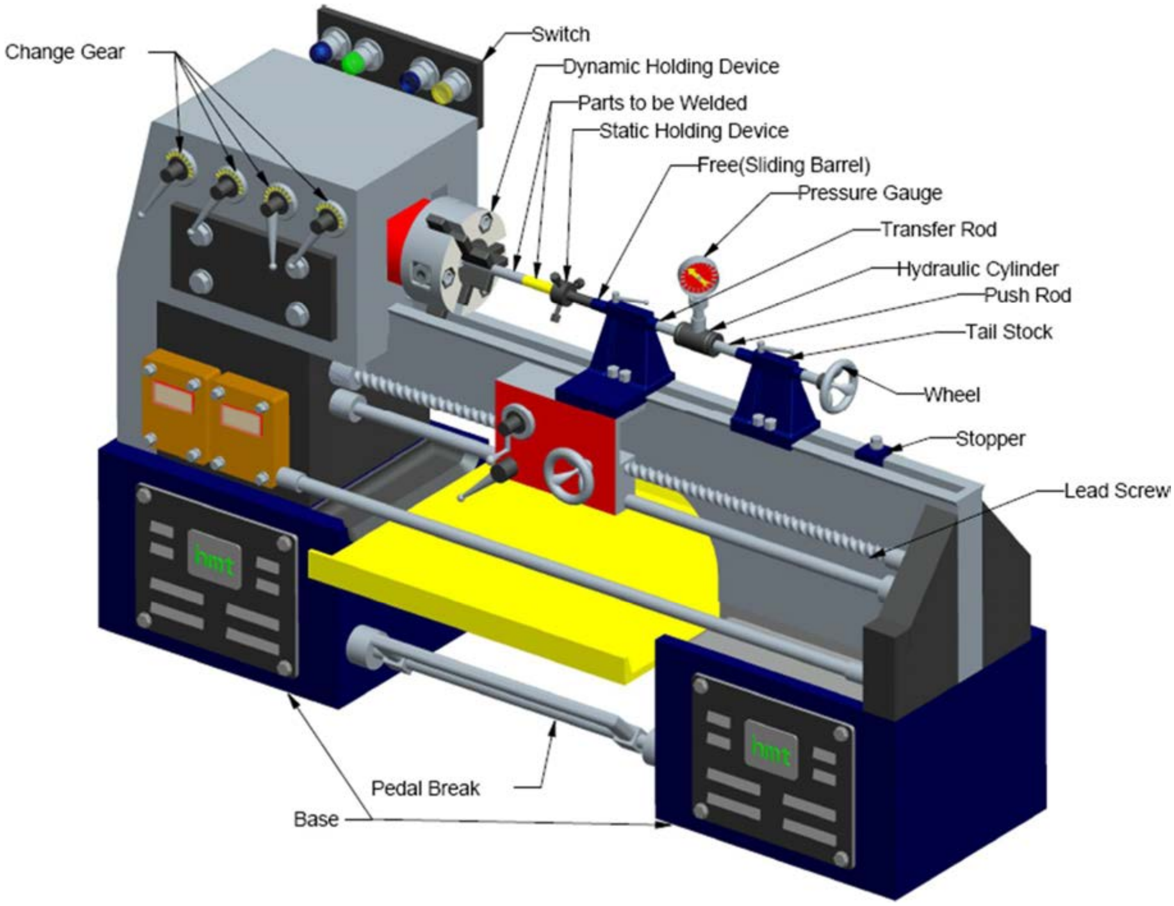

Fig. 1. *Modified lathe machine friction welding setup*

The static holding fixture was attached with tail stock of the centre lathe machine, LB-17 make HMT for holding non rotating workpiece. The sliding movement of static holding fixture was given by the transfer rod and applied load was measured with the help of pressure gauge fitted over the hydraulic cylinder.

Experimentation for performance measure of frictional weld joints

To start welding, the work piece, carbon steel rod, in the chuck was rotated and brought in contact with stationary copper specimen. The non-stationary work piece was clamped in a static holding fixture mounted to a tailstock slide. To attain the welding temperature, the tailstock barrel was advanced to bring the work piece in contact under constant axial pressure with the help of a transfer rod. Movement was given to copper piece by rotating the handle fixed at the end of outer tailstock till the two pieces come in contact with each other. When the work pieces were at or slightly above the welding temperature, the spindle motor was switched off and rotation was then stopped instantly by pressing the brake pedal of machine and final forge pressure applied, friction welding of copper bar to carbon steel bar shown in Fig. 2. Thus, various weld joints of copper and carbon steel were prepared and then taken for testing the tensile strength of welded joints.

