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A Comparative Study ON Friction Stir Welding Ofdis-SIMILAR METALS By Using Lathe Machine

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--ABSTRACT--

Friction stir welding is a solid state welding process. Investigation of mechanical and metallurgical properties of friction stir welded on dis –similar metals. Analysis of tool pin profile on mechanical properties of Aluminum and Aluminum alloy. Heat treatment improves tensile strength, ductility, hardness and microstructure. Circular tool pin profile gives fine grain structure than taper tool pin profile. Circular tool pin profile shows fine grains at weld centre.Taper tool pin profile shows higher hardness compared to circular tool pin profile.Characterization techniques were studied by using Rockwell hardness.(the metal is not melted) that uses a third body tool to join two facing surfaces. Heat is generated between the tool and material which leads to a very soft region near the FSW tool

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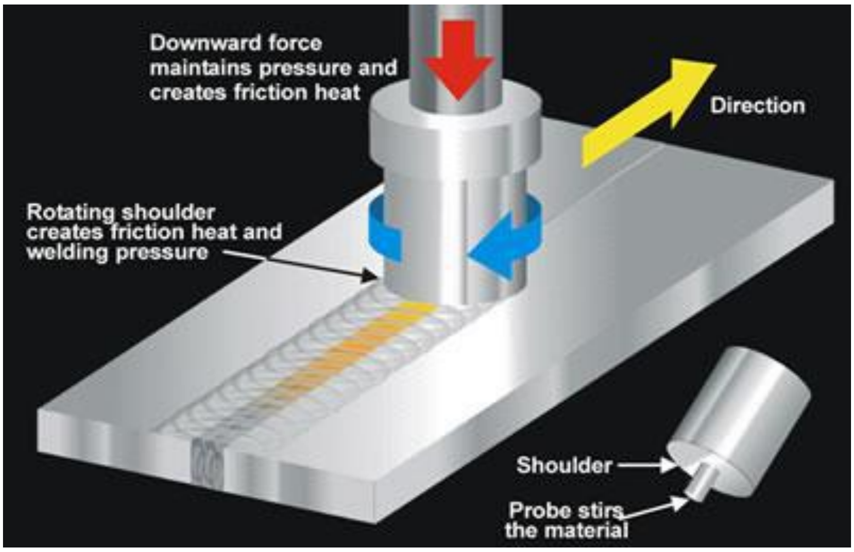
I. INTRODUCTION

1.1. Friction Stir Welding Proces:

Friction Stir Welding (FSW) is a novel welding technique invented by The Welding Institute (TWI) in 1991 (Cary H.B., 1970). FSW is actually a solid-state joining process that is a combination of extruding and forging and is not a true welding process. FSW is a derivative of conventional friction welding. The FSW process involves the translation of a rotation cylindrical tool along the interface between tow plates. The weld is formed by the deformation of the material at t4emperatures below the melting temperature. FSW does not create a Heat effected Zone nor does it use welding consumables. Since traditional heating methods are not employed, the properties of the metal in the joined area are higher than those from any other known welding process and distortion is virtually eliminated (Weisheit A.at all, 1998, Juttner S., 1998).

FSW uses a cylindrical, shouldered tool with a profiled pin that is rotated and slowly plunged into the joint line between two pieces of sheet or plate material, which are butted together. The process is solid-state in nature and relies on localized forging of the weld region to produce the joint. The plates comprising the work piece is held in compression and are rigidly fixture to the machine bed during welding. Friction stir welding uses a non consumable, rotating tool that is cylindrical in shape with a cylindrical pin of smaller diameter extending from the tool shoulder (Thomas, W.M., 1991).



Schematicillustration of the fsw process

Initially, the rotating tool is plunged into the joint until the shoulder contacts the top surface of the workpiece. Heating is caused by rubbing of the tool faces against the workpiece and by visco-plastic dissipation of mechanical energy at high strain rates developed through interactions with the tool. During welding, the material along the joint is heated to a softened condition, transferred around the periphery of the tool, and subsequently recoalesced along the back surgace of the pin to produce the weld.

