Effects of Tool Pin Profile and Weld Speed on AL 6063 Alloy Joints produced by Friction Stir Welding

Lingraju Dumpala, Laxmana Raju

***Abstract*— In the field of Mechanical Engineering, the Friction stir welding (FSW) process has been attracting an increasing amount of research interest for quite some time globally. In the present research work, the study has been carried out on FSW on 6mm thick plates of 6063 Aluminium alloy using high chromium (H13) alloy steel tool. This 6063 Aluminium alloy is commonly used in marine applications due to weight-saving, corrosion resistance, extrusion requirements and structural applications. In this work, two types of tool pin profiles have been used to join the Aluminium alloy sheets. Two different tool pin profiles namely; 3 slots horizontal and 6 slots vertical cylindrical threaded have been used to fabricate. The weld joint at different tool rotational speeds of 760, 1130, 1340 rpm and traverse speeds of 11 and 25mm/min. Aluminium alloy of grade 6063 has been selected for this project report that covers the detailed study of FSW 6063 of Aluminium alloy of weld characteristics, i.e. tensile properties like Ultimate Tensile Strength (UTS), Yield Strength and % of elongation. Besides, it vividly covers the metallographic properties of the weldments like microstructure at various zones, as well.**

***Index Terms*—Friction Stir Welding (FSW); Aluminium Alloy 6063; Tool Pin Profile; Mechanical Properties**.

I. INTRODUCTION

Aluminium alloy 6063 is suitable for all conventional welding methods. It has been most widely used in the fabrication of light weight structures because of requirement of a high strength-to-weight ratio [2] and good corrosion resistance. FSW, a solid-state welding process, was invented and experimentally proven by W. Thomas and his team at the Welding Institute in UK in December 1991. This technique is currently being applied to the aero-space and shipbuilding industries optimally.

A non-consumable rotating tool with a specially designed probe (pin) and shoulder is inserted into the joint line between two pieces of sheet or plate material, which are butted together. A rotating steel pin pierces a hole in the joint line between the work pieces to a predetermined depth and moves forward in the direction of the weld. Top surface of work piece is in contact with tool shoulder. Two main functions of this tool are: (a) to heat the work piece, and (b) movement of material to produce the joint. FSW parameters play an important role in vital properties like tool design and material, tool rotational speed, welding speed and axial force. [3] Defect- free welding on such thick aluminum plates resembling a tool like trapezoidal pin geometry is suitable. [4] Tool shape and weld configuration are influenced on the microstructure and mechanical properties of Aluminium alloy FSW joints. The changes in mechanical properties have reflected the changes in weld microstructure, in particular, the softening of the weld nugget is associated with intense dynamic recovery producing grains that are nearly free from dislocations. [5] The fatigue behaviour of the joints is strongly controlled by the material fixed on the advancing side of the tool at high stress amplitude and the difference is reduced as the loading decreases. The welding speed does not influence the fatigue behaviour so strongly. The dissimilar FSW joints exhibited lower fatigue resistance when compared to the annealed joints. [6] Optimization of FSW parameters for joining Aluminium Alloy using Response Surface Methodology (RSM). The RSM is a collection of mathematical and statistical techniques useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response. [7] Tensile properties and Micro-hardness of Al Joints produced by FSW. Square butt joint is formed by FSW in a single pass welding procedure. [8] Temperature curves for Al alloy during FSW. The torque-based heat input model is used to develop the welding temperature may be estimated for a given aluminum alloy if the tool geometry, welding parameters solidus temperature, thermal diffusivity and energy per unit length of the formation of FSP zone have been analyzed microscopically. Tensile properties of the joints have been evaluated and correlated with the FSP zone formation. From this investigation, it is found that the square pin profiled tool produces mechanically sound and metallurgically defect-free welds compared to other tool pin profiles.

This study shows that the friction stir welded dissimilar joint present intermediate mechanical properties when compared to each base material. Many attempts have been made on FSW on Aluminium alloy. The effects of

The authors are with Department of Mechanical Engineering, University College of Engineering, JNTUK, Kakinada, Andhra Pradesh, India.

+91-9247793403, dlraju@gmail.com.

different shoulder geometries on the mechanical and microstructural properties of a friction stir welded joints.

