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EFFECT OF WELDING PARAMETERS IN FRICTION WELDING OF HOLLOW ENGINE VALVES

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ABSTRACT

This paper includes the study of friction welding being performed between a hollow head and a solid stem of an engine valve. Martensitic stainless steel (X45CrSi93) of 6.5 mm diameter was used as the experimental material. The inner diameter of the hollow head was 3 mm in size. Different welding parameters were chosen which includes friction pressure, upset pressure, burn-off and rotational speed. Mechanical and metallurgical investigations were performed. The optimum welding parameters were determined for these working conditions. The microhardness variation across the weld zone was conducted using Vicker's microhardness test. The response surface methodology was adopted for determining the optimum combination of welding parameters. The regression equation was developed to predict the maximum tensile strength for the optimal parameters.

Keywords: friction welding, martensitic stainless steel, burn-off, microhardness, response surface methodology, regression equation.

INTRODUCTION

Friction welding is one of the solid state joining technique in which melting of the work pieces does not occur. This involves bringing into contact two components, one of which is held in rotation while pressure is applied to the stationary component. Friction welding has been adopted over the other fusion welding methods for the following reasons: no melting, high reproducibility, short production time and low energy input.

The schematic view of the various stages of friction welding involving four stages is illustrated in Figure-1.
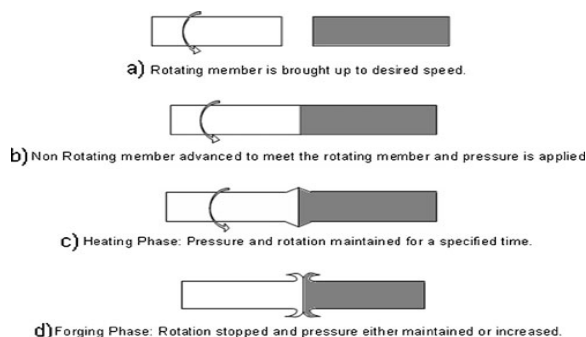

Figure-1. Various stages of friction welding process.

V. V. Satyanarayana *et al* employed the main parameters employed as friction force, forge force and burn-off. The flash was observed to be from ferritic stainless steel and austenitic stainless steel did not participate in the flash formation suggesting deformation is mainly limited to ferritic stainless steel side. The weld central region consists of fine grains while peripheral region consists of coarse grains. The fine grain size at the central region is due to dynamic recrystallization. The grain size in the weld region dictates the mode of fracture in that fine grain gives rise to ductile fracture, while coarse grain promotes cleavage fracture. Forge pressure aids in grain refinement while friction pressure aids grain coarsening [2].

Joseph Domblesky *et al* conducted the experimentation which consisted of four activities, which included preform assembly, compression testing (upsetting), side pressing and mechanical testing. Steel/copper and steel/stainless steel bi-metal performs were welded by using direct drive friction welding. The workability of welded performs was assessed using compression testing and side pressing under representative hot working conditions. All combinations of welded performs that were tested were found to exhibit good workability based on results obtained from upsetting. In bi-metal performs, deformation occurs preferentially in the lower strength specimen during upsetting [5].

G. Subhash Chander *et al* achieved dissimilar joints between austenitic stainless steel and low alloy steel by continuous drive friction welding. The parameters involved are friction force, forge force and burn-off. Burn-off has a major role on the impact toughness, increase in burn-off decreases impact toughness, while forge force has insignificant role under low frictional force, forge force, and burn-off. Under high friction conditions due to rapid cooling, the hardness is high while under low frictional force conditions, hardness is low due to slow cooling [6].

Hollow valves are preferred for weight reduction and quick temperature transfer properties. These valves are found to improve fuel efficiency as a result of their high cooling efficiency and ability to prevent engine knocking.

The hollow valves filled with a low-melting compound are used as exhaust engine valves while the ones not filled with the low-melting compound are used as inlet engine valves. Hollow engine valves can be classified

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into two: a) hollow-stem engine valve and b) hollow-head engine valve. This paper deals with the hollow-stem engine valve.

