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Friction Stir Lap Welded Joints for Aluminum Alloys: An Evaluation

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Abstract: Frictions stir processing a solid-state technique for joining plates of ferrous and non-ferrous alloys. Present work, is based on the joining of Aluminium AA1100 sheets in lap position by friction stir lap processing. A comparative microstructural analysis of different stirred zone on joints produced by CNC milling machine with three effective process parameters tool shapes, tool rotational speed and tool feed is successfully carried out using Design of Experiments, L_{27}. Three different tool of taper, triangular and square shape, tool rotational speed of 1000, 1400 and 1800 rpm with tool feed rate at 35, 70 and 105 mm/min were considered as effective parameters for the experimental investigation. The tool plunge depth of 5 mm was maintained throughout the experimentation. It is observed that for triangular pin tool engaged at 1400-rpm rotational speed and 70 mm/min traverse speed resulted in moderate grain structure with fewer voids and more surface area. Very fine recrystallized grains were observed for all pin profiles at stirred zone.The effect of pin geometry on grain orientation in thermomechanically affected stir zone and grain strecture were analysed by SEM

Keywords: Friction Stir processing, lap joint, aluminium alloy AA1100, SEM, microstructure.

1. INTRODUCTION

Friction stir welding (FSW) is a method of solid-state joining developed in 1991 by The Welding Institute (TWI) of the UK, was initially started for joining aluminum alloys [1]. To increase the joint strength of 2000 and 7000 series aluminum and some other alloys were considered to be welded using traditional technique [2].Friction stir welding and laser beam welding are similar process and they have common characteristics of adhesive joining of materials. Those process are familiar in aeronautic and it could be used as an alternate process to conventionally used riveting which is used in air frame structures. In order to induce the frictional heat in the specimen a specially designed high-speed non-consumable tool is used in a friction stir process. Due to rotational tool local changes in the stair zone because of Mechanical deformation [3] and [4]. There were two essential conventional parts for the friction stir tool. First profiled pin, which is extended at the working face collinear to the axis of the tool, second a shoulder, is known as working surface of a tool, which is normal to the axis of the tool. During FSW, the work piece was fixed to the bed and tool is fixed with the tool holder. The tool starts to rotate at certain angular speed and pin is plunged in the work piece until the shoulder makes perfect contact with work piece. At this point along the joint line, the rotating tool is moved due to very close contact between the shoulder and work piece with forging force deforming the material in its transit, leaving the formed material behind weld. Friction stir process temperature is always less than the melting point of the material [5] and [6]. Many researchers have recently investigated process parameters that have a major impact for of lap joints quality developed with various Aluminum alloys, like as AA 2024[7], AA 5083[8], AA 7075[9]. Different thickness of sheets and different tool geometric were carried for aluminium alloy AA5456, for friction stir process lap joint with different rotational speed and welding speed it was founded that optimal lap joint properties were obtained [10] carried a friction stir lap welding for AA2041 were studied the microstructure of welding zone[11].

The formation of onion rings in friction stir welds of 6061 Al alloys was investigated by Krishnan et,al. by using different FSW parameters. [12] Were investigated on Microstructure and mechanical properties of zirconium-steel by friction stir lap welding. [13]. proposed the method of evaluation of deformation relief parameters of the surface damage during fatigue test of steel 17Mn1Si by digital image processing technique [14]. Predicted the tensile strength of friction stir joined aluminum AA1100 alloy by artificial neural network using experimental results obtained by experimenting at varying parameters and different levels. A review on joining of different metallic materials by friction stir joining was presented by [15] under different process parameters. Joining of dissimilar alloys AA1100 with steel and with copper and their mechanical strength were analyzed from literatures.

AA1100 alloy being the first in the aluminum series is a ductile alloy used for architectural and structural application that requires moderate strength and hardness. A lot of research work has been reported on the frcition stir welding of various aluminum alloys. However the AA1100 alloys has gained a limited attention among research communities despite having favorable properties such as high ductility, good weldability and thermal conductivity as comapred to other Al alloys. Moreover the literature on the friction stir lap joining for AA1100 alloy is scarce. Present work is focused on the effect various tool shapes and process parameters on the friction stir lap joint for Al AA1100 alloy.

