EXPERIMENTAL INVESTIGATION ON INFLUENCES OF TOOL ROTATIONAL SPEED AND PIN PROFILE ON FRICTION STIR WELDING OF AA7075 ALUMINIUM ALLOYS

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Abstract: AA 7075 aluminium alloy with Zinc (Zn) as primary alloying element is considered as the one of the strongest material in the family of aluminium alloys. Conventional welding of AA 7075-O is difficult, and Friction Stir Welding is chosen over conventional fusion welding techniques. Friction Stir Welding (FSW) is a relatively new entrant in the domain of solid state joining techniques and is proved to be ideal for joining metals that are generally non-heat treatable. In the present work, an attempt has been made to investigate the influence of tool rotational speed and tool pin profile on the formation of weld zone of AA7075.Tests like tensile test, Vickers hardness test, Izod impact test, macro and micro structure tests have been performed on the weldments. Results revealed that the joint fabricated with tool rotational speed of 1400 rpm and with triangular pin profile tool have yielded optimum results compared to its counterparts.

***Key Words*- AA 7075, Friction Stir Welding (FSW), tool pin profile, tool rotational speed, tensile strength, impact strength, hardness, macro and microstructures.**

I. Introduction

FSW is a relatively new solid-state welding technique developed by Thomas W.M. at TWI institute, UK in the year 1991[1]. This technique involves in the use of non-consumable tool that is inserted into the welding joint and is traversed along the joint.

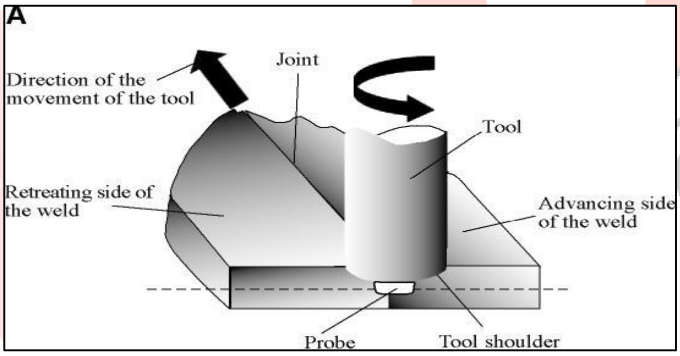

Fig. 1 Schematic representation of FSW [20]

During welding, the plasticized material in front of the tool is extruded around the pin where it is deposited behind the tool pin and forged into a solid joint. FSW is blessed to have advantages like no usage of filler material, no melting of base material, no presence of fumes, no use of shielding gases, less distortion to the base material in the weld zone. Process parameters like tool rotational speed, welding speed or feed, axial load, tool tilt angle, shoulder diameter, pin diameter, pin profile etc. effect the quality of weldments of FSW. AA-7075 [Al-Zn-Mg-Cu] is heat treatable alloy and the unique combination of characteristics like high strength to weight ratio, natural aging makes AA7075 to be considered as one of the high strength alloy which makes it a natural choice for fabrication of aircraft components, military vehicles, mobile equipment, earth moving equipment and similar applications involving highly stressed regions [3-5]. This alloy derives its strength from precipitation of Mg_2Zn and Al_2CuMg phases. The major problem associated with the AA7075 is that it is not fusion weldable. It is extremely sensitive to cracking of weld during solidification and presence of Cu particles in AA7075 results in liquation cracking in HAZ of the weldment. Even the high operating temperatures associated with the fusion welding results in evaporation of Zn particles which yields the defects like porosity, lack of fusion, hazardous fumes etc. Hence FSW is considered as an ideal technique for AA7075 and other similar Al alloys [6-8].

