Influence of Tool Geometry on Mechanical Properties of Friction Stirwelding of Aluminium Alloy Aa2014-T6

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Abstract

Friction Stir Welding (FSW) was invented by Wayne Thomas at TWI (The Welding Institute), and the first patent applications were filed in the UK in December 1991 for butt and lap welding of metals and Plastics. FSW is a solid state welding process and joining similar or dissimilar metals in which the relative motion between the tool and the work piece produces heat which makes the material of two edges being joined by plastic atomic diffusion. In this work newly design and developed tool pin profile is considered to study the effect of this tool geometry on mechanical properties of friction stir weldments of AA 2014-T6 aluminium alloy using Taguchi's one parameter at-one-time approach. The various process parameters was considered such as tool rotational speed (TRS), weld speed (WS) and tilt angle for friction stir weldments of AA 2014-T6 aluminium. From the result it is observed that the parameters i.e. TRS (710 rpm), WS (49 mm/min), Tilt Angle (2˚) gives highest tensile strength.

Keywords: Friction Stir Welding, Tool Rotation Speed, Tilt Angle, Weld Speed.

Introduction

Friction stir welding (FSW) is a relatively new solid state welding process which is used for butt joints. FSW was invented by The Welding Institute (TWI), Cambridge,UK in 1991 and has emerged as a new process for welding of aluminum alloys. This process has made possible to weld a number of aluminum alloys that were previously not recommended (2000 series & copper containing 7000 series aluminum alloys) for welding. Because the material subjected to FSW does not melt and re-solidify, the resultant weld metal is free of porosity with lower distortion. An added the advantage that it is an environmentally friendly process. FSW is a solid state, localized thermo mechanical, joining process.

FSW is a simple process in which a rotating cylindrical tool with a shoulder and a profiled pin is plunged into the abutting plates to be joined and traversed along the line of the joint. The plates are tightly clamped on to the bed of the FSW equipment to prevent them from coming apart during welding. A cylindrical tool rotating at high speed is slowly plunged into the plate material, until the shoulder of the tool touches the upper surface of the material. A downward force is applied to maintain the contact. Frictional heat, generated between the tool and the material, causes the plasticized material to get heated and softened, without reaching the melting point. The tool is then traversed along the joint line, until it reaches the end of the weld [K. Ramanjaneyulu et al. 2013].

As the tool is moved in the direction of welding, the leading edge of the tool forces the plasticized material, on either side of the butt line, to the back of the tool. In effect, the transferred material is forged by the intimate contact of the shoulder and the pin profile. In order to achieve complete through-thickness welding, the length of the pin should be slightly less than the plate thickness, since only limited amount of deformation occurs below the pin. The tool is generally tilted by 2-4°, to facilitate better consolidation of the material in the weld [P.Rohilla and N.Kumar, 2013].

In FSW, the tool typically consists of a cylindrical shoulder with a profiled probe, also called the pin. The material or materials being welded can be called the workpiece, part, sample, or plate. The joint where the samples are abutted will be referred to as the weld line. The part used to support and clamp the sample is called the backing plate, backing bar, or anvil. The tool rotates at an angular velocity given in revolutions per minute (rpm),which will be referred to as tool rotational speed (TRS).The translational velocity at which the tool travels along the weld line is called the feed rate or weld speed(WS), and will be given in millimeter per second (mm/s) or inches per minute (ipm) [K. Kumar et al. 2011].

The side of the weld where the angular velocity and forward velocity of the pin tool are additive is called the advancing or leading side. The other side where the angular velocity and translational velocity are in opposite directions is called the trailing or retreating side. As shown in Fig. 1.forces act in three dimensional spaces. The force along the X-axis, Y-axis, and Z-axis will be referred to as the translational (Fx), transverse (Fy), and axial force (Fz) respectively, and will be given in Newtons(N). The moment (Mz) about the axis of rotation will be referred to as the torque and given in Newton-meters (N-m) [C. N. Suresha et al. 2011].

Experimentation

Aluminum alloy AA 2014-T6 rolled plates each of size 30mm ×980mm×95mm were used for FSW experiments. The chemical composition and mechanical properties of the parent metal are presented in Table 1.

The plates were welded in single pass, normal to the rolling direction, with square-butt joint configuration employing vertical milling machine (Make: G. Dufour Montrenil) shown in fig 2.

The initial joint configuration is obtained by securing the plates in position using mechanical clamps. The tool material used in this study is hot worked die steel (AISIH13) hardened to 50-55 HRC with chemical composition C-0.4, Cr-0.25, Mn-0.4, Mo-1.35, Si-1, V-1, and Fe-balance (allelements in wt.%) [H. S. Patil and S. N. Soman 2010].

The range of parameters selected as per the quality of weld obtained during trial experiment is shown in table 2.

Design of experiments is a method of designing experiments, in which only selected number of experiments is to be, performed [M.Jayaraman et al. 2009]. For example if there are three parameters with three levels of each parameter, then the total number of experiments to be performed is3^3=27 experiments. But using design of experiments method, only 9 experiments are required to be performed. On the basis of these 9 experiments, the significance and optimal levels of each parameter is obtained [K. Elangovan and V. Balasubramanian (2007), M.Jayaraman et al. 2009].

All the nine experiment perform using newly design tool shown in fig. 3. This tool design by combining the features of square and tapered cylindrical tool pin profile.

