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Effect of tool pin profile on the Microstructure and Mechanical properties of Friction Stir Welded AA6061-B_4C Metal Matrix Composites

B.Ravi, B. Balu Naik, G. Raj Kumar

Abstract— Friction Stir Welding (FSW) is a solid state joining technique. It is developed to join high strength aluminum alloys and various ceramic reinforced meta matrix composites (MMCs). FSW produces sound welds in MMCs without any deleterious reaction between reinforcement and matrix. In the present work, Al-10 wt . % B_4C Metal Matrix composites (MMCs) are joined using friction stir welding (FSW) process. Different tool pin profiles are developed to weld the MMCs and the effect of tool pin profile on mechanical and metallurgical properties of the weldments are investigated. The various pin profiles i.e. Straight Cylindrical, Taper Cylindrical, Taper Threaded Cylindrical, Treaded Cylindrical are used to obtain defect free welds. It is observed that joints welded with taper threaded cylindrical pin profile have exhibited better mechanical properties compared to the other pin profiles. Weld nugget has finer grains compared to other weld zones and B_4C particulates are homogeneously present in Al matrix both in weld and parent metal.

Index Terms— AA6061 aluminum, Stir Casting, Friction Stir Welding, Tool pin profile, Tensile Properties

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1 INTRODUCTION

FRICTION stir welding (FSW) was introduced in 1991 by The Welding Institute (TWI) in Cambridge, England, as a solid- state metal joining process (1,2). In the FSW, process parts to be joined must be tightly clamped to backing plate in order to prevent them from moving during the welding process. A rotating pin tool is forced down into a hole along the weld line until the shoulder of the tool comes into contact with the parts to be joined. The rotating tool travels along the joint line direction with a constant welding (traverse) speed. The fig.1 explains the working principle of FSW process.

During the welding process, the material along the joint undergoes intense plastic deformation due to frictional elevated temperature, resulting in fine and equiaxed recrystallized grains, which in turn enhances the mechanical properties of the welded joint (3,4). The friction stir weld joint consists of four distinct zones as shown in fig. 2. They are: (a) nugget zone (NZ) or friction stir processed (FSP) zone, (b) thermomechanically affected zone (TMAZ), (c) heat-affected zone (HAZ) and (d) unaffected base metal. At the NZ, the plastic deformation will produce a recrystallized, equiaxed, and fine-grain microstructure. TMAZ exposes to lower plastic deformation (less than the NZ). Therefore, this zone consists of relatively large grains. The HAZ is not subjected to any plastic deformation. Only; it is exposed to thermal effect, which results in some modification and coarsening the grains. During the FSW process, because of the rotation of the profiled pin of the welding tool nearly concentric rings are developed in the NZ, which is called the onion rings structure (5). The process can be used in many applications, such as the joining of similar metals, dissimilar metals (6), high-strength aerospace aluminum alloys, and composite materials that have limitations to be welded by conventional fusion welding process (7). More details of the advantages and limitations of the FSW process can be found in (8).

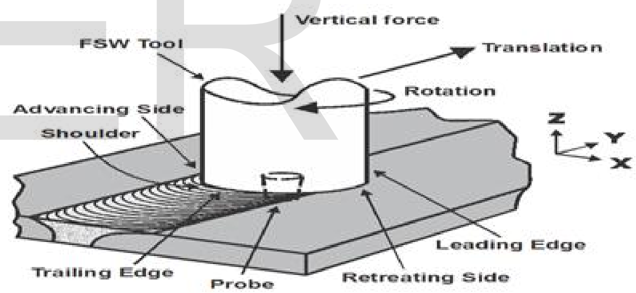

Fig.1. Schematic representation of FSW principle.

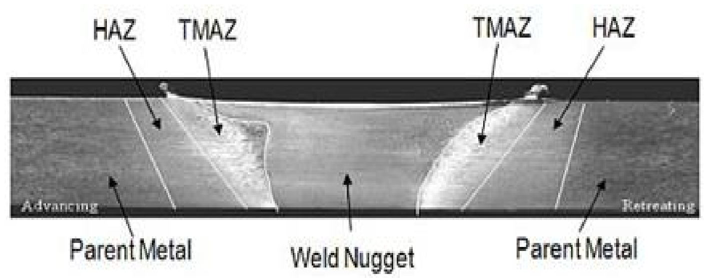

Fig. 2. Different regions of FSW joint.

