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Comparative Study of FSW Strength Versus Plate Overlap

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***Abstract* - In this paper, the mechanical properties of welded joints of AA6063 aluminium alloy obtained using friction stir welding (FSW).Lap joints of commercially pure aluminium plates on the top, and bottom side were conducted by friction stir welding using various travelling and rotation speeds of the tool to investigate the effects of the welding parameters on the joint characteristics and strength. Lap joints were obtained in the welding travelling speed range of 40 mm/min, and rotational speed range of 1200 rpm. In the present work, commercial grade AA6063 series aluminium alloys of thickness 10 mm have been welded together in both butt and lap fashion. Tests have been conducted to measure the joint's tensile strength, yieldstrength and Percentage Elongation. The use of lap welds in application areas of FSW was established.**

Keywords - Tool rotational speed, Friction Stir welding, butt and lap fashion, tensile strength.

1. INTRODUCTION

In the year 1991, The Welding Institute (TWI) invented a new technology of joining materials using the frictional heat. Therein, the heat is generated using a rotating tool that aids in joining unlike the rotating shafts that are themselves joined in friction welding. For reducing the weight of automobiles the use of lightweight material is most effective. The tool rotation and weld direction are similar on one side called as Advancing Side (AS) and opposite on the other called as Retreating Side (RS).

The solid-state nature of FSW process avoids problems of hot cracking, porosity, element loss, etc., which are common to aluminium fusion welding processes (Mishra and Ma. [1]).

He et al. [2], Hui et al. [3], and Imam et al. [4] reported that hardness in FSW of 6061-T6 and 6063-T4 aluminium alloys tends to be lower in the heat affected zone on the retreating side, which then becomes the location of tensile fracture for transverse weld specimen. Ren et al. [5] reported that tensile strength increases with increasing welding speed in friction stir welding of 6061-T6 aluminium alloys. Lim et al. [6] showed that microhard-ness distribution in weld cross-section changes with welding speed and tool rotational speed in 6061-T6 aluminium alloy. They also reported that strength and ductility decrease with decreasing welding speed and increasing tool rotational speed. Sato et al. [7] and Heinz et al. [8] reported that, in 6063-T5 and 6061-T6 aluminium alloys, hardness distribution across weld cross-sections depends on grain size distribution and state of precipitates. They also reported that coarsening/dissolution of strengthening precipitates in weld zones for these alloys are sensitive to welding thermal cycles they experience. Recently, Imam et al. [9] reported that peak temperatures in weld regions could be used as one of the monitoring parameters to evaluate friction stir weld joints properties, particularly in heat treatable alloys.
Rajakumar et al. [10] showed that lower weld zone temperatures in FSW can result in weld defects such as voids, worm holes, cracks, etc., in butt welds. Additionally, as observed by Yadava et al. [11], cold lap and hook defects can occur in lap welds at lower weld temperatures. Thus, one needs to find ways of maintaining required weld zone temperatures to avoid cold weld defects. This work aims to shed light on this aspect through investigation of microstructure and mechanical properties of butt and lap welds of 6063-T4 AA.

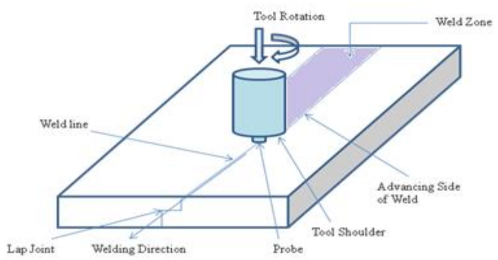

Fig 1: FSW Process

Joint configurations for FSW include square butt, edge butt, T-butt, lap, multiple lap, T-lap, etc. In the application areas of the FSW, both the butt as well as lap joints can be used. Research works done in joining of 10mm thickness plates have mainly focused on the butt joint and Lap joint configurations. However, lap joints can also be used as a replacement of fasteners and specifically at places where modifications in the current parts are not necessary. Plates of different thickness can also be easily friction stir welded when in lap joint configuration.
Tool rotation speed and tool transverse speed are two important process parameters that govern the quality of the weld done. Vijayan *et al.* [12]using multi-objective optimization and analysis of variance showed that the tool rotational speed is the highly significant factor. The alloy used was AA 6063 and in 'butt' joint configuration. Laxminarayanan *et al.* [13]

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Peel *et al.* [14] and Hirata *et al.* [15] showed that there is an optimum value of FSW process parameters for which the weld quality is the best. At other combination of these parameters the resulting weld is poor. The analysis in the present work has been done using those process parameters that gave good quality of the weld.