Schematic illustration of the FSW process is show in Figure 1 Frictional heat is generated between the wear resistant welding tool and the work piece. This hear cause the work piece material to soften without reaching the melting point and allows the tool to traverse the weld line. As it does, the plasticized material is transferred from the leading edge of the tool to the trailing edge of the tool shoulder and pin. It leaves a solid phase bond between the two work pieces.

In friction welding process heat is produced by conversion of mechanical energy to thermal energy at the interfaces of the two work pieces. In order to simulate friction welding process, combination of thermal and mechanical effects needs to be considered. The finite element analysis helps in better understanding of friction welding process and it is important to calculate temperature and stress fields during welding process. The knowledge of temperature distribution helps in predicting the tendency of intermetallic compounds formation as they strongly depends on local temperature attained during welding process.

2.7. Friction Stir Welding in Dissimilar Aluminum Alloys

Lee W.B. et all (2003) studied joint properties of dissimilar formed A1 alloys by FSW according to the fixed location of materials. They stated that the mechanical properties of the weld mainly depended on the materials fixed at the retreating side because the microstructure of the stir zone was mainly composed of the materials fixed at the retreating side. A356 A1 alloy have been used and wrought 6061 A1 alloy which size is 140 mm in length, 70 mm in width and 4 mm in thickness. To determine the tensile strength of the stir zone, tensile test specimens have been sectioned in the longitudinal direction to the weld line with an EDM. Microstructural changes form the weld zone to the unaffected zone base metal have been examined with OM and SEM.

From the different etching response of each material, 6061 A1 alloys appeared darker colored than A356 A1 alloys in the stir zone. In case A356 A1 alloys were fixed at the retreating side, more light colored regions that have been estimated as that of A356 A1 alloys occupied the large fraction in the stir zone. However, 6061 A1 alloys have been fixed at the retreating side, the microstructure of the stir zone have been mainly composed of 6061 A1 alloys. Therefore, the macrostructure of the stir zone mainly depended on the materials fixed at the re-treating side and some of the advancing sided material.

The main results have been obtained that the microstructures of dissimilar formed A356/ 6061 A1 joint showed the mixed structures of two materials. The onion ring pattern, which appeared like lamellar structure, has been observed in the stir zone. The microstructure of the stir zone has been mainly composed of the material fixed at the retreating side. The mechanical properties of the stir zone showed higher value when 6061 A1 alloys has been fixed at the retreating side.

Wert J.A. Studied macrostructures of FSW joints between an aluminum-base metal matrix composite and a monolithicaluminumalloy? They stated that microstructures in FS welds between monolithic AA2024 and AA2014 reinforced with 20 vol % particulate A1203 reveal that the narrowest layers of each material are about 0.1 mm thick. Thus, each material retains its identity in the weld zone and convoluted macro interfaces can be identified between material domains. When the harder material is on the advancing side of the tool the macro interface span is larger; this can be understood qualitatively by considering how the relative hardness affects material transport. The welds also exhibit eutectic melting. The liquid phase has the traditional form of grain boundary films in the thermo mechanical process zone. Particle strings and fragmentation fracture zones have been observe; these may also result from eutectic melting.

Cavaliere P.et all (2006) studied a mechanical and micro structural behavior of 2024-7075 aluminum alloy sheets joined by friction stir welding. The resulted microstructure due to the FSW process has been studied by employing OM either on ‘as welded’ specimens and on tested specimen after rupture occurred. The main results have been obtained that the dissimilar 2024 and 7075 aluminum alloys in the form of 2.5 mm thick sheets have been successfully joined by friction stir welding. The specimens fracture surface after testing

Have been deeply analyzed by using a FEGSEM microscope, revealing the defects typology and location after the friction stirring process and the microscopic mechanisms occurred during high stress deformations and final failure.

