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Experimental Investigation on Mechanical Properties of Friction Stir Butt Welded Joints of Aluminium 6061-T6 under Oblique Loading

D. Maneiah[1], Dr. K. Prahlada Rao[2], Dr. K. Brahma Raju[3]

[1]Department of Mechanical Engineering, CMR Technical Campus, JNTU Hyderabad, India
Email: manidakkiliphd2012@gmail.com
[2]Department of Mechanical Engineering, JNTU Ananthpur, India
Email: drkpro1@yahoo.com
[3]Department of Mechanical Engineering, SRKR Engineering College, JNTU Ananthpur, India
Email: brahmaraju@yahoo.com

Abstract— *The mechanical properties of friction stir butt welded joints of Aluminium 6061-T6 sheets under oblique loading was experimentally investigated. Six types of test specimens with different oblique butt welding angles were used for tensile test which is subjected to withstand the fixed directional loading. The effect of oblique loading on the tensile strength of the friction stir butt welded structure has been studied. Aluminium 6061-T6 is a solution heat treated then artificial aged aluminium alloy contains Magnesium and Silicon as its major alloying elements exhibits good mechanical properties and weldability. This alloy regularly used in the construction of structural components such as aircraft wings and fuselages, automotive chassis and welded widely by the TIG and MIG welding processes. Friction stir welding is a solid state welding process overcomes fusion welding by means of solidification of molten metal. Chemical properties tests has been done to check the properties of parent metal after welding. Non destructive tests has been performed to test the quality of welds.*

Keywords— Aluminum 6061-T6, Friction stir welding Oblique loading, Non destructive test, Tensile test.

I. INTRODUCTION

The Friction stir welding (FSW) is a relatively new solid-state joining process, developed at the Welding Institute (TWI), England, in 1991 [**1**]. This new technology has proven to be very successful in joining aluminium alloys. It can produce superior mechanical properties when compared to the typical electrical arc welding process and therefore has gained considerable interest in the past decade [**2, 3**]. The certain welding characteristics and physical, chemical and mechanical properties of Aluminium and its alloy, a silvery white colored metal made these alloys to be widely used. The thin film of oxide which is present on the surface of aluminium contains moisture, which reacts and forms oxide and liberates hydrogen may cause porosity formation on the weld bead during the fusion welding which greatly reduces the strength of the weld joint. And also due to high thermal conductivity, welding of aluminium and its alloys needs special attentions. The tempered grade aluminium 6061-T6 a solution heat treated then artificial aged alloy is light in weight, strong and having density of 2.7 gm/cm^3. The other properties like good workability, high corrosion resistance, favourable malleable, ductile properties made aluminium and its alloys to be used as welded, casted, rolled, and forged in different industries as structural frameworks, aero engine and automobile parts. Friction stir welding is a solid state nature of process where a non consumable rotating tool with a special designed pin or probe and a shoulder is inserted into the abutting edges of sheets to be joined and traversed along the line of joint. The rotating tool has two major functions that is localized heating and material flow. The heat thus produced by the friction between the non consumable rotating tool and workpieces to be joined. The rotating tool causes volumetric heating so that a continuous joint can be produced as the tool progressed in forward along the line of joint. Welding begins by first plunging the rotating probe into the work pieces until the rotated shoulder came in to close contact of the top surface of the workpieces. The joining action of the two sheets took place by the localized heat generated by the rotating probe and the frictional heat produced by the movement of rotated shoulder along the line of joint. As a result there is no melting of base metal and thus friction stir welding overcomes the fusion welding process in terms of solidification related defects. Dye penetrant inspection and Radiography was carefully undertaken to test the quality of the weld joint. Chemical analysis has been performed to test the changes occurs if any in the

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composition of the material due to welding. The aim addressed in this experimentation is to test the strength of the friction stir welded butt joints of aluminium 6061-T6 sheets with different oblique butt welding angle without undergoing after weld heat treatment.