Limited work has been done in joining of 10mm thickness plates by FSW. In this mechanical analysis of thick FSW and joined similar materials. FSW was used for producing only 'butt' welds on 10 mm thick sheets of AA 6063 materials. The results showed t hat the joints had excellent mechanical properties; and the tensile failure occurring in the welded zone was because of irregularities in the thickness rather than by any defect. Nishihara *et al.* [16] had studied the feasibility of µFSW and there the material used was AZ31 magnesium alloy. Sattari *et al.* [17] welded sheets of AA5083 0.8 mm thick in 'butt' joint configuration and studied its mechanical properties as well as the temperature distribution during welding. It was concluded that with higher speed the resulting weld was having microscopic defects and welds obtained between 430°C to 510° C were defect free. Scialpi *et al.* [18]again welding 0.8 mm thick alloys of 2024-T3 and 6082-T6 concluded the formation of two distinct stirred zones, one for each alloy.

The study of lap joints in FSW is still an open area of research. For applications as in joining of lid on an air tight (hermetically) sealed package which is a common requirement of high reliability electronics, both 'butt' and 'lap' weld geometries can be used to join materials having similar or dissimilar cross sections. Buffa *et al.* [19]investigated the influence of process parameters on the metallurgical and mechanical properties of friction stir welded lap joints of AA2198-T4 aluminium alloy. It was shown that to produce effective FSW lap joint the nugget area should be kept as wide as possible considering a the same time the nugget integrity. Salari *et al.* [20]studied the influence of tool geometry on the structural and mechanical properties of the lap joint of 5456 aluminium alloy and the result indicated that the stepped conical thread pin improved the joint's integrity and mechanical properties by improving the material flow during FSW. The mounting of specimens for lap joint configuration was also taken care of. Elangovan *et al.* [21] investigated the effect of pin profile on the friction stir processed zone formation in AA2219 aluminium alloy. Straight cylindrical, tapered cylindrical, threaded cylindrical, triangular and square were the five profiles that were used to fabricate the joints at three different rotational speeds. It was found that the square tool pin profile produces mechanically sound and metallurgical defect free welds as compared to other tool pin profiles. Fujii *et al.* [22] studied the effect of tool shape on mechanical properties and microstructures of welded aluminium plates. Based on the results, an optimal tool shape was suggested for high melting temperature metals such as steels. Parida *et al.* [23] surveyed that complicate d tool profile wears out after a few number of runs spe cially while working with higher tensile strength mater ials. In the present work the study was made using simple tool geometry – a straight cylindrical pin profile.

2 EXPERIMENTAL PROCEDURES

Commercial grade aluminium alloys of thickness 10 mm were joined using HSS as rotating tool. The composition of the aluminium alloy and the tool is as shown in Table 1, Table 2 and Table 3 respectively. The rotating tool was plunged into and traversed perpendicular to the base plates. To begin with, samples were prepared with certain feeds and rotations and the best samples (according to visual inspection) were recorded at some particular parameters. Tests were conducted on samples prepared at these parameters only which are shown in Table 6.

Table 1 Chemical Composition of Al alloy

Element	AA6063	
	Standard	Experimental
Mn	0.0-0.1	0.04
Fe	0.0-0.35	0.2
Mg	0.45-0.90	0.60
Si	0.20-0.60	0.30
Zn	0.0-0.10	0.06
Ti	0.0-0.10	0.03
Cr	0.0-0.10	0.05
Cu	0.0-0.10	0.08
Al	Remaining	Remaining

Table 2 Mechanical Properties

Proof Stress	160Mpa
Tensile Strength	195Mpa
Elongation	14%
Shear Strength	150Mpa
Hardness Vickers	80HV

Table 3 Physical Properties

Density	2.70Kg/m^3
Melting Point	600ºC
Thermal Expansion	23.5x10^{-6} /K
Modulus of Elasticity	69.5GPa
Thermal Conductivity	200W/m.K
Electrical Resistivity	0.035x10^{-6} Ω.m

Table 5 Composition of HSS tool

Element	C	Cr	Mo	V	W	CO
% Weight	0.8	4	0.6	1.5	18	4.6

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Table 6 Process parameters used in FSW joints

