Parametric Analysis of Friction Welding on Two Desimmilar Metal Rod of Taper End

Prof. Jignesh Patel
Assistant Professor
(1) Rahul Panchal, (2) Meet Mewada
8th Sem Students of Mechanical Engineering
Department of Mechanical Engineering
Indus University, Ahmedabad, Gujarat, India – 382115

***Abstract*— Friction welding is one of the most effective, energy saving process for solid state joining of similar as well as dissimilar materials, holds the advantage of high joint integrity. The friction welding of metal and ceramic gives new possibilities of application due to the fact that both materials have significantly distinguish physical ,chemical and mechanical properties. The specimen having different taper angle at the end of Inconel 800 and SS 304 were welded by direct drive friction welding to investigate the effect of joint geometry on micro structural development, hardness as well as tensile strength of the welded components. The welding process was carried out under different axial pressure and different rotational speed. The experimental result has shown that different end taper shows different effect on the joint of the components. Also different pressure and speed creates the significant effect.**

Keywords: Rotary Friction Welding, SS 304, Inconel 718, Taguchi, ANOVA, MINITAB

I. INTRODUCTION

Friction welding is a solid-state welding process that generates heat through mechanical friction between work pieces in relative motion to one another, with the addition of a lateral force called "upset" to plastically displace and fuse the materials. In general this welding take place on the lathe machine where one of the two jobs is being hold in the chuck of the lathe machine and another one is fitted in the tail stock with some necessary attachments. The job fitted in the chuck is rotating with the predetermined constant speed whereas the opposite one is being kept fixed. The pressure is applied from the tailstock end as per requirement of joint. For applying the axial pressure to the fixed job the hydraulic jack or pressure pump arrangement is being fitted with the tailstock. After making all the set up when the rotating element is came in contact with the fixed specimen the friction is generated and due to the generation of friction the heat is being produced. After that the predetermined pressure is applied from the tailstock end to form the uniform joint. Due to the heat generation the end of the metal specimens became softer and so when the pressure is applied the metal formed a homogenous solution and gets welded together. To replace the bar of Inconel used in the poppet valve with the joint combination welded bar of Inconel 800 and SS 304 for reducing the overall cost of poppet valve. Also study the different effect of different end taper angle (30, 45, & 60) on the welding joint.

II. LITERATURE REVIEW

"Friction Welding to Join Dissimilar Metals [2]" The purpose of this work was to join and assess the development of solid state joints of dissimilar material AA6082 aluminum alloy and AISI 304 stainless steel, via continuous drive friction welding process, which combines the heat generated from friction between two surfaces and plastic deformation. Tests were conducted with different welding process parameters. The results were analyzed by means of tensile test, Vickers micro hardness test, fatigue test, Charpy v-notch impact test, and SEM-EDX (energy dispersive X-ray) analysis in order to determine the phases that occurred during welding. The strength of the joints varied with increasing friction pressure and friction time keeping upset pressure and upset time constant. The joint strength increased, and then decreased after reaching a maximum value, with increasing friction pressure and friction time. The process of friction welding between the aluminum alloy and the stainless steel is proposed to evolve as follows: welding progresses from the outer to the inner region; an unbounded region is retained at the centre of the weld interface with shorter friction time; longer friction time causes the formation of an intermetallic reaction layer at the weld interface and the reaction layer grows as the friction time increases. [2,3].

Friction welding, one of the most effective, energy- saving processes for solid-state joining of similar and dissimilar materials, holds the advantage of high joint integrity. The friction welding of metal and ceramic gives new possibilities of application due to the fact that both materials have significantly distinguish physical, chemical and mechanical properties. Different specimen geometries (flat, pin and taper pin ceramic faces with flat metal face) of alumina and 6061-aluminum alloy were welded by direct drive friction welding to investigate the effect of joint geometry on microstructure development, micro hardness and thermal properties of friction-welded components. The welding process was carried out under different axial pressures and friction times while rotational speed (1250 rpm) and axial force (5000N) were kept constant. The experimental results showed that the shape of ceramic face had a significant effect on the joint structure, micro hardness and thermal properties.[4]

