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Influences of tool geometry on metallurgical and mechanical properties of friction stir welded dissimilar AA 2024 and AA 5052

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Abstract

The present work investigates on the characterization of friction stir welded dissimilar aluminium alloys AA2024 and AA5052. Performance of commonly used tool profiles were compared against the newly developed stepped pin profile. H13 tool steel was used as friction stir tool with various pin profiles which includes cylindrical, cylindrical-threaded, squared, tapered and stepped types. Tensile and hardness studies were done to analyze mechanical behaviour. Macrographs of cylindrical and tapered pins showed minute discontinuities whereas other profiles did not. Microstructure and SEM/EDAX analysis were done to examine the metallurgical changes for every trial. The optimized process parameters of speed and feed were identified to be 1000rpm and 40mm/min respectively. Extensive studies revealed that sound welds were produced in the plates that were welded with new stepped pin tool.

Keywords: AA2024; AA5052; Friction stir welding(FSW); Dissimilar Weld; Tool geometry.

Nomenclature	
Ds	Shoulder diameter
Dp	Pin diameter
DPi	Pitch diameter
Ld	Diagonal length
D1, D2, D3, D4, D5	Diameter of 1st 2nd 3rd 4th 5th steps in stepped pin
Dma	Major diameter in tapered pin
Dmi	Minor diameter in tapered pin

1. Introduction

AA2024 and AA5052 are two aluminium alloys widely used in aerospace, automotive, and shipbuilding industries [1-6]. Fusion welding of dissimilar aluminium alloys is very challenging mainly due to the formation of low melting eutectics by the constituent elements resulting in weld solidification cracking. Hot cracking in aluminium alloys are extremely sensitive

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to weld metal compositions [6]. Therefore solid state joining process becomes more suitable for welding aluminium alloys, since this process does not involve melting. Hence the defects like weld solidification cracking, porosity, segregation, liquid cracking on heat effected zone and brittle inter metallic formation could be avoided using this technique [1,7,12]. In FS welding techniques, tool geometry plays a major role in obtaining desirable metallurgical and mechanical properties [9, 13, 14].

In this study AA2024 and AA5052 were fabricated using friction stir welding process using five different tool pin profiles. Four traditional pin profiles namely cylindrical, threaded, squared, tapered pin and a newly designed stepped pin profile were employed in this research. Xue, et al. (2011) welded Al-Cu dissimilar metals and found that better tensile strengths were achieved in the plates which was welded at 1000 rpm where the tested speed range being 600-1000 rpm. They also concluded that the defect-free joints could be obtained when the plates that had superior mechanical properties were fixed on the advancing side. Kumar et al (2008) has discussed about two types of material flow namely shoulder and pin-driven when welding AA 7020 by FS welding technique using tapered pin. The author reported that the pin transfers the material layer by layer, while the shoulder transfers the material in bulk and forges it. Arora et al (2010) has experimented on FS welding of AA 6061 by changing ratio of shoulder to pin diameter and reported that the defect free welding can be obtained when keeping the D/d ratio is 3:1. Koilraj et al (2012) has studied the FS welding of AA 2219-AA5083 alloy by changing various pin profiles and found that, cylindrical threaded pin has produced defect free welding with good tensile strength. From extensive literature survey it can be deduced that the newly developed stepped pin profile has not been incorporated in the friction stir welding of aluminium alloys. The objective of this attempt is to investigate the microstructural and mechanical properties of the welds made using conventional tools and as compared with stepped pin which is being reported.

2. Experimental Procedure

Commercially available 5mm thick plates of AA2024 and AA5052 were friction stir welded using conventional milling machine employing a specially designed fixture. The chemical composition of AA2024 and AA5052 is tabulated in Table 1. Welding was carried out by placing AA2024 in the advancing side and AA5052 on the retreating side. Tool steel AISI H13 was used in this study with different pin profiles viz. cylindrical, threaded, squared, tapered and stepped pin. The length of tool pin is kept constant at 4.8mm. Experiments were conducted at a feed rate of 40mm/min and 28mm /min against three different speeds of 710, 1000 rpm. As the combination of feed 40mm/min and speed 1000rpm rendered better tensile strength the above parameters were used to weld with all five pin profiles which is tabulated in Table 2. The tool configurations are represented in Fig.1. Tensile test was carried out using INSTRON 8801 UTM according to ASTM E8/E8M standards of sub size specimen. The microstructural examinations were carried out using Carl Zeiss optical microscope. Keller's reagent (150ml of H_2O, 3ml of HNO_3, 6ml of HCL, 6ml of HF) was used as etchant to reveal the microstructure of various weld zones. Micro hardness test were carried out using Vickers micro hardness tester with 100gf load and dwell time of 10 seconds. In order to analyze the constituents in TMAZ and weld, SEM with energy-dispersive spectroscopy (EDS) was used and is represented in Fig 5(a-d).

