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Experimental study on the effect of welding speed and tool pin profiles on AA2014-T6 friction stir welded butt joints

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Abstract— Friction stir welding (FSW) is an origin for solid state joining process. The function of FSW process are used in several industries such as aerospace, rail, automotive and marine industries for joining aluminium, magnesium and copper alloy. Porosity, solidification, liquification and cracking do not see in FSW. Friction stir tool is that the necessary tools of friction stir welding process. The welding parameters (rotational speed, welding speed, axial force and tilt angle) and tool pin profile plays a vital responsibility in deciding the weld quality. In this research work primarily examine the effect of different welding speed and tool pin profiles on the weld quality of AA2014.Taper cylindrical threaded pin and tri-fluted taper cylindrical threaded pin are used as tool pin profiles in this research. By using these tools appearance of the weld is well and no obvious defect is initiated. Mechanical properties of AA2014-T6 welded plates will be computed at the weld center of all joints. The good weldment were obtained with tri-fluted taper cylindrical threaded pin at the tool rotational speed of 900rpm and tool welding speed of 40mm/min.

Keywords— Friction stir welding, AA2014 Al alloy, tool pin profiles, tri-fluted taper cylindrical threaded pin, tool rotational speed, tool welding speed and mechanical properties.

INTRODUCTION

Aluminium and its alloys are having been used in engineering applications. The manifestations of aluminium are low density, good mechanical properties, good surface finish and relative fine corrosion resistance. AA2014 is most widely used in the air craft structure, truck body, heavy duty forgings, extrusions for aircraft fittings, wheels, major structural components, space booster tankage, truck frame and suspension components. This application needs high strength and hardness as well as good elevated temperature properties. By alloying copper, magnesium and silicon etc the mechanical properties can be improved. In fusion welding process, it is very difficult to join 2XXX and 7XXX series aluminum alloys because of solidification microstructure is very pitiable and porosity in the fusion zone (weld zone) [1].To prevent these conventional welding problems. Wayne Thomas was invented Friction Stir Welding in 1991 at The Welding Institute (TWI) in UK. FSW is solid state joining technology and it improves better mechanical properties: fewer weld defects, low residual stresses and superior dimensional stability [2]. In this FSW process, the contact of a non-consumable tool circumvolve and traversing along the joint line creates a welded joint through viscoplastic deformation and resulting heat dissipation temperatures below the melting temperature of the materials being together [3].

Sound welds are fabricated by rotation tool having high resistance than the base metal. In this process consists of a high hardness tool is designed like that; it has non consumable and a specifically designed pin profile having circular shoulder. The friction is produced between the work piece and tool shoulder and the material gets often without attaining the melting point [4].

In this exploration, an effort has been made to understand the effect of tool pin profiles and different welding speed on the weld quality of AA2014 aluminium using FSW process. In this research, taper cylindrical threaded pin and tri-fluted taper cylindrical threaded pin are used as tool pin profiles. The pin traveled longitudinally at different welding speed (mm/min) and the tool rotation speed was seized constant at 900 rpm in all of the experiments [2]. Consequently, the effect of different welding speed and pin profiles on yield strength and elongation are analyzed. The manifestation of the weld for different welding speed has been examined and the impact of the stress as a function of strain.

FRICTION STIR WELDING

FSW is a solid state joining of weld metals and ultimate goal of the process are to generate thermal energy by frictional contact of FSW non consumable tool and welding pieces, which will soften weld pieces and stir it with solid metal into weld. Due to the relative motion of third-body region, around the immersed portion of the tool produces frictional heat that creates a plasticize material. The major frictional heat is generated due to the contact of shouldered region of the tool with the work pieces and also preventing plasticized material from being expelled. The tool is stirred (relatively) along the joint line, forcing the plasticized material to coalesce behind the tool to form a solid-phase joint [5].

Table -1: Chemical composition of AA2014-T6 (in wt. %)

Element	%
Si	0.5-12
Mn	0.4-1.2
Cu	3.9-5
Fe	0.7
Mg	0.2-0.8
Cr	0.1
Zn	0.25
Ti	0.5
Al	Balance

Principle of Operation of FSW

The process involves the dipping of a pin with a cylindrical shouldered tool rotating at a constant, with a desired configuration, into the adjoining surfaces of a joint to be welded. The welding plates have to be duly clamped tightly on a backing bar to avert the abutting joint faces from being forced apart. The length of the pin is slightly less than the required weld depth. The heat generated between the contacting surfaces of the tool, in addition to the heat generated by the mechanical amalgamation process and the adiabatic heat within the material, cause the stirred materials to soften and swiftly raises the temperature of the material being joined to its plasticizing temperature.

