INVESTIGATION ON MICROSTRUCTURE AND MICRO HARDNESS OF FRICTION STIR WELDED DISSIMILAR ALUMINUM ALLOY PLATES

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ABSTRACT

Assembly of two different grades of aluminum plates is need in many light weight vehicles structures like military, aerospace, ship building and automobile applications. This paper deals with joining of AA7075-T651 with AA6063-T6 aluminum alloys by friction stir welding (FSW) process using cylindrical straight and taper at Tool revolving speed, tool axial force and welding transverse speed of 1000,1100,1200rpm, 4, 5, 6 KN and 30,45,60 mm/min. The effect welding process parameters on weld appearance and hardness were examined experimentally. The *microstructures* were observed at various regions and analyzed by means of optical microscope. From this investigation were established that the use of taper cylindrical *pin profile* of tool provides to better flow of materials between both alloys and the formation of flaw free weld zone. The growth in Micro-*Hardness* is attributed to the development of fine grains and intermetallic in the weld zone, and in addition, the reduced size of weaker regions, such as TMAZ and HAZ regions, results in good metallurgical properties.

Keywords: *Friction stir welding*, *Dissimilar Aluminum alloys*, *Process parameters*, *Tool pin profile*, *Micro Hardness*, *Microstructure*.

INTRODUCTION

Friction stir welding process parameters mainly affect the temperature profile, heat input, imperfections, and microstructure of the weldment. The effect of process parameters on the mechanical properties of the joint, tensile strength of the joint are strongly dependent on the tool rotational speed, ratio of tool pin and shoulder diameter and tool tilt angle with an inversely proportionality (Pasquale Cavaliere, et al., 2013, FSW is an advanced solid state welding technique, wide use in aerospace and military applications Thomas, et al., 2014). In fusion welding process heat generation were more so the weld metal (aluminum) goes to liquefied level so that aluminum alloys is not suitable for other fusion welding techniques like Tungsten Inert Gas, Metal Inert Gas, Gas, Electric Arc Welding process. The efficiency of the joints was achieved 80-90 % when using friction stir welding process is not depends upon the working material's thickness of plate because 1mm plate also obtained by this process (Mohan, et al., 2014). The macrograph of weldments showed appropriate flow of materials from both side it is evident that the considered weld process parameters substantiated optimum. It is also noted that there is a micro void is presented when the sample welded at moderated welding speed of 28 mm/min which may be due to insufficient of frictional heat involved in the weld zone (RajKumar. et al., 2014). Hardness value increased at the weld zone due to work hardening takes place during welding. The failure occurred in around the heat affected zone and thermal mechanical zone of the joints which have high ductility, fracture in around the nugget zone on the advancing side if low ductility joints (Hakan Aydin, et al., 2012). In general, final grain sizes were found at stir zone (SZ), thermo-mechanically-affected zone (TMAZ), heat-affected zone (HAZ) and base metal (BM). The shape and size of these zones primarily depends on the process parameters such as weld traverse speed (TS), Tool revolving speed (RS), axial load (P) and the tool-pin geometry (Madhan, et al., 2014). Tool pin shape and geometry are the important process control constraints in FSW that effect material flow which in turn affect joint quality (Gangwar, et al., 2016). Considering medium strength 6xxx series and high strength 7xxx series aluminum alloys, resistances to deformation of 6xxx alloys are less compared to 7xxx series alloy while thermal conductivity is greater for the lower alloyed 6XXX series. Its lead to a weldability advantage of 6xxx over 7xxx series alloys (Reza E.Rabbya, et al., 2014). Less heat generation leads to fast cooling rate which results in fine microstructure. The Stir Zone microstructure formed at peak temperature with highly strain induced area and localized fast cooling rate to room temperature occurred during FSW and subsequent transformation to a completely upper bainite and lath bainitic microstructure are the key factor of the hardest weld region in the FSW joint weld zone (Raghunathan, et al., 2015). The stir zone (SZ) of As Welded (AW) joint don't have any considerable hardness difference in comparison with the Parent Metal hardness. The hardness value for the AW joint indicates a drop in the TMAZ region on retreating and advancing sides of the joint. The lowest hardness in AW joint was observed at AS-TMAZ. The Artificially Aged (A-A) treatment resulted in increase of hardness value in the stir zone region and decrease in TMAZ region. The Solution treated, and aged joint recorded the highest hardness in all the regions of the weld in comparison with AW and AA joints (Vinayak Malika, et al., 2014, Sivaraj, et al., 2014). The hardness values in and around of weld zone were comparatively low and may be attributed to the tempering of the weld zone and the dissolution & distribution of solidification precipitates. Due to addition of nano B_4C powders hardness value was improved considerably in the nugget zone (NZ) (Vijayakumar, et al., 2015). The objective of this attempt is to investigate the micro hardness and microstructure of the welded joint made under various weld process conditions and compared with two variety tool pin profile (Straight cylindrical and Taper cylindrical) which is being reported.

