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COMPARATIVE STUDY ON HARDNESS, TORSION AND MICROSTRUCTURAL CHARACTERISTICS OF FRICTION WELDED JOINTS OF Al 6061 ROD FORMED WITH VARIOUS INTERFACE GEOMETRY

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ABSTRACT

Friction welding is a solid state joining process that produces coalescence in materials, using the heat developed between surfaces through a combination of mechanical induced rubbing motion and applied load. In rotary friction welding technique heat is generated by the conversion of mechanical energy into thermal energy at the interface of the work pieces in contact during rotation under pressure. Recent studies revealed that one of the strong influencing factors which affect the tensile characteristics of the friction welded joints is the shape of interface geometry of the mating surfaces. The various interface geometry considered for those studies are Flat-Flat combination, Taper-Taper combination and Concex-Convex combination. It is reported that the Ultimate tensile tensile characteristics of friction welded joints with taper-taper and convex-convex combinations are higher than that obtained with flat-flat combination. Present study investigates the influence of these geometry on the other physical characteristics like hardness and mechanical properties like torsion. Attempts were made to analyze the variations in such properties from flat-flat combination based up on the microstructure studies carried out. The Taper angle considered for taper-taper combination is 30° and the radius of the convex-convex geometry considered is 20mm. The speed for the rotating specimen here is 775 rpm. The welding pressure was kept in the range 0.7-1.73 N/mm². The forging pressure was kept in the range 1.73-2.76 N/mm². The hardness and the Modulus of rigidity was found higher for the joints with taper-taper combination. Convex-Convex geometry also showed better modulus of rigidity than Flat-Flat combination, but less in the case of hardness value

Keywords: Friction Welding, Hardness, Torsion, Microstructure, Interface Geometry.

I. INTRODUCTION

Friction welding (FW) is a complicated process, which involves interaction of thermal, mechanical and metallurgical phenomenon. Friction welding comes under the category of solid welding process in which the heat for welding process at the interface is generated through mechanical friction between the components to be welded. FW techniques are popular nowadays in aerospace, automotive and ship building industries. Among the solid state welding techniques rotary friction welding (RFW) technique is very much suitable for rods of high strength materials like steel and high strength low weight materials like Aluminium alloys [1]. Suspension rods, steering columns, gear box forks and drive shafts and engine valves etc. are now manufacturing by friction welding process. Fig.1 indicates The working procedure of Rotary friction Welding Process. In this process, one of the components is being kept stationary and the

other part is set in motion with a friction pressure being applied. This leads the interface to plastically deform and fuse together and an upsetting begins. On forming certain upset, the rotation is stopped and a forging pressure is being applied. This is actually a forging process since the joining is done though plastic deformation only, with no melting is present. Hence the major parameters include friction pressure, forging pressure and rotational speed. It is also observed that other parameter such as the joining interface geometry also plays an important role in the weld characteristics.

Wendy Li, Taejon Ma and Jingling Li [2], did numerical simulation of the linear FW process of titanium alloy to investigate the effect of process parameters. G.KiranKumar, K. Kishore, and P.V.GopalKrishna [3] did modifications to a medium duty lathe and obtained FW joint and proved that a simple engine lathe can perform friction welding up to 12mm diameter. M.N.Ahamed Fauzi, M B Uday, H Zuhailawatti and A.B.Ismail [4] have also conducted studies on the microstructural characteristics of friction welded joints by alumina and Al 6061 alloy. To carry out the friction welding process they have made a friction welding set up by modifying a conventional lathe. R. Paventhan, P R Lakshminarayanan and V Balasubramanian [5] conducted studies to understand the fatigue behavior of friction welded joints from medium carbon steel and austenite steel. A design of experiment based optimization techniques for the friction welding parameters have been studied by P Shivasankar [6] for the joining of Copper Alloys. Uday M Basheer and Ahmed Fauzi Mohd Noor [7] have studied the influence of interface geometries of fw joints by alumina-Al 6061 Alloy. They found that tapered interface geometry of specimen in friction welding process of rods could make improvements in mechanical characteristics of welded joints. But only two taper angle have been considered by them for the study.

Fig. 1: Working Procedure-Rotary Friction Welding

Recent studies conducted by Baiju Sasidharan, Narayanan and Arivazhakan [8] reported that tensile properties of friction welded joints obtained with taper-taper interface geometry has good tensile properties compared to other combinations like flat-flat and convex-convex. Followed with that study Sreejith, Baiju Sasidharan and Narayanan [9] have found that friction welded joint from Aluminium alloy 6061 with 30° interface taper angle have good tensile properties. Present study is an addition to that to establish the same for other characteristics like hardness and torsion in supporting with microstructure characteristic studies.