Friction stir welding (FSW) is a new solid-state joining process. This joining technique is energy efficient, environment friendly, and versatile. In particular, it can be used to join high-strength aerospace aluminum alloys and other metallic alloys that are hard to weld by conventional fusion welding. Tool geometry is very important factor for producing sound welds in FSW. Welding parameters, including tool rotation rate, traverse speed, spindle tilt angle, and target depth, are crucial to produce sound and defect-free weld. [4]. The optimal tool design for welding steels, the effect of the tool shape on the mechanical properties and microstructures of 6061-T6 whose deformation resistance is relatively low, the tool shape does not significantly affect the microstructures and mechanical properties [5]. The mechanical properties of Aluminium Alloy Al 6061 is Considering with different Parameters of FSW. Two different type of tool shapes and shoulder surfaces for single weld configurations were used in experiments. Tensile strength test showed that welding speed is the main parameter which affects the tensile strength. Feed rate and tool shape are affecting second and third respectively. As a result of the experiment the welding speed 600 RPM, Feed Rate 40 mm/min and taper probe tool are the best optimum levels to get maximum strength of mechanical properties [6]. The mechanical properties of the welded joints of Aluminum alloys is focused [7]. The welds were tested by liquid penetration test and the ultrasonic test, which reveals acceptance. The samples were tested by ASTM standards of tensile test, bending test, charpy impact test. The characteristics (load at yield, yield stress, tensile strength and load at sample failure) of friction stir welded material are discussed. The inertia friction welding is used to create joints between a 6061-T6 aluminum alloy and a AISI 1018 steel using various parameters. The joints were evaluated by mechanical testing and metallurgical analysis. Microstructural analyses were done using metallography, microhardness testing, scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), X-ray elemental mapping, focused ion beam (FIB) with ultra high resolution SEM and transmission electron microscopy (TEM) in TEM and STEM modes. Results of these analysis first suggested that joint strengths on the order of 250 MPa could be achieved [8]. The microstructure and mechanical properties are evaluated on friction stir welded butt joints of aluminum alloys. Microstructure analysis of the cross-section of the joints revealed distinct lamellar bands and various degrees of intermixing that were correlated with tool rotational speed. Due to the distinct mechanical properties of the two alloys, micro-hardness measurements showed a consistent asymmetric hardness distribution profile across the weld nugget, regardless of tool rotational speed [9]. The properties of aluminium alloys is investicated by friction stir welding (FSW) process. The microstructures of various regions were observed and analyzed by means of optical and scanning electron microscope. The tensile properties and microhardness were evaluated for the welded joint [10]. The micor-structures of butt joints were produced by friction stir welding (FSW) and postweld heat treatment (PWHT) was applied to the joints obtained. The effects of initial temper condition and PWHT on the microstructure and mechanical properties of the dissimilar joints were thus investigated. It was showed that PWHT could be used in order to improve the joint properties [11].

II. EXPERIMENTAL METHOD

The materials choosen for this investigation is Aluminium 6061-T6 sheets of size 100×400×3(mm). The sheets were properly polished on grinding wheels and then with the emery papers for the removal of all burrs from the surface of the materials and a single 1 mm V-groove was made on the sheets. The chemical compositions and properties of Aluminium 6061-T6 are given below in the table 1 and 2 respectively. The two sheets are properly aligned and welded by the friction stir welding process. The various process parameters of friction stir welding process are tool geometry, welding parameters and joint design. The size and diameter of the pin is same as the thickness of the base plate. The welding parameters are tool rotation rate (w, rpm) in clockwise or counterclockwise dirction, tool traverse speed (v, mm/min) along the line of joint and angle of spindle or tool tilt with respect to the surface of the workpieces. The friction stir welding arrangements is shown below in the figure 1. The welding was taken place using a hardened carbon steel head pin having diameter of 3 mm and length 5.8 mm. A head pin rotational speed was fixed at 1120 rpm and transverse velocity was fixed at 200 mm/min. The chuck diameter into which the head pin inserted is 1.9 cm. The six welded coupons was prepared each with a different oblique welding angle θ shown below in the figure 2. Wire cut Electrical discharge machining was used for the extraction of six tensile test pieces from welded coupons of required shape and dimension. The tensile test was done universal testing machine of model UTK-60 Krystal Elmec of maximum capacity 600 KN, test procedures has been followed as per the standard ASTM A370. The chemical and mechanical properties of the weld is tabulated below in the table 4. Dye penetrant inspection

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and Radiography reports is given below in figure 3 and table 4 respectively.

Chemical properties were evaluated by the spark Atomic emission spectrometry as per test methods of ASTM E1251 standard.

III. RESULT AND DISCUSSION

There is no cracks, flaws, semas, lack of penetration and porosities found on from the Dye penetrant testing. The clearance image is shown below in figure number 3. Red dye or developer Magnaflux compositions followed ASTM E165, absorbs penetrant from the cracks and red spots or lines appears on the surface giving visible indication of flaws and cracks.

Table. 1: Chemical compositions of Aluminium 6061-T6 (wt%).

Al	Mg	Si	Cr	Cu	Fe	Mn	Ti	Zn
95.8-98.6	0.80-1.2	0.40-0.80	0.04-0.35	0.15-0.40	<=0.70	<=0.15	<=0.15	<=0.25

Table.2: Mechanical properties of Aluminium 6061-T6.