II. EXPERIMENTAL WORK

The base material used in this study is Aluminium alloy 6063 plates having thickness of 6 mm. The base material tensile strength is 130 N/mm² with elongation of 21% whose Vickers hardness number is 50. The rolled plates of 6 mm thickness, 6063 aluminium alloy, are cut into the sizes (104 mm × 54 mm) by power press and final sizes (100×50) is made on vertical milling machine. Square butt joint configuration was prepared to fabricate the joints.

Non-consumable tools made of high chromium steel (H13) have been extensively used to fabricate the joints. The dimensions of the tool are presented in Table1.

TABLE – I: Tool material and dimensions

	Values
Tool Material	HCR Steel
Length of tool	48 mm
Tool shoulder diameter	22 mm
Pin smaller diameter	2.8 mm
Pin Larger Diameter	5.9 mm
Pin length	5.7 mm
Tool-1 Horizontal Slots	3
Tool-2 Vertical slots	6

FSW is then performed at a constant tool rotation speeds of 760,1130,1340rpm and a welding speeds of 11 and 22 mm/min and tool plunge depth of 0.05 mm by the friction stir welding machine. A vertical milling machine is used to fabricate the joints. Figure-1 shows the two plates joining together with the help of FSW and tensile samples prepared for tensile test. Tensile specimens are prepared according to ASTM guidelines to evaluate the bars that are made for all six weld samples.

Set 1 plates: i) Plate 1 and 2 are welded using tool 1 with half of the plate being traversed by H13 tool steel at a speed of 760 rpm and at a feed rate of 11 mm/min and the other half of the plate at a feed rate of 25 mm/min and speed of 760rpm. ii) Plate 3 and 4 are welded using tool 1 with half of the plate being traversed by H13 tool steel at a speed of 1130 rpm and at a feed rate of 11 mm/min and the other half of the plate at a feed rate of 25 mm/min and speed of 1130 rpm. iii) Plate 5 and 6 are welded using tool 1 with half of the plate being traversed by H13 tool steel at a speed of 1340 rpm and at a feed rate of 11 mm/min and the other half of the plate at a feed rate of 25 mm/min and speed of 1340 rpm.

Set 2 Plates: i) Plate 7 and 8 are welded using tool 2 with half of the plate being traversed by H13 tool steel at a speed of 760 rpm and at a feed rate of 11 mm/min and the other half of the plate at a feed rate of 25mm/min and speed of 760 rpm.

ii) Plate 9 and 10 are welded using tool 2 with half of the plate being traversed by H13 tool steel at a speed of 1130 rpm. and at a feed rate of 11 mm/min and the other half of the plate at a feed rate of 25 mm/min and speed of 1130 rpm.

iii) Plate 11 and 12 are welded using tool 2 with half of the plate being traversed by H13 tool steel at a speed of 1340 rpm and at a feed rate of 11 mm/min and the other half of the plate at a feed rate of 25 mm/min and speed of 1340 rpm.

Fig 1. Samples used for experimentation

All the six tensile bars are tested on computerised universal testing machine. All samples are checked by software DELTA-UTM System during testing to ensure that no abnormal failures or sample slippage is occurred. A set of properties including Ultimate Tensile Stress (UTS) and elongation at fracture have been recorded by the control computer for each test. These values are then used to produce stress-strain curves for the material. Some values recorded by the computer have involved slippage and measurement errors in the initial stages of tensile testing.

III. MICROSTRUCTURE

Microscopic images are taken from Meltzer metallurgical microscope. Image is taken at the welding path. Sample preparation is done within the welding zone by using 4 grades of emerald papers of grades 120, 220, 320, 400 respectively. Samples are being rubbed on it in a sequential manner by placing first on 120 grade paper at 0º to the horizontal axis. This is done for a few hours. Later changing the grade to 220, the sample is again rubbed at 90º horizontally and continuing this for some time and then changing the grade to 320 the sample is further rubbed at 0º to horizontal axis and this is further carried on.

The samples are now ready for analysis. This is done by using Keller's reagent. Keller's reagent is a solution consisting of a combination of chemicals namely; Distilled Water of 95 ml, Hydrochloric Acid of 2.5 ml, Nitric Acid of 1.5 ml, Hydro-Floric Acid of 1 ml. Analysis was done by Met Image LxV459 image analysis software. Two samples of same rotational, welding speeds but of different tools are used for comparison.