Table 1.Chemical composition and mechanical properties of base metals

Alloy	Al	Si	Zn	Mn	Mg	Cu	Fe	Cr	UTS (MPa)	Micro hardness(HV)
Al 5052	Bal	.26	.08	.14	2.7	.14	.37	.15	330	87
Al 2024	Bal	0.4	0.25	.7	1.4	3.2	.4	.08	469	137

Table 2. Process parameters

S.No	Material used	Tool design	Rotational speed	Traverse speed	Tilt angle
1	AA2024+AA5052	Threaded	1000	40	2°
2		Squared			
3		Stepped			
4		Cylindrical			
5		Tapered			

3. Results and Discussions

3.1 Metallurgical Characterization

The different types of pin profiles used in this work along with the corresponding tool dimensions and surface morphology can be seen from Fig 1 (a-e) and Fig 2 (a-e) respectively. It is observed that macroscopic defects appeared when using the cylindrical pin tool (Fig 1 (d)). The cross sectional macrograph is represented in Fig 3 (a-e) and it clearly shows void defect while using cylindrical and tapered pin tool (Fig 3(d, e). This could be due to inferior metal flow during the welding process

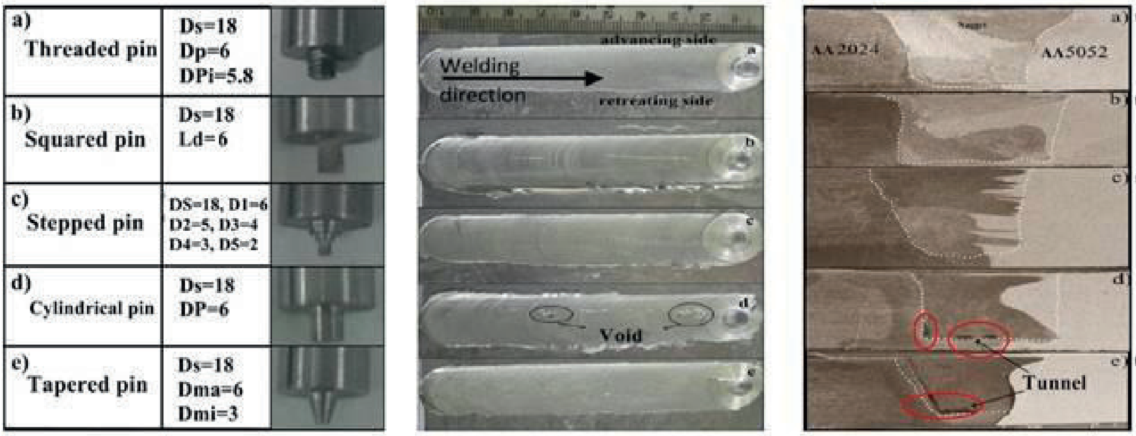

Fig. 1.Tool pin profile and its dimensions. Fig. 2. Surface morphology of the welded samples of the corresponding tool profiles (a, b, c, d, e) Fig. 3. Macrostructures taken from corresponding welded samples.

while using the corresponding profiled tools. On the other hand, the joints fabricated using threaded, squared and stepped pin appeared to be free from defects which could possibly be due to effective mix-up and proper inter diffusion of elements from both base metals Fig. 3(a-c). It could also be due to optimized heat input within the weld nugget while using these profiled tools. This may be due to lack of heat input during the welding process and the nature of pin profile. Comparing all tool pin profiles, threaded pin and stepped pin resulted in uniform mix-up of elements from both base metals Fig. 2(c). The micrographs of FS welded samples obtained using these tool profiles are represented in Fig. 4(a-f). It is observable from Fig 4(a, d) that the material flow from advancing side of AA2024 to the weld nugget is vivid in both threaded and stepped pin profiles. Further refined grain structures appeared on the weld nugget as well as on the AA2024 side.