Process parameters

The various process parameters taken into consideration here are: friction pressure (pressure required to generate the required heat for welding), upset pressure (the axial pressure applied on the stationary work piece once rotation of the spindle is stopped), burn-off length (loss of overall length after welding) and rotational speed (the speed at which the spindle is rotated).

EXPERIMENTAL WORK

The material of the valve is selected as X45CrSi9-3 (martensitic stainless steel). The chemical composition and mechanical properties of this material are presented in Table-1 and 2 respectively.

Table-1. Chemical composition (wt%) of X45CrSi9-3.

Elements	C	Si	Mn	Cr	Ni	P	S
X45CrSi9 -3	0.45	3.0 0	0.8	9. 0	0. 5	0.0 4	0.0 3

Table-2. Mechanical properties of X45CrSi9-3.

Material	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)
X45CrSi9-3	450	765	16.5

The work pieces were prepared as head and stem pieces. The head piece which was received as head cut bar had to undergo upsetting and forging; solutionising and aging; and gun drilling. The outer diameter was 6.5 mm and the inner diameter of the hole drilled was 3 mm and the length of the hole was 68 mm. The concentricity and the surface finish are 0.14 mm and Rz 12.4 respectively. The head pieces prepared for friction welding is depicted in Figure-2.

Figure-2. Gun drilled head work pieces.

The stem piece which was received as stem cut bar has to undergo hardening and tempering; stress relieving; end touch. The diameter of the stem was 6.5 mm.

Process specifications

The welding experiments were carried out and the specimens were tested using 40 kN electro-mechanically controlled Universal testing machine for determination of the tensile strengths. The parameters chosen for the friction welding have been presented in Table III. Five trials were conducted using each parameter combination and the tensile strength value was obtained by averaging the five tensile strength values

Table-3. Parameters chosen for friction welding experiment.

Welding Factors	Range of Factors
Friction Pressure (MPa)	13.8 – 20.7
Upset Pressure (MPa)	27.6 – 34.5
Burn-off Length (mm)	10 -12
Spindle Speed (rpm)	1600 – 2000

Response surface methodology was adopted to determine the optimal parameters. Regression equation for the determination of optimal tensile strength was also developed. The microhardness determination across the weld was done using Vicker's microhardness tester. The specimens for microhardness examination were sectioned to the required size from the welded joints and polished using different grades of emery sheets and with alumina powder for final disc polishing.

RESULTS AND DISCUSSION

Friction welding experiments were conducted between each of the hollow head piece and solid stem piece. The friction welding process being carried out is shown in Figure-3.
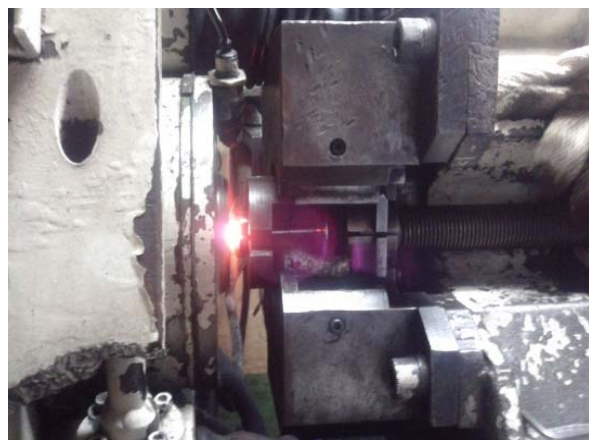

Figure-3. Friction welding process.

The friction welded specimens with flash are shown in Figure-4. The tensile strength was observed for each experiment, the observed values have been tabulated in the Table IV.

Figure-4. Friction welded samples.

Design of experiments

Response surface methodology (RSM) explains the relationship between several input variables and one or more response. The main aim of RSM is to use a sequence of designed experiments to obtain an optimal response.

Table-4. Experimental layout for friction welding trials.