In the FSW process, the microstructure evolution and the mechanical properties of the weld joints is influenced by the material flow in the weld zone. The most significant parameter affects the materials flow is the tool geometry (9). Among other parameters affecting the material flow are the friction rotational speed and welding (transverse) speed. All these parameters have a remarkable influence on grain size of the NZ microstructure, which, in turn, will affect the mechanical properties of the weld zone (10). In general, it can be stated that FSW

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is a combination of extruding, forging, and stirring of the material (9). Most of the previous studies in the recent developed field of FSW have focused on the effect of welding (transverse) speed and rotational speed on the properties of welded joints (11). Little work has been done to study the effect of the welding pin profile too on properties of friction stir welded joints (12), especially on composite materials. Accordingly, the present work was concentrated on studying the effect of pin profile geometry of the welding tools on mechanical properties, geometry of the welding tools on mechanical properties, utilizing aluminum matrix composites.

2 Experimental work

The rolled plates of 7mm thickness, (AA6061+B4C) aluminum metal matrix composite , have been cut into the required size (100X50 mm) by power hack saw cutting and milling. Square butt joint configuration, as shown in figure 3 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 made of super HSS(high speed steel) have been used to fabricate the joints. The tool dimensions are shown in fig. 4. The chemical composition and mechanical properties of base metal are presented in Table 1. An indigenously designed and developed machine (15 HP; 3000 rpm, 25kN) was used to fabricate the joint. Four different tool pin profiles as shown in Fig. 4 were used to fabricate the joints. Using each tool, 3 joints were fabricate and in total 12 joints (4 X 3) were fabricated. In this investigation, trial experiments were carried out to find out the working limits of welding parameters. The three different welding speeds (0.5 mm/s, 0.67 mm/s, and 0.83 mm/s) and three different tools tilt angles (0^0, 1^0 and 2^0) were used to fabricate the joints. Then the joints were visually inspected for exterior weld defects and it was found that the joints fabricated at the welding speed of 0.83 mm/s and tool tilt angle of 2^0 was free from any external defects. The welding parameters are presented in table 2.

The welded joints were sliced using power hacksaw and then machined to the required dimensions to prepare tensile specimens as shown in Fig. 5. American Society for Testing of Materials (ASTM) guidelines were followed for preparing the test specifications. Tensile test was carried out in 100kN, electro-mechanical controlled Universal Testing Machine. The specimen was loaded at the rate of 1.5 kN/min as per ASTM specifications, so that tensile specimen goes deformation. The specimen finally fails after necking and the load versus displacement was recorded. The 0.2% offset yield strength, ultimate tensile strength and percentage of elongation were evaluated.

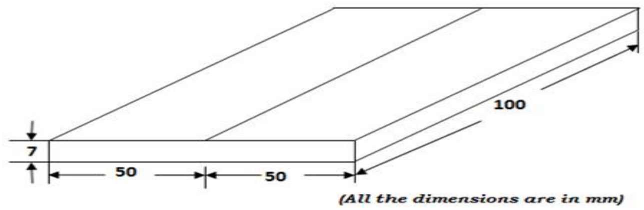

Fig. 3. Dimensions of Square butt joint.

The chemical composition and mechanical properties of base metal are presented in table 1. An indigenously designed and developed machine (15 HP; 3000 RPM; 25KN) has been used to fabricate the joints. Four different tool pin profile, as shown in fig. 5 have been used to fabricate the joints. The welding parameters and tool dimensions are presented in table 2

Table1a
Chemical Composition (wt%) of Aluminum alloy (AA6061).

Elements	***Si***	***Fe***	***C***	***Mn***	***Mg***	***Zn***	***Cr***	***Ti***	***Al***
% by weights	0.64	0.294	0.261	0.095	0.88	0.033	0.089	0.032	Bal

Table 1b
Mechanical Properties of Base metal

Material	*Yield Strength* **(MPa)**	*Ultimate Tensile Strength (MPa)*	*Elongation* **(%)**
Base Metal	198	212	8.5

The welded joints are sliced using power hacksaw and then machined to the required dimensions to prepare tensile specimens as shown in fig.6. American societies for testing materials (ASTM) guidelines are followed for preparing the test specimens. Tensile test has been carried out in 100KN, electromechanical controlled universal testing machine. The specimen is loaded at the rate of 1.5KN/min as per ASTM specifications, so that tensile specimen undergoes deformation. The specimen finally fails after necking and the load versus displacement has been recorded. The 0.2% offset yield strength, ultimate tensile strength and percentage of elongation have been evaluated.

Microstructral analysis was carried out using a light optical microscope (VERSAMET-3) incorporated with an image analyzing software (Clemex-Vision). The spemens for metallographic examination were sectioned to the required sizes from the joint comprising FSP zone, TMAZ, HAZ and base metal regions and polished using different grades of emery papers. Final polishing was done using the diamond compound (1µm particle size) in the disc polishing machine. Specimens were etched with Kellers reagent to reveal the microstructures.