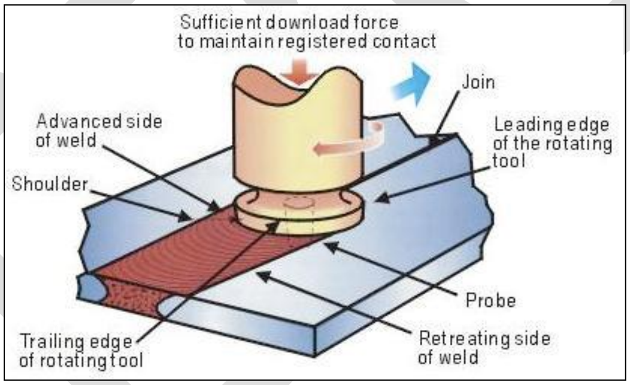


Fig 1: Schematic drawing of FSW process

The material undergoes extreme plastic deformation at elevated temperature during FSW process, resulting in production of equiaxed and fine recrystallized grains. The representation view of the operation is shown in Fig 1.Friction stir welding can be viewed as an autogenous keyhole joining method. The consolidated welds do not show fusion welding defects and solid-phase in nature. FSW is considered to be the most important development in metal joining in a decade and is a ‘‘green’’ technology due to its energy efficiency, environment friendliness, and flexibility [4]. As compared to the conventional welding methods, FSW consumes significantly less energy.

EXPERIMENTAL WORK

Aluminum alloy 2014-T6 was used as a base metal to fabricate the weld. The chemical and mechanical properties of AA 2014-T6 are shown in Table 1 and Table 2 respectively. Two aluminum plates, having the dimensions are 4 mm in thickness, 210 mm length and 60 mm in width, were placed on a flat metal plate as shown Fig.2.Before starting the FSW process, these two aluminum plates were cleaned by using ethanol to eradicate the oxides created on the surface of the plates.

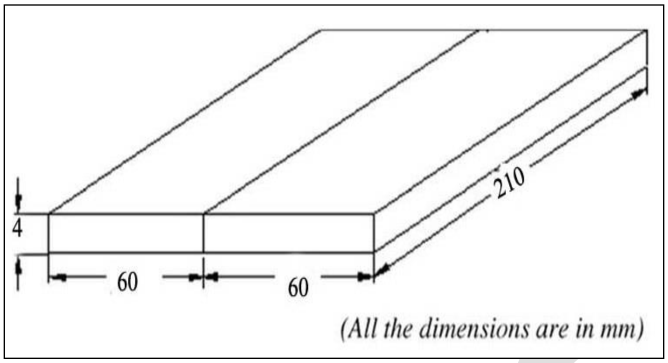


Fig. 2 Schematic diagram of aluminum alloy plates

Fig 3: Fabricated FSW tools

Fig 4: Fixture to hold work material

In this research two variant geometries of tool pin profiles (Taper cylindrical threaded pin and tri-fluted taper cylindrical threaded pin) and welding speed were used to fabricate the joints (Fig. 3). The H13 tool was made of standard tool steel and both the shoulder and the pin. The H13 tool process parameters used in this study are given in Table 3. The shoulder of the tool was the same with the diameter of 24 mm. The length of the pin was 3.8 mm as the required welding depth of the plates. The welding process was carried out rotating the tool at 900 rpm and at a feed rate of 40 mm/min and 50mm/min, with a 2^0 tilt angle. The butt weld was produced on FSW machine (Bharat Fritz Werner Ltd). The geometrical design of tool and the FSW process parameters are shown in Table 3.

Fig 5: FSW tools after welding

After welding, the specimens were slashed along the cross-sections of the traverse direction for doing mechanical tests (tensile, impact, micro hardness).

