International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 3, No. 3, July 2014

Research Paper

EXPERIMENTAL INVESTIGATION ON EFFECT OF ROTATIONAL SPEED AND TOOL PIN GEOMETRY ON ALUMINIUM ALLOY 2014 IN FRICTION STIR WELDING OF BUTT JOINT

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Friction Stir Welding (FSW) is a solid state welding process for joining metallic alloys and has been employed in several industries such as aerospace, marine and automotive industry for joining aluminium, magnesium and copper alloys. The various parameters such as rotational speed, welding speed, axial force and tool pin geometry play vital roles in FSW process in order to analyse the weld quality. The aim of this study is to investigate the effect of different rotational speed and tool pin profile on the weld quality of AA2014 aluminium which has gathered wide acceptance in the fabrication of light weight structures requiring a high strength-to-weight ratio. Five different tool pin profiles (straight cylindrical, taper cylindrical, straight cylindrical threaded, taper cylindrical threaded, taper cylindrical with concavity) were used, in this research, to fabricate the joint. The appearance of the weld is well and no obvious defect is found using these tools. The welded specimens were tested on UTM machine in order to obtain the ultimate load for getting the tensile strength of welded joint. The joint fabricated using rotational speed of 560 rpm, taper cylindrical threaded pin profile showed higher tensile strength compared to other joint.

Keywords: Friction stir welding, Tool rotation and welding speed, Axial force, Tool geometry, Universal testing machine

INTRODUCTION

Friction Stir Welding (FSW) is a material joining process. It is a highly important and recently developed joining technology that produces a solid phase bond. It is particularly appropriate for the welding of high strength alloys. Its main characteristic is to join material without reaching the fusion temperature. It enables to weld almost all types of aluminium alloys, even the one classified as non-weldable by fusion welding due to hot cracking and poor solidification microstructure in the

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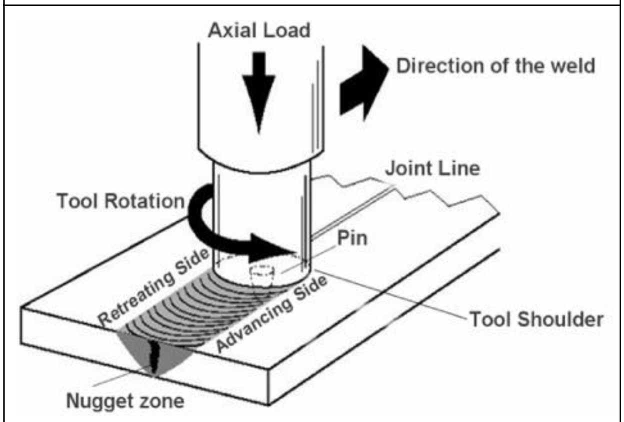
fusion zone. FSW is considered to be the most significant development in metal joining and is a "green" technology due to its energy efficiency, environment friendliness, and versatility (Mishra and Ma, 2005).

FSW PROCESS

The working principle of Friction Stir Welding process is shown in Figure 1. The FSW process utilizes a rotating tool to perform the welding process. The rotating tool consist of small pin (probe) underneath a larger shoulder. The tool serves three primary functions, that is, heating of the workpiece, movement of material to produce the joint, and containment the hot metal beneath the tool shoulder. In FSW, rotating shouldered tool plunges into the joining point of plates and the heat is originally developed from the friction between the welding tool (including the shoulder and the probe) and the welded material, which causes the welded material to soften at a temperature less than its melting point. The tool shoulder restricts softened material underneath the shoulder is further leads to movement of material from the front of the pin to the back of the pin by the rotational and transverse movements of tool. It is expected that this process will inherently produce a weld with less residual stress and distortion as compared to the fusion welding methods, since no melting of the material occurs during the welding (Elangovan and Balasubramanian, 2008).

Figure 1: Schematic of Friction Stir Welding



PARAMETRIC STUDY OF FSW

Many investigators have performed friction stir welding to study the effect of various parameters on quality of friction stir welded joint.

