Parametric Experiment Analysis of Friction welding of two dissimilar metal Inconel 718 and SS 304

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Abstract— Friction welded joints are formed in the solid state by the heat generated by friction. As the technological advancements take place on daily bases the advancements in automobiles are not out of the race. Any form of boosting for engine power leads to increased temperatures and pressures in the combustion chamber, and much higher exhaust gas temperatures. The exhaust valve, which already has much higher temperatures to deal with than the inlet valve in a naturally aspirated engine, will see its temperature increase still further. So bi-metal valves made of Inconel 718 and SS 304 are under development. Exhaust valves are required to be very precise. They are produced by friction welding. The objective of the following study is to study the effects of the parameters on the Tensile strength of friction welded taper Inconel 718 and flat SS 304 for production of Bi-metal Valve. The study here discuses the use of Design of Experiments by Taguchi Method. Here Orthogonal Array of L27 is used. Using ANOVA effects on the Ultimate Tensile strenght of welding by Welding Parameters (Rotational Speed, Friction Pressure and Time) are analyzed using MINITAB 17.

Key words: Rotary Friction Welding, Flat SS 304, Taper Inconel 718, Taguchi, ANOVA, MINITAB

I. INTRODUCTION

The process of friction welding involves two stages. Two components are moved relative to each other under an applied axial load and the heat generated by friction causes a narrow plastic layer to form at the interface. The components are then forged together, usually with an increased axial load and no relative motion. As the weld does not become molten, materials of vastly different properties can be joined by it including different steels, aluminum and steel, aluminum and copper and much more. Other advantages of friction welding include material, machining and weight savings. [1]. In this Study work Inconel 718 and SS 304 will be friction welded together for the production of bi-metal poppet exhaust valve. In automobile production systems, accuracy and precision are one of most desirable qualities for performance of the engine. Controlled parameters also mean less requirements of machining. The tensile strength of joint is mandatory to obtain desirable qualities in weld. So its need to optimize parameter which affects tensile strength of welded joint. This study will be carried out for the combination of Materials with different shape used on the friction welding. The study will give the effects of friction welding parameters such as Speed, Friction Pressure and Time on the Ultimate tensile strength of the produced welds.

II. LITERATURE REVIEW

Both theoretical and experimental studies on these parameters can be seen in various articles. Various researchers such as Vill and Tylecote investigated the parameters that influence the welding quality, the strength of the joint and the hardness of the heat-affected zone (HAZ). [2, 3].

Inconel 718 has good weld ability by GTAW method but it encounters some problems in conventional joining processes as three main problem areas were encountered and investigated by J Gordine in 1971, which were, Poor penetration during welding, Micro-fissuring in the heat affected zone and poor impact and ductility properties of the weld fusion zone.[4].

C R G Ellis' studies on Continuous Drive Friction Welding of Mild Steel concluded that temperature and the temperature distribution in the HAZ are both pressure and speed dependent for a given burn off setting. Some of very important conclusions they derived were, the equilibrium torque, burn off rate is linearly related with pressure to a substantial extent and approximately inversely related to the speed of rotation. [5] Zhou et al. investigated the influence of joining parameters (rotational speed, frictional time and pressure) on the NTS (Notched Tensile Strength) of dissimilar aluminum-based metal matrix composite MMC/AISI304 stainless steel friction joints. It was observed that frictional pressure and rotational speed have a statistically-significant effect on the NTS values. [6]

S. Vardhan Lalam, G. Madhusudhan Reddy, T. Mohandas, M. Kamaraj and B. S. Murty researched on Continuous drive friction welding of Inconel 718 and EN24 dissimilar metal combination. Nickel based superalloy Inconel 718 and low alloy steel EN24 are welded by continuous drive friction welding in annealed condition and then post-weld heat treated (PWHT).[7]