II. EXPERIMENTS-MECHANICAL CHARACTERISTICS

Experiment involved mainly the formation of friction welded joints from Al 6061 alloys with various interface geometries like Flat-Flat (F-F), Taper-Taper (T-T) and Convex-Convex (CX-CX). The joints obtained were then subjected to physical characteristic study like hardness. It was then subjected to one of the mechanical characteristic studies like torsion. Microstructure characteristic studies have also carried out to correlate the results from hardness and torsion tests.

2.1 Material

The material used here is **Aluminum 6061** alloy rods. It has good mechanical properties and exhibits good weld ability. The chemical composition of the Al 6061 is given in table 1.

Table 1: Chemical composition of al 6061

Component	Al	Si	Mg	Mn	Fe	Cu	Cr	Ti	Zn	Ni	Ca	Bal
(WT%)	96	2.1	0.95	0.04	0.33	0.17	0.066	0.022	0.014	0.014	0.013	<0.01

2.2 Friction welding set up

A medium duty lathe was mainly used to conduct friction welding process. Three different speeds suited for the joining of aluminium rods can be set with the lathe used.. A hydraulic system was used to maintain constant loading during the process to develop frictional heat and to produce instant upset loading at the time of joining. The range of load it can produce and measure from 1 to 20 KN. Fig. 2 shows the Friction welding setup developed for the present study. Fig 3 represents the hydraulic system attachment in the set up for the axial loading.

Fig. 2: Friction welding setup

Fig. 3: Hydraulic system used for the loading

2.3 Test specimen

The test specimens are prepared from Aluminium Al 6061 rod of diameter 20mm. It is cut into 20 pieces of 150mm length in lathe machine. The end surfaces were smoothened. The tapered and convex interfaces were prepared in lathe machine. The taper angle considered is 30° . The radius of the convex surface considered is 10mm. A flatness of 2mm diameter was provided at the tip of specimen with tapered and convex interface geometry. This was provided for initial setting such as alignment to the interfaces for friction welding. Samples of various specimen prepared for friction welding process are given in Fig 4 to 6.

Fig.4: FSW Specimen (F-F)

Fig.5: FSW Specimen (T-T)

Fig.6: FSW Specimen (CX-CX)

2.4 Friction welding Process

Six numbers of friction welded joint from each combination have been made using the friction welding set up. The rotation speed was kept at 775rpm. The welding pressure was kept in the range $0.7\text{--}1.73 \text{ N/mm}^2$ also the forging pressure was kept in the range $1.73\text{--}2.76 \text{ N/mm}^2$. These parameters were fixed based on the weld trials made.

2.5 Hardness and Torsion Tests

A 50 mm portion of specimen of different interface geometries with weld joint as centre is taken for hardness test. Each specimen was then cut through longitudinally using milling machine. Flatness provided to the curved surface so that it can be suitably placed on apparatus table while testing. The hardness test was conducted in brinell hardness testing machine. The impinge has been made on the welded joint using 500 Kg of load, 10mm ball, 15sec. The impinge diameter dimension has been measured using microscope. samples of hardness test specimen are shown in Fig. 7 below. The testing procedure (as per IS 1500-2005 test procedure) for each specimen took around 15-20 minutes. FW

Specimens obtained with different interface geometries (F-F, T-T and CX-CX), with weld joint as centre, have subjected to torsion test. Modulus of rigidity for the specimens have been calculated for 5° and 10° angles of twist.

Fig. 7: Test samples for hardness test

Fig.8: Test samples for Torsion test

III. RESULT AND DISCUSSION –MECHANICAL TESTS

Various test results obtained from Hardness and Torsion tests for the friction welded joints formed with various interface geometries are discussed in following sessions.

3.1 Hardness

The brinell hardness number obtained for various friction welded joints with different interface geometries (F-F, T-T, CX-CX) has been presented in Table 2. A comparison of the result obtained with parent metal is indicated as a histogram shown Fig. 9. The results obtained were comparable to that of parent material. It can be observed that friction welded joint obtained using Taper-Taper interface geometry showed improved hardness value than other combinations. This may be due the adequate taper angle for the one to one material transfer and gradual development of thermoplastic stage and its setting by uniform cooling from weld region to other zones, by the friction welding, compared to others. The next highest result was found for Flat-Flat combinations.

Table 2. Hardness test result (BHN)

Various combinations	BHN
Parent metal	25.92
FW joint (Flat-Flat)	21.82
FW joint (Taper-Taper)	26.6
FW joint (Convex-Convex)	19.85

Fig.9: Comparison of Hardness test values (BHN)

3.2 Torsion Test

The modulus of rigidity obtained for weld specimen with various interface geometry has been given in Table 3. From the Table it can be seen that friction welded joints formed with Taper-Taper interfaces showed two times the value compared to the parent metal. The reason for the same may be as explained above.

