VOL. 11, NO. 20, OCTOBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

INFLUENCES OF TOOL PIN PROFILE ON THE FRICTION STIR WELDING OF AA6061

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ABSTRACT

AA6061 aluminum alloy is very useful material in the light weight fabrication. Friction stir welding (FSW) is a solid state joining process that is feasible for this material. Appropriate pin profiles and tool design can generate proper heat and mixing the plasticized materials. In this study AA6061-T6 used as a base metal and H13 steel is selected for fabrication of different pin profiles. Four pin profiles used to fabricate joints with different rotation and traverse speed. Obtained results showed that threaded cylindrical produced better joints. Furthermore, increasing the FSW speeds has influence on tensile strength.

Keywords: friction stir welding, FSW, pin profile, tool geometry.

INTRODUCTION

Friction Stir Welding (FSW) is a solid state joining process that was invented and patented by The Welding Institute (TWI) UK [1]. This invention is a big success for joining aluminum alloys as well as low melting temperature materials [2]. Recently, FSW has been proven as an alternative joining technique for high melting materials such as steels, titanium, and so on. Figure-1 illustrates the schematic of FSW process. The applications of FSW can be found in marine, aerospace, automotive, rail and construction industries. Nowadays FSW is gradually being introduced to oil and gas industries such as offshore structure [3].

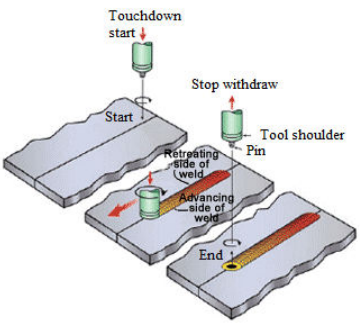

Figure-1. Schematic of friction stir welding.

In FSW, the parameters that influence the quality of weld joint can be categorized into primary and secondary parameters. The primary parameters are traverse speed, rotational speed, and tool geometry. Meanwhile the secondary parameters are thickness of the workpiece, workpiece material, welding tool material, and pin profile.

In the last decade many researches have done on various FSW parameters. Among them, there are some studies that concentrated on pin profiles. In order to obtain the best and optimum pin profiles, the geometry of pin will be evaluated with other parameters such as rotation and traverse speeds, and force.

Elangovan *et al* [4-7] had many researches on pin profiles on aluminum alloys. They investigated the influence of pin profile and rotational speed, traversing speed, shoulder diameter, and axial force on the formation of friction stir processing zone. Furthermore, there are many other researchers who investigate the influence of pin profiles on microstructural and mechanical properties of the weld joint [8]. However, there are many challenging issues to optimize the welding process for joining hard materials. One of the issues is the appropriate tool pin profile design.

Tool geometry has an effect on weld joint for improving its properties and quality [9]. FSW tool has two main functions during the welding process. The tool shoulder rubs the workpiece and generates the heat and tool pin stirs the material [10]. In FSW, the tool materials also play very important role during the welding process for preventing the wear problem. The suitable tool material for welding a high melting workpiece should possess wear resistance with high strength as well as high toughness. [11]. In addition, proper tool design reduces the force needed to push the tool along the weld line.

Based on the literatures, the popularity to study on the pin profile is increased. However, there are little effort that focuses on FSW pin profiles.

Tool geometry have an influential on FSW for improving the process. FSW tool fabricated of two parts; shoulder and pin. The tool has two main duty; heat generation and material flow. In aspect of heat generation, size of pin and shoulder is important, and regarding to stirring the material and material flow, pin profile have an critical role [10].

Appropriate pin profiles and tool design can generate proper heat and mixing the plasticized materials. Moreover, FSW parameters such as rotating speed, traveling speed, and axial force has influence on quality of weld. In this investigation an attempt has been made to study the effect of tool pin profiles and different rotational and welding speeds on mechanical properties and heat generation.

EXPERIMENTAL

In the present work, plates of aluminum alloys AA6061-T6 were used as a base material (BM). Tool steel H13 which is a type of hot working tool steel is selected and used to fabricate the four FSW tools with different profiles. The chemical composition of BM and tool is shown in Table-1.

Table-1. Chemical composition and mechanical properties of BM and tool.

