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OPTIMAL PARAMETER ESTIMATION OF FRICTION WELDED JOINT FOR HIGHER BENDING LOAD AND HARDNESS IN SS316 AND EN8

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Abstract: In this study the effect of friction welding parameters such as rotational speed, forging pressure and cooling method on bending load and hardness of a joint between SS316 and EN8 is experimentally investigated. A partial factorial design of experiment based on Taguchi analysis is conducted to study the main effects of the process parameters on the responses. Analysis of variance (ANOVA) and main effects plot is used to determine the significant parameters and set the optimal level for each parameter. A linear regression equation is derived to extrapolate the response for other input parameters beyond the range of thid experiment. Based on the experimentally determined optimal parameters a confirmation experiment is conducted. The results are useful to the industry in selecting optimal process parameters while performing a friction welding joint of the pump shaft.
Keywords: Friction welding, pumpshaft, inconel, En8, Taguchi, Optimal Parameters.

1. INTRODUCTION

Friction welding has been used extensively in industry in joining similar and dissimilar materials efficiently as it is the only method of joining dissimilar materials and also because of the advantages such as material saving, low production time , elimination of filler material and production of joints as strong as parent metal with very little heat affected zone.

Different studies have been undertaken by Midling et.al{1} who have examined the properties of friction welded joints between AlSiMg(A357) alloy containing 10% Volume of Sic particles with a mean diameter of 20microns. Kreyr and Reiner{2} studied the joint strength of mechanically alloyed aluminium alloy(Dispal) containing a fine dispersion of Alumina and carbide particles. Aritoshi et al {3} compared the friction welding characteristics of Oxygen free Cu-Al joints. Cola and Baeslack {4} have examined the relationship between joining parameters and the tensile properties of 6061 alloy tubing,

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containing 10% volume Al2O3 particles. Ananthpadmanabhan{5} reported the experimental studies on the effect of process parameters on strength of steel. Dobrovidor{6} studied the optimal parameters while welding high speed steel to carbon steel.

Hence as the literature survey indicates that no work has been carried out in welding SS316 and EN-8 joints by friction welding process, the importance of conducting this experimental study is to assist a pump manufacturing industry to reduce the cost of the pump shaft by replacing the expensive materials such as Inconel and SS316 with a cheaply available EN-8 to an extent of $2/3^{rd}$ length of the shaft. Generally the pump manufacturers use highly corrosion resistant materials such as SS316 and Iconel to manufacture a pump shaft used in corrosion and chemical environment, even though the entire length of the shaft does not come in contact with the corrosive fluids. Hence an attempt has been made to replace 2/3 of expensive shaft material with cheaper material like EN-8 by making a friction welded joint between 1/3 of Inconel /SS316 and 2/3 if EN-8, thus saving cost of manufacturing of shaft, having done so now the challenge lies in welding the two dissimilar materials by friction welding and also identify the optimal process parameters in order to obtain higher strength of the joints.

2.0. Preparation of specimen:

This project involves the experimental study on friction welding of dis-similar materials of SS 316 and EN-8. For all the friction welding system, rotational speed, friction pressure, forging pressure applied to the stationary part and friction time are the principle controlling variables which influence the metallurgical and mechanical properties of friction welded joints. These dissimilar joints thus prepared by continous friction welding technique have been studied for bending load before fracture and hardness values. All the specimens were prepared on afriction welding setup at MUFAKHAM JAH COLLEGE OF ENGINEERING AND TECHNOLOGY Labs. The power pack and a hydraulic mechanism is used to vary and exert the pressure during friction stage and final forging stage.

3.0. EXPERIMENT NO. 1.

Bending and Hardness of SS 316 and EN-8:-

Bending load of the joint prepared for various levels of rotational speed, forging pressure and cooling method.

3.1. Taguchi Orthogonal Array Design for L9 (3**3):-

Table 1. Taguchi Orthogonal Array Design for L9 (3**3)

S.No	**C1**	**C2**	**C3**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

The above table.1 shows the Orthogonal Array matrix Of L9 (3^3). In this,the First row indicates the number of factors that are tested which are 3. The First column shows the number of specimens that must be prepared as per the Taguchi design of Experiment, in this case being 9. The other columns show the levels of each factor, in this case 3 i.e. (High-3, Medium-2 and Low-1).