K. Dehghani et al. [9] has studied the microstructure evolution of weld zone and reported that there are micro structural evolutions including the variations in the size and distributions of precipitates after FSW. He also reported that the precipitates are relatively coarser in HAZ and relatively finer in SZ. A.H. Lofti et al. [10] has studied the effect of welding parameters on AA7075 on both –O condition and –T651 condition and have concluded that weldments from –O plate exhibited better properties when compared it with that of –T651. (The reason is due to strength in NZ increased due to better fine grain refinement whereas for –T651 condition, strength decreases due to dissolution and coarsening of particles in age-hardening. S. Rajakumar et al. [11] have achieved a weld strength of 77% of base material with process parameters as TRS 1400 rpm, WS 60mm/min, force 8kN, shoulder diameter 15 mm and pin diameter as 5 mm T. Srinivas Rao et al. [12] studied the microstructure and mechanical properties of Friction Stir Welded AA7075-T651 and have concluded that joints fabricated with plates of thickness up to 10 m have yielded better results in terms tensile strength and microstructure, when compared with that of 16mm thick plates. T. Azimzadegan et al. [13] studied the effect of high rotational speed on properties of AA7075 during FSW and reported that defect free joints were obtained for a speed of 900 rpm and with threaded taper tool and 700 rpm for four-flute tool. Hamad J. A. [14] studied the effect of tool pin profile on mechanical and micro structural behaviors in dissimilar FSW of AA6082 and AA7075 and reported that peak temperature was recorded by conical probe with three grooves than by square frustum probes. He also reported that a decrease in weld pitch resulted in decreased strength of welds and coarser grain sizes in the weld nugget, square frustum probe showed finer recrystallized grains than one with –O designation. Kush. P. Mehta et al. [15] has studied the influence of tool pin design on formation of defects in FSW and reported that defects will be decreased with an increase in the number of polygonal edges. Detachment of Cu particles were observed in case o0f polygonal edges in case of polygonal pin designs. Defect free macro joint was reported for cylindrical tool profile. The available literature on Friction Stir welding of AA7075 is relatively low. Hence in this present research work, an attempt has been made to understand the influence of tool rotational speed and tool pin profile on the properties of weldments fabricated by Friction Stir Welding.

II. Experimental Work

Rolled plates of 6mm thickness AA7075 with dimensions of 100 mm x 150 mm were cut with power hacksaw. The plates were setup in butt configuration initially by securing the position with the help of mechanical clamps. Non- consumable tools of H13 hardened tool steel material is used for the fabrication of joints. Single pass welding has been employed for the fabrication of joints. The direction of welding is normal to direction of rolling and the welding has been carried out on conventional vertical milling machine of make: HMT. The specifications of the machine are as follows:

Number of speeds : 18
Speed range (rpm) : 25.5-1800
Main motor (kW/rpm) : 5.5/100
Feed motor (kW/rpm) : 1.5/100
Overall dimensions (mm x mm) : 1520 x 310

The dimensions of tool employed in the present study are tool shoulder diameter as 18mm, pin diameter as 6mm, pin length as 5.7mm.


Fig. 2a) Tapered cylindrical pin profile tool


Fig. 2b) Triangular pin profile tool

For tapered cylinder tool diameter of pin at the base of tool is 6mm and at the end it converges to 3 mm and for the tool with triangular pin profile the pin is made of equilateral triangle

Table 1. Chemical composition of AA7075

Al	Cr	Cu	Fe	Mg	Mn	Si	Zn
88.23	0.22	1.31	0.457	2.18	0.042	0.057	5.98

Table 2. Mechanical properties of AA-7075

Material	0.2% proof stress (MPa)	Ultimate tensile strength (MPa)	% Elongation	Hardness (Vickers)
AA7075	549.1	577.1	11.9	184.3

Table 3. The value of process parameters chosen

Welding speed (mm/min)	40
Tool rotational speed (rpm)	900, 1120, 1400, 1800
Axial load (kN)	5
Tool Tilt Angle (Degrees)	0
Tool pin profiles	Tapered cylinder (TC), Triangular (T)

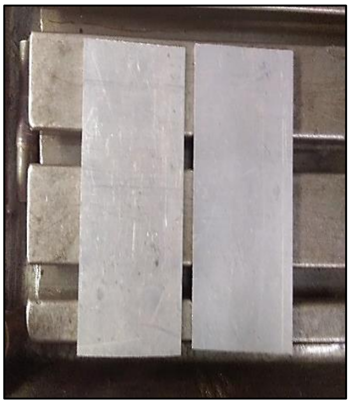
Fig. 3a) Shows the individual plates of AA7075 cut in required dimensions


Fig. 3b) Shows the Friction Stir Welding is performed.