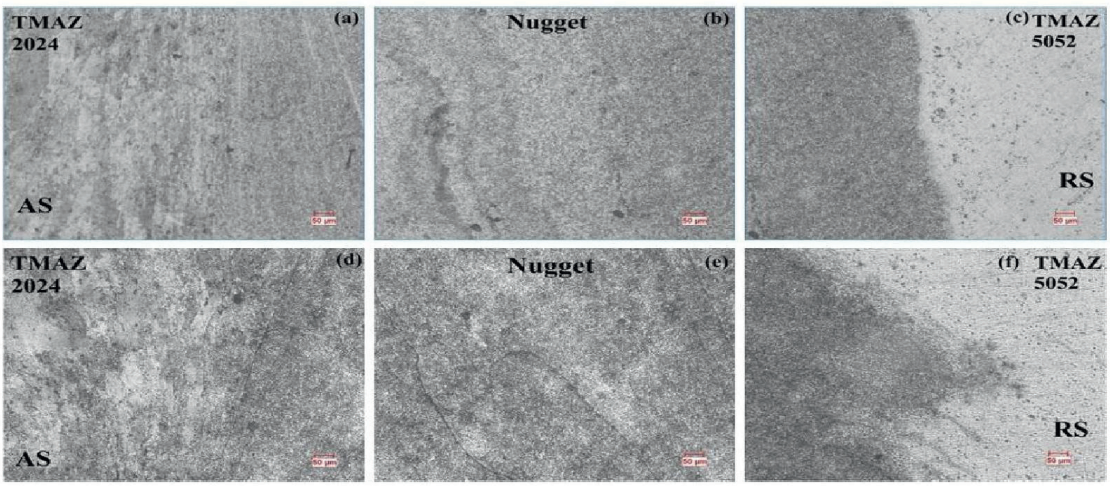

Fig. 4. Microstructure (a) AA 2024 & weld interface of sample welded with threaded pin, (b) Nugget of sample welded with threaded pin (c) AA 5052 & weld interface of sample welded with threaded pin.(d) AA 2024 & weld interface of sample welded with stepped pin(e) Nugget of sample welded with stepped pin (f) AA 5052 & weld interface of sample welded with stepped pin.

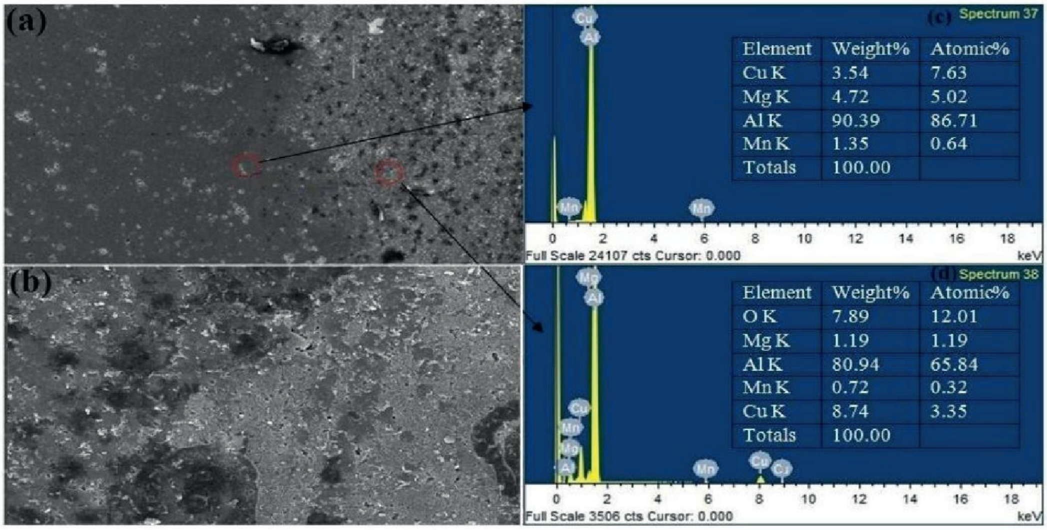

Fig.5.(a)EDS analysis of stepped pin joint (b) SEM of nugget joint made by stepped pin (c)spot analyses of AA2024 TMAZ (d)spot analysis of weld

From the SEM/EDS results, it is evident that the amount of Cu in the weld nugget is higher (8.74%) as compared to TMAZ (3.5%) whereas the content of Mg and Mn are higher in TMAZ as compared to weld nugget. Apparently oxide formation is noticed in the weld nugget but absent in the TMAZ.