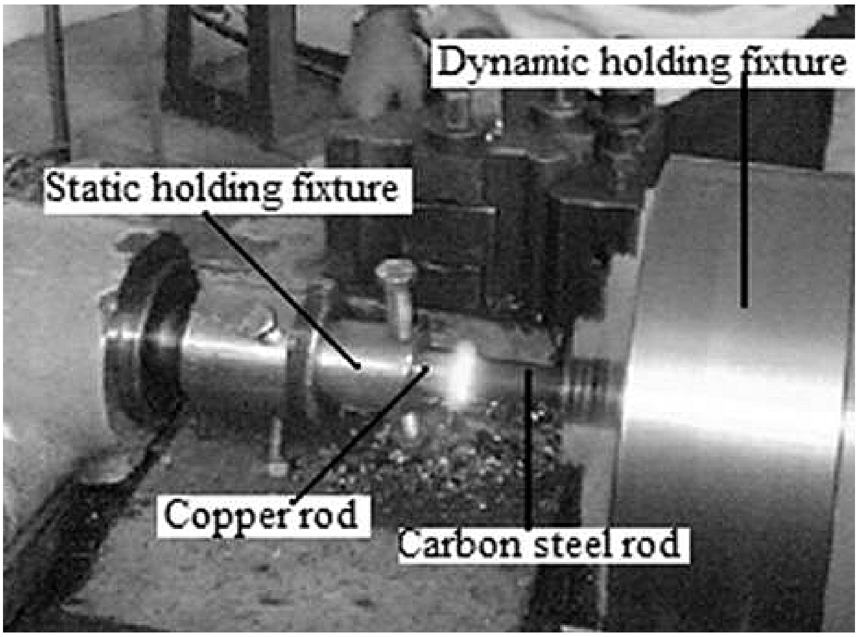

Fig. 2. *Friction welding of copper bar to carbon steel bar*

Design of experiments

The process parameters were optimized by using analysis of variance (ANOVA) based on the Taguchi method.

Taguchi approach

The Taguchi method is best used when there are an intermediate number of variables (3 to 50), few interactions between variables, and when only a few variables contribute significantly [8]. Since, the effect of three process parameters (N, P_a and P_f) on two performance measures (breaking load and upset) were studied in the present work, three levels of each were considered. The minimum number of trials in the orthogonal array is given in [9]:

$$N_{\min} = (L-1)\cdot K + 1, \quad (1)$$

where K is a number of factors and L is a number of levels. In this study, $K = 3$ and $L = 3$ which gives $N_{\min} = 7$; and hence L9 orthogonal array has been selected for multi-performance optimization. All experiments were repeated thrice to minimize the nuisance error. Thus a total of $9 \times 3 = 27$ experiments were performed. The process variables and their notations are listed in Table 3.

The total 27 samples prepared (Fig. 3) were finally taken for testing the tensile strength of welded joints.

Analysis of variance (ANOVA)

The process parameters (N , P_a and P_f) determined experimentally was analyzed through ANOVA for optimization. Software package MINITAB was used to obtain the ANOVA table containing the degrees of freedom (DoF), sum of squares (SS), mean square (MS) and Probability of significance (P-value). The parameters with lower P value at particular confidence level are ranked higher and have significant effects in controlling the overall response. The Sum of squares is measure of the deviation of the experimental data from the mean value of the data. Mean square also called variance measures the distribution of the data about the mean of the data [10]. F-value is called the variance ratio and defined as:

$$F_{\text{calculated}} = \frac{\text{MS for any term}}{\text{MS for error tem}} \text{ and } \text{MS} = \frac{\text{SS}}{\text{DoF}}.$$

Table 3

Process parameters and their limits

Process Parameters	Units	Levels		
		1	2	3
Rotational Speed (N)	rpm	510	1080	1650
Axial Pressure (P_a)	kgf/cm^2	25	35	45
Forge Pressure (P_f)	kgf/cm^2	50	60	70

Fig. 3. *Friction welded pieces at different levels of process parameters*

$F_{\text{calculated}}$ thus obtained is compared with $F_{0.05}$ and $F_{0.01}$ (from standard F tables) for investigating whether the term (main effect or interactive effect) imposes a significant effect on selected response at 95 % and 90 %. A factor with tabulated F-value less than calculated F-value has significant effect on response.