The establishment of energy saving and natural resource saving systems is an important issue, and relevant research and development should be accomplished without delay. Making structures lighter is one way to save energy. The study of light metals such as aluminum alloys and

magnesium alloys has received much attention. Aluminum alloys are especially attractive because of superior recyclability and workability. However, present structures made of stainless steels cannot be entirely replaced with aluminum alloy structures, taking into account strength, weld ability, and economics, although it is possible to replace part of a structure with aluminum alloy components in this case, it is necessary to join stainless steels to aluminum alloys. Few sound joints have been obtained, owing to the formation of a large amount of brittle
Intermetallic compounds in the weld using fusion welding. In the recent years welding of dissimilar metals by conventional welding techniques has become difficult. The flux used for the welding will create lot of heat which declines the strength of the welded joints. In order to overcome this, Friction welding is more effective in joining dissimilar metals when compared with fusion welding, because it is a solid state process. Heat in friction welding is generated by conversion of mechanical energy into thermal energy at the interface of work pieces during rotation under pressure. Various ferrous and non-ferrous alloys having circular or non-circular cross sections and that have different thermal and mechanical properties can easily be joined by the friction welding method.[5]

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.

L_{18} orthogonal array is used for the specimen generation. The lengths of Specimen before and after the friction welding are noted and by ANOVA the individual effects of the parameters on UTS are found.

The setup is prepared in the workshop at Indus University, Ahmedabad, Gujarat, India.

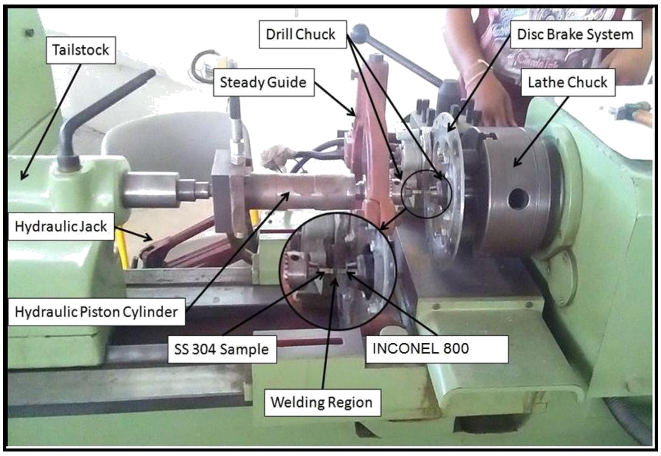

Fig. 1: Setup Layout

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 fulfil the speed requirements (increased up to 2036 RPM) 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 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. Specimens were joined from Inconel 800 to 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: 90-95 mm
Diameter: $8^{\pm 0.1}$mm

TABLE. 1 : CHEMICAL COMPOSITION OF INCONEL 800

ELEMENTS	SYMBOL	UNIT %
CARBON	C	0.029
SILICON	Si	0.483
MANGANESE	Mn	1.105
PHOSPHORUS	P	0.020
SULPHUR	S	0.002
CHROMIUM	Cr	20.510
NICKEL	Ni	30.120
COPPER	Cu	0.095
ALUMINIUM	Al	0.520
TITANIUM	Ti	0.370
IRON	Fe	46.020

TABLE. 2 : CHEMICAL COMPOSITION OF SS 304

ELEMENT	SYMBOL	UNIT %
CARBON	C	0.021
SILICON	Si	0.445
MANGANESE	Mn	1.67
PHOSPHORUS	P	0.35
SULPHUR	S	0.011
CHROMIUM	Cr	18.27
NICKEL	Ni	8.01

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,

- 1800
- 2036

According to the results of trial and experiments we have minimum of 12 Kg/cm^2 and maximum of 18 Kg/cm^2
The Pressure gauge is attached to the Hydraulic Jack and shows the line pressure of the Hydraulic jack. The pressure measured here is in **kg/cm^2** and psi.

- The Diameter of Piston used in hydraulic cylinder is 40mm.
- The Diameter of the Samples is $8^{\pm 0.1}$ mm. So the area will be $50.265^{\pm 0.94}$ mm^2
- Pressure Exerted for the friction welding will be $52.272^{\pm 0.89}$ MPa when applied the force of 12 kg/cm^2

Studies carried out by Johannes Löhe, Marc Lotz, Mark Cannon, and Basil Kouvaritakis in 2013 showed requirement of better control systems such as PID control systems to overcome the non linear nature of the friction welding parameters. The control by PID systems ensures better quality control on friction welding. [10]

The Friction Pressure at the faying surface is shown in the bracket.

