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Studies on friction stir welding of AA 2024 and AA 6061 dissimilar metals

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Abstract

The joining of dissimilar AA2024 and AA6061 aluminium plates of 5mm thickness was carried out by friction stir welding (FSW) technique. Optimum process parameters were obtained for joints using statistical approach. Five different tool designs have been employed to analyse the influence of rotation speed and traverse speed over the microstructural and tensile properties. In FSW technique, the process of welding of the base material, well below it's melting temperature, has opened up new trends in producing efficient dissimilar joints. Effect of welding speed on microstructures, hardness distribution and tensile properties of the welded joints were investigated. By varying the process parameters, defect free and high efficiency welded joints were produced. The ratio between tool shoulder diameter and pin diameter is the most dominant factor. From microstructural analysis it is evident that the material placed on the advancing side dominates the nugget region. The hardness in the HAZ of 6061 was found to be minimum, where the welded joints failed during the tensile studies.

Keywords: Friction stir welding; Aluminium alloys; Dissimilar welding; Butt joints

1. Introduction

Aluminium alloys, AA6061 and AA2024, are widely used in many emerging fields of aerospace industry and marine industry in the construction of frames, pipelines and storage tanks. Dissimilar joining process is considered as a challenging one when compared to similar welding process, due to variation in chemical composition and mechanical properties of the base materials [1-3]. Since fusion welding of dissimilar aluminium is tedious, Friction Stir Welding (FSW) process is widely used for welding of dissimilar materials, where the formation of secondary phase is absent since the temperature involved in this process is well below the melting temperature of base materials. Previous studies indicate, the optimum parameters for welding of dissimilar aluminium alloys, with rotation speed of 600-1000 Rpm, traverse speed around 15-40 mm/min and D/d ratio of 3:1[4]. Better mechanical properties are obtained when harder material is placed on the advancing side and softer material in retreating side [5,7]. Since tool geometry plays a vital role in dissimilar welds, different tool profiles are widely being used these days. Tool pin profiles such as threaded, squared and triangular are

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efficient to transfer the material from top to bottom of the joint and vice versa by stirring action [6]. Table 1 indicates the chemical composition and mechanical properties of the base material that was considered for the research work.

Table: 1 Chemical Composition and mechanical properties of the alloys.

Material	Mg	Mn	Cu	Fe	Si	Cr	Zn	Ti	Al	Hardness(HV)	%of Elongation
AA 2024	1.5	0 .6	4.35	0.5	0.5	0.10	0.25	0.15	Remaining	19	137
AA 6061	1	0.15	0.27	0.7	0.6	0.19	0.6	0.15	Remaining	22	75

2. Experimental procedure

The materials used in this study are 5mm thick plate of AA 2024-T4 (Al-Cu alloy) and AA 6061-T4 (Al-Mg-Si alloy), and the chemical compositions for 2024 and 6061 are shown in table 1. The rolled plates were cut into rectangular samples of 100 × 50 mm and the welding was carried out using vertical milling machine. The welding tool used in this study was AISI H13 tool steel, which has high resistance to thermal fatigue. The various pin profiles used in this work include cylindrical threaded pin, cylindrical pin, squared pin, tapered pin and stepped pin (Fig 1 (a-e)). The process parameters used in this work is given in table 2. AA2024 was placed on the advancing side due to its higher mechanical strength and the tool pin was positioned at centre of joint line. To study the microstructure of the weldments of these dissimilar aluminium alloys Keller's reagent was used. Optical microscope, scanning electron microscope (SEM) and energy dispersive spectroscope (EDS) were used to evaluate the metallurgical characterization. For the tensile studies, the samples were prepared according to the ASTM E8 standards and the tests were carried out at a strain rate of 0.5mm/min. Micro Hardness were carried out at a load of 100gf with dwell time of 10secs and distance of 0.25mm interval across the weldment.

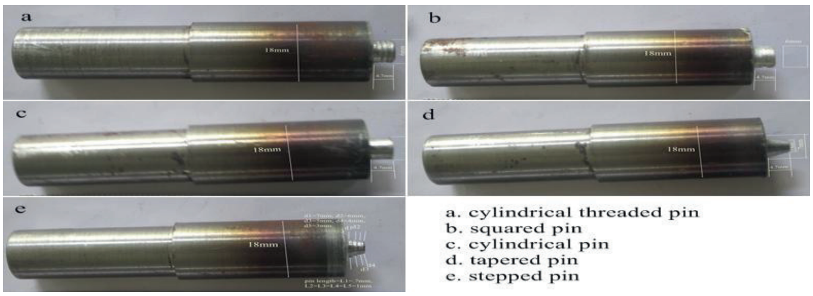


Fig 1 shows the tool diagram used for this experimental work

Table 2: Process parameters for friction stir welding of AA 2024 and AA 6061.