Yield strength	Ultimate strength	Modulus of elasticity	Poisson's ratio	Elongation	Hardness (HB)
276 MPa	310 MPa	68.9 GPa	0.33	17%	95

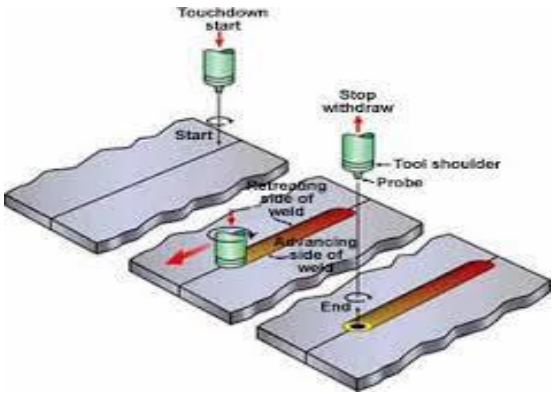

Fig.1: Friction stir welding set up and general mechanism

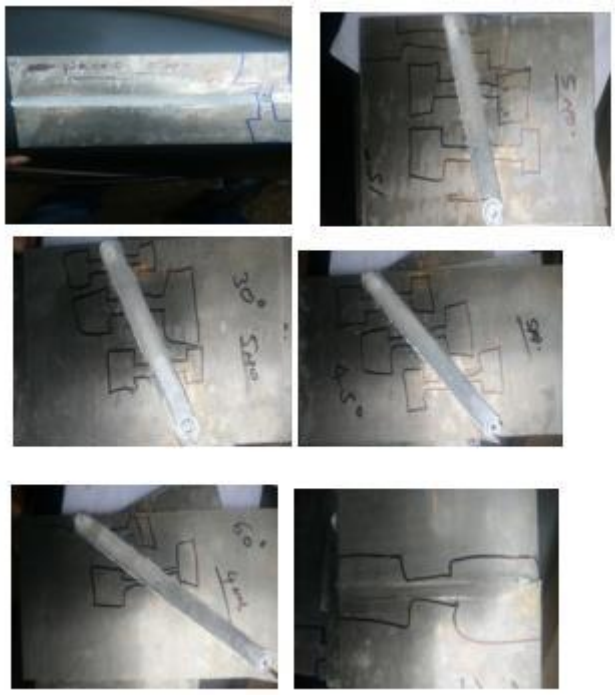

Fig.2: Friction stir welded coupons at different welding angles 0^0,15^0,30^0,45^0,60^0,90^0 respectively.

Fig. 3: Dye penetrant test image having no defects

Sl.No.	Job Identification No.	Film Size	Interpretation	Results
1.	00	8" X 6"	No significant defect	Acceptable
2.	150		No significant	Acceptabl

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			defect	e
3.	300		No significant defect	Acceptable
4.	450		No significant defect	Acceptable
5.	600		No significant defect	Acceptable
6.	900		No significant defect	Acceptable

Table.3: Radiography reports

Job No.	**Al.**	**Source**	**X-ray**
Drawing No.	----	Voltage	125 KV
Material	Aluminium	current	3.5 mA
Thickness	3mm	Focal Spot Size	1.5 x 1.5mm
Weld process	Friction Welding	Exposure Time	1 Min.
Screen-Lead F/B	0.1/0.15mm	Source to film Distance	100 cm
Density	1.8 to 2.5	Film – Make & Type	KODAK AA 400
IQI (Hole/Wire type)	ASTM 2A 6	Sensitivity	2%
Acceptable Standard	ASME SEC IX Article – 2	RT Technique	SWSI-single wall single image
Film processing	Manual-Developing – 5Min. Stop bath-1Min & Fixing – 10Min at 20-22°C		

Sl.No.	**Job Identification No.**	**Film Size**	**Interpretation**	**Results**
1.	00	8" X 6"	No significant defect	Acceptable
2.	150		No significant defect	Acceptable
3.	300		No significant defect	Acceptable
4.	450		No significant defect	Acceptable
5.	600		No significant defect	Acceptable
6.	900		No significant defect	Acceptable

IV. CONCLUSION

Welding angle θ has major effect on the strength of the weld joint. The friction stir welding was used successfully for the joining of Aluminium 6061-T6 sheets. There is no defects found on the weld confirmed from the Radiographic testing. Chemical testing shows there is no major change in the compositions of the material due to welding heat. Tensile strength of the weld is lesser than the strength of the base metal. After weld heat treatment will imporove the strength of the weld. Welding at 90^0 shows the higher tensile strength and percentage elongation satisfies the ductile property of aluminium 6061-T6 weld which is desirable

Table.4: Mechanical properties test results

II.	**Mechanical Properties as per ASTM A370**		**00**	**150**	**300**	**450**	**600**	**900**
1.	Tensile strength	MPa	74	135	139	139	136	142
2.	0.2% Proof strength or yield strength	MPa	69	127	132	131	123	128
3.	Elongation	Percent	1.2	6.1	8.5	6.3	15.5	16.3

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