3.2 INPUT Variables for 9 Runs, 3 Levels and 3 Factors:-

Table 2. Input variables for 9 Runs, 3 Levels and 3 Factors

Runs	**Speed**	**Forging pressure**	**Cooling Method**
1	980	22	Air
2	980	25	Water
3	980	28	Oil
4	1250	22	Water
5	1250	25	Oil
6	1250	28	Air
7	1580	22	Oil
8	1580	25	Air
9	1580	28	Water

The Above Table.2 Explains about the Input variables which were considered for testing the Bending load for the joint between SS316 and EN-8 for three levels of factors which are High, Medium and Low. These 3 factor levels are selected based on data from literature as indicated above as per the Taguchi design matrix.

3.3 Bending load Test results:-

Table 3.0. Bending load Test results

RUNS	Bending Load Kg
1	80
2	100
3	50
4	130
5	180
6	300
7	90
8	300
9	290

3.4 Optimum input variables of friction welded joint for Maximum Bending Load

- Rotational speed :1580 R.P.M
- Friction Pressure :25 bar
- Cooling Method :Air

3.5 Summary of Experimental Results of Bending load in Kg

Table 4. Summary of Experimental Results for Bending Load

S.NO	Speed r.p.m	Forging Pressure Bar	Cooling Method	Fails at	Bending Test Kgs	
1	980	22	Air	WELD	80	
2	980	25	Water	WELD	100	
3	980	28	Oil	WELD	50	
4	1250	22	Water	WELD	130	
5	1250	25	Oil	WELD	180	
6	1250	28	Air	WELD	300	
7	1580	22	Oil	WELD	90	

8	1580	25	Air	WELD	300	
9	1580	28	Water	WELD	290	

3.6. Taguchi Analysis of Bending Load using Minitab software and Signal to Noise Ratio

Table 5. Response Table for S/N Ratio of Bending Load

Level	Speed	Forging pressure	Cooling Method
1	37.35	39.81	45.72
2	45.64	44.88	43.84
3	45.96	44.26	39.39
Delta	8.61	5.07	6.33
Rank	1	3	2

The response table5 shows the average S/N ratio of each response characteristic for each level of control factor. The table5 includes ranks based on Delta statistics, which indicate the relative magnitude of main effects of control factors on response. The Delta statistic is the highest minus the lowest average for each factor. Minitab assigns ranks based on Delta values; rank 1 to the highest Delta value, rank 2 to the second highest, and so on.