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IV. RESULTS & DISCUSSIONS

Tensile Testing:

The welded specimens are taken observation from tensile testing machine by the observation breaking zone and quality of weld is found which is then examined. The results of tensile loading of welded specimens are the ultimate tensile strength. The specimens are welded at different speed rates and feed rates and different tool profiles those are tested in computerized UTM. In this UTM Ultimate Tensile Stress and elongation at fracture are recorded by the control computer for each test. Those samples are tested by using UTM. Several test samples were welded with various combinations of tool rpm and welding speed for both the tool geometries.

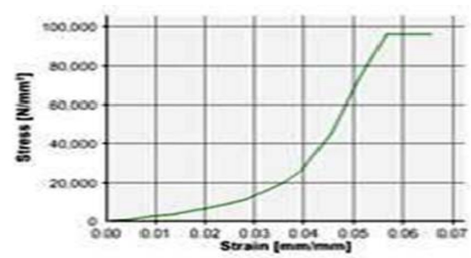

Figure 2. Sample welded using tool 1 at a speed of 760 rpm and feed of 11mm/min

Fig 3. Sample welded using tool 2 at a speed of 1340 rpm and feed rate of 11mm/min

TABLE-2: Process parameters for horizontal slotted pin and Welding process parameters for vertical slotted pin

S.no	Plate thick-ness	Tool speed (rpm)	Tool traverse speed(mm/min)	Observation from tensile test	Quality of weld
1	6	760	11	Middle of the weld	Poor
2	6	760	25	Middle of the weld	Poor
3	6	1130	11	Outside the weld	Good
4	6	1130	25	Middle of the weld	Good
5	6	1340	11	Outside the weld	Good
6	6	1340	25	Middle of the weld	Poor

MICROSTRUCTURE:

Sample preparation is done within the welding zone polished in a sequential manner. Samples are ready for analysis. Microscopic images are taken from the metzar metallurgical microscope. Image is taken at the welding path. Two samples of same rotational, welding speeds but of different tools are used for comparison. The results are as follows:

Grain size sample of image with rotational speed 760 rpm. and feed rate of 11mm/min welded with horizontal slotted tool shown in Figure 4 and the data reported in table 3.

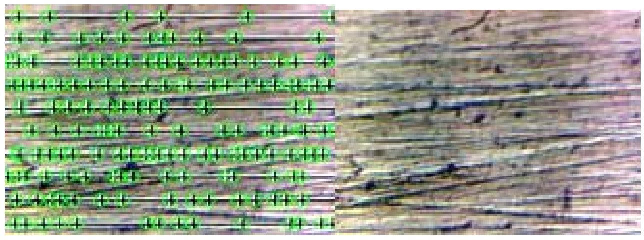

Fig 4. Grain size analysis of sample 1

TABLE-3: Grain size analysis for sample 1.

Grain Size analysis: Result Summary for sample 1	
Fields measured	1
Analysed Area	2.3237 sq.mm
Standard used	ASTM E1382
ASTM grain size	3.
Mean Int.length(μm)	108.6528

Grain size sample of image with rotational speed 760 rpm. and feed rate of 11mm/min welded with vertical slotted tool is shown in Figure 5 and tabulated in table 4.

Fig 5. Grain size analysis of sample 2

TABLE-4: Grain size analysis for sample 2.

Grain Size analysis: Result Summary for sample 2	
Fields measured	1
Analysed Area	2.3237 sq.mm
Standard used	ASTM E1382
ASTM grain size	4
Mean Int.length(μm)	83.42067

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Successful friction stir welding is achieved for 6063 A luminium alloy plates which are being welded with different tool profiles namely-horizontal slotted pin and vertical slotted pin at 3 different speeds 760, 1130, 1340 rpm. and two different feeds 11,25 mm/min respectively. Altogether giving a set of 12 different samples. Higher tool rpm. with low welding speed resulted in finer grain structure leading to higher strength as well as higher ductility of welded joints.

V. CONCLUSIONS

From the present investigation, the tensile strengths of Friction Stir welds were found to be similar to that of base metal. Lower welding speed resulted in higher ductility exhibited through higher elongation. This indicates that lower range of weld speed is suitable for achieving superior mechanical properties. Usage of horizontal slotted pin leads to the better stirring of material at welding zone which leads to the finer grain size.

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