2. EXPERIMENTATION DETAILS

This experimental research is focused on developing an experimental setup with suitable modification and incorporation of attachment on the CNC milling machine. The experimentation is done with various parameters, for example, tool rpm, welding speed, the shape of tool pin, and plunge depth during friction stir welding. The impact of these parameters on microstructure has been evaluated for joining two comparable AA-1100 aluminium alloys. The weld region's microstructure and heat affected zone are examined by a scanning electron microscope (SEM) study. The scanning electron microscope has reviewed grain structure. The effects of rotational speed, translational speed, and position within the processed area on hardness are presented.

In this experiment, AA-1100-grade Aluminium alloy of 200x125x3mm plates is chosen for experimention because of their huge applications in heat exchangers, light reflectors, fan blades, and food containers. The most widely used aluminium amalgam for welded joints are toughened (O) 1100, Heat-treated AA-1100, and heat-treated aged AA-1100 H4 are the few examples. AA-1100 is a solidified precipitate alloy with primary alloying material of Magnesium and silicon. Their walkability and mechanical properties are the major factors for using AA-1100 in the joining process. The chemical composition of AA-1100 was found using an XRF spectrometer at Centurion University, Odisha, India is given below.

The measured value of AA-1100 element weight percentage are (Si 0.153, Fe 0.593, Cu 0.154, Mn 0.006,Zn 0.006, Ni 0.0016, Cr 0.0019, Ti 0.003, Al rem). The most flexible of the warm treatable aluminium alloys while keeping the vast majority of aluminium's great characteristics. This evaluation has an extraordinary scope of mechanical properties and corrosion resistance. It tends to be manufactured by the vast majority of the regularly utilized systems. It has great functionality in the toughened condition.

Aluminium alloy plate has been cut by cutting machine with dimensions of 200×125×3mm, and then cleaned by a metal polishing brush to remove oxide. The FSLW joints of the different Al-alloys were ready to create a longitudinal lap joint arrangement perpendicular to the rolling direction. Friction stir welding tools were designed in CATIA and manufactured by CNC lathe and milling machine from H13 tool steel. Three tools with different shapes, taper, triangle, and square with varying lengths of the pin, as shown in figure 1, were manufactured for joining aluminium plates by friction stir process.

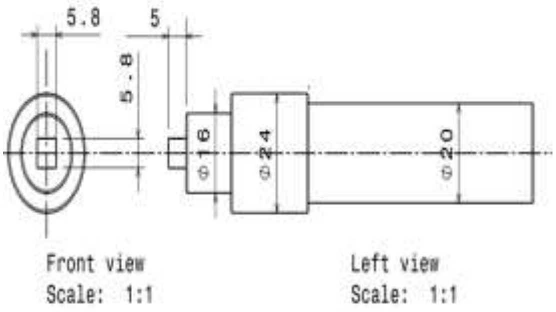

Fig .1(a) Square pin profile

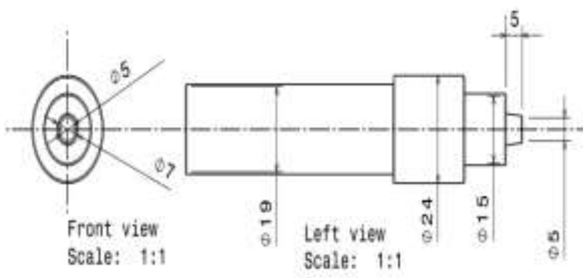

Fig. 1(b) Tapper pin profile

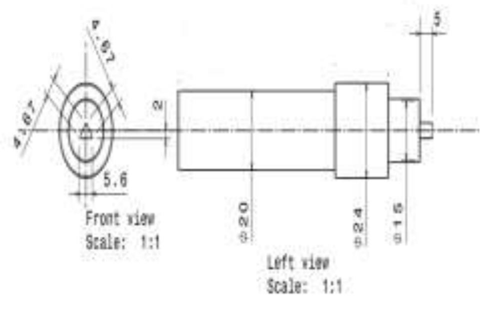

Fig. 1(c) Triangle pin profile

Fig. 1(d) Tool shapes post machining

The detailed setup for the friction stir welding process used to make lap joints for similar aluminium alloys is shown in fig 2. Vertical CNC milling machine of Chandra make with Fanuc controller having bed traverse: 800mm*350mm, accuracy 10 microns with proper fixtures is used to fix the AA1100 plates to avoid vibrations and displacement during the welding process. For determining the suitable process parameter set in order to obtain the defect free joint with suitable grain structure specimen, a set of 27 experiments were designed by Design of Experiments using three effective parameters with three levels. The process parameters are three different tool shapes taper, triangular, and square, tool rotational speed 1000, 1400 and 1800 rpm with tool feed rate of 35, 70 and 105 mm/min. All the process parameters with their levels are presented below in table 1.