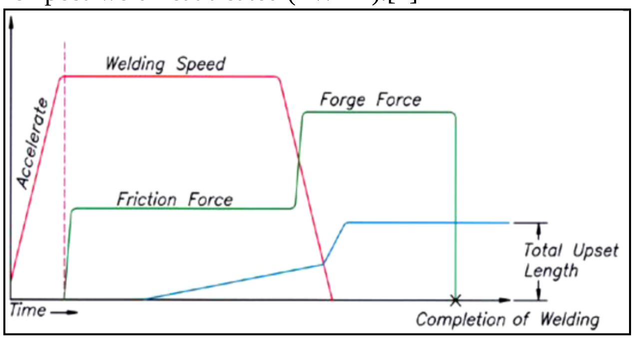

Fig. 1: Rotary Friction Welding Phase Diagram

Eder Paduan Alves, Francisco Piorino Neto ,Chen Ying An developed Welding of AA1050 aluminum with AISI 304 stainless steel by rotary friction welding process.[8] An attempt was made by R Paventhan,P R Lakshminarayan and V Balasubramanian to develop an empirical relationship to predict the tensile strength of friction welded AISI 1040 grade medium carbon steel and AISI 304 SS, incorporating the process parameters. Response surface methodology was applied to optimize the friction welding process parameters to attain maximum tensile strength of joint.[9] Hussein Mesmari and Fawzia Krayem studied Mechanical and Microstructure Properties of 304 Stainless Steel Friction Welded Joint. The effect of the individual selected parameters was investigated, as well as the combined effect of interaction of the two parameters was also analyzed by Analysis of Means. Weld joints exhibit a comparable strength with the base material with maximum efficiency of 105% that indicates the austenitic stainless steel is quite tolerant with friction welding technique

The literature suggest that the Speed required for friction welding are generally in the range of 1200 to 2000 RPM, Friction Pressure is in the range of 20MPa to 100 MPa and the Time required is in the range of 2 sec to 30seconds.[7,8].

In this study we have selected combination of Taper Shaped Inconel 718 and SS 304 and they are friction welded.

III. EXPERIMENTAL SETUP

The set-up used in the friction welding experiments is shown in Fig. 2.

The set-up was designed and constructed as continuous drive friction welding. The friction time and friction pressure are controlled manually.

Taguchi's design of experiment is used and Friction pressure, Speed and Friction time are taken as controlled parameters.

L27 orthogonal array is used for the specimen generation.UTS of Samples are measured by UDM machine in TEST WELL Laboratories, Ahmedabad, Gujarat, India. The setup is prepared in the workshop at Indus University, Ahmadabad, Gujarat, India.

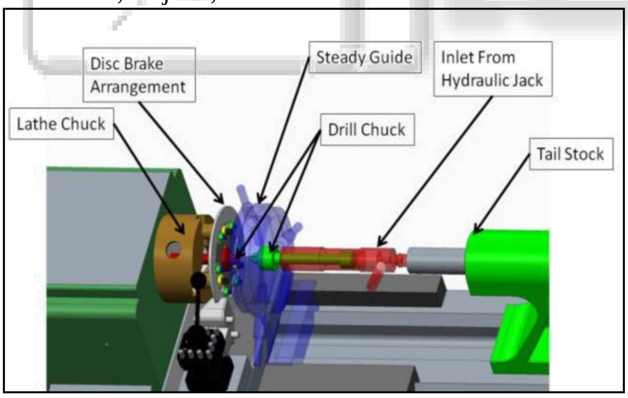

Fig. 2: Setup Layout

The setup is a modified lathe. The lathe is ALL Geared Lathe and is having the range of 40 – 1200 RPM. The pulley ratio was changed to fulfill the speed requirements of the experiment. For pressure application Hydraulic Cylinder is used which is attached to tail stock.

It is the requirement of Continuous drive friction welding that, in the initial condition, one piece is held stationary and other piece is rotated at required speed. Then maintaining that Speed N, pressure is applied (Friction pressure P) for Time T. Then rotation is stopped and the speed is decreased to zero in fraction of second (as shown in Fig 1) and Forging Pressure is applied for some specified time.

For sudden stop arrangement, Disc brake system is attached to the chuck which stops the chuck in less than a second.

A. Chemical Composition and Specimen Dimensions

A. Component	B. Wt %
Aluminum-Al	0.2-0.8
Boron – B	Max 0.006
Carbon – C	Max – 0.08
Cobalt –Co	Max 1
Chromium - Cr	17-12
Copper – Cu	Max 0.3
Iron – Fe	17
Manganese - Mn	Max 0.35
Molybdenum - Mo	2.8 – 3.3
Niobium –Nb	4.75 – 5.5
Nickel – Ni	50 – 55
Phosphors – P	Max 0.015
Sulphur – S	Max 0.015
Silicon –Si	Max 0.35
Titanium – Ti	0.65 – 1.15

Table 1: Chemical Composition Of Inconel

Component	Wt %
Carbon – C	Max 0.08
Chromium – Cr	18 – 20
Iron – Fe	66.345 -74
Manganese –Mn	Max 2
Nickel –Ni	8 -10.5
Phosphors – P	Max 0.045
Sulphur – S	Max 0.03
Silicon - Si	Max 1

Table 2: Chemical Composition Of Ss 304

Specimens were machined from Inconel 718 and SS 304. The standard chemical composition of the materials is shown in Tables 1 and Table 2.