After welding, the FSW plates were sectioned perpendicular to the weld direction for tensile testing. Transverse tensile specimens were prepared according to the ASTM-E23.

Figure 4 illustrates schematically the configuration of different tensile specimens used in the present study and the locations from which they were extracted.

Result and Discussion

A. Effect of Tool Pin Profile on the Appearance of the Weld:

Table 4 shows the macrostructure of the weld surfaces producing by newly design tool profile.

From the above result it is observed that the condition 1, 4, 8 shows defect free weld surface as shown in table 4. due to sufficient amount of heat generated during welding. Other weld sample shows defects like pin hole and tunnel as shown in table 4.

B. Effect of Tool Pin Profile on the tensile strength:

Table 5 shows the tensile strength of nine weld samples.

From the above obtained result it is clear that the parameters 710-49-2 show the highest tensile strength among the other weldments.

Conclusions

From the results of this present investigation and the discussion presented in the earlier chapters, the following conclusions are drawn.

I. Tool rotation speed of 710 rpm shows the finer grain structure in macrostructural observation.

II. Lower weld speed 48 mm/min shows highest tensile strength due to finer grain structure observed in the nugget region.

III. Lower tilt angle ˚2shows highest tensile strength because a suitable tilt of the spindle towards the trailing direction ensures that the shoulder of the tool holds the stirred material by the pin and moves the material efficiently from the front to the back of the pin.

Table 1. Chemical and Mechanical Properties of AA2014-T6

Element, wt.%								YS,	UTS,	El.,
								MPa	MPa	%
Cu	Si	Mn	Mg	Zn	Cr	Fe	Al			
4.0	0.8	0.60	0.4	0.25	0.1	0.7	Bal	412	455	7

Table 2. Welding parameters and their levels

Symbol	Welding parameter	Unit	Level 1	Level 2	Level 3
A	Rotational Speed	Rpm	710	900	1180
B	Weld Speed	mm/min	49	83	108
C	Tilt Angle	Degree	2	3	4

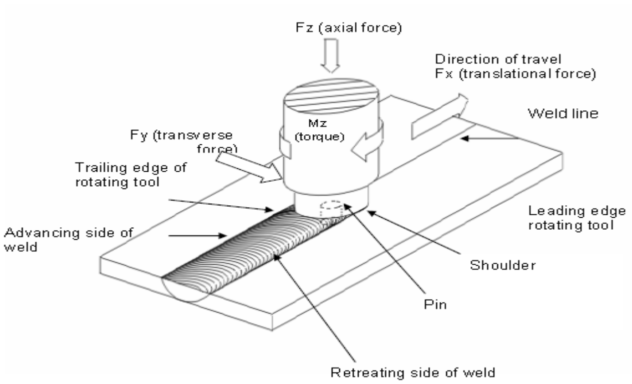

Fig. 1 Schematic of the FSW Process [Kumar et al., 2011]

Fig. 2 Vertical Milling Machine

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Fig. 3. Design of tool.

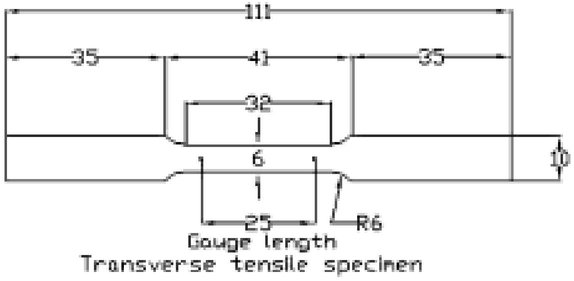


Fig. 4. Transverse Tensile Specimen

Table 3. Experimental layout using an L9 orthogonal array

Experiment No.	Welding Parameter		
	Rotational Speed (Rpm)	Weld Speed (mm/min)	Weld Angle (º)
1	710	49	2
2	710	83	3
3	710	108	4
4	900	49	3
5	900	83	4
6	900	108	2
7	1180	49	4
8	1180	83	2
9	1180	108	3

Table 4. Macrostructure of the weldments

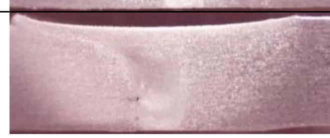
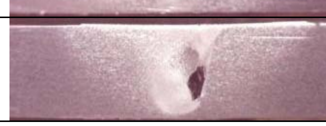
Sr. No.	Condition	Microstructure	Name of The Defect
1	710-49-2		No macro porosity, Crack observed.
2	710-83-3		No macro porosity,Crack observed.
3	710-108-4		Visible pinhole at the bottom portion
4	900-49-3		No macro porosity, crack observed.
5	900-83-4		Tunnel defect
6	900-108-2		Tunnel defect
7	1180-49-4		Tunnel defect
8	1180-83-2		No macro porosity, crack observed.
9	1180-108-3		Tunnel defect

Table 5. Tensile Strength of weldments

Sr.no.	Condition	UTS (N/mm^2)		Avg.
		Trial 1	Trial 2	
1	710-49-2	332.92	330.88	331.90
2	710-83-3	101.46	155.2	128.33
3	710-108-4	184.22	142.70	163.46
4	900-49-3	265.45	226.62	246.04
5	900-83-4	127.19	99.64	113.42
6	900-108-2	130.72	58.57	94.65
7	1180-49-4	93.33	125.94	109.64
8	1180-83-2	260.6	216.24	238.42
9	1180-108-3	113.22	69.4	91.31

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