

# ***Mechanical and Physical Characteristics of Friction Welded Al 6061 Rod with various Tapered interface geometry***

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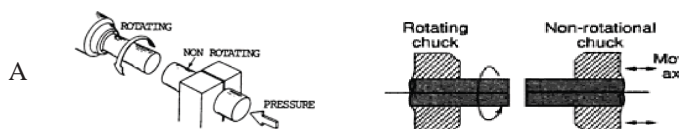
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*Abstract— Friction welding is a solid state joining process that produces coalescence in materials, using the heat developed between surfaces through a combination of mechanical induced rubbing motion and applied load. In rotary friction welding technique 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 interface geometry, especially tapered interface geometry has strong influence on the mechanical and microstructure characteristics of friction welded joints. In the present work, steps were made to modify a conventional lathe to rotary friction welding set up to obtain friction welded joints with various tapered interface geometries. The various interface tapered angles considered here are 15°, 30°, 45° and 60°. In order to compare the properties of the same with friction welded joints formed with pure flat interface geometry, 0° has also been considered as one of the tapered angles. The speed for the rotating specimen here is 775 rpm . The welding pressure was kept in the range 0.7-1.73 N/mm<sup>2</sup>. The forging pressure was kept in the range 1.73-2.76 N/mm<sup>2</sup>. The welded joints obtained with various tapered interface geometry have subjected to hardness, torsion, Impact and Micro hardness tests. It is seen that friction welded joint obtained using 45° tapered interface geometry showed improved hardness value followed by that obtained with 30° taper angle. In the case of torsion characteristics joints with 30° taper found to have better result. Joints obtained with 60° tapered angle showed double the value for impact characteristic compared to that obtained with flat interface geometry. Microhardness values were also found high for friction welded joints with 60° tapered angle. In all the cases it is seen that values are higher than that obtained with flat interface geometry. From the study it is inferred that adequate taper angle can influence much on the Mechanical and Physical characteristics of friction welded joints.*

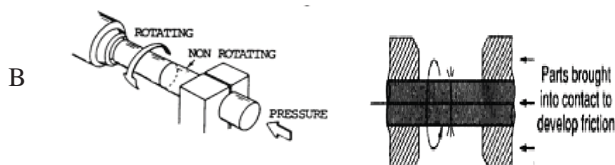
**Keywords—Friction welding, Mechanical and Microhardness Tests tests.**

## I. INTRODUCTION

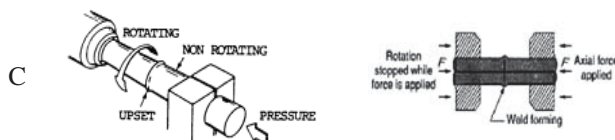
Friction welding (FW) is a complicated process, which involves interaction of thermal, mechanical and metallurgical phenomenon. Friction welding comes under the category of solid welding process in which the heat for welding process at the interface is generated through mechanical friction between the 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]. A modern car made of Aluminium components can be 24 percent lighter than one with components made of steel, which also allows fuel consumption to be reduced by 2 litres per 100 kms. In automobile industry rotary friction welding process is the most commonly used of the processes to assemble many carbon steel vehicle axles and sub-axles. The process is also used to fabricate suspension rods, steering columns, gear box forks and drive shafts, as well as engine valves. The working procedure of RFW process is as shown in Fig 1. In this process, one of the components is 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.



Stationary specimen held in non-rotating chuck is moved axially and is brought into contact with the rotating specimen.



Heat is generated at the contact interface due to friction.



When metal in the joint zone reaches plastic state due to high temperature and heat generation, because of friction, rotation is stopped and axial pressure is increased instantly.



Rotary friction welded joint is formed.

Fig. 1. Working procedure-rotary friction welding

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 Balasubramaniyan [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 studies the influence of interface geometries of fw joints by alumina-Al 6061 Alloy. They 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. Recently Sreejith, Baiju Sasidharan and Narayanan [8 ] have found that friction welded joint from Aluminium alloy 6061 with 30° interface taper angle have good tensile properties. Present study is an extension to that to establish the same for other characteristics like hardness, torsion , Impact toughness and micro hardness characteristics.

## II. EXPERIMENTS-MECHANICAL CHARACTERESTICS

Experiment involved mainly the formation of friction welded joints from Al 6061 alloys with various interface taper angles. The interface taper angle considered here from 0° to 60°. The joints obtained were then subjected to physical characteristic study hardness. It was then subjected to mechanical caracterestic studies like torsion and charpy impact tests. In order to study the characteristic in micro level microhardness test were also conducted.