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Tabe2:
Welding parameters and tool dimensions

Process Parameters	*Values*
Rotational Speed(RPM)	800, 900, 1000, 1100, 1200
Welding Speed (mm/min)	50
Tool Tilting Angle (Degree)	2
D/d Ratio of tool	3
Pin Length (mm)	6.5
Tool Shoulder Diameter, D (mm)	21
Pin Diameter, d (mm)	7

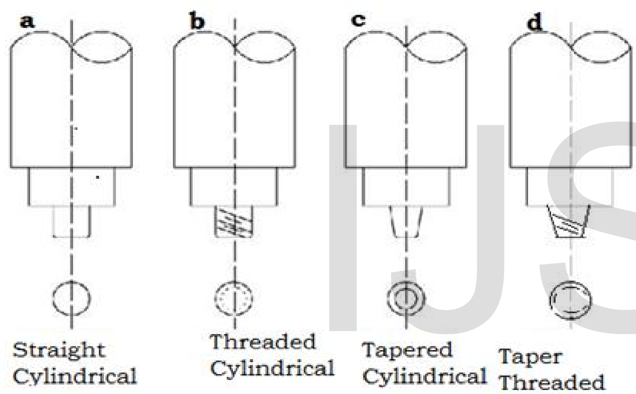

Fig. 4. FSW tool pin profiles.

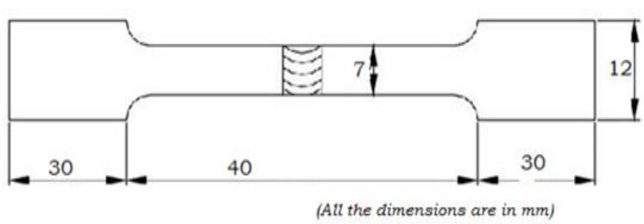

Fig. 5. Dimensions of tensile specimen.

3 Results and Discussion

The various pin profiles i.e. Straight Cylindrical, Taper Cylindrical, Taper Threaded Cylindrical, Treaded Cylindrical are used to obtain defect free welds. In the photomicrographs shown in figs.6, as expected, the weld nugget has a fine equiaxed recrystallized structure, while the parent metal has a coarse grain structure as it is produced using stir casting process.