Aluminium

Elangovan and Balasubramanian (2008) investigates the effect of welding speed and tool pin profile on friction stir processing zone formation in AA2219 aluminium alloy. They found that the square pin profile tool at a welding speed 45.6 mm/min, produced mechanically sound and metallurgically defect free welds with maxium tensile strength, higher hardness. Vivekanandan *et al.* (2012) study microstructure and hardness of aluminium 6035 and 8011. At the rotating speed 550 rpm and welding speed 60 mm/min, the fine grain are formed at the center of the weld, due to dynamic recrystallization, which result in higher tensile strength of 50 N/mm^2 with the maximum hardness of 91 HV. Abbasi Gharacheh *et al.* (2006) found that increase in the ratio of rotational speed/traverse speed results in formation of large weld nugget, because of increase in heat input easier material flow, therefore probability of formation of incomplete root penetration defect is reduced. Kumar *et al.* (2011) focus on optimization of FSW parameters in different conditions of base material and the microstructures of the as-welded condition are compared with the post weld heat treated microstructures welded in annealed and T6 condition. The result show that in annealed condition tool rotation speed 800 rpm and welding speed 10 mm/min and 15 mm/min are the optimal parameters. The tool rotation speed 1000 rpm and welding speed 10 mm/min are the optimal parameters in 'T6' condition. Cavaliere *et al.* (2008) study mechanical and microstructural properties of AA6082 joints. The material welded with the advancing speed of 115 mm/min and fixed rotating speeds of 1600rpm exhibited the best fatigue properties and the higher fatigue limit. Kumar *et al.* (2013) find optimum mechanical properties of Al 6061-T6 alloy and Mg AZ31B alloy. The joint fabricated using rotational speed of 1120 rpm, a welding speed of 40 mm/min, taper thread pin profile, shoulder diameter of 18 mm (D/d) = 3 shows higher tensile properties. Rajakumar *et al.* (2010) study tensile strength properties of AA7075-T6 joints produced by friction stir welding. They found that the joint fabricated at a tool rotational speed of 1400 rpm, welding speed of 60 mm/min, axial force of 8 kN, using the tool with 15 mm shoulder diameter, 5 mm pin diameter, 45 HRc tool hardness yielded higher strength properties. Prashant Prakash *et al.* (2013) found that at rotational speed 1400 rpm, welding speed 25 mm/min and pin length 5.7 mm maximum tensile strength obtained is 182 MPa, gives 60% joint efficiency. Ayad Takhakh and Asmaa Abdullah (2012) optimum result gained at 80 mm/min weld speed and 1500 rpm rotation speed, the efficiency reaches to 89% of the ultimate tensile strength of the alloy 3003 H13. Patil and Soman (2010) found that the joint fabricated using taper screw thread pin at welding speed of 70 mm/min exhibits superior tensile strength of 92.30% of base metal ultimate strength and % elongation of 27.58% in AA6082-0 aluminium.

EXPERIMENTAL WORK

Configuration of the Workpiece

The friction stir welding have been carried by using a properly clamping fixture that allows the user to fix the two AA2014 plates (200 mm × 75 mm × 6 mm) to be butt welded on a vertical milling machine. In this research, experimentation were carried out with rotational speed variation of 1400 rpm, 900 rpm, 560 rpm. Welding speed is kept constant, i.e., 22.2 mm/min.

The mechanical properties and chemical composition of AA2014 are shown in Tables 1 and 2 respectively.

Table 1: Mechanical Properties of AA2014

Material	Yield Stress (MPa)	Tensile Strength (MPa)	Total Elongation (%)
AA2014	410	483	13

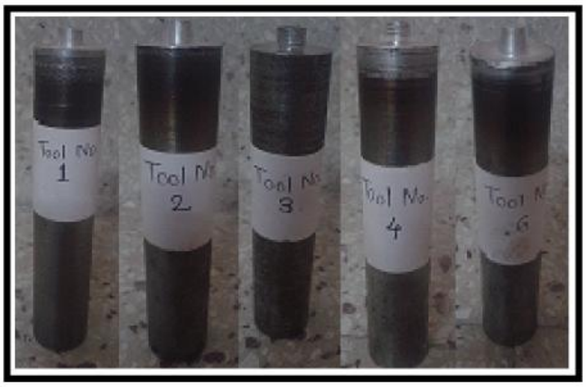
Table 2: Chemical Composition of AA2014

Element	% Percent
Si	0.15-1.2
Fe	0.7
Cu	3.9-5
Mn	0.4-1.2
Cr	0.1
Mg	0.2-0.8
Zn	0.25
Ti	0.15
Other	0.15
Al	Balance

Configuration of the Tool Geometry

The tools are made of H13 hot die steel. Figure 2 shows the image of five different tool profiles used in this study in order to fabricate the joints in which first is straight cylindrical pin, second is taper cylindrical pin, third is straight cylindrical threaded pin, fourth is taper cylindrical threaded pin, fifty is taper cylindrical pin with concavity.

