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An Analytical Study of Dissimilar Materials Joint Using Friction Welding and It's Application

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Abstract- In this research paper the effect of friction welding parameters such as rotational speed, friction time, forging pressure and friction pressure on tensile strength of a joint between SS316 and EN8 is experimentally investigated. A partial factorial design of experiment based on Taguchi analysis is conducted to obtain the response measurements. Analysis of variance ANOVA and main effects plot is used to determine the significant parameters and set the optimal level for each parameter. Based on the experimentally determined optimal parameters a confirmation experiment is conducted. These results will be useful to the industry in selecting optimal process parameters while preparing a friction welded joint of SS316 with EN-8.

I. Introduction

Friction welding has been used widely in industry in joining similar and dissimilar materials efficiently 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, containing 10% volume Al_2O_3 particles. Esslinger{5} reported the experimental studies on the effect of process parameters on strength of steel.Roder{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 and the purpose 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 length of the shaft. Generally the pump manufacturers use highly corrosion resistant materials such as SS316 and Inconel 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 SS316 and 2/3 of EN-8, thus saving costs of manufacture of shaft. Having done so, now the challengelies 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. This work involves the experimental study on friction welding of dis-similar materials such as SS 316 and EN-8. For all the friction welding system, rotational speed, friction pressure, forging pressure and friction time are the principle controlling variables which influence the metallurgical and mechanical properties of friction welded joints. These dissimilar joint specimens thus prepared by friction welding have been studied for tensile strength.

Table 1: Specifications of the Material

Material used	SS 316 & EN-8
Specifications of work piece	
Diameter of Rod	16mm
Length of Rod (SS-316)	200mm
Length of Rod (EN-8)	100mm
Total length	300mm

Table 2: Specifications of Machine

F.W.M/c Type	FWT-12
Max weld area	800 mm^2
Min weld area	70 mm^2
Max bar capacity (solid dia)	16 mm
Min bar capacity (solid dia)	10 mm
Max length of rotating piece	220mm
Max length of non rotating piece	300mm
Max forge force	120kN
Spindle speed variable	1000-2000 RPM
Spindle bore depth from collet face	200mm
Slide stroke	350mm
Total connected wattage	30KVA
Supply voltage	400V/50HZ
Spindle drive	15KW
Control voltage	24VDC

Table 3: Friction welding factors varied in 3 levels

Levels Factors	High	Medium	Low
Speed (RPM)	1580	1250	980

Forging Pressure (Bar)	28	25	22
Cooling method	Air	Water	Oil

II. DESIGN OF EXPERIMENT

In this research work the type Taguchi Design selected is a 3 Level 3factor design represented as Taguchi Orthogonal Array Design, L9 (3^3), where number of Factors is 3 and number of Runs is 9 and number of Levels of each factor is3.Taguchi Orthogonal Array Design selected to carryout this experiment is as given in Table 2. The control factors considered for TAGUCHI design matrix are rotational speed, forging pressure, cooling method and the response variables is tensile strength. The experiment conducted to identify the optimal parameters for maximum tensile strength of the joint. 9 orthogonal arrays for tensile test is considered with friction-welding factors varied in 3 levels

Table 4: Taguchi Orthogonal Array Design L9 (33)**

S.NO	A	B	C
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 2 shows the Orthogonal Array matrix Of L9 (3**3). In this the First row indicates the number of factors which will be tested which are 3 in this case. The First column shows the number of Experiments that must be completed, in this case being 9. The other columns underneath show the levels of each factor, in this case 3 i.e. (High-3, Medium-2 and Low-1). INPUT Variables for 9 Runs, 3 Levels and 3 Factors.

Table 5: Factors/ Input variables for 9 Runs, 3 Levels and 3 Factors

Runs	Speed	Friction 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

Fig.1: Specimens of joint between SS316 and EN-8 as per $L_9 3^3$

III. EXPERIMENTAL PROCEDURE

The test material is comprised of 16 mm diameter rods of SS 316 and EN-8.According to Taguchi design, the 9 specimens of 16mm diameter and 300 mm length were prepared and facing operation was done for all specimens on Lathe machine The friction welding setup is prepared according to the selected factor levels as indicated in orthogonal matrix before performing welding. Friction welding was performed using a Continuous drive Friction welding machine setup where one of the work piece is attached to a rotating motor drive while the other is fixed in an axial motion system and one work piece is rotated at constant speed as setup on the machine. The Two work pieces are brought together under pressure, after a red hot state is reached at the interface, the rotating power is disengaged and the forging pressure is applied. When the rotating piece stops, the weld is completed. This process can be accurately controlled when speed, pressure and time are closely regulated. These weld joints of SS 316 and EN-8 are taken for Tensile strength testing on a UTM.