Table 1. Different process parameters and their level

Sl.No.	Tool shape	Tool speed rpm	Tool feed rate
1	Taper	1000	35
2	Triangular	1400	70
3	Square	1800	105

Similarly the 27 experimentation designed with Design of Experiments (DOE) is presented in table 2.

Table 2. Experiments designed by Design of Experiments

Expt. No	Spindle rotation in rpm (A)	Feed rate in mm/min (B)	Pin geometry (C)
1	1000	35	Taper
2	1000	35	Triangular
3	1000	35	square
4	1000	70	Taper
5	1000	70	Triangular
6	1000	70	square
7	1000	105	Taper
8	1000	105	Triangular
9	1000	105	square
10	1400	35	Taper
11	1400	35	Triangular
12	1400	35	square
13	1400	70	Taper
14	1400	70	Triangular
15	1400	70	square
16	1400	105	Taper
17	1400	105	Triangular
18	1400	105	square
19	1800	35	Taper
20	1800	35	Triangular
21	1800	35	square
22	1800	70	Taper
23	1800	70	Triangular
24	1800	70	square
25	1800	105	Taper
26	1800	105	Triangular
27	1800	105	square

Fig. 2 CNC milling with friction stir welding setup

The aluminium alloy specimens AA1100 is prepared and put overlap 20mm distance and attached by the help of fixture on the CNC milling machine bed by stirring and welding, plunging steps. The welding specimens are as shown in the Fig. 3 before and after welding

Fig.3 (a) Before joining **Fig.3(b)** After joining

Fig.3 (c) After joining of aluminium plates

Among the 27 number of experiments, the specimens with lesser defects and good mechnanical strength were analysed for their microstructure studies. Parameters with set of combination in experimentation number 1, 14 and 27 were studied for their surface morphology. For microstructural examination the weld zone surfaces are polished the with emery papers of 600,800 and 1000 grades. Later these are mirror polished with diamond paste (0.5micron grain size) using a special polishing cloth. Post polishing, it was etched with Keller's reagent followed by water cleaning and later dried. The microstructure of the sample cross-section surface was observed by using SEM.

3. RESULTS AND DISCUSSION

The joint processed with triangular tool as per process parameters combination in 14th set of the design of experimentation exhibited fine grain structure with grain boundaries at the stir zone or nugget zone as shown in Figure.4 (c). A higher tool rotational speed of 1400 rpm coupled with 70 mm/sec feed has resulted in lesser voids and uniform grain structure. Fig.4 (b) represents lap joint produced with 1800 rpm and 105 mm/sec feed rate using square pin tool. Similarly microstructure for joint produced by 1000 rpm and 35 mm/sec feed rate with taper tool is presented in Fig.4(a) It is observed that higher tool rotational speed and feed in case of square shaped tool have adversely affected the surface texture of the joined specimen. Similarly lower speed of 1000 rpm with feed 35 mm/sec resulted in more voids in joint processed by square shape tool. However, the joints in Fig.4 (b) also found to have similar smaller shaped voids. Smaller grain structure is observed for both the above cases, indicating improper joining of the materials. This phenomenon was found to have similarity in result with investigation carried out by [16]. For friction stir processed lap joint of AA1100 with Cu with tool plunge depth equal to thickness the Al plate.

Authors found to have reported reduced tensile strength at joint with brittle fracture observed during specimen preparation. Similar work was also reported by [16]. to join 2 mm thick A1100H24 to 1.0 mm thick Cu sheet with zinc foil of 10 µm thick as intermediate filler material. In Figure 4(c) fewer voids and more surface area with moderate grain formation are noticed. The surface was found to be smoothly transitioning from the stir zone to the heat-affected zone. Primarily three distinguishable zone such as fine equalized grains in the stir zone (SZ) of the nugget, highly elongated grain at thermo-mechanical affected zone (TMAZ), and slightly elongated coarse grain in the heat-affected zone (HAZ). Also reported the improvement in tensile strength up to 12.82% with 5% SiC reinforcement in AA1100 in friction stir processed specimen [17]. Onion structure on the surface of friction stir lap joint shows no cracks and voids which is shown in Fig.5 for different pin profiles.