Figure 2: Images of the Tool Pin Profiles



The details of the tool were listed in Table 3 in which the configuration of these geometries is determined. Table 4 shows the chemical composition of H13 hot die steel.

Table 3: Different Pin Geometry

No.	Pin Profile	PD1 (mm)	PD2 (mm)	PL (mm)
1	Straight Cylindrical	7	7	4.8
2	Taper Cylindrical	7	5	4.8
3	Straight Cylindrical Threaded	7	7	4.8
4	Taper Cylindrical Threaded	7	5	4.8
5	Taper Cylindrical Concavity	7	5	4.8

Table 4: Chemical Composition of H13 Hot Die steel

Element	% Percent
C	0.32
Mg	0.2
Si	0.8
Cr	4.75
Ni	0.3
Mo	1.10
V	0.8
Cu	0.25
P	0.03
S	0.03
Fe	balance

TENSILE TESTS

Tensile tests were performed to determine the ultimate load for calculating the tensile strength of welded joints. Fifteen specimens were tested on UTM machine in order to calculate the corresponding tensile strength of welded joints.

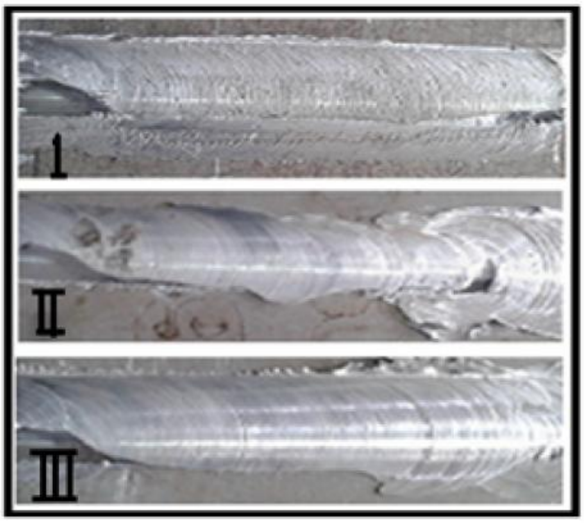
RESULTS

Effect of Tool Pin Profile and Rotational Speed on the Appearance of the Weld

Figure 3 shows the photos of weld surface appearance made with the straight cylindrical tool pin profile at different rotational speed (560, 900, 1400 rpm). It can be seen from the pictures that surface appearance of the weld is discontinuous improper stirring of material with the combination of this tool pin and rotational speed.

Figure 4 shows the photos of weld surface appearance made with the taper cylindrical tool pin profile at different rotational speed (560, 900, 1400 rpm). It can be seen from the pictures that good surface appearance has been obtained at these rotational speed

Figure 3: Appearance of the Weld Using Straight Cylindrical Tool Pin (I) 560, (II) 900, (III) 1400



except at 560 rpm due to the fact that rotational speed is proportional to the heat generation from pin and in this rotational speed the heat input required in order to fabricate the joints isn't sufficient. Therefore it causes a crack in the surface of the obtained weld.

Figure 4: Appearance of the Weld Using Taper Cylindrical Tool Pin (I) 560, (II) 900, (III) 1400

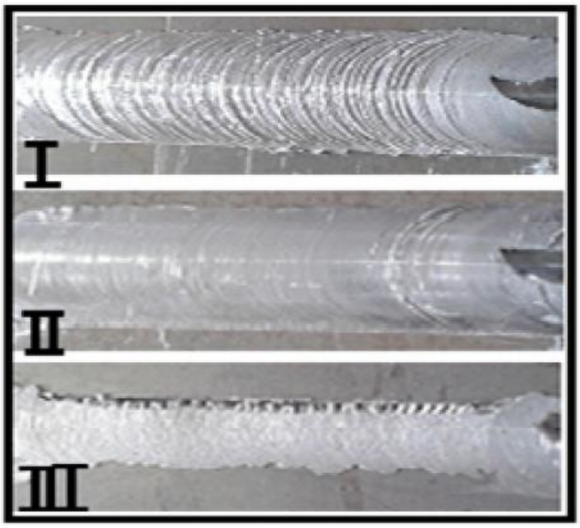


Figure 5 shows the photos of weld surface appearance made with the straight cylindrical threaded tool pin profile at different rotational speed (560, 900, 1400 rpm). It can be seen from the pictures that second weld surface appearance is good as compare to other two.

