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Influence of Tool Pin Profile on Mechanical Properties and Microstructure of Friction Stir Welded Aluminium AA7075 Alloy

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ABSTRACT

The present investigation describes the effect of different tool pin profiles on microstructure and mechanical properties of friction stir welded aluminium AA-7075 alloy. The tool pin profiles namely taper cylindrical threaded (TT), cylindrical (CT), square (SQ), triangular (TR), pentagonal (PT), hexagonal (HX) with constant shoulder diameter have been selected to make joints. The friction stir welding was done at constant tool rotational speed and traverse speed. From this study, it is noted that the weld joints prepared using taper cylindrical threaded pin profile exhibited good mechanical properties when compared to other pin profiles. It is due to more surface contact of tool pin and production of equiaxed fine grain structure in the weld region.

KEYWORDS: *AA7075 aluminium alloys, Tool pin profile, Friction stir welding*

INTRODUCTION

Friction stir welding (FSW) is a new welding technique in which, a non- consumable rotating tool pin advances along the weld interface, generates frictional heat resulting recirculating flow of deformed material around to the FSW tool surface. The deformed metal is moved from the advancing side to retreating side of the tool pin where it is pressed into a weld joint and leaving the solid phase bond between two sheets (Thomas, 1991).

Literature reported that FSW process has been applied for welding of many materials including aluminium, steel, magnesium, titanium copper, and other dissimilar materials (Jayaraman et al, 2009; Jayaraman et al, 2010; Padmanabhan et al, 2009; Raynolds et al, 2003; Park et al, 2004 and Lee et al , 2005). The alloy under this study is Al 7075 alloy used many industrial applications including aircraft, defense, shipbuilding and automotive due to its good strength, corrosion resistance and weldability (Chandler et al, 1987) Jayaraman et al. (2010) carried out the optimization of FSW process parameters to yield high tensile strength of FSWed cast A319 aluminium alloy. Karthekeyan et al. (2012) explained the tool design influence on microstructure and mechanical properties of FSWed aluminium 6351 alloy. They reported that the tool pin profile has more impact on the ultimate tensile strength of the weld. Sakthivel et al. (2009) studied the influence of welding speed on mechanical properties and microstructure of friction stir welded aluminium material. They concluded that there is a correlation between welding speeds and mechanical properties.

Padmanaban et al. (2008) found that 18 mm shoulder diameter threaded tool pin profile produced mechanically sound and metallurgically defect free welds. Elangovan et al. (2007) conducted experiments to find out the influence of FSW tool pin profile and size of shoulder diameter on the production of friction stir processing zone in aluminum 6061 alloy and reported that the 18 mm shoulder diameter square pin profiled tool fabricated mechanically sound and metallurgically defect free welds when compared to other pin profiles. Rajakumar et al. (2011) investigated the effect of FSW process and tool parameters on tensile strength of aluminium AA7075- T6 alloy joints. Ilangovan et al. (2015) studied the mechanical properties and microstructure of FSWed dissimilar AA6061 and AA5086 alloy joints and maximum hardness of HV 115 for dissimilar joint. Kumar et al. (2012) studied the influence of different tool pin profiles on FSW of copper. They reported that square tool pin profile fabricated defect free joints resulted better mechanical properties compared to other pin profiles. Suresha et al. (2011) studied the influence of various tool pin profiles on ultimate tensile strength of FSP welded. The main aim of this study is to find the effect of different types tool pin profiles on mechanical properties and microstructure of FSWed AA 7075 alloy.

EXPERIMENTAL WORK

In this work, the base material was cut into 120 mm × 100 mm specimens using milling machine. The tensile test was performed for welded samples to determine mechanical properties such as tensile strength, yield strength and percentage elongation. Table1 and Table 2 represent chemical composition and mechanical properties of the base metal respectively. Before performing friction stir processing, the specimen needs to be welded in FSP was tightly clamped onto the supported plate using holding clamps that were bolted to the machine work table. Frictional heating is provided by rubbing the rotating shoulder with work piece material, whereas the rotating pin stirred the locally heated material and caused plastic deformation within the work piece. Fig.1 shows experimental setup for friction stir welding. The tool pin profiles used in this study to make welds are shown in Fig .2.