Material	**Tool design**	**Speed (rpm)**	**Traverse speed mm/min**	**Tilting angle degree**
AA2024+AA6061	Threaded pin	710	28	2°
AA2024+AA6061	Threaded pin	1000	40	2°
AA2024+AA6061	Squared pin	1000	40	2°
AA2024+AA6061	Squared pin	710	28	2°
AA2024+AA6061	Tapered pin	710	28	2°
AA2024+AA6061	Cylindrical pin	710	28	2°
AA2024+AA6061	Cylindrical pin	1000	40	2°
AA2024+AA6061	Stepped pin	1000	40	2°

3. Results and Discussion

3.1. Surface Morphologies of weld

The surface morphologies of the weld fabricated using cylindrical, threaded and squared pin tool profile are shown in fig 2 (a& b). The rotational speed and the traverse speed for the threaded and squared pin were maintained at 710 rpm, 28 mm/min and 1000 rpm, 40 mm/min respectively. By varying the process parameters and different tool geometry, no external defects were found on the weld except for tapered pin. Insufficient heat diffusion and defective surface morphologies were observed when tapered pin was used (Fig 2 b).

(a) (b)

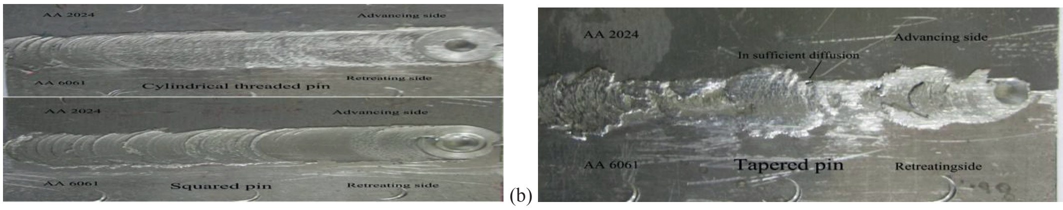


Fig 2, Surface morphologies of weld, a- without defects, b- with defects.

3.2. Macrostructure

From the macro-graphic studies, different regions of weldments are identified and it represents the effective stir of both the base material in the nugget zone Fig 3 (a, b). Also, the presence of AA2024 in the stirred zone is more when compared with AA6061, as the former was kept on the advancing side. Defect free welds were produced on using cylindrical threaded pin and squared pin with process parameter of 710 rpm, 28 mm/min for the former and 1000 rpm, 40 mm/min for the later. On the other hand, few macroscopic defects occurred on using cylindrical, tapered and stepped pin, for the same process parameters and it could be due to absence of vertical motion of the material. Further it is supported by Balasubramanian et al. [6] where the author discussed the effect of tool pin profile with respect to weld property.

(a) (b)

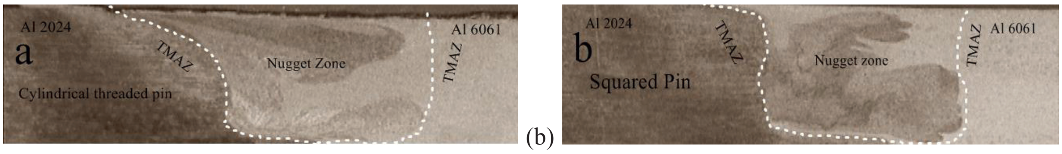


Fig 3. Macrostructure, a-cylindrical threaded pin and b- squared pin.

3.3. Microstructure

The microstructure of the different regions of the welded dissimilar material is shown in Fig. 4 (a-g). Though the weld undergoes considerable amount of thermal cycle, there is no significant changes in the microstructure of the base metals. On the other hand, the thermal cycle, has considerably influenced the Heat affected Zone (HAZ), which is evident from the microstructure (Fig 4 (b, f)). However, there is no plastic deformation occurring in this area. In the thermo-mechanically affected zone (TMAZ), there is considerable growth in the grain boundaries which could be due to the plastic deformation and the less heat developed during the process. Also, it is evident from the microstructure that a distinct grain boundary separates the recrystallized zone (weld nugget) from the deformed zones of the TMAZ. The dynamically recrystallized zone is the stirred zone, where the material has undergone severe plastic deformation resulting in fine equiaxed grains [8]. The term stirred zone is commonly used in friction stir processing, where sufficient volume of material is processed. Further from the microstructure of the weld nugget (Fig 4 (d)), it is evident that the grains are highly refined, which could enhance the strength of the weldment [9].