Specimen size used in the experiment is
Length: 100 ± 0.1mm
Diameter: 12 ± 0.1mm
Taper angle: 30 degree
Taper length: 5 ± 0.1mm

B. Selection of Welding Parameters

According to the Trial and Experiments, the range that can be used is as below.

The Lathe used over here is ALL- Geared Lathe. With help of changing the driving pulley, the speeds that are achieved and useful for our range of experiment are,

- 1180
- 1346
- 2040

According to the results of trial and experiments we have minimum of 6 Kg/cm2 and maximum of 12 Kg/cm2 And the minimum time required for successful friction welding at 6 kg/cm2 is 8 seconds so Parameters selected for time are

- 8 sec
- 12 sec
- 16 sec

Forging Pressure is kept constant to 25-30 Kg/cm2 throughout the experiment and Forging time is also kept constant to 20 Seconds.

IV. Sample Preparation and Data Collection

A. Sample Preparation

According to the Taguchi's O.A of L27 samples were prepared. Their Ultimate Tensile Strength are collected.

B. Data Collection

Collected data is as shown in Table 3.

	Speed RPM	Friction pressure Kg/cm2	Time Seconds	UTS Mpa
1	1180	6	8	105
2	1180	6	8	124
3	1180	6	8	141
4	1180	8	12	112
5	1180	8	12	125
6	1180	8	12	102
7	1180	10	16	150
8	1180	10	16	135
9	1180	10	16	113
10	1346	6	12	138
11	1346	6	12	118
12	1346	6	12	172
13	1346	8	16	173
14	1346	8	16	130
15	1346	8	16	119
16	1346	10	8	120
17	1346	10	8	106
18	1346	10	8	152
19	2040	6	16	145
20	2040	6	16	104
21	2040	6	16	154
22	2040	8	8	98
23	2040	8	8	117
24	2040	8	8	141
25	2040	10	12	172
26	2040	10	12	181
27	2040	10	12	138

Table 3:

V. Result and Discussion

Effect of individual parameters of friction welding such as Speed, Friction Pressure and Time are analyzed here by ANOVA. For the analysis Statistical Software like MINITAB is used here.

By plotting the response of Speed over UTS, we get to know that the as the speed is increased, the UTS increases gradually but after speed of 1346 RPM, there are slightly change in UTS till 2040 RPM . The Interval plot of UTS vs. Speed is shown in Fig 3 Percentage contribution of Speed is **8.94%.**

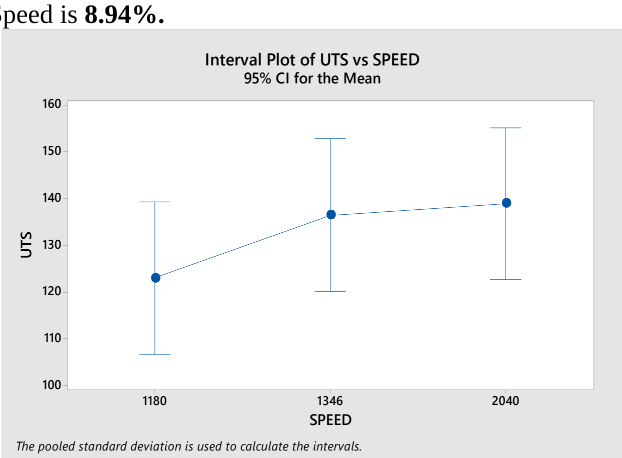

Fig. 3: Interval Plot of UTS Vs. Speed

A. Minitab Summary for One-way ANOVA: Ultimate tensile strength versus Speed

Method
Null hypothesis All means are equal
Alternative hypothesis At least one mean is different
Significance level α = 0.05
Equal variances were assumed for the analysis.
Factor Information
Factor Levels Values
SPEED 3 1180, 1346, 2040
Analysis of Variance
Source DF Adj SS Adj MS F-Value P-Value
SPEED 2 1318 658.8 1.18 0.325
Error 24 13425 559.4
Total 26 14743
Model Summary
S R-sq R-sq(adj) R-sq(pred)
23.6512 8.94% 1.35% 0.00%