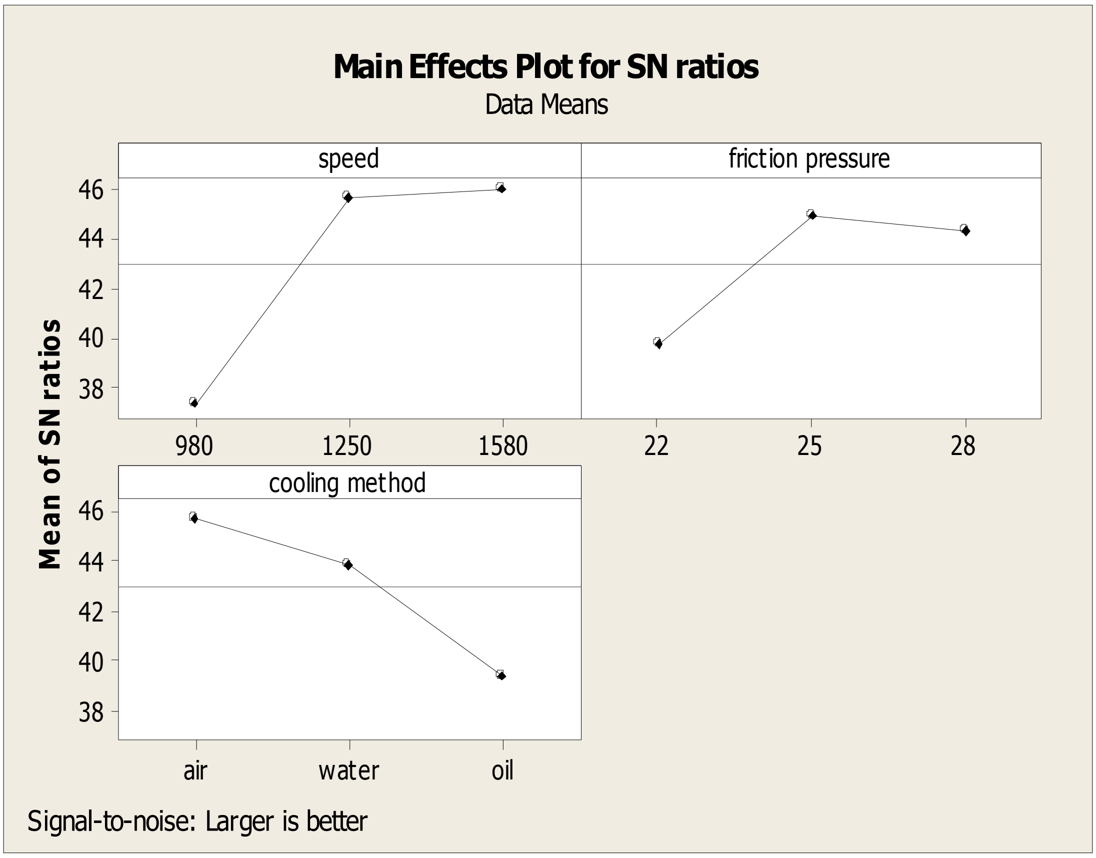

Fig.1. Main effects plot for S/N Ratio for Bending Load

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	**2**	39089	39089	19544	40.91	0.024
Friction Pressure	**2**	21956	21956	10978	22.98	0.042
Cooling Method	**2**	21689	21689	10844	22.70	0.042
Error	**2**	956	956	478		
Total	**8**	83689				

Table 6. Analysis of Variance for Bending Load.

S= 21.8581 R-Sq = 98.86% R-Sq(adj) = 95.43%

Predicted Values:-

S/N Ratio = 50.5914

Mean = 308.889

3.7. The Regression equation is

Bending Load = - 613 + 0.243 Speed + 18.9 Friction pressure

Table 7. T P ratios

Predictor	Coef	SE Coef	T	P
Constant	-612.5	281.0	-2.18	0.072
Speed	0.24345	0.09970	2.44	0.050
Friction pressure	18.889	9.986	1.89	0.107

S = 73.3842 R-Sq = 61.4% R-Sq(adj) = 48.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	51377	25689	4.77	0.058
Residual Error	6	32311	5385		
Total	8	83689			

Source	DF	Seq SS
Speed	1	32111
Friction pressure	1	19267

1. CONCLUSION OF EXPERIMENTAL NO. 1

Table 5. shows the response for S/N ratio and the most significant factor among the three control factors is the SPEED followed by COOLING METHOD and then FORGING PRESSURE.

The R^2 value indicates that the predictors explain 98.86% of the variance in Bending Load. The Adjusted R^2 is 95.43% which accounts for the number of predictors in the model. Both values indicate that the model fits the data well.

The value of R^2 and adjusted R^2 signify that regression model provides an excellent explanation of the relationship between the independent variables (factors) and the response variable.i.e. Bending Load.

The associated P value 0.058 for the model which is less than α=0.5 indicates that the model is statistically significant and hence the Null Hypothesis(H0: The response is independent of control factors) is rejected.

5. CONFIRMATION EXPERIMENT FOR L9 BENDING LOAD

The confirmation experiment is the final step in the first iteration of the design of the experiment process. The purpose of the confirmation experiment is to validate the conclusions drawn during the analysis phase. The confirmation experiment is performed by conducting a test with optimal combination of the factors and levels previously evaluated. Here after determining the optimum control factor levels the response i.e, bending load is tested again under these conditions, A new experiment conducted with the optimum levels of the welding parameters. The final step is to predict and verify the improvement of the response characteristic using MINITAB software. The predicted response is calculated using equ.(1).

$$\eta=\eta_m + \sum_{i=1} (\eta_j - \eta_m) ; \; j= 1, 2, 3 \ldots\ldots k \qquad \ldots\ldots\ldots\ldots(1)$$

where η_m is total mean of S/N ratio, η_j is the mean of S/N ratio at the optimal level, and η is the number of main welding parameters that significantly affect the performance. The results of experimental confirmation using optimal welding parameters and comparison of the predicted bending strength with the actual bending strength using the optimal welding parameter are shown in table.