Table 3: Torsion test result for various combinations of FW joints

Various combinations	Parent metal	(F-F)	(T-T)	(CX-CX)
Mod. of rigidity (x 10 ⁴ N/mm ²)	1.67	1.68	2.40	1.75

IV. MICRO HARDNESS TEST

Sample preparation starts by cutting of centre portion of 5mm length including the weld as centre from the FW specimens in lathe. These are machined so as to obtain cross section of the weld region through milling. This was the major time consuming process initially. Flatness has been provided to the curved surface so that it can be suitably placed for observation and this surface is made parallel to the surface to examine. All the sharp edges are chamfered for safety

during polishing process. Surfaces of the samples to be examined are polished using emery paper of grade 320, 600, 1000 and 1500. Each polishing process took 20 minutes. The emery paper with grade 1500 was attached to disk polishing machine. Machine polishing was carried out in Ecomet twin variable speed grinder-polisher. Selvate cloth is used in disc for polishing. The disc is then rotated at 250rpm throughout the polishing process. First polishing was done using alumina polishing suspension of 0.05μ and specimens were polished for 20 minutes each. Final polishing is done using Diamond suspension paste (1μ) as lapping cement and kerosene as Lubricant. Polishing takes around 1 hour for each specimen. The specimens were then washed with mineral water and dried. Etching of the specimen has been carried out using HF solution (10% HF, 90% distilled water) for 30 seconds. Specimens (see Fig. 10) were dried again after etching. In the case of specimen prepared from Convex-Convex combination, the etching solution was prepared by mixing hydrofluoric acid (1%), HCL (1.5%), HNO_3 (2.5%) and distilled water (95%).

Fig. 10: Microstructure test specimen of various combinations (F-F, T-T and CX-CX)

V. RESULTS FROM MICROSTRUCTURE STUDIES

Microstructure photograph of weld regions in each combinations have been taken. Region above and below the weld centre have been considered. All the photographs (see Fig.) have been taken in $200\mu\text{X}$. Photographs presented in the first column represents the weld region for the combination Flat-Flat. Too much dark regions with thick dispersion of finer particles indicate the region where strong bonding has been occurred. Compared to the central region such regions are seen towards the outer region. This may be the reason for its higher rigidity modulus and less hardness compared to the parent metal.

Fig.11: Microstructure photograph at friction weld region of each combination

Second column indicates the photographs for the Taper-Taper combination. All the regions are found almost alike. This is the indication of the transfer of materials in both sides equally due to friction welding. Taper-Taper geometry may be helped more for the uniform heat development due to friction there by the loosening of particles one by one and its equal transfer in both regions and the uniform setting after the plastic deformation. This property may be

attributed to the higher hardness, higher rigidity modulus compared to other combinations. The values are also found comparable with the parent metal.

Third column represents the photograph for the combination Convex-Convex. Here also at the centre, denser particles are seen dispersed somewhat equally. At the outer region also symmetric dispersion of particles are visible, but not much denser. This may be the reason for the less hardness and higher rigidity modulus compared to the Flat-Flat combinations.

In all the above said cases minute cracks are visible toward the outer region. Even though such cracks are present the hardness and torsion characteristics for all the combinations are comparable with the parent metal. If such cracks are avoided the performance of welded joints can be improved much. In a sense, it can be inferred that variation in interface geometry can influence much in the mechanical and metallurgical characteristics of friction welded joints.

VI. CONCLUSIONS

The friction welding process has been found very suitable and comfortable for joining aluminium rods. Brinell hardness value was found high (26.6) for friction welded joint formed with Taper-Taper interface geometry. The next was found for Flat-Flat combination.

In the case of Torsion test all the joints showed improvement than the parent specimen. For the parent metal it was $1.67 \times 10^4 \text{ N/mm}^2$. But for all the welded joints formed with various interfaces like Taper-Taper, Convex-Convex and Flat-Flat it was $2.40 \times 10^4 \text{ N/mm}^2$, $1.75 \times 10^4 \text{ N/mm}^2$ and $1.68 \times 10^4 \text{ N/mm}^2$ respectively. This indicates that interface geometry can strongly influence on the torsion characteristics friction welded joints. It can also be inferred that Taper-Taper geometry can contribute much in this aspects.

From the microstructure studies it is clear that by making use of interface geometry other than Flat-Flat strong bonding of joints can be achieved towards the centre of the joining faces. This will attribute for the better mechanical characteristics.

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