The Micro structure of weld zone, stir zone (SZ) and thermo-mechanical affected zone (TMAZ) are shown in Fig.4. The tool pins used in this experiments such as taper pin, triangular pin and square pin having speed(1000rpm,1400rpm and 1800rpm)and corresponding feed rate(35mm/min, 70 mm/min and105 mm/min) the relevant surface morphology structure of tool pins observed in Fig.4(a-c).

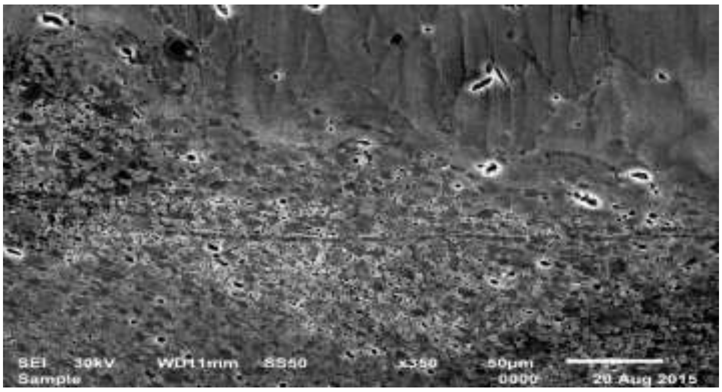

Fig.4 (a) Micro-structures of a lap weld with Tapper tool

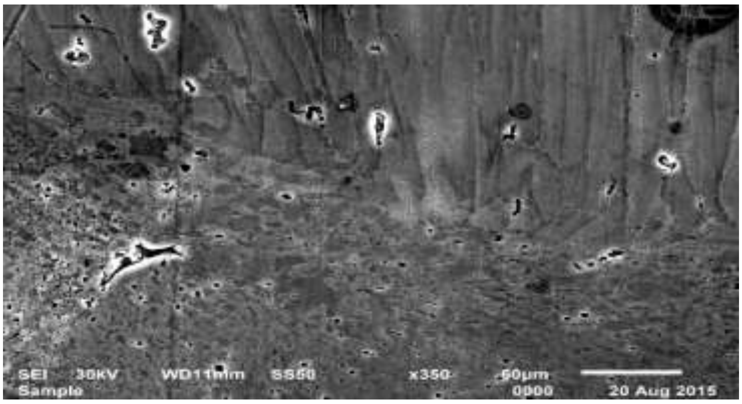

Fig. 4 (b) Micro-structures of a lap weld with Square tool

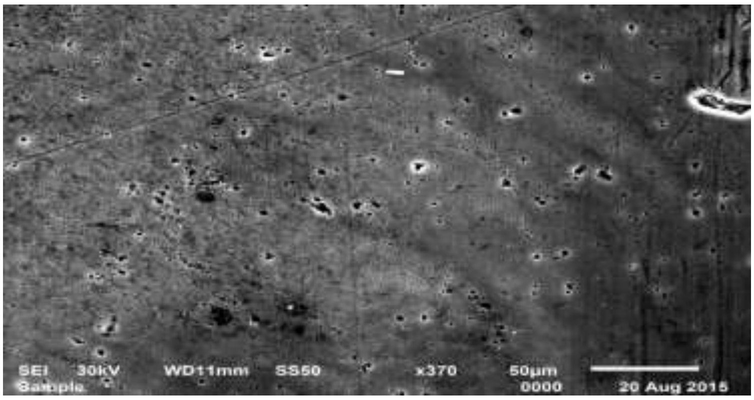

Fig.4(c) Micro-structures of a lap weld with Triangular tool

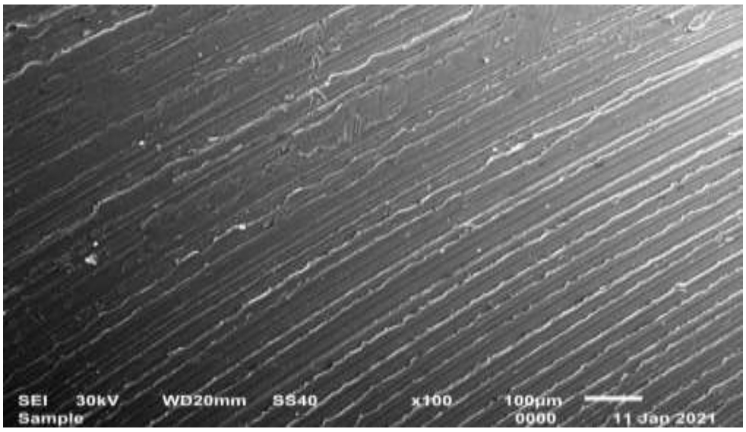

Fig.5 (a) Tool with Tapper tip rotational speed 1000 rpm and feed rate of 35 mm/min