MATERIALS AND METHODS

AA7075-T651 and AA6063-T6 thickness of 6mm aluminum plate was selected for this investigation. The weld plate of 100 x 50 x 6.35mm extracted from the standard size flat. The joint was fabricated in single pass, perpendicular to the plate rolling direction and placing the plates of AA7075-T651 in retreating side and AA6063-T6 in advancing side. Since if the soft alloy is positioned at the retreating side, the fabricated weld will become weaker than when the weaker alloy is at the retreating side (Ravikumar, et al.,2014). Experiments were conducted with straight cylindrical and taper cylindrical tools are made up of ANSI H13 steel are shown in table 1. All weld is made under the following process parameters: Tool revolving speed of 1000, 1100 and 1200 rpm, Axial force of 4, 5 and 6 KN, Welding speed of 30, 45, 60 mm/min.

Table 1: Tool Parameters

S.No	Process parameters	Values
1	Tool Profile(Circular)	Straight, Taper
2	Tool Shoulder Diameter	18mm
3	Tool pin diameter	6mm
4	Tool pin length	5.7mm

The Micro Hardness were measured using Vickers Micro Hardness Tester with 100g load and dwell time of 10 seconds. The Micro hardness value measured across the welding direction at regular interval of 10mm from the weld center line to each side of the weld. A row of indentation tests has been conducted at different 5 location of the sample along the longitudinal direction of the weld. Microstructural examination was conduct using an optical microscope (MEJI, Japan; Model MIL-7100). The specimens for microstructure study were polished by various grades of emery sheets (500, 1000, 1500 and 2000). Final polishing was done using diamond paste in disc polishing machine. The specimens were etched with standard Keller's reagent (150ml of H_2O, 3ml of HNO_3, 6ml of HCL, 6ml of HF) with etching time of 10-15 seconds after that to reveal the microstructure of various weld regions.

Effect of Process parameter on Micro-hardness: The micro hardness was measured across the weld line as shown in figure 1. Showed that the base metal AA6063 hardness of 52Hv and AA7075 hardness of 191Hv. The hardness of the weld zone extensively varied than that of metal heedlessly of process parameters. The grain size or reform plays a vital role in the materials strengthening. Average Vickers hardness number measured across the joint shown in figure 2 that lowest hardness was observed in the joint made with a straight circular tool and taper circular toolat a Tool revolving speed of 1000 rpm as 56Hv and 57Hv on AA6063 side respectively at TMAZ and highest hardness was observed in the joint made with a straight circular tool and taper circular tool at a Tool revolving speed of 1200 rpm as 142Hv and 144Hv on AA7075 side respectively at TMAZ. The figure 3 show that lowest hardness was observed in the joint made with a straight circular tool and taper circular tool at axial force of 5KN as 57Hv and 58Hv on AA 6063 respectively and highest hardness was observed in the joint made with a straight circular tool and taper circular tool at axial force of 5KN as 143Hv and 137Hv on

AA7075 side respectively at TMAZ. The figure 4 show that lowest hardness was observed in the joint made with a straight circular tool and taper circular tool at welding speed of 30 mm/min as 62Hv and 58Hv on AA6063 side respectively and highest hardness was observed in the joint made with a straight circular tool and taper circular tool at axial force of 45mm/min as142Hv and 137Hv respectively at TMAZ. From the figures 3, 4, 5 interspacing between two lines 1.5mm on AA70-75 and 0.5mm on AA6063. It was found that the micro-hardness values are strong function of the distance from the weld zone.