After Plotting the Interval Plot of UTS vs. Friction Pressure ,we get to know that the UTS is decreased in the beginning and then it inclines after 8Kg/cm2 Pressure, then it is increasing. The percentage contribution of friction pressure is **8.52%.**

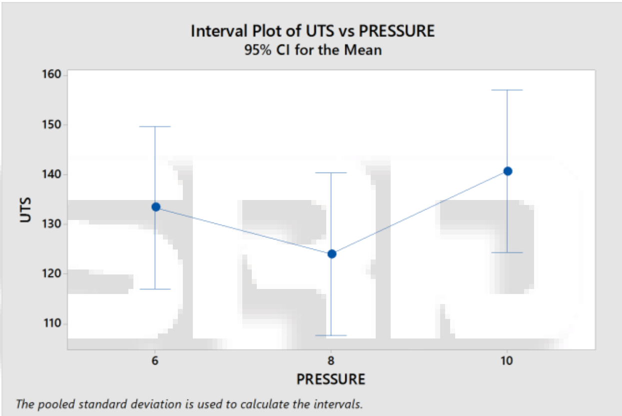

Fig. 4: Interval Plot of UTS Vs. Friction Pressure

B. Minitab Summary for One-way ANOVA: UTS versus Friction pressure

Method
Null hypothesis All means are equal
Alternative hypothesis At least one mean is different
Significance level α = 0.05
Equal variances were assumed for the analysis.
Factor Information
Factor Levels Values
PRESSURE 3 6, 8, 10
Analysis of Variance
Source DF Adj SS Adj MS F-Value P-Value
PRESSURE 2 1256 628.0 1.12 0.344
Error 24 13487 561.9
Total 26 14743
Model Summary
S R-sq R-sq(adj) R-sq(pred)
23.7054 8.52% 0.90% 0.00%

Plot from Fig 5, shows that as the time is increased, there is increase in the UTS. At 12 seconds, the UTS is maximum but after 12 seconds, UTS is reduced. Percentage Contribution by Time for Burn Off length is 9.82%.

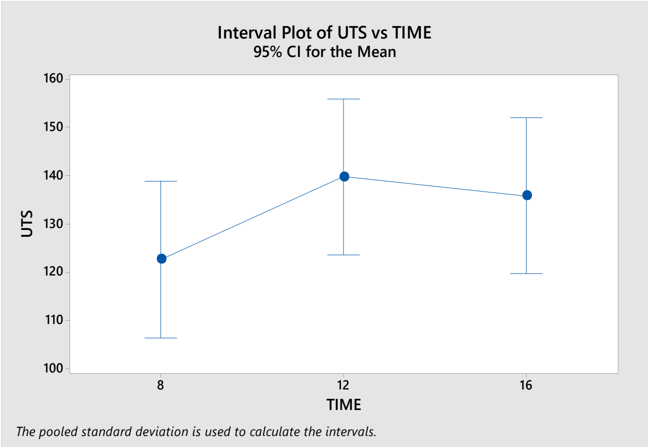

Fig. 5: Interval Plot Of UTS Vs. Time

C. Minitab Summary for One-way ANOVA: UTS versus Time

Method
Null hypothesis All means are equal
Alternative hypothesis At least one mean is different
Significance level α = 0.05
Equal variances were assumed for the analysis.
Factor Information

Factor	Levels	Values
TIME	3	8, 12, 16

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
TIME	2	1448	724.1	1.31	0.289
Error	24	13294	553.9		
Total	26	14743			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
23.5358	9.82%	2.31%	0.00%

VI. Conclusions and Future Scope

The experiment concluded that the Speed, Friction Pressure and Time are contributing all most equally on Ultimate tensile Strength for friction welding of taper Inconel 718 and Flat SS 304.

The results can be very helpful for generating FEA Models for friction welding. Other properties such as burn off length, toughness, hardness and fatigue properties can be analyzed and can be used for Bi-metal Production of Poppet Exhaust.

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