Fig. 3c) Shows the welded plates

Table 3. The value of process parameters chosen

Welding speed (mm/min)	40
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Axial load (kN)	5
Tool Tilt Angle (Degrees)	0
Tool pin profiles	Tapered cylinder (TC), Triangular (T)

Table 4. Design of experiments carried for joining of AA7075

Experiment no.	Name of the tool	Tool rotational speed (rpm)
1	Tapered cylinder	900
2	Tapered cylinder	1120
3	Tapered cylinder	1400
4	Tapered cylinder	1800
5	Triangle	900
6	Triangle	1120
7	Triangle	1400
8	Triangle	1800

The flash of the welds was removed manually with chipping tool and wooden mallet. The tensile specimens were cut with wire cut EDM perpendicular to weld direction

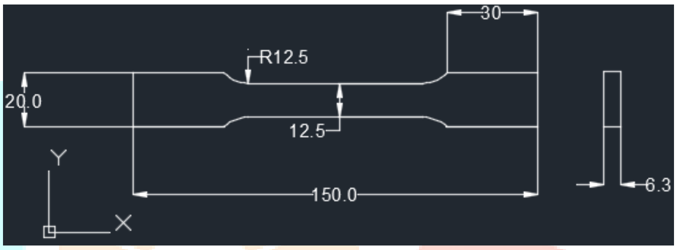

Fig. 4 ASTM E8 standard tensile test specimen [21]

Tensile test has been carried out on 40 Ton UTM. 0.2% offset yield strength, ultimate tensile strength and percentage of elongation have been evaluated two specimens from each weldment were cut for performing tensile strength and the average of two values were taken for the calculation of tensile strength.

Izod impact test specimens were cut from weld joints with wire cut EDM according to ASTM E23-16b as shown in Fig. 5.

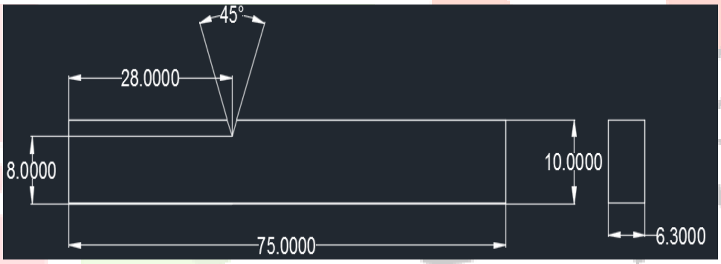

Fig. 5 ASTM E23-16b standard Izod impact test specimen [22]

Specimens of dimensions 30 mm x 5 mm were surface finished with emery papers in the order of 1/0,2/0,3/0,4/0 respectively and polished on a disc polishing machine with alumina paste as abrasive media. The specimens are then treated with Keller's reagent to study the macro and micro structures of the weldments. Hardness tests are performed on the same specimens that are used for macro and micro structures on Vickers hardness tester machine with a load of 0.5 kg and dwell time of 10 seconds.

III. Results and Discussions

All the weldments fabricated with FSW are examined under light optical microscope to understand the quality of fabricated joint. Void defects were observed in all the joints except for the weldments fabricated for welding parameters, Tool rotational speed of 1400 rpm in case of both tapered cylinder and triangular pin profile. Most of the joints contained voids and tunnel defects because of low tool rotational speed, less heat generation and improper mixing of the plasticized material in the FSP region, this is because of loss of frictional heat generated between the tool, backing plate and to the surrounding atmosphere. For the joints fabricated with tool rotational speed of 1800 rpm exhibited flash defect. This might be due to excessive deformation of material in the FSP region that leads to the loss of material in the FSP region, resulting in a lower efficient joint

Tensile test:

Tensile tests were performed over the specimens with the help of Universal Testing Machine (UTM) with a load rate of 1kN/min and the results can be depicted in the form of a graph as in Fig. 6.