Figure 5: Appearance of the Weld Using Taper Cylindrical Tool Pin (I) 560, (II) 900, (III) 1400

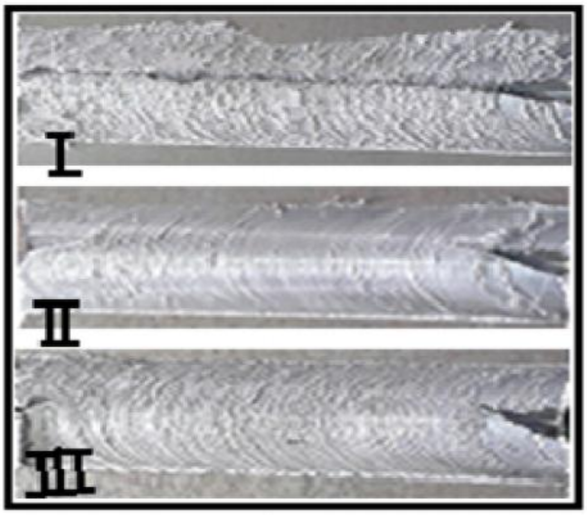


Figure 6: Appearance of the Weld Using Taper Cylindrical Threade Tool Pin (I) 560, (II) 900, (III) 1400

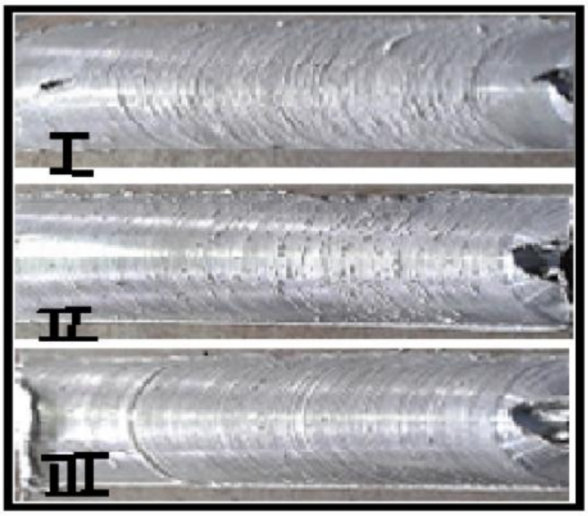
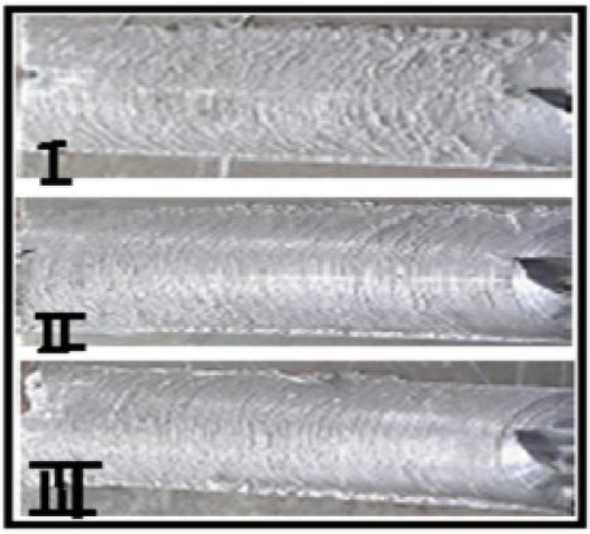


Figure 6 shows the photos of weld surface appearance made with the taper cylindrical threaded tool pin profile at different rotational speed (560, 900, 1400 rpm). It can be seen from the pictures that in all the three cases weld appearance is good, it means that these rotational speed and tool combination is good.

Figure 7 shows the photos of weld surface appearance made with the taper cylindrical tool pin profile with concavity at different rotational speed (560, 900, 1400 rpm). It can be seen from the pictures that in all the three cases weld appearance is good, in this case tool concavity play vital role to restrict material inside shoulder.