RESULTS AND DISCUSSION

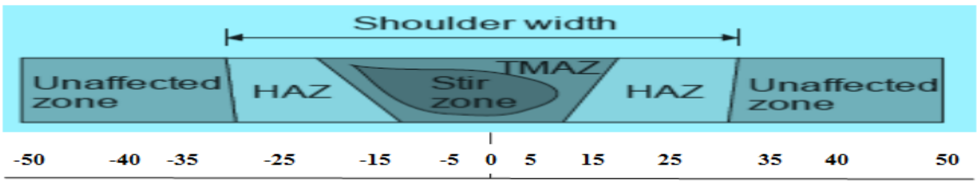


Figure 1: Micro-hardness measurement locations

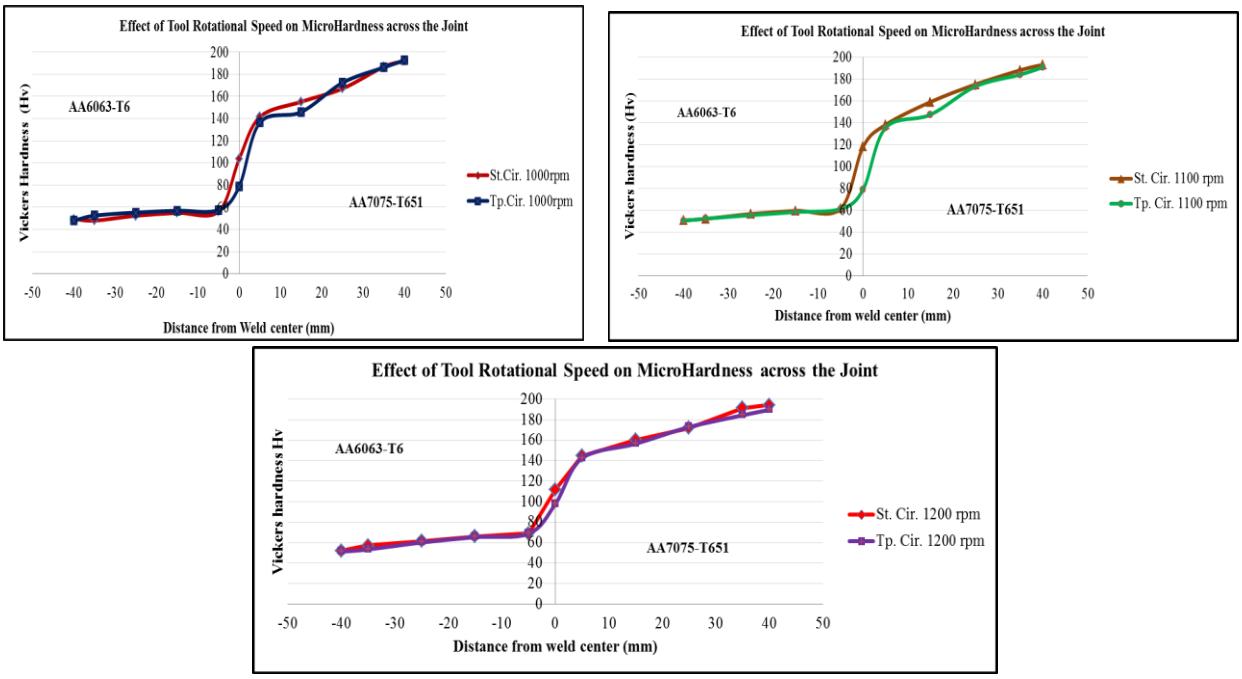
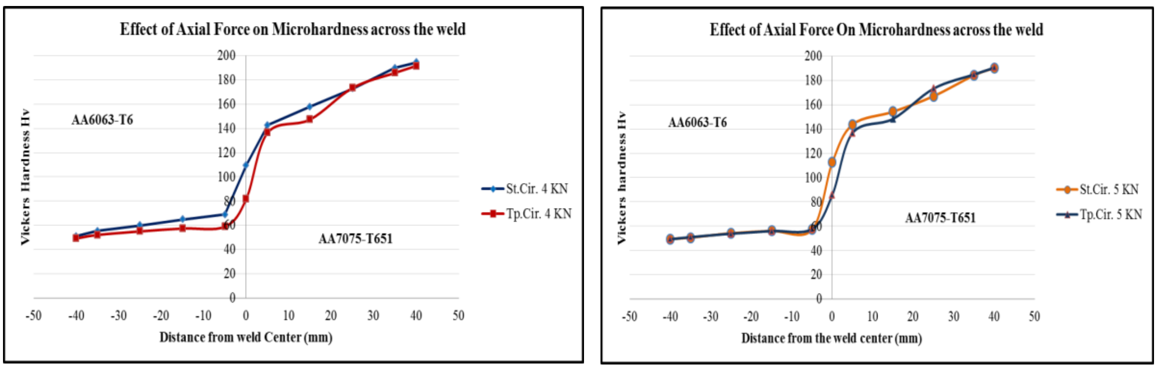