Table 1. Chemical composition of AA7075

Element	Si	Fe	Mn	Mg	Cu	Zn	Al
% Wt	0.31	0.20	0.20	2.67	1.71	5.72	89.06

Table 2. Mechanical properties of parent metal

Tensile strength (MPa)	Yield strength (Mpa)	Elongation (%)	Hardness (H_V)
567	496	11	50

Due to high thermal fatigue resistance, high strength at higher temperature and low wear resistance, H13 tool steel has been selected as tool material. Preliminary tests were done for different rotational speeds and traverse speeds to fix the optimal process parameters of FSW. The better results were obtained at 900 rpm rotational speed and 40 mm/min traverse speed. The welding joints were made for various tool pin profiles namely, TT, TC,TR, PT, SQ, HX (Fig 2) at constant tool rotational speed 900 rpm and 40 mm/min welding speed. The FSW parameters and tool nomenclature used to make weld joints are shown in Table 3.

Table 3. Welding Process parameters and Tool dimensions

Process parameter	Value
Rotational speed	900 rpm
Welding speed	43mm/min
Tool shoulder diameter	21mm
Pin diameter	7mm
D/d ratio	3
Pin length	5.7mm
Tool tilt angle	3 degrees

Figure 1 Friction stir welding experimental set-up

Figure 2 Tools used for welding

The tensile test was performed on welded components to determine the mechanical properties such as tensile strength, yield strength and percentage of elongation. The samples have been prepared parallel to processed direction from the processed composites as per ASTM E8M-04 standards and carried out on a 60 ton universal testing machine. Vickers Micro-Hardness testing machine has been used to test the micro hardness of the welded specimen under the load of 5 kgf and dwell period of 10 s. Optical microscope was used to analyze the microstructure of the base metal and welded specimens. The welded specimens were cut into the required size and polished by emery papers with different grades. To reveal the microstructure, the etching has been done by standard kellers reagent prepared by hydrofluoric acid, nitric acid and diluted water.

RESULTS AND DISCUSSION

Tensile Properties

Tensile properties such as tensile strength (UTS), yield strength (YS), ductility or percentage of elongation of welded joints made using different tool pin profiles of the friction stir welded joints are shown in Table 4. It can be clearly found from the results that profile of the tool pin has major influence on the results of FSW joints. The joint made using TT pin profile exhibit higher tensile properties with 91.7 % weld joint efficiency compared to other welds. It is due to high surface area contact of tool and dynamic volume to static volume ratio (DV/SV) (1.01) results more amount of heat generation during processing compared to other profiles. More heat input and severe strain induced by pin enhance the flow of the plastic material resulting dynamic recrystallization of the material. Finer grain microstructure can be obtained during dynamic recrystallisation either at lower temperature with higher strain rate or at higher temperature with lower strain rate. This production of equiaxed fine grain structure in the weld zone is cause for superior mechanical properties of the welded metal. The tool without the screw thread generates less amount of heat and transfers material insufficiently as a result of void in the weld. The welds made by other tool pin profiles such as SQ, TR, PT, and HX show poor mechanical properties; this is due to low surface area contact of tool with work piece. The weld joints made with TR SQ, CT,PT, HX pin profile are showed tensile strengths 471 Mpa, 437 Mpa, 405 Mpa, 425 Mpa and 364 Mpa respectively and their joint efficiencies are 17.7%, 23% , 28.6 %, 25.1 35.8 % less than based material. The dynamic volume and static volume relationship determines the path for the deformed metal from the advance side to retreating side of the tool [12]. This ratio is 1 for CT, 1.20 for HX, 1.01 for TT, 1.31 for PT, 1.56 for SQ, 2.41 for TR pin profiles. When the tool rotates at 900 rpm speed, SQ profile induces 60 pulses/s, TR pin profile induces 45 pulses/s, HX pin profile induces 90 pulses/s, PT pin profile produces 75 pulses/s and there is no such pulsating action in the case of TT and CT pin profiles. The TT tool showed highest tensile properties, even though HX pin profile produces more number of pulses, it indicates that the pulsating action has no influence on the properties of FSWed material.

Table 4. Mechanical properties of FSWed AA7075 and DV/SV for different pin profiles

Pin Profile	UTS (MPa)	Yield Stress (MPa)	% Elongation	Joint efficiency (%)	DV/SV
TT	520	153.1	5	91.7	1.01
CT	405	93.8	2.9	71.4	1
SQ	437	124.6	3.4	77.0	1.56
HX	364	90.4	2.7	64.2	1.20
TR	471	145.4	3.6	82.3	2.41
PT	425	104	3.6	74.9	1.31

Microhardness

The micro hardness variation across the weld region was measured for different profiles and presented in the Fig.3. The hardness of the base metal is 50Hv. Fig. 3 shows that the weld made with TT pin profile revealed superior hardness in the weld zone compared to other profiles and. It is observed that the hardness of all joints lower than that of base material due to plasticizing of material during dynamic recovery and dynamic recrystallization (Kumar et al, 2012). However, TT profile has produced highest hardness value of 46 Hv at the weld zone compared to other welds prepared by different tool pin profiles. It is due to generation of fine equiaxed grain structure at weld zone of the weld joint. It is also found that the micro hardness values of the region far-off from the nugget zone are closer to base material hardness value. It is due to the inadequate mechanical deformation and heat exposure in thermo-mechanical affected zone of advancing side and retreating side.