Jata K.V.et all (2006) studied a continuous dynamic recrystallization during FSW of high strength aluminum alloys. They stated that the stir welded plates of an A1=Li-Cu alloy (A1-1.8 Li-2.7Cu.33Mg-33Mn-0.04Zr-0.7Zn) have been used which had been hot rolled, homogenized, solution heat treated, water quenched, and naturally aged prior to joining. OM has been performed to reveal the general microstructure of the weld and the base metal.

Li Y. et all (1999) studied a flow visualization and residual microstructures associated with the friction stir welding of 2024 aluminum to 6061 aluminum. They state that the FSW of 0.6 cm plates of 2024 A1 (140 HV) to 6061 A1(100HV)is characterized by residual, equiaxed grains within the weld zone having average sizes ranging from 1 to 15 mm, exhibiting grain growth from dynamically recrystallized grains which provide a mechanism for super plastic flow; producing intercalated, lamellar like flow patterns. These flow patterns are visualized by differential etching of the 2024 A1 producing contrast relative to 6061 A1. The equiaxed grain and sub grain microstructures have been observed to vary according to estimated temperature profiles referenced to the rotating tool axis. Dislocation spirals and loops have been also observed in the 2024 A1 intercalation regions within the weld zones at higher speeds (> 800 rpm) corresponding to slightly elevated temperatures introducing dislocation climb, and residual micro hardness profiles follow micro structural variations which result in a 40% reduction in the 6061 A1 work piece micro hardness and a 50% reduction in the 2024 A1 work piece micro hardness just outside the FSW zone.

Chao J. et all (2001) studied the effect of FSW on dynamic properties of AA2024-T3 and AA7075-T7351. Dynamic, compressive stress-strain curves have been obtained of AA2024-T3 and AA7075-T7351 aluminum alloys and their welds as produced by the FSW process. The experimentsl results have been obtained that the FSW reduces the yield stress of the weld metal to below that of the base metal, both materials exhibit the strain rate effect. Yield stresses of both base and FS welded material of AA2024-T3 exhibited ratre sensitivity. In addition, AA7075-T7351 base metal had some rate dependence. However, no rate effect have been found for AA7075-T7351 FS welded material up to the strain rate of 500/s. FSW reduced the yield stress of both AA2024-T3 and AA7075-T7351 under both high strain rate and quasistatic loading conditions.

2.8. Friction Stir Welding of Aluminum Alloy and Steel

Chen C.M. et all (2004) studied a joining of A1 6061 alloy to AISI 1018 steel by combined effects of fusion and solid state welding. The process has been derived from FSW but with an adjustable offset of the probe location with respect to the butt line. Metallographic studies by OM, EDM, and the utilization of the X-ray diffraction technique have been conducted. It has been found that the intermetallic phase A113 Fe4 and A15 Fe2 exist in the weld …

II. GENERATION OF FLOW HEAT:

For any welding process it is, in general, desirable to increase the travel speed and minimise the heat input as this will increase productivity and possibly reduce the impact of welding on the mechanical properties of the weld. At the same time it is necessary to ensure that the temperature around the tool is sufficiently high to permit adequate material flow and prevent flaws or tool damage.When the traverse speed is increased, for a given heat input, there is less time for heat to conduct ahead of the tool and the thermal gradients are larger. At some point the speed will be so high that the material ahead of the tool will be too cold, and the flow stress too high, to permit adequate material movement, resulting in flaws or tool fracture. If the "hot zone" is too large then there is scope to increase the traverse speed and hence productivity.

The welding cycle can be split into several stages during which the heat flow and thermal profile will be different:[25]

- *Dwell*. The material is preheated by a stationary, rotating tool to achieve a sufficient temperature ahead of the tool to allow the traverse. This period may also include the plunge of the tool into the workpiece.
- *Transient heating*. When the tool begins to move there will be a transient period where the heat production and temperature around the tool will alter in a complex manner until an essentially steady-state is reached.
- *Pseudo steady-state*. Although fluctuations in heat generation will occur the thermal field around the tool remains effectively constant, at least on the macroscopic scale.
- *Post steady-state*. Near the end of the weld heat may "reflect" from the end of the plate leading to additional heating around the tool.