Figure 2: Influence of Tool revolving speed on Micro-hardness



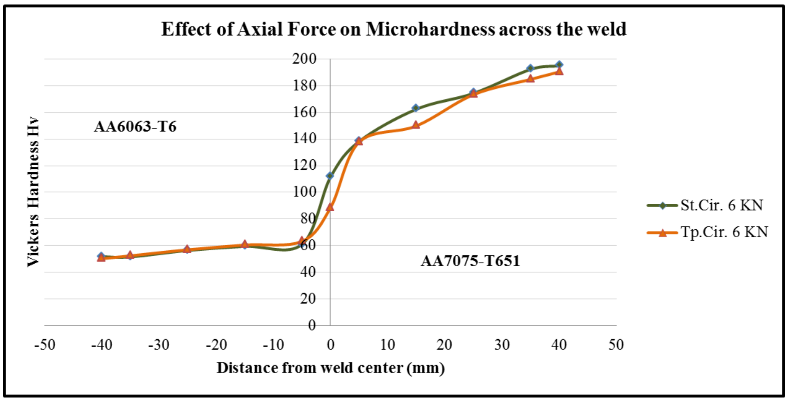


Figure 3: Influence of axial force on Micro-hardness

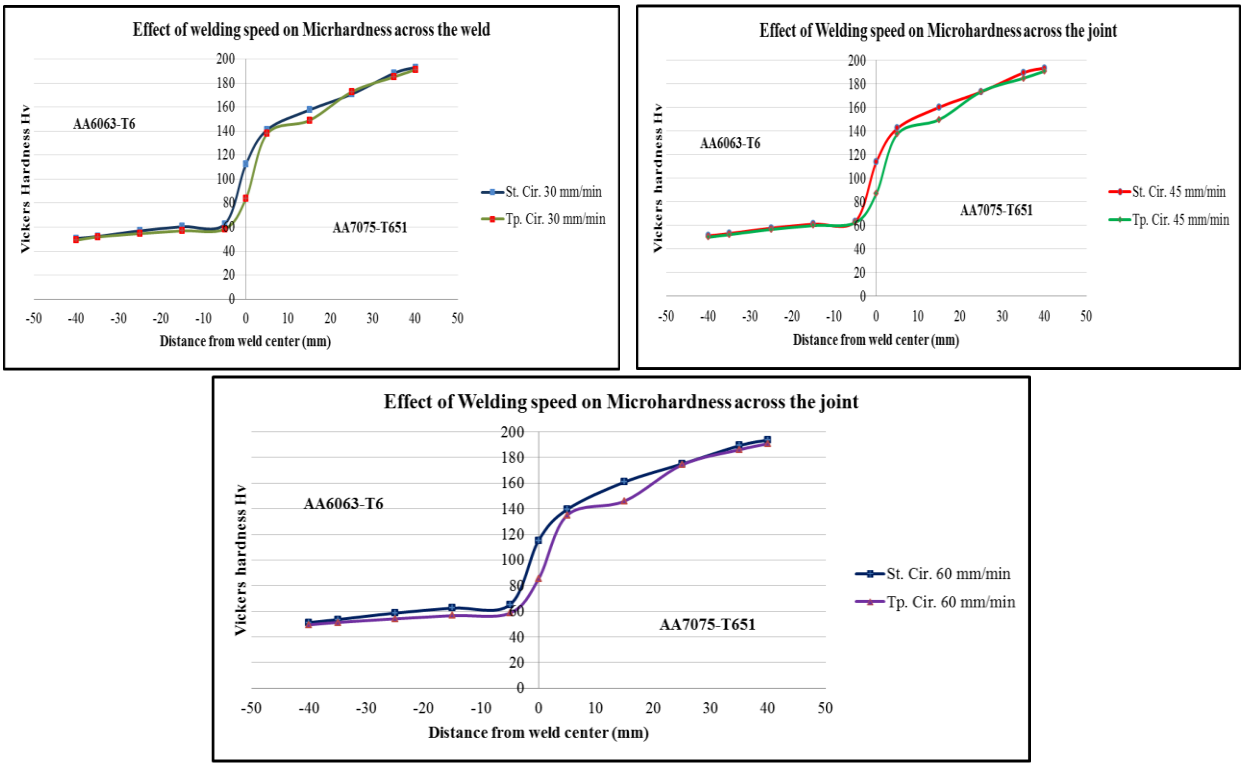
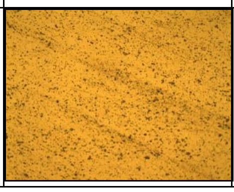
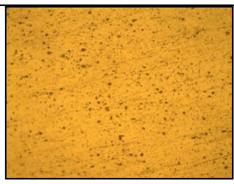
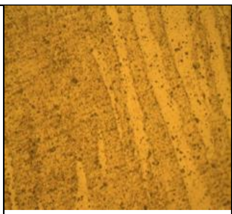
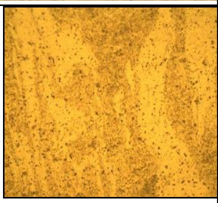
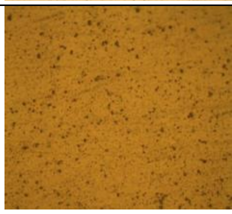
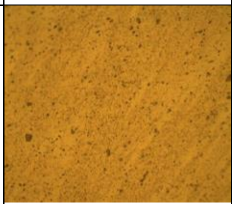