Results and discussion

The values of mean upset and mean breaking load computed from experimental results for each trial of an orthogonal array are summarized in Table 4.

Table 4

L9 orthogonal array along with the mean of responses

Std Run	Speed (rpm)	P_a (kgf/cm^2)	P_f (kgf/cm^2)	Mean Upset (mm)	Mean Breaking Load (kN)
1	510	25	50	8.00	15.36
2	510	35	60	11.30	16.30
3	510	45	70	8.30	22.90
4	1080	25	60	7.73	18.38
5	1080	35	70	8.93	18.91
6	1080	45	50	9.30	21.10
7	1650	25	70	4.30	22.84
8	1650	35	50	6.60	18.90
9	1650	45	60	7.30	28.20

Analysis of test results for upset (mm)

Results of ANOVA for S/N ratio are shown in the Table 5, which gives the average effects of the parameters on the upset. The table gives the results obtained for S/N ratio data. The plot of main effects with S/N values is shown in Fig. 4.

Table 5

Analysis of Variance for S/N ratios of Upset

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F-value	P-value
N (rpm)	2	27.0073	13.5037	55.33	**0.018**
P_a (kgf/cm^2)	2	10.6753	5.3376	21.87	**0.044**
P_f (kgf/cm^2)	2	6.5773	3.2886	13.47	0.069
Residual Error	2	0.4881	0.2441		
Total	8	44.748			

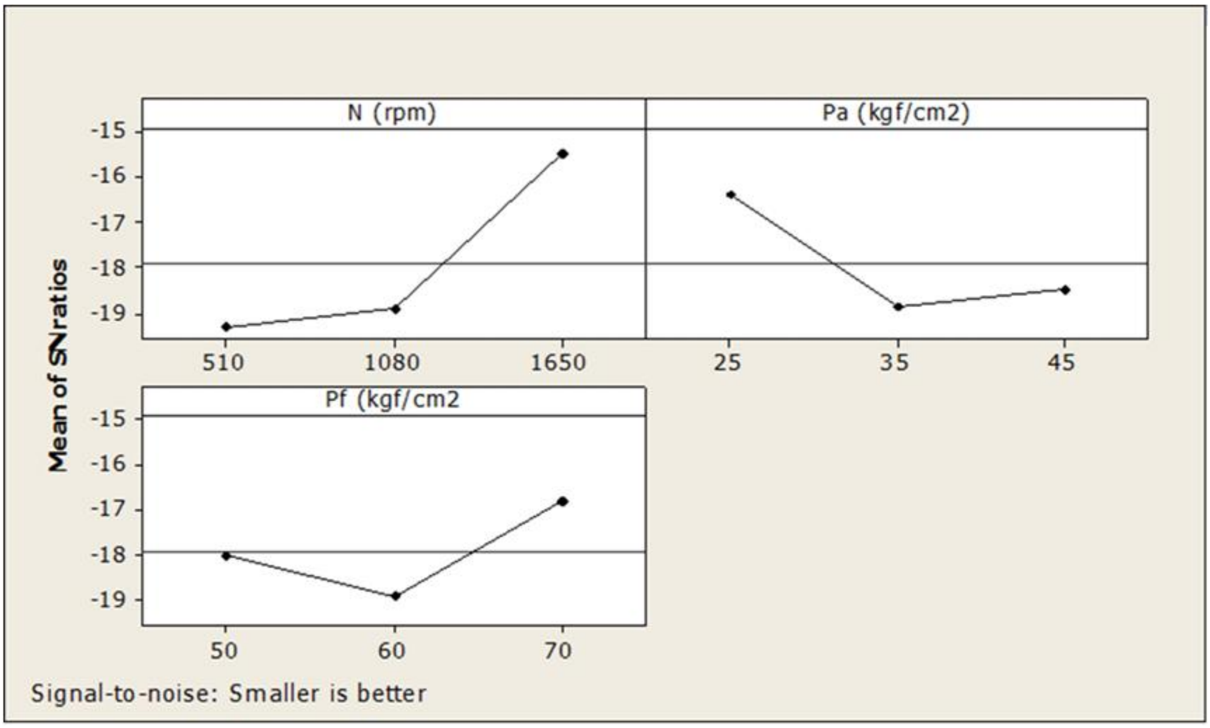

Fig. 4. *Main effect plot for signal to noise ratio of upset*

It is evident (Table 5) that the effect of rotation speed and axial pressure on upset becomes significant at both 95 % and 99 % confidence level and the P-values less than 0.05. The effect of forge pressure on upset is significant at 99 % confidence level only but P-value comes out to be more than 0.05 so from here it is concluded that the forge pressure has not significant effect on the upset at 95 % confidence level.