Si.No	Rotational speed (rpm)	Weld Speed (mm/min)	Heating Time (sec)	width in (mm)	Plunge Depth (mm)
1	1200	40	30	0.0	6
2	1200	40	30	2.5	6
3	1200	40	30	5	6
4	1200	40	30	7.5	6
5	1200	40	30	10	6
6	1200	40	30	12.5	6
7	1200	40	30	15	6

2.1 Development of Tool

Friction stir welding require a sufficiently hard welding tool which can soften the material without itself being deformed. Similarly while making an approach to weld materials hardness play a vital role. The tool material used here was HSS. Development of the tool geometry having dimensions was achieved through turning on Lathe Machine. The operation was performed at 100 rpm spindle speed and a manual feed in millimetres. Fig. 2 shows the tool geometries that were used for welding 'butt' and 'lap' configurations and that were chosen as per the literature survey.

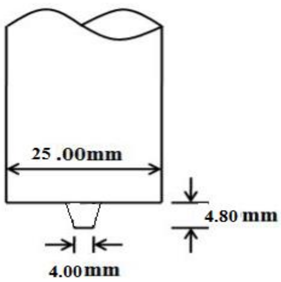

Fig. 2 Geometry of the HSS tool used for FSW

2.2 Development of Fixture

FSW require very high precision. The fixture plays a major role in this technique. The plate should be aligned very accurately without any deflection at the top surface. It has to be held very tightly so that by nullifying its movement during machining we get joints without defects. Also due to high heat conduction rate of aluminium, the high rate of loss in heat can make it very difficult to soften the sheets. So, the fixture must be made up of heat resistant material. The two work pieces to be welded, with square mating edges, are clamped on a rigid back plate. The fixture prevents the work pieces from spreading apart or lifting during welding process. The fixture consisted of two major components- one was backing plates and the other was top clamps. Fig.3 is FSW machine and Fig.4 shows the corresponding FSW experimental setup. The backing plate used was of heat resistant material Bakelite.

Fig.3 FSW Machine

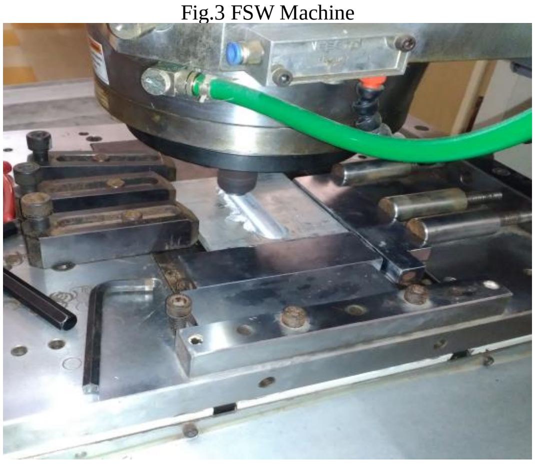

Fig. 4 FSW experimental set up

2.3 Welding Operation

The aluminium sheets were cut as per the required dimensions on wire-EDM. The welding operation was performed using the FSW machine. The rotating tool was mounted on the spindle using a suitable collet. The plates to be joined were clamped onto the Bed in such a way that any movement of the plates could be avoided during welding. With the help of contact probe the tool pin was made to touch the plates at the weld line and the co-ordinates were set to zero at that point. Next, the G-code, where the rotational speed, plunge depth, transverse speed and weld length were set before hand, was executed for performing the welding operation. While performing lap welding it was taken care that the advancing side of the probe was located near the top plate edge. Fig. 5 & 6 shows some of the weld specimens on FSW.

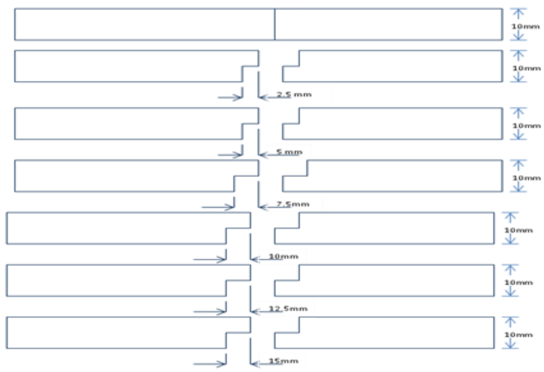

Fig. 5 Dimensions at the specimen joints

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Fig. 6 Weld specimens on FSW Machine

3 RESULTS AND DISCUSSION

The results of longitudinal tension test, for 'butt' and 'lap' joint configurations are described in subsequent sub-sections.