The S/N ratio η (dB) is calculated for higher the better option as under

$$\eta= - 10\log\{1/N\}\sum 1/y^2 \quad \text{where } N=1 \text{ and summation to the extent of } y1\ldots\ldots\ldots y9$$

Improvement in response variable is calculated as

$Y2-Y1/ Y2 \times 100$

Table 8. Improvement in S/N ratio

	Initial Process Parameter	Optimal Process Parameter		Improvement in s/n ratio and Bending strength in %
	(y1) Nominal value	Predicted value	Confirmation experiment value (y2)	
Bending Load(kgs)	168.888	308.889	440	61.61
S/N (dB)	44.551	50.59	52.86	15.71

The improvement in Bending Load at optimal factor levels compared to nominal Bending Load is significant and found to be 61.61%.

6. EXPERIMENT NO.2

Following the experiment no1. Conducted , the experiment no.2 is carried out on similar lines and the S/N ratio for hardness is calculated as shown in Table 9.

Table 9. Response Table for S/N Ratio **for Hardness**

Level	Speed	Friction pressure	Cooling Method
1	43.90	44.05	45.75
2	44.05	44.21	44.05
3	43.75	43.44	43.90
Delta	0.30	0.77	0.31
Rank	3	1	2

The response tables show the average of each response characteristic (s/n ratio) for each level of the control variable. In this experiment for hardness, forging pressure has the highest delta rank and effect on the response, followed by cooling method and finally the speed.

Here our goal is to increase the Hardness of friction welded joint between SS 316 and EN-8 materials and determine the factor levels which give the highest hardness of the joint. As shown in fig.2, the means were maximized at rotational speed of 1580r.p.m and friction pressure of 25bar and cooling method followed being cooled in air.