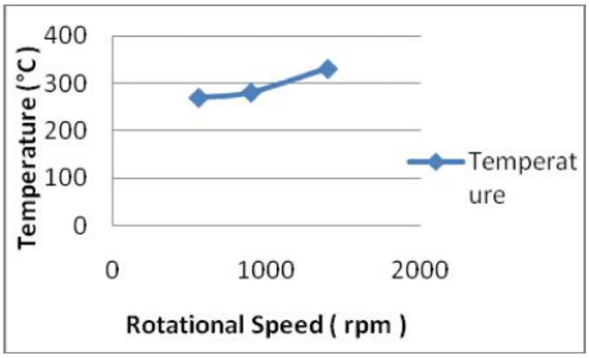
Figure 7: Appearance of the Weld Using Taper Cylindrical Tool Pin with Concavity (I) 560, (II) 900, (III) 1400



Effect of Variation in Tool Rotational Speed on Temperature Generation

At 560 rpm temperature required was 269 ^{o}C whereas a highest temperature 331 ^{o}C was required at 1400 rpm. The plot between temperature and tool rotational speed progressively increased. As the tool rotational speed was increased, temperature also increases. The reason behind this progression is generation of frictional heat by tool. The higher rotational speed tends to produce high frictional heat which in turn increases the temperature of the joint.

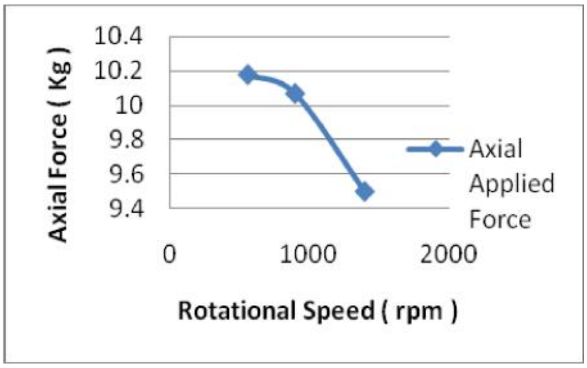
Figure 8: Tool Rotational Speed vs Temperature



Effect of Variation in Tool Rotational Speed on Axial Applied Force

The graph indicates the variation between the axial applied force and tool rotational speed. At 560 rpm axial applied force required is 10.06 Kg whereas a lowest axial applied force required is 9.5 Kg was required at 1400 rpm.

Figure 9: Tool Rotational Speed vs Axial Applied Force (Kg)

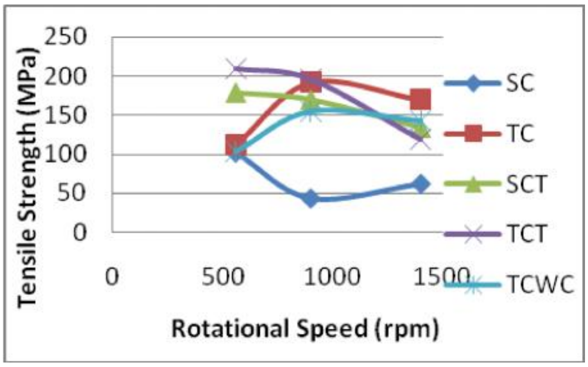


As the tool rotational speed was increased, axial applied force required decreases. This phenomenon also based on the frictional heat generation and the temperatures encountered in the weld joint. Naturally, as the tool rotational speed increased, material got soften in the smallest time and hence, axial force required for the tool plunge is minimum as compared to values of force required at lower tool rotational speeds.

Effects of Tool Profiles and Rotational Speed on Tensile Strength

The graph indicates the effect of rotational speed and tool pin profiles on the tensile strength of the welded joint. For taper cylindrical threaded tool profile, a maximum tensile strength of 209.09MPa was obtained, at 560 rpm. For taper cylindrical tool profile, at 900 rpm, a maximum tensile strength of 191.82 MPa was obtained. For straight cylindrical threaded tool profile, at 560 rpm, a maximum tensile strength of 178.79 MPa was obtained.

Figure 10: Rotational Speed vs Tensile Strength



CONCLUSION

From experimentation it is observed that:

1. The experimental results indicate that the shape of the tool pin and rotational speed has a significant effect on the joint structure and the mechanical properties.
2. It is observed that rotational speed is directly proportional to temperature generation, as the rotational speed increases, temperature generation also increases and rotational speed decreases, temperature generation also decreases.
3. The rotational speed is inversely proportional to the axial force required for tool plunging, as the rotational speed increases, required axial force was decreases and rotation speed decreases, required axial was increases.
4. It is found that the joint fabricated using Taper cylindrical threaded pin profiled tool exhibits superior tensile strength of 209.09 MPa compared to other tool pin profile, at rotational speed of 560 rpm.

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