### A. 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
(WT%)	96	2.1	0.95	0.04	0.33	0.17
Component	Cr	Ti	Zn	Ni	Ca	Bal
(WT%)	0.066	0.022	0.014	0.014	0.013	<0.01

### B. 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. The range of load it can measure is from 1 to 20 KN. 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. Fig. 2 shows the setup used.



Fig. 2: Friction welding setup

**C. 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 smoothed. The tapered interfaces were prepared in lathe machine. The taper angles considered are 15°, 30°, 45° and 60°. A flatness of 2mm diameter was provided at the tip of each tapered specimen before joining. This was provided for initial setting such as alignment to the interfaces for friction welding. A schematic representation of the specimen is given in Fig. 3.

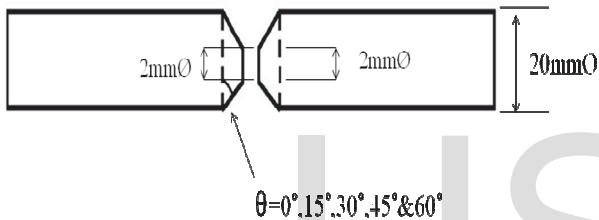


Fig. 3. Geometric details of test specimen

**D. Experimental work**

The 20 specimens with 5 different interface geometries (see Fig. 4) have been welded using friction setup ( Same geometries were welded together). The rotation speed was kept at 775rpm. The welding pressure was kept in the range 0.7-1.73 N/mm<sup>2</sup> also the forging pressure was kept in the range 1.73-2.76 N/mm<sup>2</sup>. These parameters were found experimentally on the friction welding setup used.

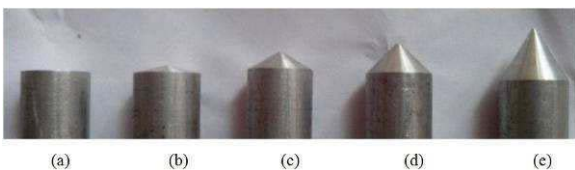


Fig. 4. Different interfaces considered, (a) 0° taper, (b) 15° taper, (c) 30° taper, (d) 45° taper, (e) 60° taper.

Three joints from each combination have been made for each mechanical characteristic studies.

**D. Hardness Test**

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. The samples tested are shown in Fig. 5 below. The testing procedure (as per IS 1500-2005 test procedure) for each specimen took around 15-20 minutes for each specimen.



Fig. 5. Samples from FW joints subjected to hardness test

**E. Torsion Test**

Specimens of different tapered interface geometries with weld joint as centre is taken for torsion test. Modulus of rigidity specimens are calculated for 5°, 10° angles of twist.

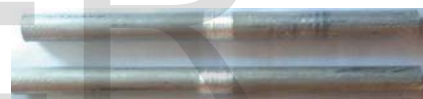


Fig. 6 Friction-welded specimen for torsion testing

**F. Impact Test**

Toughness of the welded joints was found using Charpy impact test. A 55 mm portion of specimen of different interface geometries with weld joint as centre is prepared initially for toughness test, using lathe. Then the specimens (see Fig.7) were machined to a cuboid shape of dimension 55mm x10mm x10mm through milling. A V-notch of 2mm depth is provided through the weld area along one of the faces in all specimens. The dimensions have been taken according to material testing standard prescribed in IS 1499-1997 test procedure.

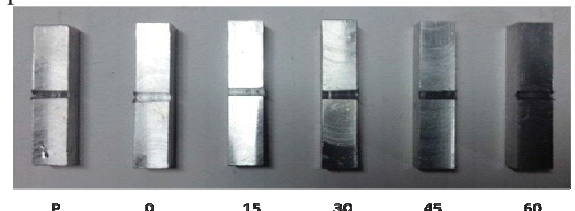


Fig. 7 Impact test specimen from various friction welded joint

### III. RESULT AND DISCUSSION –MECHANICAL TESTS

Various test results obtained from Mechanical characteristic studies are discussed in following sessions

#### A. Hardness

The Brinell hardness number obtained for various friction welded joints with different interface taper angles has been indicated in the histogram shown Fig. 8. The results obtained were comparable to that of parent material. It can be observed that friction welded joint obtained using 45° taper interface geometry showed improved hardness value followed by that obtained using 30° taper interface geometry. It is also noted that hardness value of joint obtained using 45 deg interface showed improved value than the parent itself. This may be due to 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. It is also noted that those obtained using tapered showed comparable values with parent material