	Chemical composition %							
	Mg	**Cr**	**Ti**	**Zn**	**Mn**	**Fe**	**Si**	**Cu**
AA6061-T6	0.98	0.19	0.05	0.01	0.07	0.3	0.47	0.23
	Mechanical Properties							
	UTS (Mpa)		Yield strength (Mpa)			Elongation (%)		
	305		253			12		
H13	Chemical composition %							
	C	Si	Mn	Cr	Mo	V	P	S
	0.4	0.92	0.34	5.07	1.25	0.95	0.019	0.001

The welding was done with FSW-TS-F16 friction stir welding device host. Four different pin profiles used to perform the friction stir welding, namely threaded cylindrical (TC), stepped cylindrical (SC), conical (C), and square (S).

Single pass welding procedure has been used to fabricate the joints. Heat treatment on FSW tool has been done before welding and testing. The first step of heat treatment is preheating cycle. According to Figure-2 the temperature for preheating is around 760 °c, held for 15 minutes. The next step is soaking cycle in austenite formation zone. The temperature raised to 1010 °c and held for 30 minutes. After the soaking cycle, the tool is to be removed from the furnace and cooled to 65 °c, once the furnace has reach a temperature of 565 °c the tools are allowed to temper for a 2 hours [12].

Three rotational speeds and three traverse speeds selected in order to evaluate the different speeds. Using each tool, 9 joints have been fabricated and in total 36 joints have been fabricated in this study. The welding parameters and tool dimensions are given in Table-2.

Table-2. Welding parameters and tool dimensions.

Process parameters	Values
Rotational Speed (rpm)	800,1200,1600
Traveling speed (mm/min)	40,70,100
Axial force (kN)	7
Pin length (mm)	8
Tool shoulder diameter (mm)	24
Pin diameter (mm)	8

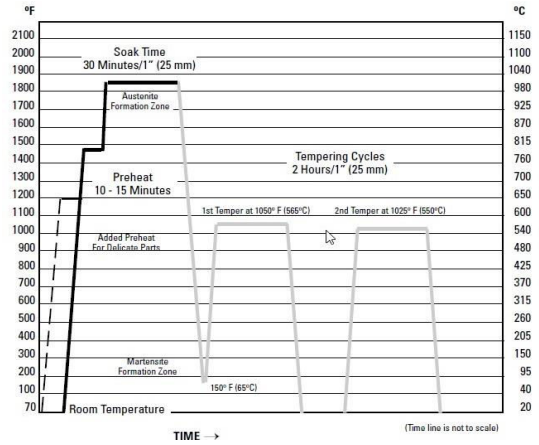

Figure-2. Heat treatment process for H13 tool steel.

During welding thermocouples (K type) embedded in samples with specified distances in order to record the heat generation. Figure-3 also shows the position of the thermocouples.

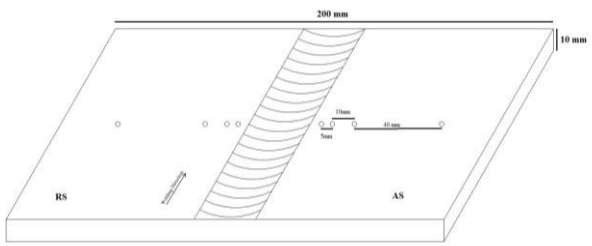

Figure-3. Workpiece and thermocouples position.

The welded joints are sliced using wire cut machine to prepare tensile specimens. American society for testing of materials (ASTM-E8M) guidelines followed to prepare the tensile test specimens. Figure-4 shows the schematic of tensile sample.

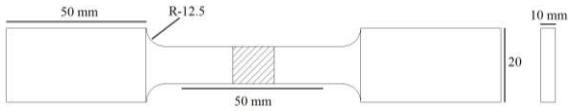

Figure-4. Schematic of tensile test specimen.

Tensile test carried out in 100kN, universal testing machine. Speed of testing (0.9mm/min) defined in term of free-running cross head speed that was calculated as per ASTM specification. The specimens undergo the deformation until finally fails after necking and the load versus displacement has been recorded.

THERMAL CYCLE

Heat generation and peak temperature of the material during FSW is affected by pin profile.

As shown in Figure-5 square pin profile generate higher temperature as compare to other pin profiles. However, the graphs show that differences between peak temperatures of samples welded by different pin profiles are very little and not significant.