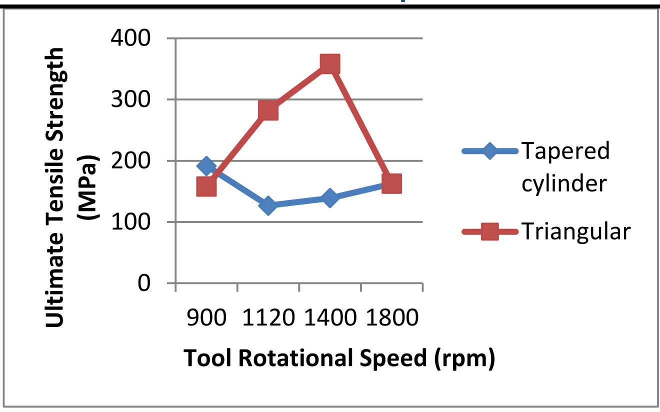

Fig. 6 Tensile strength of AA7075 weldments

The effect of tool rotational speed and profile of the tool on the tensile strength of the joints is plotted in the above graph and it is clear that the joints fabricated with triangular pin profile tool has exhibited superior tensile properties at tool rotational speeds of 1120, 1400, 1800 rpm. According to palanivel et al. [16] the factors that determine the tensile strength of the aluminium joints are 1) presence of macroscopic defects in the weld zone 2) amount of mixing and degree of plastic flow of the material in the weld zone 3) size of the grains in the HAZ.
It is observed that most of the joints have failed in the Heat Affected Zone of the weldment and this might be due to the presence of coarser grains in the zone.

Impact test:

Izod impact tests are performed using Izod impact testing machine at room temperature. Single specimen from each joint is considered for the analysis of impact strength of weldments and the results are shown in the Fig. 7.

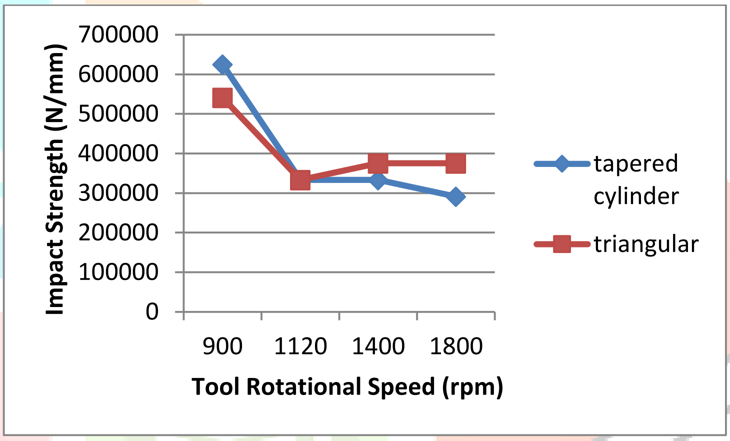

Fig. 7 Impact strength of AA7075 weldments

It is evident from the graph that, the tool rotational speed and tool pin profile have considerable effect on the impact strength of the weldment. It is also notable that the joints fabricated with triangular tool pin profile at 900 rpm have superior impact strength over joints fabricated with tapered cylinder pin profile and this might be due to the effective mixing of plasticized material in the weld zone and sufficient heat generation between the tool and workpiece required for the fabrication of the joint.

Vickers hardness test:

Vickers hardness test is performed on the Nugget Zone or weld zone of the joint of the specimen. Test is performed with application of 1 kg load for dwell time of 10 seconds. Average of two values of hardness is considered for the calculation of hardness of the weld zone. The following graph shows the variation of hardness in the Nugget zone of the weldments with variation of tool rotation speed for two different tool pin profiles.