Heat generation during friction-stir welding arises from two main sources: friction at the surface of the tool and the deformation of the material around the tool.[26] The heat generation is often assumed to occur predominantly under the shoulder, due to its greater surface area, and to be equal to the power required to overcome the contact forces between the tool and the workpiece. The contact condition under the shoulder can be described by sliding friction, using a friction coefficient μ and interfacial pressure P, or sticking friction, based on the interfacial shear strength at an appropriate temperature and strain rate. Mathematical approximations for the total heat generated by the tool shoulder Q_{total} have been developed using both sliding and sticking friction models: [25]

$$Q_{total} = \frac{2}{3}\pi P\mu\omega\left(R^3_{shoulder} - R^3_{pin}\right) \text{(Sliding)}$$

$$Q_{total} = \frac{2}{3}\pi\tau\omega\left(R^3_{shoulder} - R^3_{pin}\right) \text{(Sticking)}$$

where ω is the angular velocity of the tool, $R_{shoulder}$ is the radius of the tool shoulder and R_{pin} that of the pin. Several other equations have been proposed to account for factors such as the pin but the general approach remains the same.

A major difficulty in applying these equations is determining suitable values for the friction coefficient or the interfacial shear stress. The conditions under the tool are both extreme and very difficult to measure. To date, these parameters have been used as "fitting parameters" where the model works back from measured thermal data to obtain a reasonable simulated thermal field. While this approach is useful for creating process models to predict, for example, residual stresses it is less useful for providing insights into the process itself.

III. EXPERIMENTAL DETAILS

Details of metal composition, friction stir welding processes and metallographic techniques are described in the following.

Base Metal

In this present work, the aluminum alloy plate with 6 mm thickness whose chemical composition and mechanical properties are listed in table.

Mg	Si	Cu	Mn	Fe	S	p	Al
1.2	1	1.1	0.08	0.5	0.05	0.65	Remaining

Mechanical properties:

Mechanical property	UTS(N/mm2)	% of Elongation
6013-T6	359	8

Friction stir welding process methodology:

The rolled plates of 6 mm thickness, AA6013 aluminum alloy, have been cut into the required size (300x200 mm) by power hacksaw cutting. Square butt joint configuration, as shown in Fig.1 has been prepared to fabricate FSW joints. The initial joint configuration is obtained by securing the plates in position using mechanical clamps. The direction of welding is normal to the rolling direction. Single pass welding procedure has been followed to fabricate the joints. Non-consumable tools dimensions and two tool pin profiles have been used to fabricate the joints are shown in Fig. 2. An indigenously designed and developed lathe machine (3HP,1400RPM) has been used to fabricate the joints as shown in Fig.3. In each pin profile, two tools have been fabricated with two shapes of pin profile (i.e., circular pin and taper pin) and same shoulder diameters (D) have been fabricated, each tool is used to fabricate one butt joints and hence 6 joints have been fabricated in this investigation. The welding parameters and tool dimensions are presented in Table 2. The welded joint and samples are prepared as per the dimensions of tool post in lathe machine as shown figure

Fig.**1.0**

Fig.**2.0**

Tool profiles:

Tool length: 75mm
Shank diameter: 16mm
Pin height : 5mm

Pin diameter : 5mm

Welded plates

Taper pin profile

Fig.5.0

Cylindrical pin profile

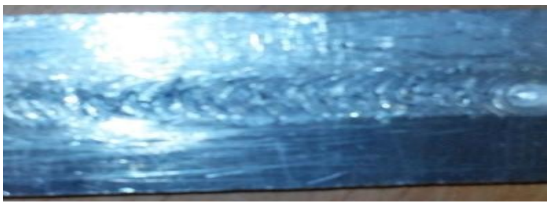


Fig.6.0

Hardness varying with Taper pin profile:

Distance in mm	Hardness value at heat effected zone	Dia of indentation in mm	Hardness at welded zone	Dia of indentation in mm
5	29	0.12	24	0.11
10	32	0.11	23	0.13
15	31	0.125	29	0.12
20	95	0.12	30	0.12
25	21	0.12	21	0.125
30	43	0.11	15	0.13
35	50	0.11	16	0.13
	Average=43		Average=22.57	

Hardness varying with cylindrical pin profile:

Distance in mm	Hardness value at heat effected zone	Dia of indentation in mm	Hardness at welded zone	Dia of indentation in mm
5	26	0.12	15	0.12
10	26	0.115	17	0.115
15	26	0.12	30	0.12
20	37	0.12	16	0.115
25	16	0.12	17	0.12
30	42	0.125	19	0.12
35	37	0.118	18	0.121
	Average=30		Average=18.85	

Metallographic Technique:

Microstrutural Characterization:

Sample for metallographic observation were cut from both the FSW plates.The cut samples, 0.5 in. square in cross-section, were mounted in Bakelite and then dry ground on progressively finer grades silicon carbide impregnated emery paper. Fine polishing to a perfect mirror-like finish of the surface was achieved using disc polishing kerosene solution as the lubricant. The polished aluminium alloy and aluminium samples plates etched using Keller's reagent (a solution mixture of 1 drop hydrofluoric acid, 25 ml concentrated nitric acid, 25 ml hydrochloric acid and 25 ml methanol).The etched surface of each sample containing the weld region was observed in an optical microscope and photographer using bright field illumination (AVER CAP software) technique.

CIRCULAR TOOL PIN PROFILE

Fig. 8 shows onion rings at the weld zone in without heat-treat gives lower tensile strength and higher percentage of elongation.