Sl. No.	Factors				Tensile Strength (MPa)
	Friction Pressure (MPa)	Upset Pressure (MPa)	Burn-off length (mm)	Spindle Speed (rpm)	
1	13.8	27.6	10	1600	798
2	13.8	27.6	12	2000	794
3	13.8	34.5	10	2000	863
4	13.8	34.5	12	1600	785
5	20.7	27.6	10	2000	789
6	20.7	27.6	12	1600	882
7	20.7	34.5	10	1600	856
8	20.7	34.5	12	2000	817
9	17.2	31	11	1800	905
10	17.2	31	11	1800	878
11	17.2	31	11	1800	810
12	17.2	31	11	1800	914

Analysis of Variance is used to check the adequacy of a model in which the level of confidence is chosen to be 95%. The various process parameters are taken for the calculated value of the F-ratio of the model developed should not exceed the standard tabulated value of F-ratio. And 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, since the P value (Probability of the model terms) is less than 0.0500. This indicates that model terms are significant. Here the model terms FU, FL and FN are the interaction effect. The measured amount of variation around the mean coefficient of determination (R^2) value is always between 0 and 1, and its value indicates fitness of the model. For a good statistical model, R^2 value should be close to 1.0. The model predicts a response value Pred R^2 of 0.9041 that implies that the model could explain 90% of the variability in predicting new observations.

The final regression relationship to calculate the tensile strength was calculated using the coefficients, and the developed final regression relationship is given by the equation (1)

Tensile Strength = -1028.35+1910.33*(F)+118.84*(U)-88.5*(L)+0.607*(N)-454.16*(F²)-56.71*(FU)+49.27*(FL)-0.373*(FN) (1)

where F – friction pressure, U – upset pressure, L – burn-off length, N – rotational speed and FU, FL, FN are the interaction effects between parameters.

To obtain the influencing nature and the optimized condition of the process parameters on tensile strength, the response surface and contour plots (illustrated in Figures-5, 6 and 7) which are indicative of factors and response were developed for the proposed regression relation. The response plot shows the maximum achievable tensile strength.
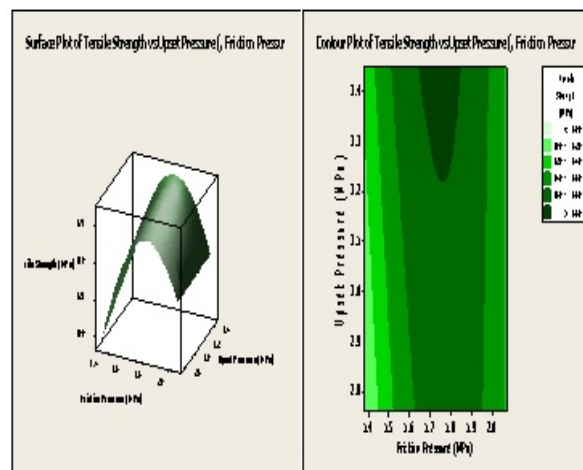

Figure-5. Surface and contour plot of tensile strength (vs.) F, U. Interaction effect of friction pressure and upset pressure.
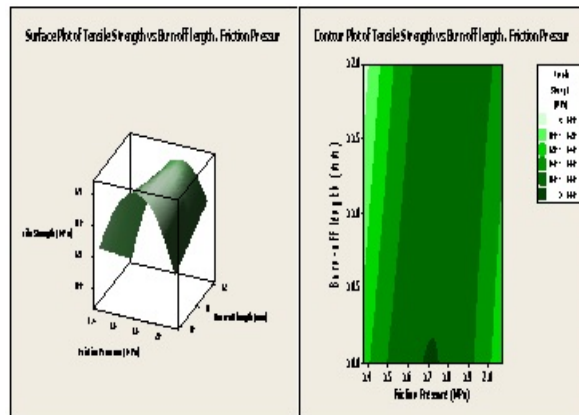
Figure-6. Surface and contour plot of tensile strength (vs.) F, L. Interaction effect of friction pressure and burn-off length.
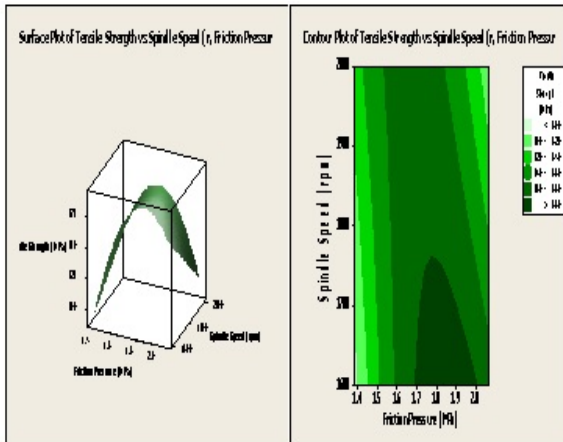

Figure-7. Surface and contour plot of tensile strength (vs.) F, N. Interaction effect of friction pressure and spindle speed.