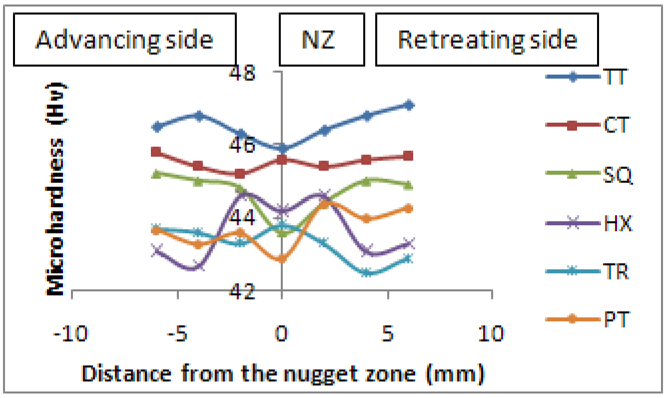

Figure 3 Micro hardness distribution of FSW joints for different pin profiles

Microstructural Studies

In this investigation, microstructure analysis in the dynamically recrystallised stir zone and thermo mechanically affected zone is studied. The FSP area is divided in to three distinct zones such as the stir zone, thermo mechanical affected zone and the heat affected zone(HAZ), based on thermo mechanical application. The nugget zone corresponds to the area previously settled by the tool pin, which is completely recrystallized region. Thermo mechanically affected zone (TMAZ) is the area in which the material has undergone intense deformation and also affected the microstructure by the temperature rise that occurred through the tool pin rotation. Heat affected zone (HAZ) is far away from TMAZ in which no plastic deformation was occurred. Moreover, due to the thermal process a minor change in the microstructure may have occurred. Beyond this, there will not be any change in the microstructure.

The optical micrographs were taken at NZ and TMAZ of the advancing side (AS) and the retreating side (RS) for all the joints presented in Fig.4. It is observed from optical micrographs that the joint made with threaded pin profile shows finer grains along with sub grains in the nugget region compared to other joints. The appearance of very fine equiaxed grains in the nugget region is the reason for better mechanical properties of these welded joints compared to others. The parent material aluminium 7075alloy contains of acicular eutectic precipitates $MgZn_2$ immersed in aluminium matrix and also grain size is not uniform as shown in the microstructure. Due to stirring action at the plastic condition of FSW process, MgZn2 particles breakup resulting formation of uniform fine grains in the aluminium matrix.

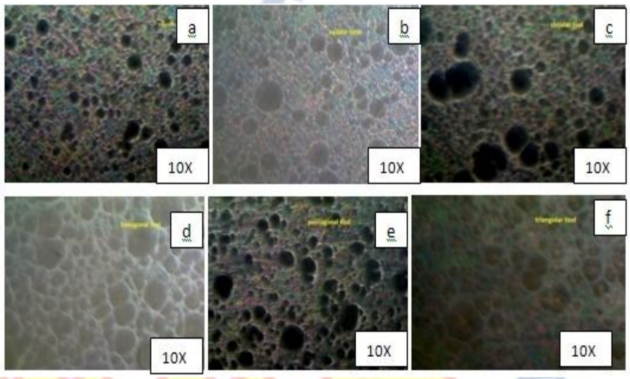

Figure 4 Microstructures of weld zones of welded samples by various pin profiles (a) TT, (b) SQ, (c) CT, (d) HX, (e) PT and (f) TRA

Conclusion

The effect of different tool pin profiles on micro structure and mechanical properties of FSW of AA 7075 was studied. The conclusions are as follows

1. The tool pin profile has significant influence on the mechanical properties of the friction stir welded AA7075 aluminium alloy.
2. Taper threaded tool pin profile produced better mechanical properties due to more surface area contact and having DV/SV ratio 1.01 and also showed finer grains along large quantity of sub grains in the nugget region.
3. The weld joint fabricated using a TT pin profile showed high joint efficiency (91.7%) than welds made by other tool pin profiles.

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