Table 6 shows the Main effects for S/N ratios of the parameters on the upset and for smaller the best criterion. The parameters have been ranked according to the values of the Main effect. The main effects of the parameter on the upset (Fig. 3) shows that rotational speed (N) has more significant effect on upset because of the high value of slope of the curve as compared to axial pressure (P_a) and forge pressure (P_f). Therefore for the optimum combination to get the low value of upset is at standard run (Std run) 7th (refer Table 4).

It can be observed from Fig. 5, *a* that there is considerable interaction effect of rotational speed (N) variation on upset for a given value of axial pressure (P_a). On the other hand from Fig. 5, *c* for given speed (N), the effect of axial pressure variation on upset is comparatively less.

Table 6

Response Table for S/N Ratio for Upset (Smaller- the- best)

Parameters	Average Value of Upset			Main Effects	Rank
	Level 1	Level 2	Level 3	$\Delta = L_{max} - L_{min}$	
N	-19.33	-18.91	-15.47	3.87	1
P_a	-16.38	-18.86	-18.48	2.48	2
P_f	-18.01	-18.9	-16.81	2.09	3

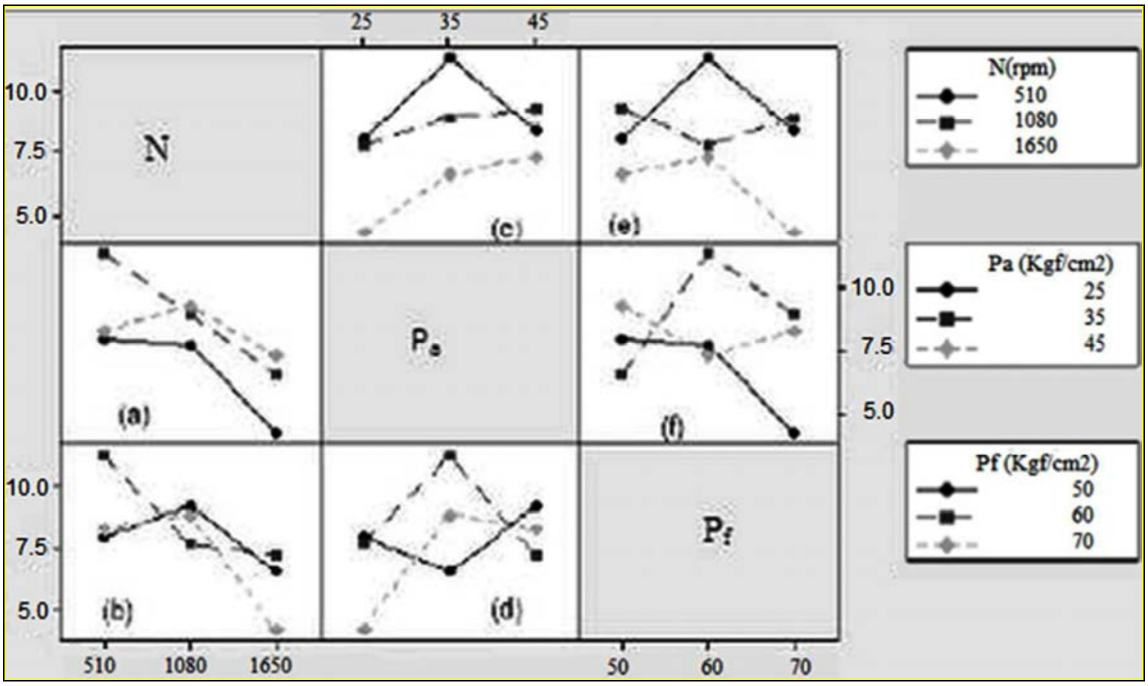

Fig. 5. *Interaction effect plots (a), (b), (c), (d), (e) and (f) of rotation speed (N), axial pressure (P_a) and forge pressure (P_f) for mean upset*

From the contour plot shown in Fig. 6 and Fig. 7, it has been observed that the effect of variation of rotation speed is more than that of axial pressure on upset. The desired (low) upset is obtained when rotation speed and forge pressure are at high level and at low level of axial pressure.