- 12 Kg/cm^2 ($52.272^{\pm 0.89}$ MPa)
- 15 Kg/cm^2 ($65.34^{\pm 1.038}$ MPa)
- 18 Kg/cm^2 ($78.40^{\pm 1.1836}$ MPa)

The angle of taper at the end of rod is shown below

- 30 degree
- 45 degree
- 60 degree

IV. SAMPLE PREPARATION AND DATA COLLECTION

A. Sample preparation

According to the Taguchi's mathod of L_{18} samples were prepared. Their respective length before the welding is collected.

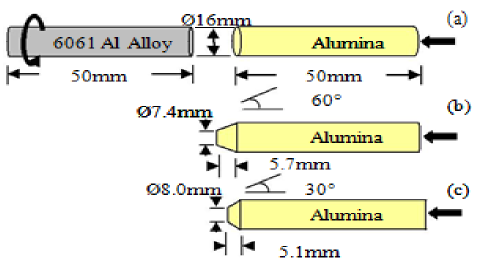

Fig.2 sample end geometry

B. Data collection

Collected data is as shown in Table 3

TABLE. 3: FACTOR TABLE FOR PARAMETERS

Sr No.	Speed (RPM)	Pressure (kg/cm^2)	Angle (degree)
1	1800	12	30
2	1800	12	45
3	1800	12	60
4	1800	15	30
5	1800	15	45
6	1800	15	60
7	1800	18	30
8	1800	18	45
9	1800	18	60
10	2036	12	30
11	2036	12	45
12	2036	12	60
13	2036	15	30
14	2036	15	45
15	2036	15	60
16	2036	18	30
17	2036	18	45
18	2036	18	60

V. RESULT AND DISCUSSION

Effect of individual parameters of friction welding such as Speed, Friction Pressure and taper angle are analyzed here by ANOVA. For the analysis Statistical Software like MINITAB is used here.
That all factor is also responsible for UTS of joint. The result of the tensile test carried out in the laboratory shows that the maximum tensile strength 431.649 N/mm2 can be achieved at max speed of 2036 RPM and at the max pressure of 18 kg/cm^2 and at the angle of 60 deg that joint can carried ultimate tensile load of 20.840 KN. Result is shown in table 4.

TABLE. 4: READING TABLE

Sr No.	Speed (RPM)	Pressure (kg/cm^2)	Angle (degree)	UTS (n/mm^2)
1	1800	12	30	188.350
2	1800	12	45	217.757
3	1800	12	60	263.549
4	1800	15	30	310.486
5	1800	15	45	211.870
6	1800	15	60	255.734
7	1800	18	30	364.522
8	1800	18	45	353.496
9	1800	18	60	322.317
10	2036	12	30	258.169
11	2036	12	45	221.230
12	2036	12	60	163.182
13	2036	15	30	270.753
14	2036	15	45	260.710
15	2036	15	60	239.144
16	2036	18	30	278.040
17	2036	18	45	308.038
18	2036	18	60	431.649

By plotting the response of Pressure over UTS, we get to know that the as the pressure is increased, the UTS increases gradually. The Interval Plot of UTS vs. Pressure is shown in Fig 3

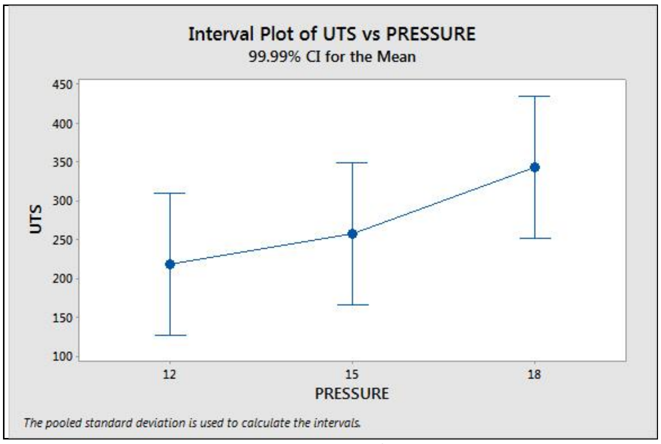

Fig. 3: Interval Plot of UTS vs PRESSURE

A. Minitab Summary for One-way ANOVA: UTS 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
Friction Pressure	3	12, 15, 18

Analysis of Variance

Source	SS	DF	MS	F	Percentage
Pressure	48423.004	2	24212	13.31	0.0%
Error	27295.0	15	1820		100%
Total	75719.0	17			100%

Model Summary

S	R-Sq	R-Sq(Adj)	R-Sq(Pred)
42.6577	63.95%	59.15%	48.09%

After Plotting the Interval Plot of UTS vs. Friction Pressure ,it is clear that the variation if the friction pressure is not a major affecting parameter as its variation is independent. The UTS is increased with incising pressure.