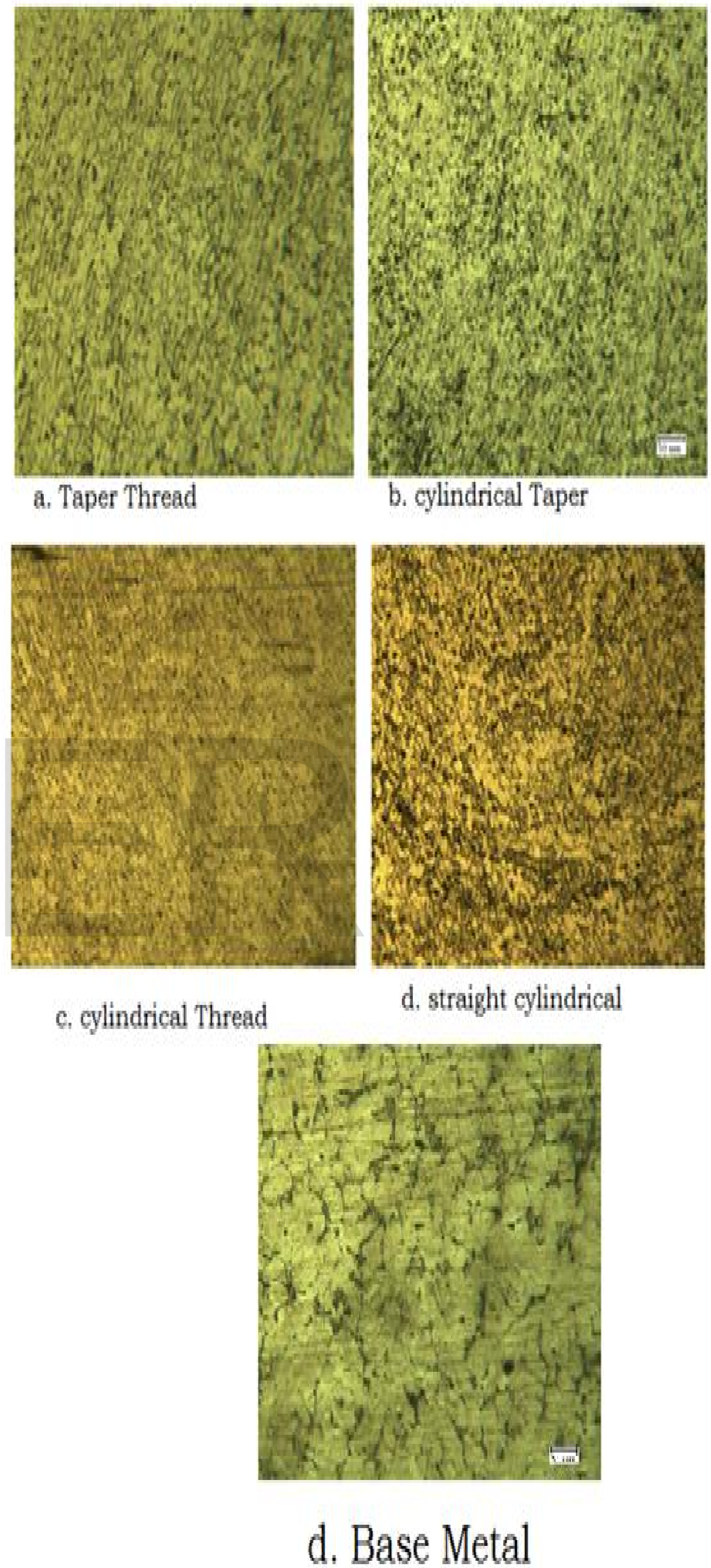

Fig. 6. Photographs of the nugget welded zones

Tensile properties of FSW joints such as yield strength, tensile

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strength, percentage elongation and joint efficiency were evaluated. Three specimens were tested at each condition. Since the observed variation in yield strength and tensile strength data was ±3% and the variation in elongation was ±2%, the average of the results of three specimens was calculated. From the fig.7, it can be inferred that the tool profile is having influence on tensile properties of the FSW joints. Of the four joints, the joints fabricated by taper threaded pin profile exhibited superior tensile properties compared to other joints. The joints fabricated by taper cylinder pin profiled tool and straight cylinder profiled too are almost matching the same results. But the joints fabricated by straight cylindrical pin profiled tool exhibited inferior tensile properties compared to their counterparts. It is due to the difference in dynamic orbit created by the eccentricity of the rotating tool of the FSW process (13). The relationship between the static volume and dynamic volume decides the path for the flow of plasticized material from the leading edge to the trailing edge of the rotating tool. This ratio is equal to 1 for straight cylindrical, 1.01 for threaded cylindrical, 1.09 for tapered cylindrical and 1.26 for taper threaded pin profiles.

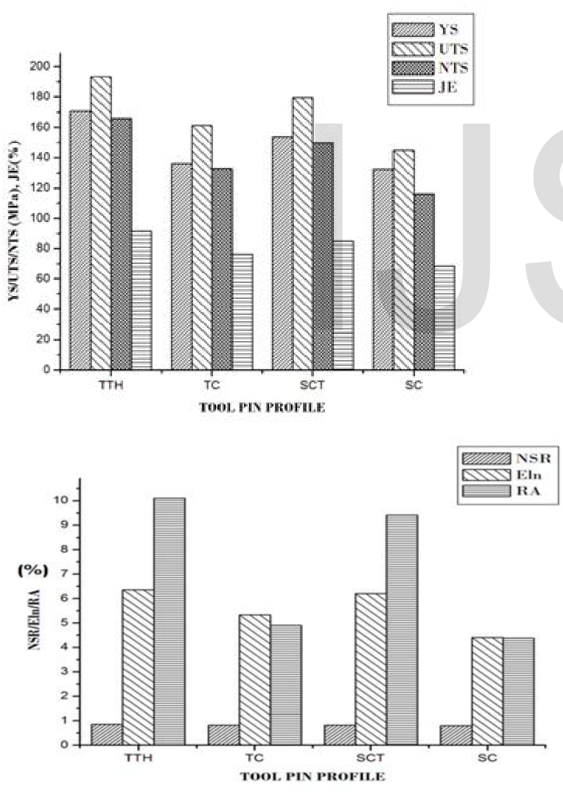

Fig.7. Effect of tool pin profile on tensile properties.

Fig.7. also shows the effect of tool pin profiles on the %elongation of the welded AMCs. It is evident from the graph that the effect of tool pin profile on the % elongation is insignificant except for the straight cylindrical pin profile tool. The reason is the presence of B4C particles in the parent metal which considerably reduces the % elongation of the material (14). The effect of tool pin on the joint efficiency is also similar to that of tensile strength. The joint efficiency is high when the AMC is welded using taper thread pin profile tool and low when it is welded with straight cylindrical pin profile tool.

The failure location is noticed far away from nugget zone, which means welds are stronger than base metal. It is mainly due to fine grain structure observed in nugget zone as shown in microstructure.

4 CONCLUSIONS

The following conclusions can be derived from the above work:

1. Weld nugget has finer grains when compared to the cast parent metal
2. Since the parent metal was cast by stir casting process, it shows larger grains with dendrites.
3. The microstructure of the FS welded specimen is affected by the tool pin profile.
4. The tensile strength of the friction stir welded specimen is also affected by the tool pin profile.
5. The taper threaded tool pin profile exhibited better tensile strength when compared to other tools.
6. Joint efficiency of the taper threaded tool pin profile is more when compare to other tools.

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