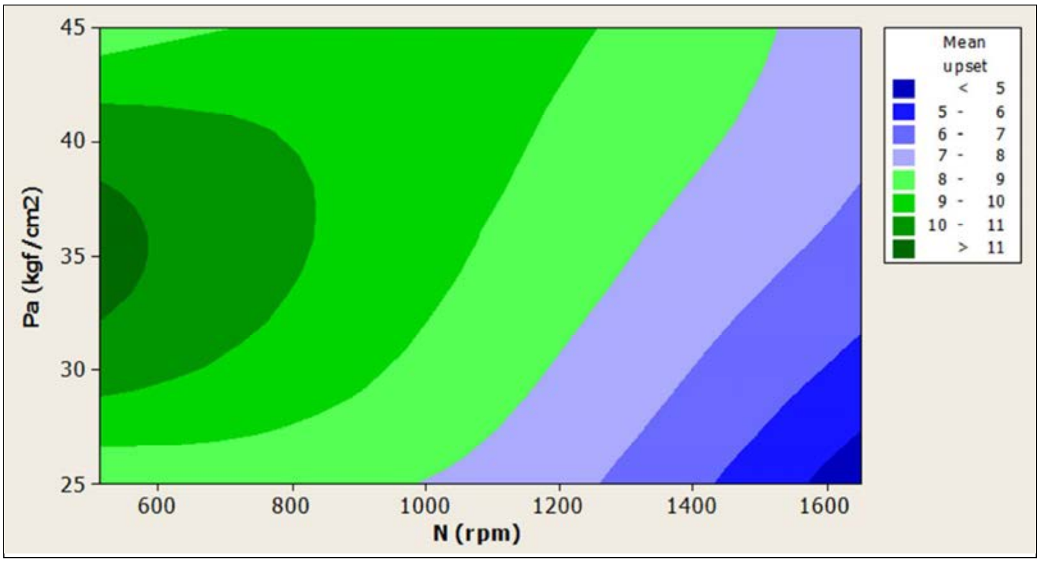

***Fig. 6.** Contour plot of P_a vs N for mean upset*

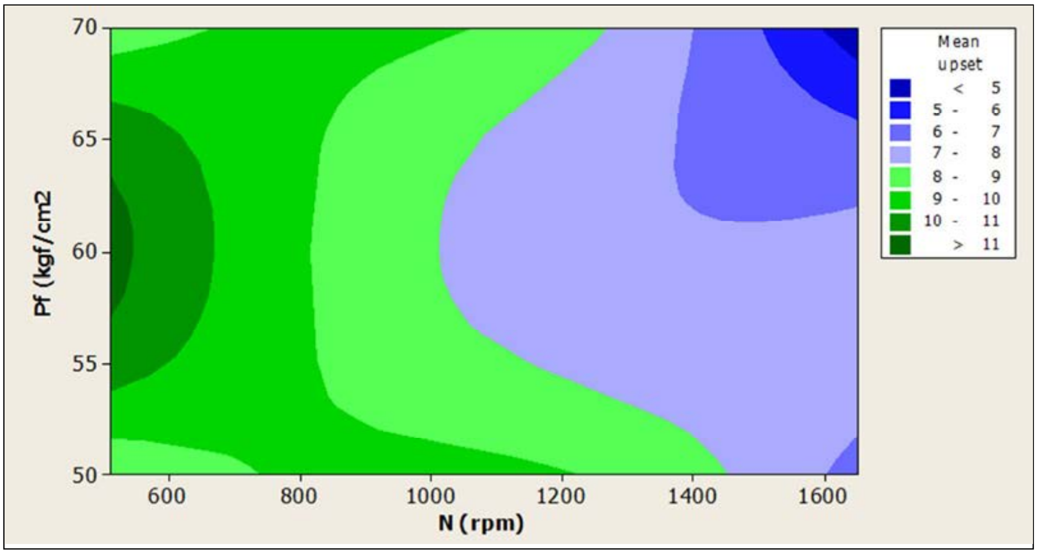

***Fig. 7.** Contour plot of P_f vs N for mean upset*

Analysis for breaking load (kN)

Results of ANOVA for S/N ratio are shown in the Table 7, which gives the average effects of the parameters on the upset.