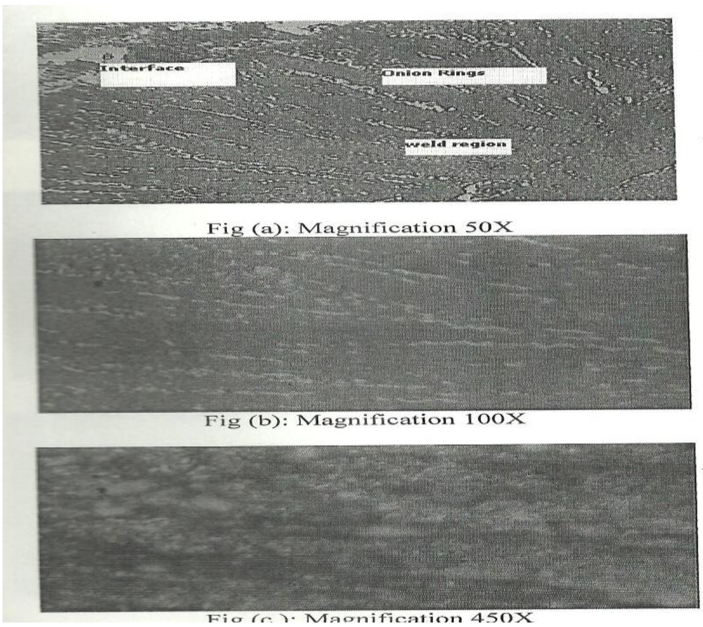


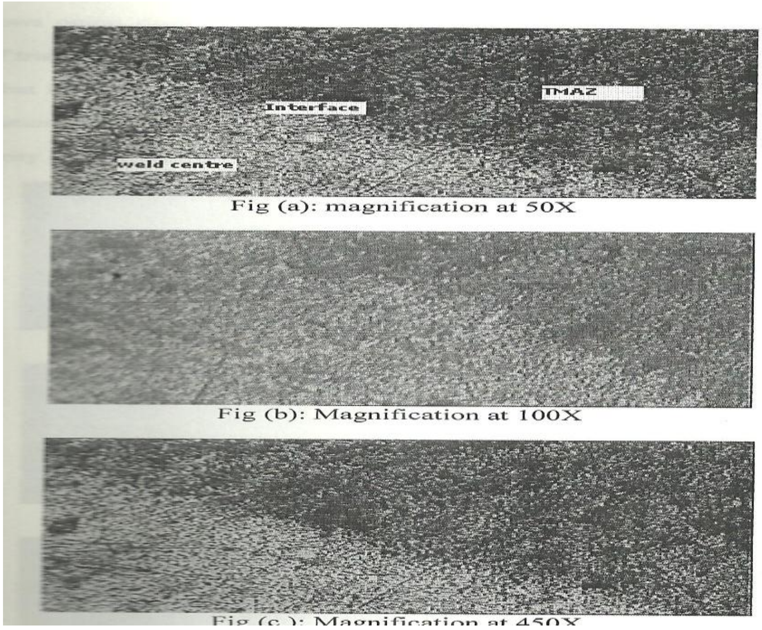
Fig (a): Magnification 50X

Fig (b): Magnification 100X

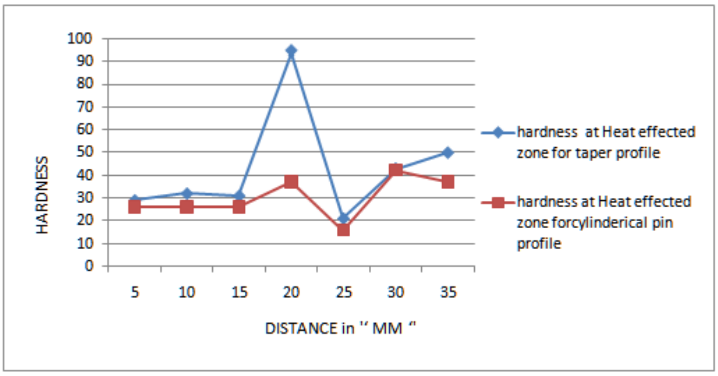
Fig (c): Magnification 450X

TAPER TOOL PIN PROFILE

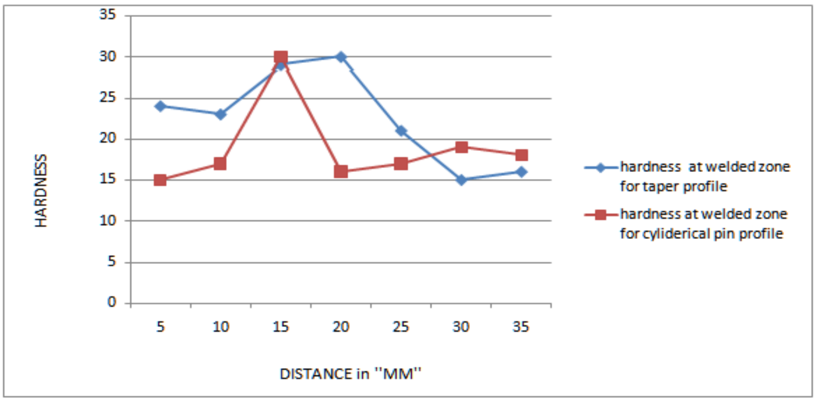
Fig 11 shows weld region of without heat treatment of taper tool pin profile. Due to sharp edges the speed tool is reduced in the metal, so that low temperature is generated. This much temperature is not sufficient to bond formation in the weld zone. Due to that the grains are coarse at that weld region and bond integrity is poor. Fig.12.shows interface of the welded sample



Hardness at heat treated zone with cylindrical pin profile & taper profile



Hardness at welded zone with Pin profile: Cylindrical & taper profile.



CONCLUSION

The microstructure shows fine grains at weld centre in Circular tool with heat treatment for air-cooling. In case of taper tool, sharp taper the speed of tool is reduced in the metal, so that low temperatures are generated. This much temperature is not sufficient to bond formation in the weld zone. Due to the grains are coarse at the weld region and bond integrity is poor. The hardness is high at heateffect zonein taper tool pin compare to circular tool pin. In all the condition the hardness is high than the base metal.

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