By plotting the response of Speed over UTS, we get to know that the as the speed is increased that is not major change in UTS. At speed of 1800 RPM average UTS is 276.5 n/mm^2 and at 2036 RPM average speed is 270.1 n/mm^2. We got almost same UTS at both speed after taking 9 reading at both Speed.graph shown in fig 4

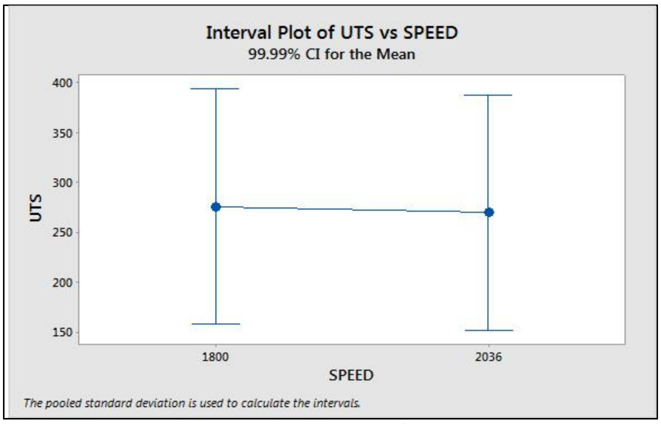

Fig. 4: Interval Plot of UTS vs SPEED

B. Minitab Summary for One-way ANOVA: UTS 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	2	1800, 2036

Analysis of Variance

Source	SS	DF	MS	F	Percentage
Speed	181.5529	1	181.55	0.038	84.7%
Error	75537.0089	16	4721.06		15.3%
Total	75718.56	17			100%

Model Summary

S	R-Sq	R-Sq(Adj)	R-Sq(Pred)
70.5259	1.47%	0.00%	0.00%

Fig 5 shows that as the Angle is increased, there is decrease in UTS and then further increase Angle UTS is also increase. We are performing experiment on three different angle which is 30, 45 and 60 degree. We got 278.6 n/mm2 average UTS at angle of 30 degree, 262.2 n/mm2 at angle of 45 degree and 279.3 n/mm2 at angle of 60 degree. maximum result has been got when taper angle is 60 degree. also getting good result at 30 degree taper angle. that all result have been got after performing 6 experiment for each angle

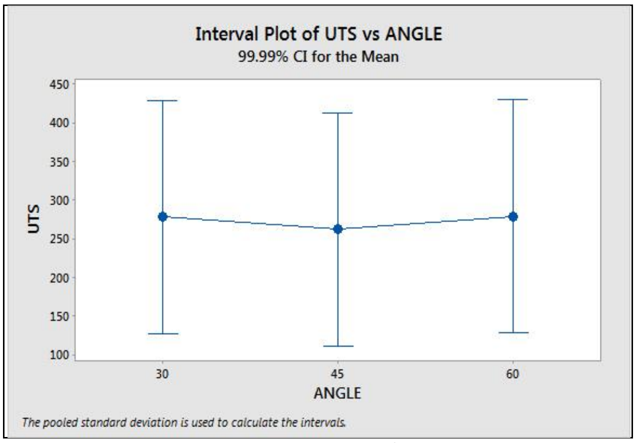

Fig. 5: Interval Plot of UTS vs ANGLE

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

Source	SS	DF	MS	F	Percentage
Angle	1110.002	2	555	0.11	89.5%
Error	74609.0	15	4973.9		10.5%
Total	75719.0	17			100%

Model Summary

S	R-Sq	R-Sq(Adj)	R-Sq(Pred)
70.5250	1.47%	0.00%	0.00%

VI. CONCLUSIONS AND FUTURE SCOPE

After performing the experiment we can conclude that the end geometry of the specimen plays an important role in the welding process along with the pressure and operational speed. Also the tensile strength is not too much low compare to that with Inconel material as Inconel has UTS of 536 MPA so if it is allowable as per the use inplace of Inconel we can use the welded part by keeping the cost of the Inconel in mind so that we can reduce the overall cost without compromising so much strength.

Other properties such as Toughness, Hardness, Impact Strength can be analyzed after Heat Treatment of the produced valve or component.

All the work carried out can help in deriving Finite Element Model for the Rotary friction welding of dissimilar welding.

During the work, Inconel 800 and SS 304 have emerged as the promising replacement for SS 304 where it is used for high pressure and temperature applications.

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