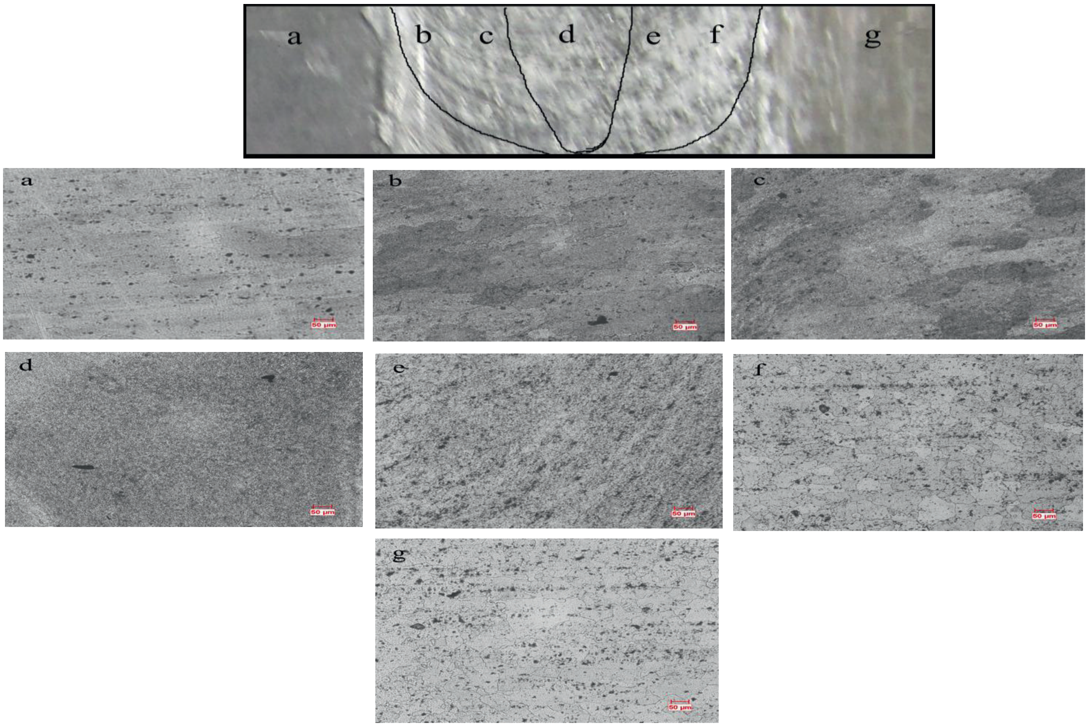


Fig 4. Microstructure of the different regions, a-2024 base metal, b- HAZ of 2024, c-TMAZ of 2024, d- Nugget zone, e- TMAZ 0f 6061, f- HAZ of 6061, g- 6061 base metal

3.4. SEM and EDAS analysis.

SEM image was analysed at a magnification of 2.5KX. EDAS was taken at the centre of the weld zone as shown in Fig 5. Presence of Al(83.85%)and Cu(8.73%) were prominent in that region. Formation of the oxide layer within the weld zone, could most probably enhance the corrosion properties.

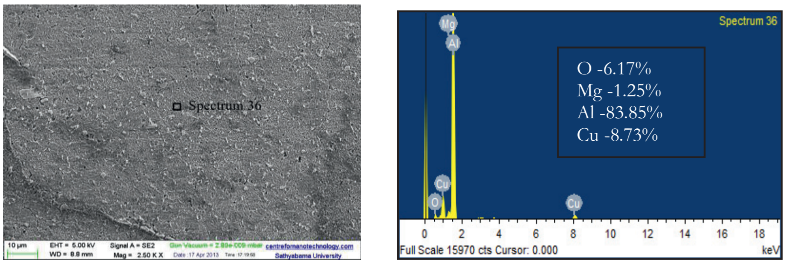
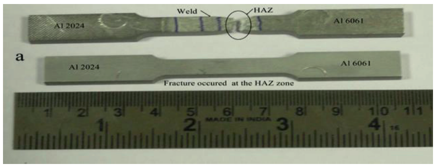


Fig 5. SEM and EDAS analysis

3.5 . Tensile test

Maximum weld strength of 194 Mpa and 209Mpa were obtained for cylindrical threaded and squared pin, respectively. In fig 6 for both the tool pin geometry fracture occurred at the HAZ of 6061 side. On the other hand, fracture occurred at the stirred zone, for other tool pin geometry. The welded specimen shows lower strength compared to both the base material. Joint efficiency obtained is 80% for cylindrical threaded pin and 87% for squared pin.