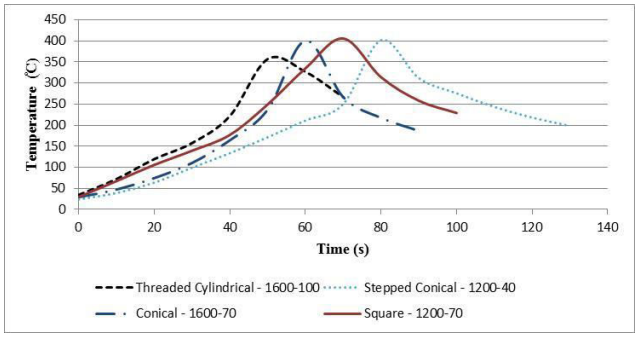

Figure-5. Maximum heat generated by each pin profiles.

During FSW, heat is generated by friction between the tool and the work-piece and via plastic deformation. The local interfacial heat generation due to friction is the product of frictional force and the sliding velocity where the interfacial deformation heat is the product of shear stress and the velocity of the work-piece material that sticks to the tool as it moves. The tool moves along the weld joint at a constant speed U, as it rotates about its axis with speed ω. At any point on the tool work-piece interface, the tangential speed of the tool with respect to the work-piece is given by Equation (1), where r is the radial distance from the tool-axis and θ is the angle between radial vector and the welding direction. The term $Usin\theta$ may be neglected when $r\omega$ is much larger [13-16].

$$V_r = r\omega - Usin\theta \quad (1)$$

Equations. (2) and (3) give the local heat generation rate due to friction and deformational work respectively.

$$de_f = \delta(r\omega - Usin\theta)\mu_f p dA \quad (2)$$
$$de_s = (1-\delta)(r\omega - Usin\theta)\tau_y dA \quad (3)$$

Where δ is the extent of slip, μ_f is the friction coefficient, μ_s is the shear yield stress and p is the local pressure applied by the tool on the elemental area dA. When δ is 1, no material sticks to the tool and all the heat is generated by friction. In contrast, when δ = 0, work-piece material sticks to the tool and all the heat is generated by plastic deformation [14, 17].

The most of the heat is generated by shoulder design [13] and therefore in a constant shoulder design pin profile may not have significant effect on heat generation during FSW. Only the way heat is generated (friction of deformation) may be varied with pin profile [15, 18].

TENSILE PROPERTIES

From 36 welded samples only 11 samples were defect free. Therefore, according to ASTM-E8M tensile test carried out for these samples. Transverse tensile properties of FSW joints such as yield strength, tensile strength, and percentage of elongation have been evaluated. Figure-6 shows the tensile strength from each sample.

As shown, maximum tensile strength is for threaded cylindrical profile with rotational speed of 1600 rpm and welding speed of 100 mm/min. the inferior properties is belong to conical profile with 800 rpm and 40 mm/min as rotational and welding speeds respectively.

The Figure shows that by increasing the welding speed tensile strength will be increased. In another aspect, primary parameters such as welding speed have a significant role on tensile properties.

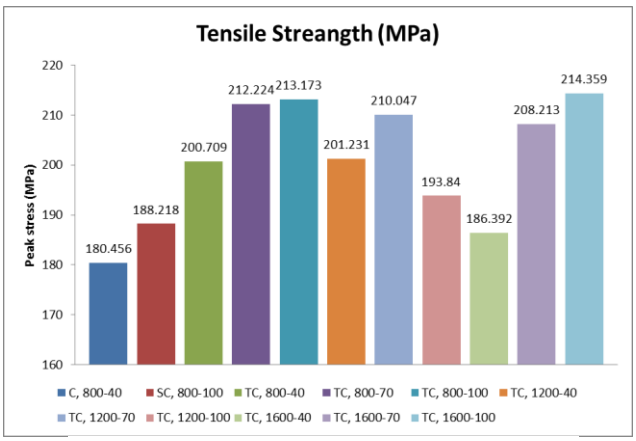

Figure-6. Tensile strength from different

CONCLUSION

In this investigation an attempt has been made to study the effect of tool pin profiles and different rotational and welding speeds on mechanical properties and heat generation. From this investigations following conclusion are derived.

1- Increasing the welding speed will effect on tensile properties.

2- Threaded shape is effectiveness on mechanical properties.
3- Differences between peak temperatures of samples welded by different pin profiles are very little and not significant. However, square pin profile produced higher temperature.

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