6.1 Based on these results, for maximized Hardness we should set the control factors at:

Forging pressure :25 bar

- Rotational Speed :1580 R.P.M.
- Cooling Method : Air

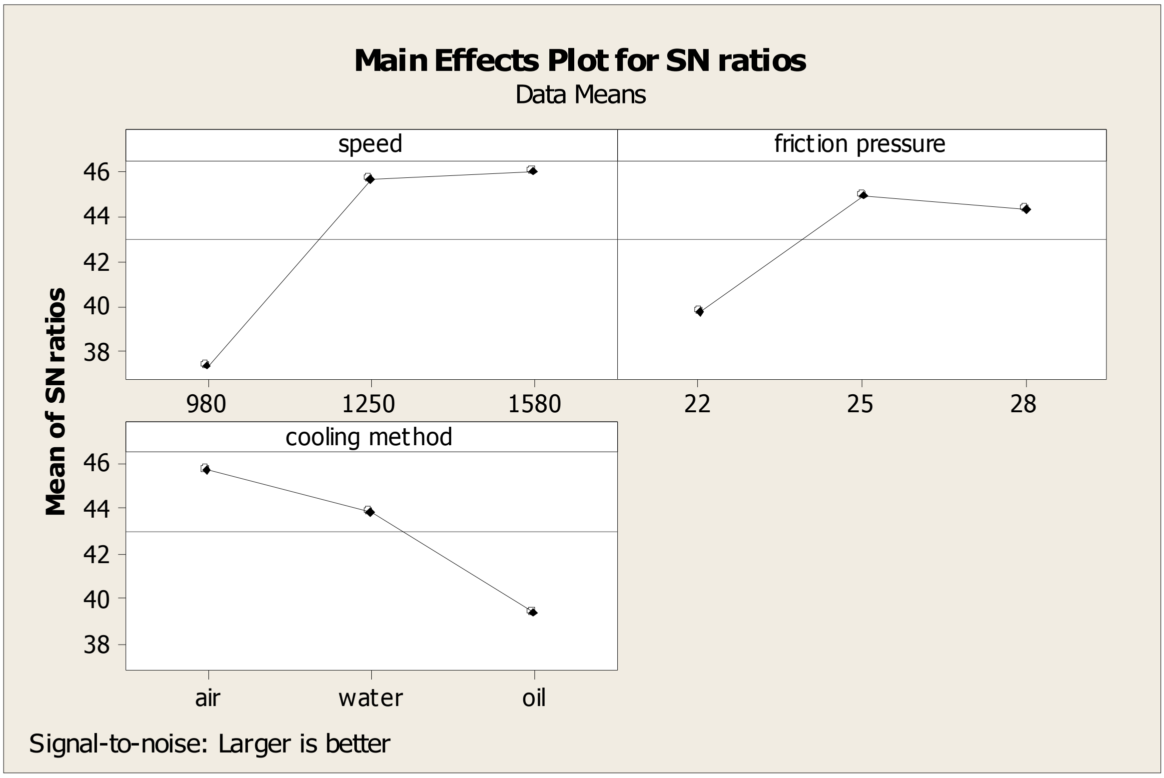

Fig 2.0. Main effect plot for S/N ratio for hardness test

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	**2**	49.18	49.18	24.59	0.36	0.733
Friction Pressure	**2**	315.08	315.08	157.54	2.33	0.300
Cooling Method	**2**	45.02	45.02	22.51	0.33	0.350
Error	**2**	135.05	135.05	67.52		
Total	**8**	544.33				

Table 10. Analysis of Variance for Hardness Test

S= 8.21733   R-Sq = 75.19%   R-Sq(adj) = 0.76 %

Predicted Values:-

S/N Ratio = 43.9034

Mean = 156.786

The Regression equation is

Hardness test = 209 - 0.0050 Speed - 1.83 Friction pressure

Predictor	Coef	SE Coef	T	P
Constant	208.91	29.27	7.14	0.000
Speed	-0.005035	0.01038	-0.48	0.045
Friction pressure	-1.826	1.040	-1.76	0.130

Table 11. T P ratios

S = 7.64374 R-Sq = 35.6% R-Sq(adj) = 14.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	193.77	96.88	1.66	0.267
Residual Error	6	350.56	58.43		
Total	8	544.33			

Source	DF	Seq SS
Speed	1	313.72
Friction pressure	1	180.05

7. CONFIRMATION EXPERIMENT FOR L9 HARDNESS TEST:-

The purpose of the confirmation experiment is to validate the optimal parameters determined by Taguchi method. The confirmation experiment is performed by conducting a test with a specific combination of the optimal levels of factors and a marginal improvement in hardness is observed as tabulated below.

Table 12. Improvement in S/N ratio for hardness

	Initial Process Parameter	Optimal Process Parameter		Improvement in s/n ratio and Hardness strength in %
	(y1) Nominal value	Predicted value	Confirmation experiment value (y2)	
Hardness (kgs)	156.87	162.265	157.86	0.62
S/N (dB)	43.910	44.2044	44.910	0.331

CONCLUSION

In this study It is observed that the **bending load** is increased considerably by employing the optimal levels of the control factors. It is found that the optimum control variables for high bending load are 1580 r.p.m, 25 bar friction pressure and Air as the Cooling method, whereas the optimal parameters determined by Taguchi method do not have considerable effect in improving the hardness value of the joint..

A study of the regression analysis for both bending load and hardness was done and the regression equation for both Bending load and hardness was established to predict the values of Bending load and hardness at levels beyond the scope of this experimental study, A correlation co-efficient of 0.971 and 0.975 was established indicating that the model is satisfactorily representing the data. The p-value less than 0.5 indicates that there is a relation between the control factors and the response thus rejecting the null hypothesis H0:

And from the main affect plots the level of factors that have more effect on the **Bending load** and **Hardness** were noted. The importance of conducting this experiment for the pump industry was to reduce the cost of the shaft by using the friction welding technique. The chemicals that are used in the chemical pumps flow across the shaft in a small area. Thus by replacing 2/3rd of the expensive material SS316 of the shaft, which is not in contact with the chemicals or corrosive fluids,with cheaply available EN8, it is possible to save substantial amounts in mass production of pumps.

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