(a) 

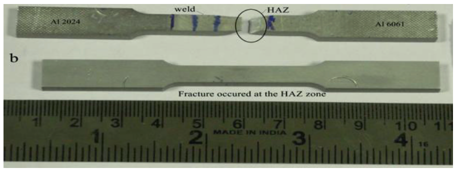
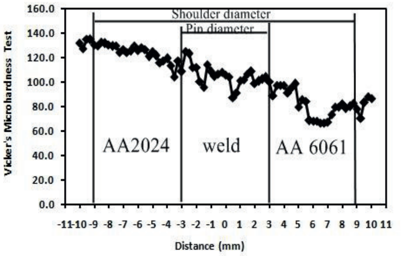
(b) 

Fig 6 Tensile test. a-cylindrical threaded pin and b-squared pin.

3.6. Hardness

Vicker's hardness tests were conducted across the various regions of the weld spacing of (0.25mm) shown in Fig 7. Average hardness value of 105.15 HV was obtained across the weldment for cylindrical threaded pin, and 135.6 HV for squared pin. The hardness of weld nugget was considerably lower than that of AA2024; on the other hand, the hardness is comparatively higher than 6061 base material and TMAZ.

(a) 

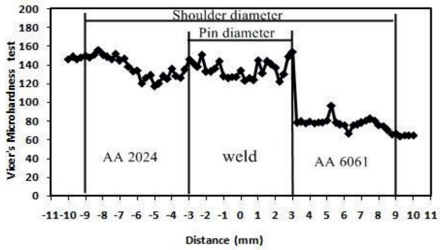
(b) 

Fig 7 Vicker's hardness test. a-Cylindrical threaded pin, b-Squared pin

4. Conclusion

The FSW process parameters were optimized with respect to mechanical and metallurgical properties of the weldments. In addition, tool pin profile has also influenced the weld quality. From this research work, it is inferred that the rotational speed of 710 rpm, traverse speed of 28mm/min and D/d ratio of 3, for cylindrical pin, is considered to be the most efficient. Furthermore, better mechanical properties were observed with 6 mm squared pin, rotational speed of 1000 rpm and traverse speed of 40mm/min. in addition, the cylindrical threaded and squared pin tool profile are found to be the best among other tool profiles that were considered.

References

[1] Heidarzadeh, A., Khodaverdizadeh, H., Mahmoudi, A., & Nazari, E. Tensile behavior of friction stir welded AA 6061-T4 aluminum alloy joints. JOURNAL OF MATERIALS&DESIGN 2012; 37:166–173.

[2] Sheikhi, S., & Bolfarini, C. Preliminary study on the microstructure and mechanical properties of dissimilar friction stir welds in aircraft aluminium alloys 2024-T351 and 6056-T4 2007; 6:132–142.

[3] Rao, P. Microstructure and Mechanical Properties of Friction Stir Lap Welded Aluminum Alloy AA2014. Journal of Materials Science & Technology 2011; 28(5): 414–426.

[4] Koilraj, M., Sundareswaran, V., Vijayan, S., & Rao, S. R. K. Friction stir welding of dissimilar aluminum alloys AA2219 to AA5083 – Optimization of process parameters using Taguchi technique. Materials and Design 2012; 42:1–7.

[5] Xue, P., Ni, D. R., Wang, D., Xiao, B. L., & Ma, Z. Y. Effect of friction stir welding parameters on the microstructure and mechanical properties of the dissimilar Al – Cu joints 2011; 528:4683–4689.

[6] Padmanaban, G., & Balasubramanian, V. Selection of FSW tool pin profile, shoulder diameter and material for joining AZ31B magnesium alloy – An experimental approach. Materials and Design 2009; 30(7): 2647–2656.

[7] Kwon, Y. J., Shigematsu, I., & Saito, N. Dissimilar friction stir welding between magnesium and aluminum alloys 2008; 62:3827–3829

[8] Ramesh Babu, S., Senthilkumar, V.S., Madhusudhan Reddy, G., Karunamoorthy, L. Microstructural changes and mechanical properties of friction stir processed extruded AZ31B alloy Procedia Engineering 2012;38:2956 – 2966.

[9] El-hafez, H. A. Mechanical Properties and Welding Power of Friction Stirred AA2024-T35 Joints 2011; 839–845.