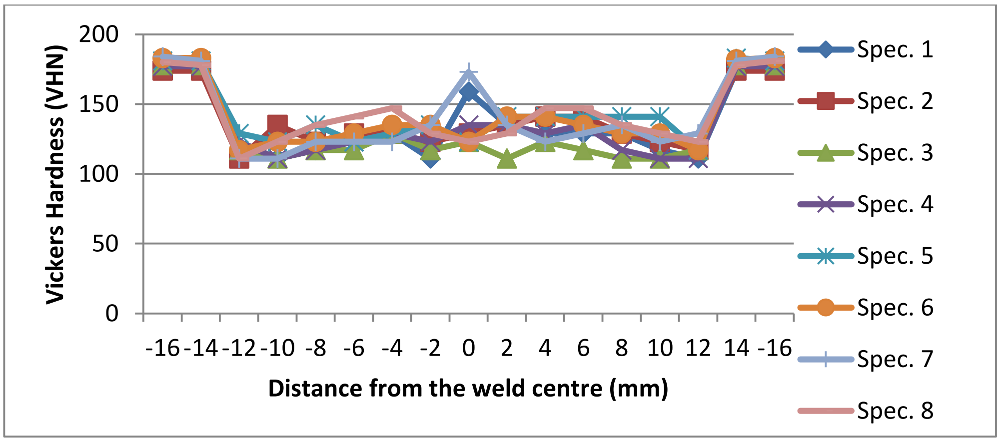

Fig. 8 Vickers hardness of AA7075 weldments

The hardness test is carried over the length of the specimen with an interval of 2mm to determine the variation in the hardness across various zones. During the FSW process the material from the advancing side of the joint is excavated from the front face of the tool and is deposited in the retreating side of the tool and flows from rear of the tool to front of the tool to fill the vacancy formed during the excavation of the material [6]. Stir zone consists of mainly three regions i) Un Mixed Region (UMR) ii) Mechanically Mixed Region (MMR) iii) Stirring induced Plastic Flow Region (SFPR) [17]. The variation in the hardness in the stir zone is mainly due to the presence of these regions and is mainly influenced by the type of tool pin profile employed for the fabrication of the joint. As displayed in the graph the first four specimens represent the weldments fabricated by the tapered cylinder tool pin and the next four weldments represent the weldments fabricated with triangular tool pin profile. It is evident from the graph that the weldments fabricated with triangular tool pin have yielded higher hardness values than the ones with tapered tool and this might be due to because cylindrical pin profile does not result in SPFR [16] where the intense mixing of the plasticized material takes place during the welding.

Macrostructure and microstructure: Macro structure refers to the examination of specimen at a magnification of 10x by using light optical microscope and revealed the following structure.

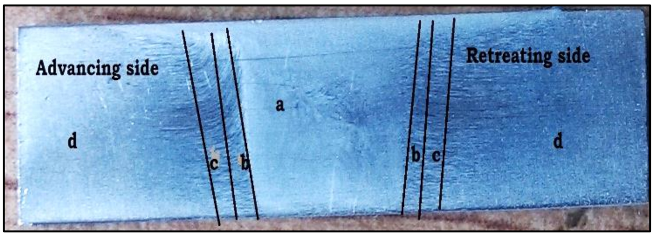

Fig. 9 a) NZ b) TMAZ c) HAZ d) BM

The Fig.9 shows the formation of various zones in FSW joints of AA7075 at tool rotation speed of 1400 rpm with tapered cylinder tool pin profile.

Microstructure of the specimens is examined with a magnification of 100x under Optical metallurgical microscope (MET SCOPE-I).