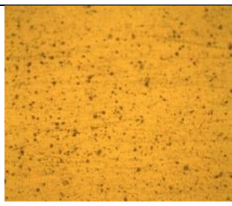
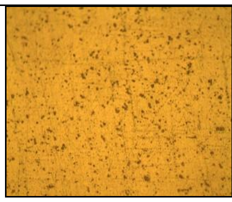
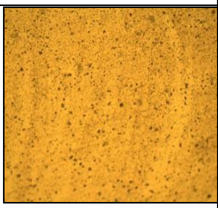
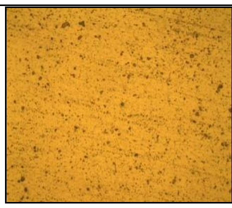
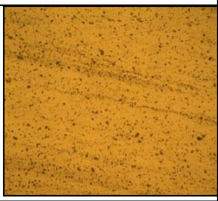
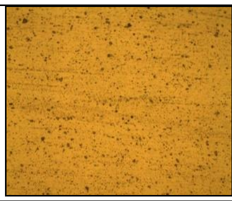
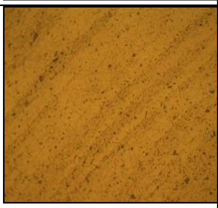
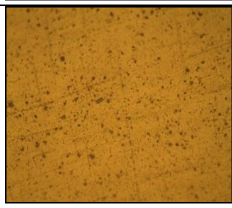
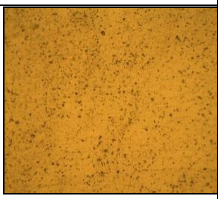
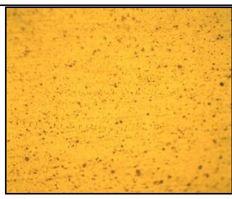