Table-3: FSW process parameters and tool dimensions

Process Parameters	Values
Tool rotation speed (rpm)	900
Welding speed (mm/min)	40, 50
Axial force (KN)	5
Pin length (mm)	3.8
Shoulder diameter(mm)	24
Pin diameter(mm)	8
Tool pin geometry	Taper cylindrical threaded pin & tri-fluted taper cylindrical threaded pin
Tool material	H13 tool steel
Triflute angle	120^0

RESULTS AND DISCUSSION

Effect of the pin geometry on the appearance of the weld

Fig 6 shows photos of appearance the weld surface made by different friction stir tools. It can be observe from the pictures that good surface appearance will be obtained by using No.1 and No.2 friction stir tools. Different pin geometries of friction stir tools are shown in Table 4. The appearance of the weld was clean and no apparent defects can be found. The superiority of the weld is defined by the material flow around the weld zone and it was deformed by the tool shoulder.

Table-4: Different pin geometry of two friction stir tools

No	Description of the pin	Big diameter of the pin	Small diameter of the pin	Pitch
1	Taper cylindrical threaded pin	8mm	6mm	0.5mm
2	Tri fluted taper cylindrical threaded pin	8mm	6mm	0.5mm

(a)

(b)

(c)

(d)

Fig 6: Appearance of the weld **(a)** welded by tool **1** (at welding speed 40mm/min) **(b)** welded by tool **2** (at welding speed 40mm/min) **(c)** welded by tool **1** (at welding speed 50mm/min) **(d)** welded by tool **2** (at welding speed 50mm/min)

Effect of the pin geometry and welding speed on the tensile properties

The obtained results are plotted as graphs and they are showed from Figure 10 to 16. The effect of FSW process parameters such as welding speed, tool profiles on tensile strength of friction stir welded AA2014-T6 aluminium alloy joints can be efficiently used to understand by the plotted graphs.

The transverse tensile properties such as yield strength, ultimate tensile strength, and percentage of elongation, of friction stir welded AA2014 alloy joints were evaluated with rotational speed of 900 rpm, and welding speed 40 and 50 mm/min by using different tool pin profiles. The change in the tool geometry had an imposing effect on strength and ductility. The tensile properties are summarized at the room temperature are show in the Table 5.

Table-5: Mechanical properties of AA2014 Friction stir weldments

Mechanical properties	**Tools**			
	1	2	1	2
Yield strength (N/mm^2)	382.35	381.20	184.97	110.91
Welding speed (mm/min)	40	40	50	50
UTS (N/mm^2)	398.43	415.90	210.26	182.02
% of elongation	4.3	3.72	3.4	2.6
Impact strength (Joule)	6	5	5	4
Hardness (BHN)	130	132	123	126

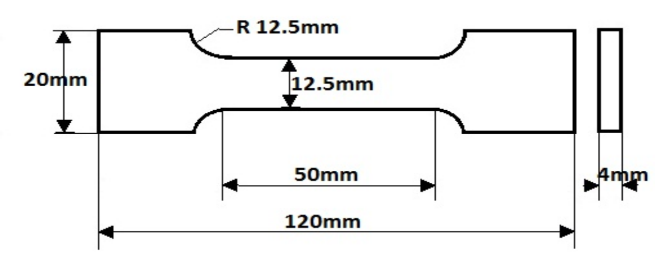


Fig 7: Tensile test specimen standard dimension

Fig 8: specimens before tensile testing

The Fig 7 shows the specimen dimensions for tensile test. Tensile strength was observed at the fusion zone of AA2014-T6 weldments at 900 rpm with a welding speed of 40 and 50 mm/min with different tool pin profiles. Fig 8 shows samples of tensile specimens before tensile testing. By changing profile of the tool there is a significant difference in the heat input through friction and material deformation and Tool no 2 exhibited better mechanical properties than other pin profiles. By using tri fluted taper cylindrical threaded pin profiled tool with the welding speed of 40mm/min and rotational speed 900rpm, obtained superior tensile properties at the FSW region of the joint due to combined effect of tool pin profile and sufficient heat. Fig 9 shows the samples of tensile specimens after tensile testing.

Fig 9: specimens after tensile testing

At each condition specimens are tested and average of the results of specimens is presented as the outcome of this research work. Figures 10 and 11 show the engineering stress-strain relationship of the welded products for taper screw thread and tri-flute taper screw threaded pin profiles respectively.