Table 7

Analysis of variance for S/N ratios of breaking load

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F- value	P-value
N (rpm)	2	8.1424	4.07121	67.54	**0.015**
P_a (kgf/cm^2)	2	11.9078	5.95390	98.78	**0.010**
P_f (kgf/cm^2)	2	2.9659	1.48293	24.60	0.039
Residual Error	2	0.1206	0.06028		
Total	8	23.1366			

It is evident from the Table 8 that the effect of rotation speed, axial pressure and forge pressure on breaking load becomes significant at 95 % confidence level and the P values less than 0.05 and the parameters have been ranked according to the values of the Main effect for the larger the best criterion. Hence, the most significant parameter for breaking load is axial pressure and the least significant parameter comes out to be forge pressure.

Table 8

Response Table for S/N Ratio for Breaking Load

Parameters	Average Value of Breaking Load			Main Effects $\Delta = L_{max} - L_{min}$	Rank
	Level 1	Level 2	Level 3		
N	24.86	25.23	27.04	2.18	**2**
P_a	24.8	25.01	27.34	2.54	**1**
P_f	24.95	25.85	26.34	1.39	3

Fig. 8 suggests that for S/N ratio larger the best value of the Friction Welding parameters are at rotational speed of 1650 rpm, axial pressure of 45 kgf/cm^2 and forge pressure of 70 kgf/cm^2.

From the plots of two factor interaction effects on multi-response characteristics (Fig. 9), it can be concluded that the interaction effect is minimal either due to rotation speed or forge pressure. The forge pressure seems to be less significant in getting high value of breaking load strength.

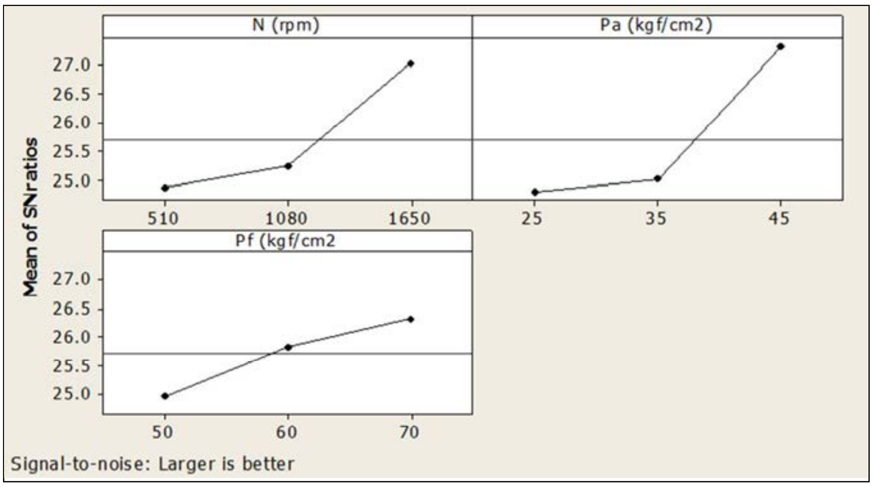

Fig. 8. *Main effect plot for signal to noise ratio of breaking load*

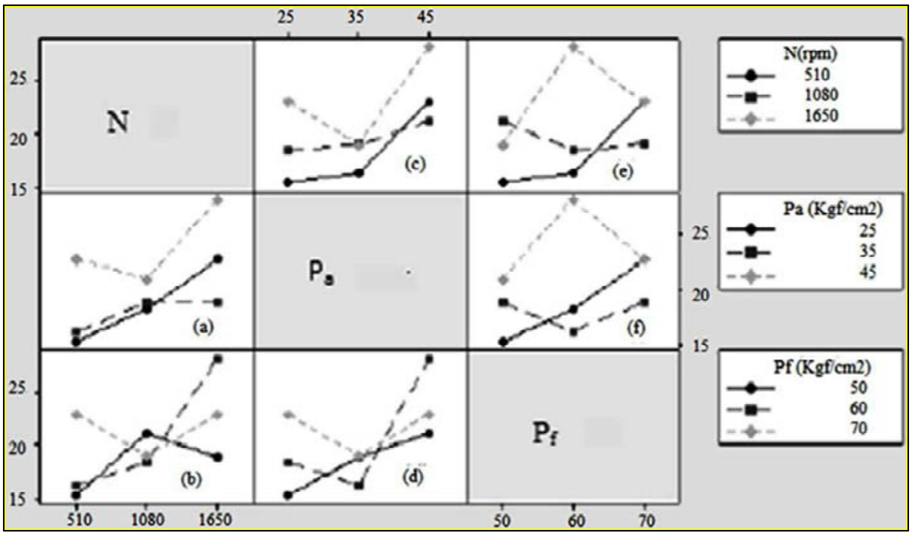

Fig 9. *Interaction effect plots (a), (b), (c), (d), (e) and (f) of rotation speed (N), axial pressure (P_a) and forge pressure (P_f) for mean breaking load*