Table 6: Tensile Strength Test results

RUNS	Tensile Strength, KN/mm^2
	0.0895
2	0.2225
3	0.1919
4	0.0686
5	0.1996
6	0.2735
7	0.2516
8	0.2608
9	0.2837

Table 7: Response Table for S/N Ratio of Tensile Strength Test

Level	Speed	Forging pressure	Cooling Method
1	-16.12	-18.74	-14.63
2	-16.18	-12.91	-15.76
3	-11.53	-12.18	-13.44
Delta	4.64	6.56	2.32
Rank	2	1	3

The response table above shows the average of each response characteristic (s/n ratio) for each level of each factor. The tables include ranks based on Delta statistics, which compare the relative magnitude of effects. 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. In this Experiment the ranks indicate that Forging Pressure has the greatest influence on the S/N ratio, followed by Rotational speed then Cooling method. Our goal is to increase the Tensile strength of friction welded joint for SS 316 and EN-8 material. Since by determining the optimal factor levels that produce the highest mean. The level averages in the response table.5. show that means were maximized when the rotational speed was 1580 R.P.M and forging pressure was 28 bars and cooling method is Oil. Based on these results for maximized Tensile Strength the control factors should be set at the levels indicated below in the S/N ratio plot. It has been observed that with Oil Quenching the optimized parameters are 28 Bar as Forging Pressure and Rotational Speed as 1500RPM

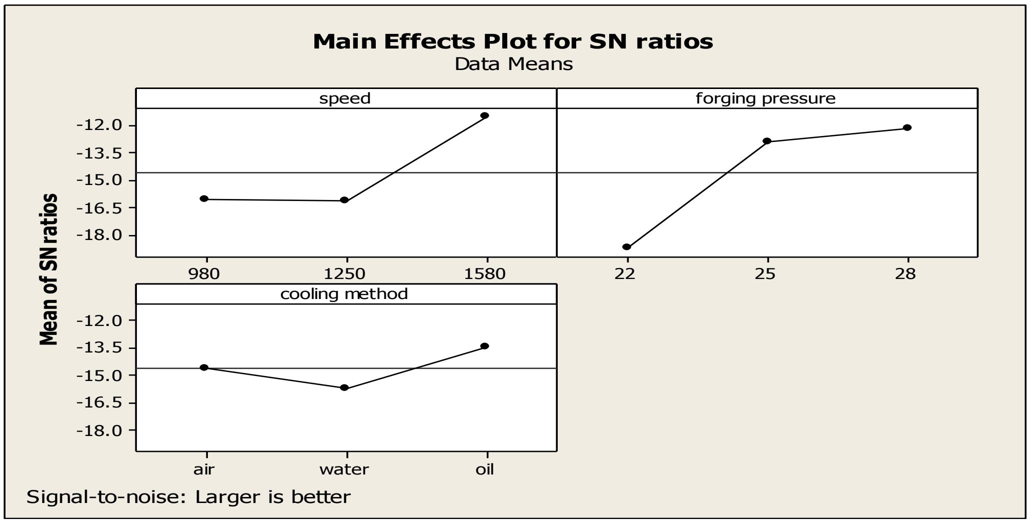

Fig 2: Main effect plot for S/N ratios

Table 8: Analysis of Variance for Tensile Strength test data

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	**2**	0.0016837	0.0016837	0.008418	1.79	0.358
Friction Pressure	**2**	0.021579	0.021579	0.010790	2.30	0.303
Cooling Method	**2**	0.000826	0.000826	0.000413	0.09	0.919
Error	**2**	0.009380	0.009380	0.004690		
Total	**8**	0.048622				

S= 0.0684832 R-Sq = 80.71% R-Sq(adj) = 22.83 %
Predicted Values:
S/N Ratio = -7.93544
Mean = 0.320167

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 a the optimal combination of the factor levels previously evaluated. In this study, after determining the optimum conditions and predicting the response under these conditions, a new experiment was designed and conducted with the optimum levels of the welding parameters. The final step is to predict and verify the improvement of the performance characteristic. The predicted S/N ratio η using the optimal levels of the welding parameters can be calculated as

$\eta=\eta_m + \sum^{k}_{j=1} (\eta_j - \eta_m)$; j= 1, 2, 3………..k

where η_m is total mean of S/N ratio, η_j is the mean of S/N ratio at the optimal level, and j 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 tensile strength with the actual tensile strength using the optimal welding parameter $_{are}$ shown in table. The summary statistics for the S/N ratio η (dB) is given by $\eta= - 10\log 1/N\sum 1/y^2$, Improvement formula Y2-Y1/ Y2 $\times$ 100

Table 9: Improvement in S/N ratio

Performance measure	optimal Process Parameter settings	Predicted values	Confirmation experiment values	Improvement in s/n ratio and tensile strength in %
Tensile Strength(kN)	0.20463	0.320167	0.31831	35.71
S/N (dB)	-13.78061	-7.93544	-9.94295	-38.59

IV. CONCLUSION

Mechanical behavior of the friction welded joint for SS 316 and En-8 is studied by the Taguchi design of experiment and it is observed that the friction processed joint exhibited good strength and joint strength increased with increase in friction pressure and forging pressure at high and moderate levels of rotational speeds and the optimal value of process variables for a higher tensile strength from the Taguchi design is 1580 R.P.M, 28 bar forging pressure and oil quenching. A study of the regression analysis for tensile strength was also studied (presented else where) and the correlation between experimental values and predicted values of tensile strength was established with a correlation co-efficient of 0.971 . The main effect for SN ratio and relation between parameters by employing ANOVA was studied for Tensile strength of the joint.and it was observed that at all levels of variables, there is an interaction between control factors and the response variable and the contribution of the interaction between control factors is negligible.And from the main affects plot the level of factors that have more effect on the Tensile. Strength was noted. From the Taguchi design of experiment it is observed that the factor that has more effect on the Tensile Strength is forging pressure then speed and finally cooling method. Thus it can be concluded that the joint between the dissimilar materials SS316 and EN-8 can be successfully carried out and the process can be optimized. This enables a pump manufacturing industry to replace 2/3 of expensive material of the shaft with cheaper material EN-8 and thus save huge amounts.

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