By analyzing the response surface methodology and their corresponding contour plots, the maximum value of tensile strength 891.552 MPa is achieved. Of the four factors, the 17.2 MPa friction pressure is the most significant factor, which is then followed by 1800 rpm spindle speed, 31 MPa upset pressure and 11 mm burn-off length.

The maximum tensile strength values predicted by regression equation relationship along with experimental values are shown in Figure-8. It has been found that the regression predicted tensile strength values and experimental results are close together.
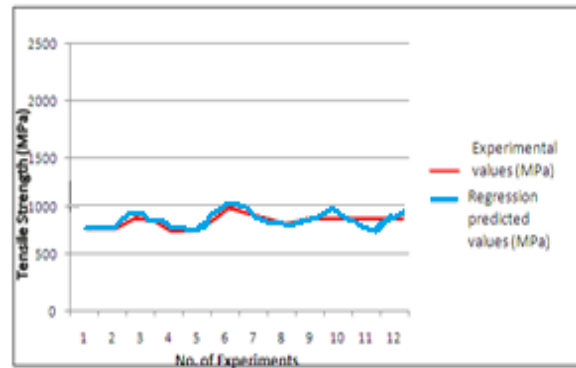

Figure-8. Comparison of regression predicted and experimental values.

The confirmation test was carried out with the optimum parameter combination with five trials, the tensile strength obtained with this test was 920 MPa which was found to be repeated as in the initial experiments.

Microhardness across the weld zone
The hardness across the weld as shown in Figure-9 was measured in order to obtain the hardness profile existing. The hardness in the weld zone is found to be high while low at the heat affected zone then reaching the base metal hardness. The hardness is found to be high in the weld zone and heat affected zone due to the high temperature being reached during welding. The hardness when found to reach the base metal hardness implied that the particular zone is unaffected by the welding temperature.
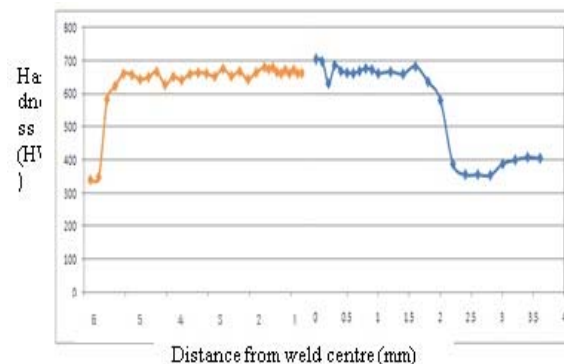

Figure-9. Hardness variation across the weld.

CONCLUSIONS
The friction welded joints of X45CrSi9-3 were investigated based on the experimental results.

▪ From the effect of process parameters, it is found that friction pressure has greater influence on tensile strength (P-value=0.02), followed by upset pressure (P-value=0.033) and rotational speed (P-value=0.036).

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- Response to input relation was developed by response surface methodology for predicting the tensile strength of friction welded X45CrSi9-3 material. The response graphs and contour plots have been drawn to study the interaction effect of process parameters.
- From the experimental results maximum tensile strength of 914 MPa could be attained for the friction welding conditions of 17.2 MPa friction pressure, 31 MPa upset pressure, 11 mm burn-off length and 1800 rpm spindle speed.
- The optimal combinations of process parameters for 17.2 MPa friction pressure, 31 MPa upset pressure, 11 mm burn-off length and 1800 rpm spindle speed from the confirmation test gives the maximum tensile strength value 891.552 MPa was predicted by RSM and regression values. It shows that RSM can be good tool for predicting optimal parameters for maximum tensile strength for the present conditions.

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