Figure 4: Influence of Welding Speed on Micro-hardness

Effect of process parameters on Microstructure

Process parameter combinations	Straight cylindrical tool	Weld zone	Taper cylindrical tool	Weld zone
TRS-1000 rpm AF-4KN, WS-30mm /min		Uniform fine grain structure with some fine nuggets of alloy silicids, No cavity and crack observed		Uniform fine grain structure with some fine nuggets of alloy silicids, No cavity and crack observed

TRS-1000 rpm AF-5KN WS-45mm/min		Uniform fine grain structure with some fine nuggets of alloy silicids, No cavity crack oninon rings observed		Uniform fine grain structure with some fine nuggets of alloy silicids, No cavity and crack observed
TRS-1000 rpm AF-6KN WS-60mm/min		Uniform fine grain structure with distributed fine lumps nuggets of alloy silicids, No cavity crack		Uniform fine grain structure with some fine nuggets of alloy silicids, No cavity and crack observed
TRS-1100 rpm AF-4KN WS-45mm/min		Uniform fine grain structure with distributed fine lumps nuggets of alloy silicids, No cavity crack		Uniform fine grain structure with some fine nuggets of alloy silicids, No cavity and crack observed
TRS-1100 rpm AF-5KN WS-60mm/min		Uniform fine grain structure with distributed fine lumps nuggets of alloy silicids, No cavity crack		Uniform fine grain structure with some fine nuggets of alloy silicids, No cavity and crack observed
TRS-1100 rpm AF-6KN WS-30mm/min		Uniform fine grain structure with distributed fine lumps nuggets of alloy silicids, No cavity crack		Uniform fine grain structure with some fine nuggets of alloy silicids, No cavity and crack observed
TRS-1200 rpm AF-4KN WS-60mm/min		Uniform fine grain structure with some fine nuggets of alloy silicids,		Uniform fine grain structure with some fine nuggets of alloy silicids, No cavity and crack observed
TRS-1200 rpm AF-5KN WS-30mm/min		Uniform fine grain structure with some fine nuggets of alloy silicids, No cavity crack oninon rings observed		Uniform fine grain structure with some fine nuggets of alloy silicids, No cavity and crack observed
TRS-1200 rpm AF-6KN WS-45mm/min		Uniform fine grain structure with some fine nuggets of alloy silicids, No cavity and crack observed		Uniform fine grain structure with some fine nuggets of alloy silicids, No cavity and crack observed

CONCLUSION

Dynamic recovery and recrystallization are the main softening mechanism during welding. The average value of hardness across the weld zone plotted against two different tool pin profile at various process parameter levels. The strain hardened tempers of the non-heat treatable alloys the recrystallization occurs in the weld zone during welding, would eliminate some or all the cold work effects. Compare with base metal hardness decreases towards the weld center. The shear stress induced by the tool motions in between materials, which is leading to generate very fine grain structure. The materials flow pattern like onion ring, which is appeared like lamellar structure was observed in the weld region and fine grains and consistently spread very fine strengthening precipitates in the weld region. The dendrite structure, which are characteristics in the base metal disappeared and showed the dispersed eutectic s_i particles in the weld zone.

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