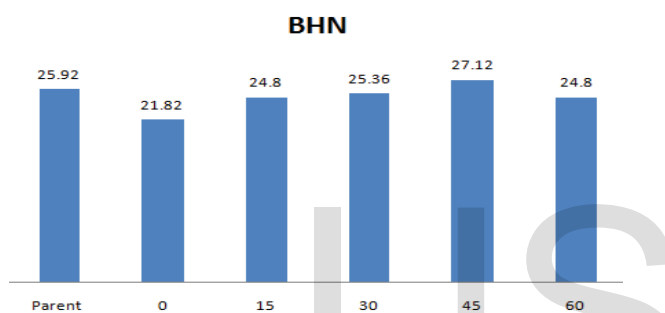


Fig. 8. BHN for the parent metal and FW joints tested

#### B. Torsion Test

The modulus of rigidity obtained for various specimen have been indicated in Fig. 9. From the figure it can be seen that friction welded joints formed with tapered interfaces showed improved torsional properties than the parent metal or that formed with flat interfaces. It is also noted that friction welded joints obtained using 30° tapered interface geometry possessed high modulus of rigidity than others.

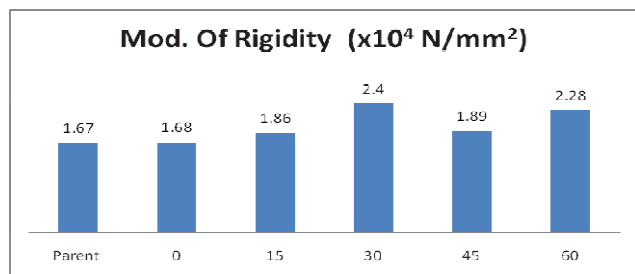


Fig. 9 Graphical representation – Modulus of rigidity

#### C. Impact Test

The standard specimen preparation for this test was the toughest when compared with other mechanical tests. High precision milling operation was carried out to prepare the impact test specimen

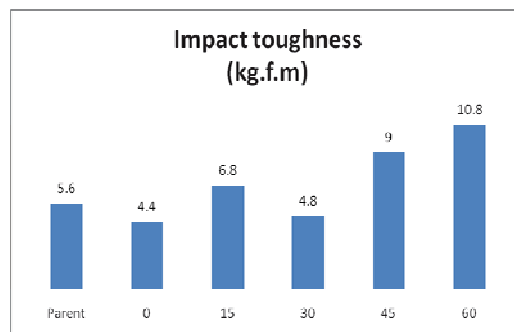


Fig. 10 Graphical representation -Charpy impact toughness.

The toughness value of 60 deg showed much improvement when compared with other joints. It is also noted that the impact toughness value is less for the friction welded joints obtained with lower taper angles. However we can understand that adequate taper angle can improve the impact toughness characteristics of friction welded joints similar to other mechanical characteristics.

### IV. MICRO HARDNESS TEST

Sample preparation starts by cutting of centre portion of 5mm length including the weld as centre from the friction-welded 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 is 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. One interesting fact noted that after the polishing operation it was quite difficult to identify easily, which surface is of welded region. This could only be identified after carrying out the etching process. Etching of the specimen has been carried out using HF solution (10% HF, 90%

distilled water) for 30 seconds. Specimens (see Fig. 11) were dried again after etching.



Fig. 11. Specimens after etching

The white portion seen at the middle portion of the samples prepared for micro hardness studies after etching is the weld zone. The micro hardness test was conducted using micro indentation hardness tester. The impinges (see Fig.12) were made on the specimen by a loading of 0.05 kgf.



Fig. 12 Indentations made on the fw joint during Vickers hardness test

The load is applied for 15sec at weld zone, HAZ and the parent metal region in all specimens. The diagonal lengths of impression made by the impinges were measured through microscope and the average values have been taken. The result obtained from the microhardness tests are discussed in the following sessions.

A. Results - Vickers Microhardness test

Vickers Microhardness test gives an additional information to the hardness property of material, in addition to the Brinell hardness test values. The results obtained from microhardness test at weldzone , heat affected zone and parent metal region of each specimen have given in Table 3. Specific comparison of the microhardness values at various region corresponding to respective welded joints formed with various interface angles have been presented as histograms shown in Fig 13 to 14 .