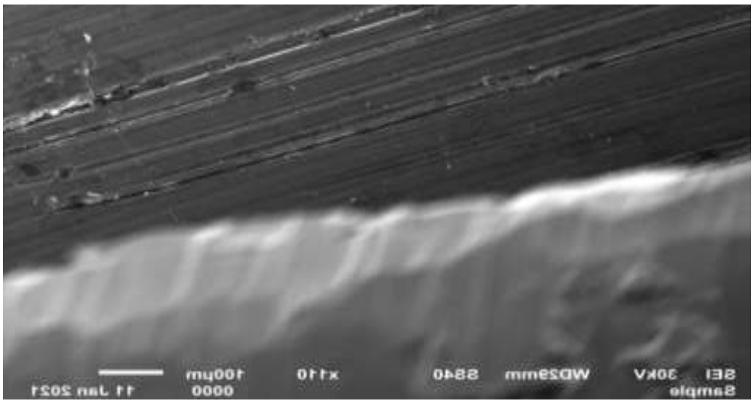

Fig.5 (b) Tool with square tip rotational speed 1800 rpm and feed rate of 105 mm/min

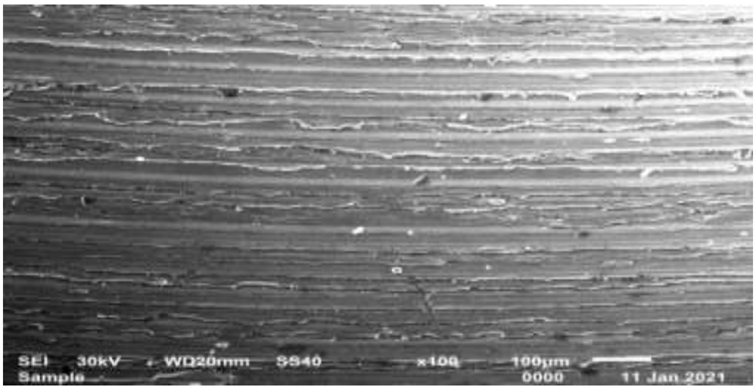

Fig.5 (c) Tool with Triangle tip rotational speed 1400 rpm and feed rate of 70 mm/min

A. TENSILE TESTS

Tensile shear test as per ASTM B 557M-02a was carried out to determine the maximum shear strength of the welded joints at following welding parameters for welded joints for AA1100. One specimen of each tool shape along with base material was tested to evaluate tensile shear strength using universal testing machine of TUE-C-100 model.

Table 3. Tensil strength of speciemens

Tool shape	**Tool speed (rpm)**	**Tool feed rate (mm/s)**	**Yeild sttength (MPa)**	**Tensile strength (MPa)**
Taper	1000	35	67.769	85.108
Triangular	1400	70	104.278	130.778
Square	1800	105	57.188	71.667
Unwelded			105.307	131.711

The friction stir joined speciemen with traingular shaped tool have shown similar strength as that of the original speciemen, where as the taper and square shape exhibited around 35.4% and 45.6% decrease in tensile strength. Simiarly the yeild strength also found to decreased by 35.64 % and 45.7% as compard to original specimen be also also exhibited.

4. CONCLUSIONS

In this research, friction stir joining of AA1100 3mm thick sheets in lap position is successfully accomplished with three different shaped tools in CNC milling. Following observations can be noted from the study are presented in point wise as below.

At lowest speed of 1000 rpm and 35 mm/min the joint processed with taper tool has 34% lower joint strength as compared to that for pure alloy. Coarse grain structure was much prevalent at the joint due to lower speed. For the joint processed with traingular tool at speed of 1400 rpm and 70 mm/min speed resulted in better grain structure as compared to joints processed with taper and square tool.

The onion pattern structure is prevailed in all the specimens and found to have equi-spaced serration arcs with smoother surface compared to other specimens. The TMAZ and HAZ regions is clearly identifiable in the SEM images for all specimens. Tool speed found to have significantly effecting the stength annd microstructure of the weld. However very high rpm resulted in fragmentaion of weld surface exhibiting deteriorated weld surface.

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