The microstructure of specimens is as follows:

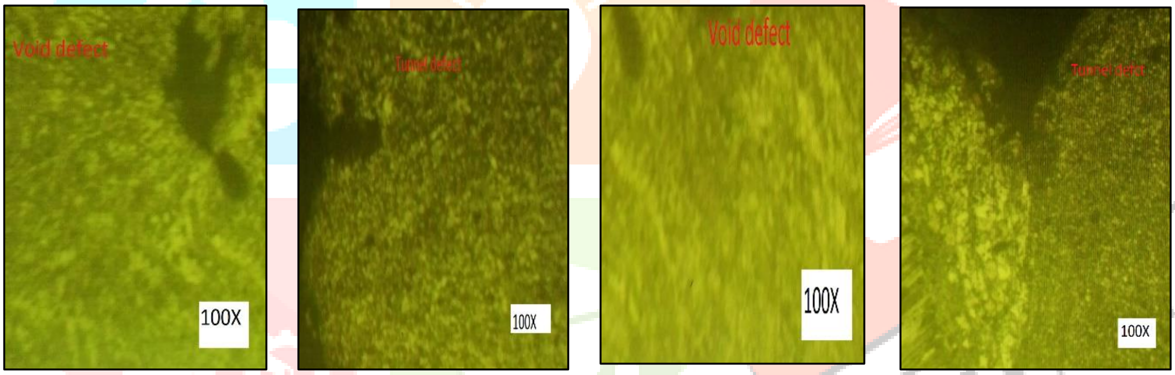

Fig. 10a) TRS-900rpm, Tapered Cylindrical pin tool

Fig. 10b) TRS-1800 rpm, Tapered Cylindrical pin tool

Fig. 10c) TRS-900 rpm Triangular pin tool

Fig. 10d) TRS-900rpm Triangular pin tool

The macrostructure represented in the figure 9 represents the joint fabricated with triangular pin tool and at tool rotational speed of 1400 rpm. It is observed that most of the weldments are defect free. Tunnel defect at the bottom is identified for the weldments fabricated with tapered cylindrical tool at tool rotational speeds of 900 rpm and 1120m rpm implying insufficient heat generation in the weld zone. The two process parameters tool rotational speed and tool pin profile significantly affect the properties of weldments during friction stir welding [17]. The straight profiled tool will have the more contact area than tapered profile tools [18] and this relatively less contact area might be the reason for insufficient heat generation in the weld zone and principal reason for the formation of defects.

Microstructure of the weldments revealed that the weldments in size in the fabricated with tool rotational speeds of 1400 rpm have showed finer grain size in the weldments irrespective of the tool used for fabrication. This is due to the use of tools with flat surfaces. Flat surface of the shoulder having associated eccentricity [19] will provide better stirring action in the weld zone and results in the finer grains in the stir zones. The combination of flat shoulder surface and three faces of the pin of triangular tool pin profile has made the triangular pin tool to fabricate weldments with finer grains in the weld zone.

IV. Conclusions

Influence of tool pin profile and tool rotational speed on properties of Friction Stir welded joints have been studied and following conclusions are drawn:

1. Out of both tools the tensile strength obtained was more at the joint fabricated by the triangular tool pin at tool rotational speed of 1400 rpm and it accounts for 62% of the tensile strength of base material.
2. The maximum impact strength obtained for the weldment fabricated by tapered cylindrical tool at tool rotational speed of 900 rpm.
3. The maximum hardness value is obtained for the weldment fabricated by triangular pin tool at tool rotational speed of 1800 rpm.
4. Blow hole defects are observed in the weldments fabricated at the tool rotational speeds of 900 rpm and 1800 rpm in the case of both the tools.
5. Macroscopically defect free joints were obtained for all the joints except for the weldment fabricated at lower tool rotational speed of 900 rpm with tapered cylinder and triangular pin profile.

ACKNOWLEDGEMENT

I express my deep sense of gratitude to my Project Guide M. Subramanya Srinivasa Rao, Assistant professor, VNRVJIET for directing me throughout the project with his valuable suggestions, Dr. B. D. V. Chandra Mohan Rao and M. Shiva Prasad for giving the opportunity to utilize various testing facilities at VNR VJIET.

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