From Fig. 10, it has been observed that the effect of variation of axial pressure is more than that rotation speed on breaking load. The desired (high) breaking load is obtained when both, the rotation speed and axial and axial pressure are at high level and axial pressure is at medium level.

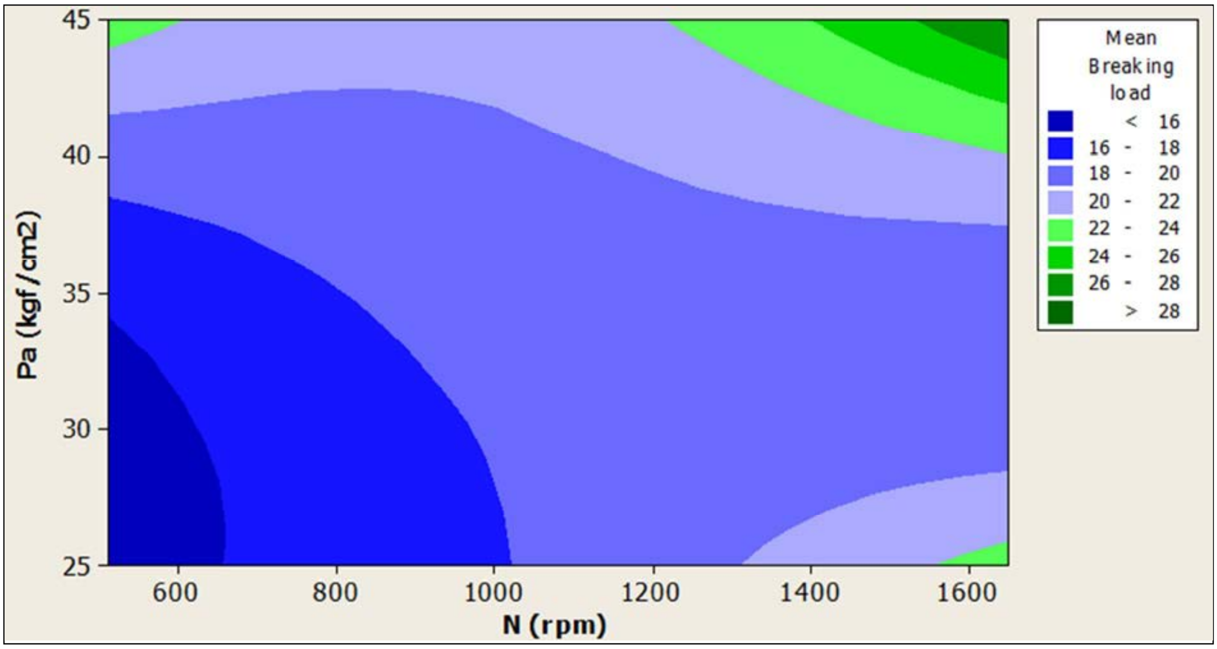

Fig. 10. *Contour Plot of mean breaking load*

Conclusions

In the present work, optimization of multi-performance characteristics has been carried out in order to search optimal parametric combination by using Taguchi method of L9 OA, capable of producing high weld strength and at the same time ensuring reduced upset in the friction welded joint. Based on the results presented herein, it is concluded that,

– for friction welding of copper with carbon steel the axial pressure is the highly significant parameter which affects the weld strength considerably and most favorable range is 30–40 kgf/cm^2;

– the rotational speed largely affects the upset and the most favorable speed is 1080–1650 rpm;

– applying a forging pressure of 60 kgf/cm^2 at the end of the process cycle can improve weld integrity, especially when the power input is lower than that required to achieve satisfactory welding conditions.

Optimum welding parameters should be properly selected in the friction welding of parts. Statistical analysis is an economical and reliable method for optimizing welding parameters.

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