3.2 Mechanical Characterization

The tensile test has been carried out for the FS welded samples and the graphs and the averaged results are represented in Table 3 and Fig 6 respectively. Two samples were tested on weldments fabricated with each tool pin profiles to ensure the repeatability of weld consistency and testing. Samples welded with threaded pin gave tensile strength of 259 MPa which is 78% of the strength of AA5052. Interestingly the stepped pin profile yielded tensile strength of 297MPa. The fracture also occurred at the TMAZ of AA5052 and not in the weld.

Table.3. Tensile test report

Ex. no	Tool design	Ultimate Tensile Strength (MPa)	Percentage strength (%)	Fracture spot
1	Threaded	259	78	TMAZ of 5052
2	Squared	200	60	weld
3	Stepped	297	90	TMAZ of 5052
4	Cylindrical	195	59	weld
5	Tapered	202	61	weld

Squared pin, cylindrical pin, and tapered pin fractured in nugget with 60, 59, and 61 percentage of base strength of AA 5052. Stress versus strain graphs are plotted for both samples as depicted in Fig.6. The hardness profiles of the samples welded with traditional tool pins were found to have lower range of hardness value in the weld nugget and heat affected zone. In both the cases, it is apparent the hardness values in the weld nugget seems to be higher than that of the base metal of AA 5052 and less that of AA2024. This is due to the reason that presence of Cu is more in the nugget which is confirmed by EDS analysis from Fig. 5(d). Hardness plot for threaded and stepped pin profile weldments can be seen from Fig. 7. Sudden drop in the hardness value from weld zone to TMAZ in retreating side led to the fracture at that point as micro hardness values are directly proportional to the strength of weld which is also evident from the tensile test. The hardness profile noticed in the weld region of the sample welded with stepped pin is comparatively higher than that of the hardness achieved in joints obtained using other tool profiles eventually proving high strength. Average micro-hardness value of 150HV was obtained in the welded joints produced through stepped pin tool.

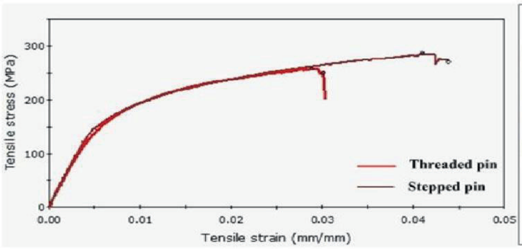

Fig. 6. Tensile strain Vs Tensile stress

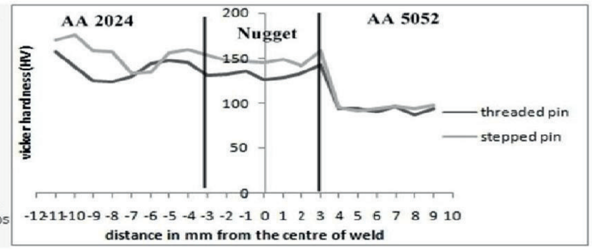

Fig. 7. Hardness profile for sample welded with threaded and stepped pin

3. Conclusions

- Defect free welds were produced using newly designed stepped pin tool, at 1000rpm and 40mm/min.
- From the microstructural studies, it is evident that there is considerable reduction in the grain size of the weld nugget on comparison with the base materials.
- Maximum tensile strength of 297Mpa was obtained on plates that were welded using stepped pin tool. This strength is comparatively higher than that of the ones that were welded with other profiled pins.
- Though cylindrical threaded pin produced sound welds, free from defects, their corresponding tensile and micro-hardness properties were lower than that of the plates that were welded with stepped pin tool.
- Henceforth, stepped pin profiled tool can be considered as a better alternative to the other basic tool pin profiles.

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