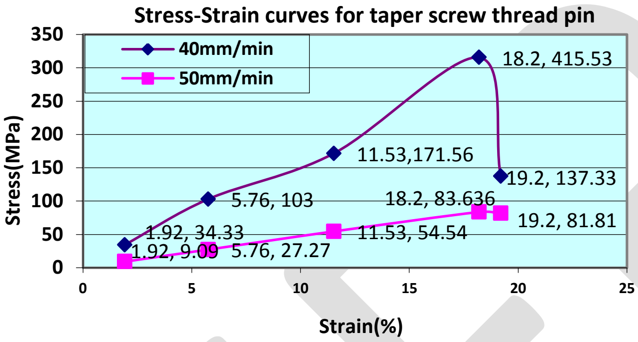


Fig 10: Stress Strain Curves for taper screw threaded pin

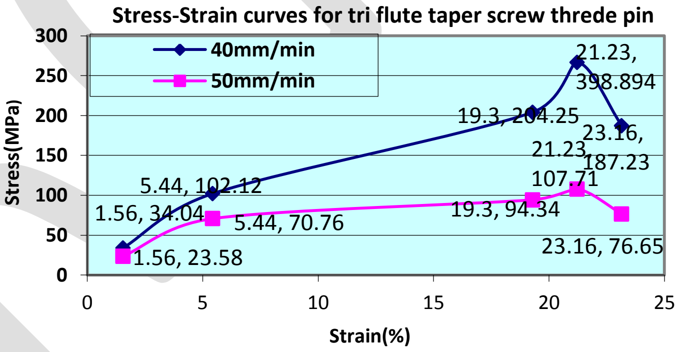
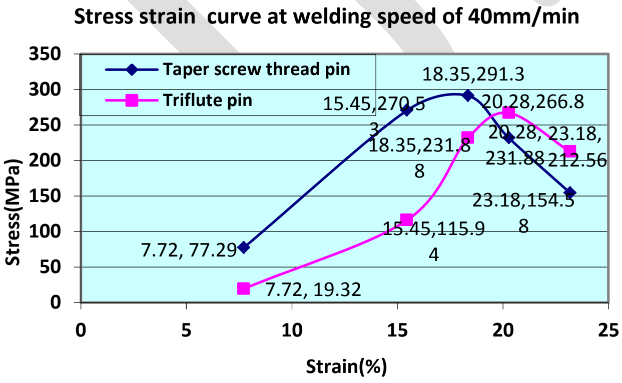


Fig 11: Stress Strain Curves for tri fluted taper cylindrical threaded pin

Figures 12 and 13 show the discrepancy of engineering stress and engineering strain for taper screw thread and tri-fluted taper cylindrical threaded pin profiles at 40 and 50mm/min respectively.



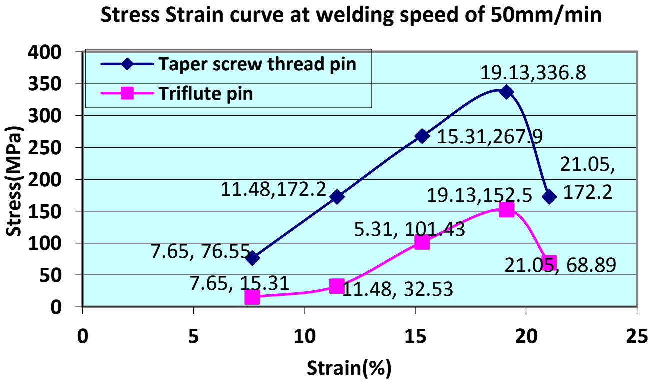


Fig 12: Stress Strain Curve at welding speed of 40mm/min

Fig 13: Stress Strain Curve at welding speed of 50mm/min

Figure 14 demonstrates the effect of tool pin profiles and welding speed on ultimate tensile strength of FSW joint. As experimental, the taper screw thread joints fabricated at the welding speed of 40mm/min have shown superior tensile strength (ultimate and yield strength) compared to the joints fabricated at a speed of 50mm/min. At a welding speed of 40mm/min joints are fabricated and it shows superior tensile strength for this pin profile. Similarly, this consequence can be seen for tri-flute joints. The tri-flute joints fabricated at the welding speed of 50mm/min have demonstrated less tensile strength in assessment with other welding speed 40mm/min.

Figure 15 shows the variation of % elongation with welding speed for these two joints. The percentage of elongation for taper screw thread pin shoots up as a result of increasing in the welding speed from 4.3% at 40mm/min to approximately 3.72% at 50mm/min. Similarly, for tri-flute pin profile the percentage of elongation decreases at welding speed of 50mm/min.

At the welding speed 40mm/min joints fabricated by tri-fluted taper cylindrical threaded pin exhibited more hardness comparison with other welding speed 50mm/min. Figure 16 presents the variation of hardness with welding speed for these two joints. Similarly, for taper cylindrical thread pin profile the hardness decreases at welding speed of 50mm/min.