Table 3. vickers Microhardness test results for the fw joints

Sl no	Interface taper angle	Parent metal region	Weld zone	HAZ
1	0°	89.2	81	87.8
2	15°	82	80.8	83.3
3	30°	89.4	84.4	82
4	45°	88.9	86	87.5
5	60°	85.2	87.9	89.7

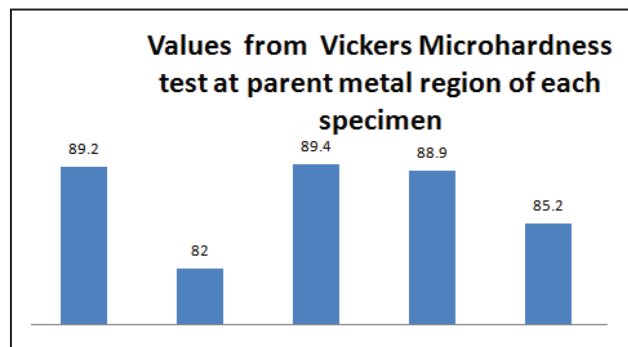


Fig. 13. Microhardness at parent metal region of each specimen

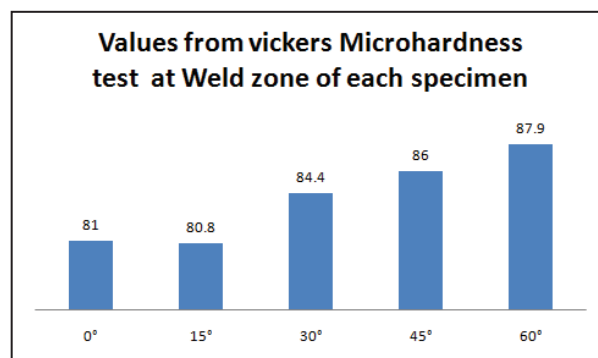


Fig. 14. Microhardness at weld zone of each specimen

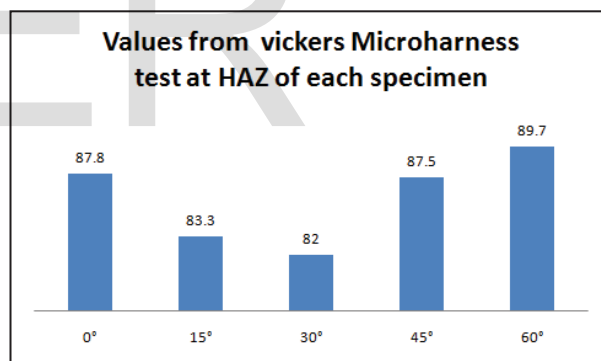


Fig. 14. Microhardness at HAZ of each specimen

The average microhardness values at parent metal region for all specimen range from 80 to 90. This indicates that friction welding process do not affect the basic properties of parent metal unlike the welded joints formed with conventional welding techniques due to high heat transfer.

From the microhardness distribution at the weld zone of various specimen it is seen that the value ranges from 80 to 88. It is also seen that the Vickers microhardness value increases with the increase in interface taper angle except for 15°. The value was found maximum corresponding to welded joints

formed with interface taper angle of  $60^\circ$ . It may be due to the appropriate material transfer with the development of temperature by friction to form strong welded joints. It may also attributed to the higher value of high Torsion and Impact toughness characteristics.

From the histogram showing the microhardness distribution at HAZ of welded joints formed with various interface angles (see Fig. 14), it is seen that the values are higher except for the specimen formed with interface angle  $15^\circ$  and  $30^\circ$ . It is also seen that the highest value is for the specimen formed with taper angle of  $60^\circ$  similar to the result found in the case of weld zone. The same has been comparable with the result obtained for BHN values.

## V. CONCLUSIONS

The major conclusions made from this studies are as follows

The friction welding process has been found very suitable and comfortable for joining aluminium rods.

Brinell hardness value was found high (27.12) for friction welded joint formed with interface taper angle of  $45^\circ$ . In the case of joints formed with  $30^\circ$  and  $60^\circ$  interface taper angle it was found near to 25.

In the case of Torsion test all the joints showed improvement than the parent specimen. For the parent metal it was 1.67. But for all the welded joints formed with various interface taper angle the values were found very high. Exceptionally higher values found in the case of friction welded joint formed with interface taper angles  $30^\circ$  and  $60^\circ$ .

Impact toughness value was also found better for friction welded joint formed with interface taper angle of  $60^\circ$ . From  $30^\circ$  degree onwards the value was found increasing with the interface taper angle.

The vickers micromicrohardness distribution at various zone of friction welded joints formed with various interface angle showed that the value was found increases with increase in interface taper angle. In addition it is seen that the value was higher in the case of joints formed with  $60^\circ$  interface taper angle. (87.9 at weld zone and 89.7 at HAZ). No much variation for the micro hardness value will be resulted for the parent metal region of all the specimen.

Thus from the present study it can be seen that proper interface taper angle for the specimen prepared for the friction

welding process can strongly influence the the physical, mechanical characteristics of friction welded joints. It is also concluded that to obtain good results the interface taper angle should ranges between  $30^\circ$  to  $60^\circ$ . However the best value of interface taper angle is  $60^\circ$ , if the joint is not subjected to tensile loads [8].

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