3.1 Tensile test

The transverse tension test, where the applied load is orthogonal to the weld direction investigates the joint's efficiency by studying its mechanical behaviour. The longitudinal tension test, where the applied load is along the direction of the weld, is used to study the mechanical behaviour of the zone subjected to stirring. The results of these tests obtained w ere compared to with that of the base material. Tab le 4 gives some mechanical properties of the Al-alloy w e have used.

Table 4 Mechanical properties of Al alloy

Yield tensile strength (MPa)	90
Ultimate tensile strength (MPa)	110
% Elongation	8

To ensure the accuracy of the measurement, the tests were conducted on three welded samples. First, the welded samples of specific weld length were produced using this technology and then these were cut using wire-EDM as per the specifications of the standard test method for tension testing, ASTM-E8 as shown in Fig. 5.

Fig.7 Tensile Specimens from Welding Piece

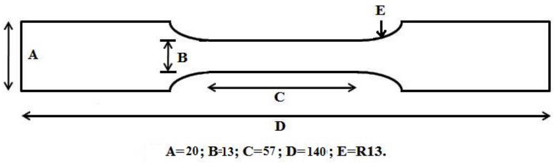

Fig.8 Dimensions of Tensile Specimens

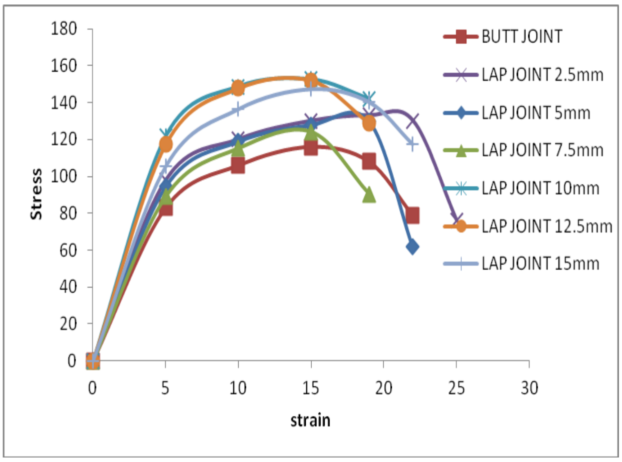

Fig.9 Stress -strain curve for tension test

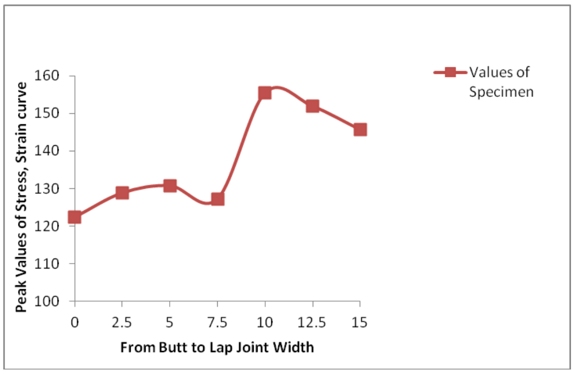

Fig.10 Optimum values of Stress, Strain Curve

The tensile tests were performed on UTM machine. Fig. 6 shows the engineering stress-strain curve of the base metal, butt weld and lap weld in transverse tension test. And Fig. 8 shows the engineering stress-strain curve of the tension test. Through the plots it can be seen that the lap welds are having better tensile properties than butt welds in transverse tension tests. Failure of the lap joint in transverse tension was observed to be in the thinner upper weld instead of at the nugget between the plates.

4 CONCLUSIONS

In this work, using FSW, 10 mm thick aluminium alloys have been successfully welded in both 'butt' and 'lap' joint configurations and following conclusions were drawn.

- In application areas where possibility of butt as well as lap configuration of joints is available, joining the materials in lap fashion would produce better joint strength.

- Thickness increase near and along the joint line when producing lap weld is a demerit in its application areas.
- It was seen that the more the material is available for stirring, the stronger is the joint.
- For materials having thickness in the range of 10 mm, it is better to opt for lap welding.

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