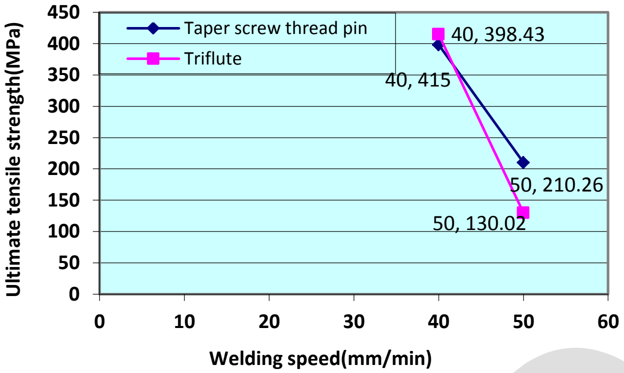


Fig 14: Effect of tool pin profile and welding speed on UTS

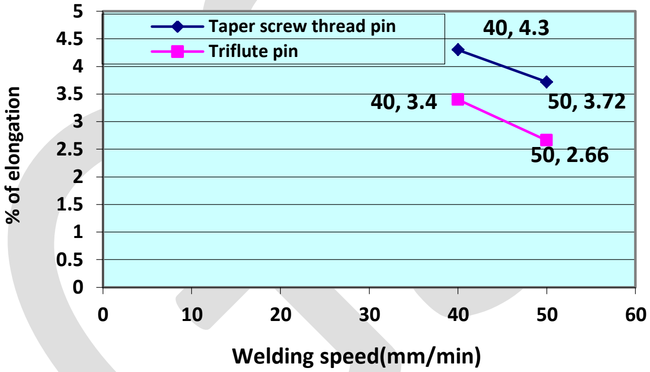


Fig 15: Effect of tool pin profile and welding speed on % of elongation

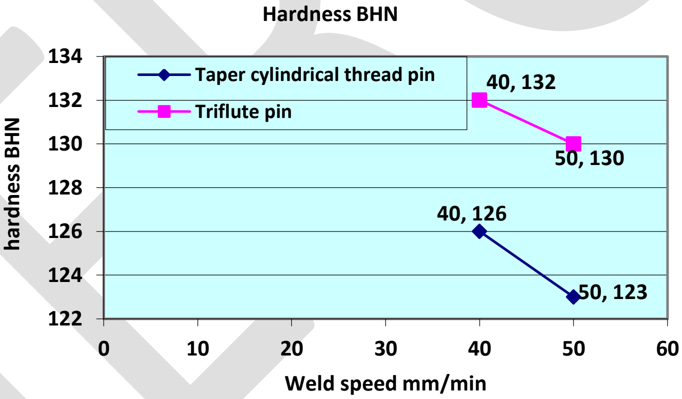


Fig 16: Effect of tool pin profile and welding speed on hardness

For improving the hardness of stir zone, there are two main causes; In general hardness mainly depends on the impulsive distribution rather than grain size. It is likely that low hardness in the stir zone can be attributed to dissolution of the precipitate during FS welding. Stir zone temperature ranges from450^{0}C to 480^{0}C. In AA2014-T6 aluminium alloy, these temperatures are adequate to dissolve all precipitates and cooling rate after welding is sufficiently rapid to retain alloying elements in saturated solid solution.

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CONCLUSION

In this research, FSW process was done on AA 2014-T6 alloy. To study the influence of the pin geometry on the weld shape and mechanical properties on AA2014, two different friction stir pin profiles were designed. Also, the effects of various welding speeds are investigated in this exploration. From this research, the following conclusions are derived:

- The consequence of tool pin profile and process parameters plays a vital role on the emergence of the weld is presented and no obvious defect was found. The results designate that the shape of the pin has a major effect on the joint structure and the mechanical properties.
- Four joints are fabricated in this exploration; the tri fluted taper cylindrical threaded pin profile and taper cylindrical threaded tool are used to fabricate the joints with welding speed of 40mm/min showed superior tensile properties in comparison with welding speed of 50mm/min.
- The taper cylindrical threaded pin ultimate tensile strength goes up to the 82.4% of the base metal ultimate tensile strength.
- The ultimate tensile strength of tri-fluted taper cylindrical threaded pin reaches to the 85.9% of the base metal ultimate strength.

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