EXPERIMENTAL INVESTIGATION AND NON DESTRUCTIVE TESTING OF FRICTION STIR WELDED ALUMINIUM ALLOY AA 6082 USING TOOL WITH AND WITHOUT SHOULDER GEOMETRY

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Abstract - ***Friction Stir Welding (FSW) is a novel solid state welding process for joining materials. It produces sound welds and does not have common problems such as solidification associated with the fusion welding techniques, so this process is widely used. Aluminum alloy has gathered wide acceptance in the fabrication of light weight structures requiring a high strength to weight ratio. The welding parameters such as tool pin and shoulder Geometry, tool rotational speed, welding speed play a major role in deciding the joint strength. In present study an effort has been made to develop a model to predict ultimate tensile strength and hardness of weld zone with and without tool shoulder geometry of the friction stir welded AA6082 aluminium alloy by Response surface methodology (RSM). Non destructive testing has been carried on FS welded area. Liquid penetrant testing method is chosen for NDT.***

Key Words: *FSW (Friction Stir Welding), WZ (Weld Zone), SMAW (Shielded metal arc welding) SAW (Submerged arc welding), FCAW (Flux-cored arc welding), ESW (Electro slag welding), ASTM (American Society for Testing of Materials), DOE (Design of Experiments), TWI (The Welding Institute), NDT(Non destructive testing), PT(Penetrant testing)*

1. INTRODUCTION

Joining two or more elements to make a single part is termed as a fabrication process. The various fabrication processes can be classified as follows: (i) mechanical joining by means of bolts, screws and rivets, (ii) Adhesive bonding by employing synthetic glues such as epoxy resins and (iii) welding, brazing and soldering. Because of permanent nature of the joint and strength being equal to or sometimes greater than that of the parent metal makes welding one of the most extensively used fabrication method. The unique combination of light weight and relatively high strength makes aluminum the second most popular metal that is welded.[1] It is very difficult to make high-strength, fatigue and fracture resistant welds from aluminum alloys (2XXX and 7XXX) series for joining aerospace structures. These aluminum alloys are generally classified as non-weld able because of the poor solidification microstructure and porosity in the fusion zone. Due to these factors, making the joints from these alloys by conventional welding processes are unattractive and difficult. As a matter of fact, all these problems can be solved by using an innovative method of welding called 'Friction Stir Welding' (FSW).[2] Friction Stir Welding is used to join different metal sheets like a range of aluminium alloys, titanium, magnesium alloys, copper, stainless steels and nickel alloys plates without filler rod or shielding gas. Material can be welded with thickness of 0.5 to 65mm from one side on full penetration, without any porosity or inner voids. The FSW process takes place in the solid-phase at below the melting temperatures point of the material, and as a result does not experience problems related to resolidification such as porosity, and cracking. [3] Any arc welding process that requires the use of a flux, such as SMAW (Shielded metal arc welding), SAW (Submerged arc welding), FCAW (Flux-cored arc welding), and ESW (Electro slag welding), is not applicable to aluminum alloys. Aluminium alloys have been made defect free welds with good mechanical properties, even those previously thought to be not weld able.[4]

2. RESEARCH METHODOLOGY

The procedure described below has been used to obtain the objective of present work:

2.1 Experimental set-up

Fixtures used to hold the work pieces in position during welding and to prevent the specimens from moving while being welded. Design and development of non-consumable tool, made of H13 die steel to fabricate the joints.[5]

2.2 Experimental investigation

Prepare tensile test specimens from welded joints as per guideline of American Society for Testing of Materials (ASTM) using ASTM-E8 M-11.Evaluate ultimate tensile strength by performing tensile test on universal testing machine (AI-UTM-40T). Evaluate hardness of weld zone by performing Vicker harness test on Vickers hardness tester Develop mathematical model for ultimate tensile strength and hardness of WZ using response surface methodology (RSM).[6]

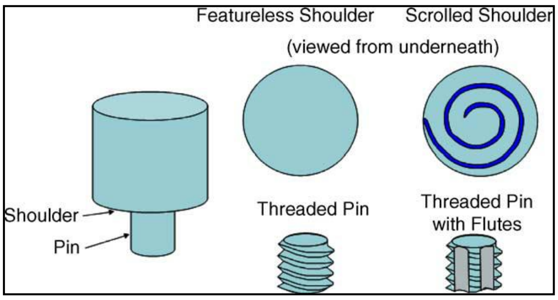


Fig1: schematic diagram of the FSW tool.[1]

2.3.3 Welding parameters

For FSW, two parameters are very important: tool rotation rate (rpm) in clockwise or counterclockwise direction and tool traverse speed (mm/min) along the line of joint. The rotation of tool results in stirring and mixing of material around the rotating pin and the translation of tool moves the stirred material from the front to the back of the pin and finishes welding process.[7] In addition to the tool rotation rate and traverse speed, another important process parameter is the angle of spindle or tool tilt with respect to the work piece surface. A suitable tilt of the spindle towards trailing direction ensures that the shoulder of the tool holds the stirred material by the tool pin profile and move material efficiently from the front to the back of the pin. Preheating or cooling can also be important for some specific FSW processes.[8] For materials with high melting point such as steel and titanium or high conductivity such as copper, the heat produced by friction and stirring may be not sufficient to soften and plasticize the material around the rotating tool.

3. CNC Milling Machine

The original class of machine tools for milling was the milling machine (often called a mill). After the advent of computer numerical control (CNC), milling machines evolved into machining centers (milling machines with automatic tool changers, tool magazines or carousels, CNC control, coolant systems, and enclosures), generally classified as vertical machining centers (VMCs) and horizontal machining centers (HMCs).[9] In present study the VMC is used and its specification as following:

Table 1: Specifications of Milling Machine: CMO 1060

Make	Cosmos
Model	CMO 1060
Controller	Mitsubishi M70
Table size	1200*800
Table travel (mm)	X 100 * Y 600 * Z600
Feed rate (mm/min)	0-10,000
Rapid rate (mm/min)	25,000
Spindle rpm (rpm)	35-10,000
Spindle taper	BT40
Spindle power (kw)	7.5-11
ATC	24

Fig. 2 CNC milling machine: CMO 1060[8]

4. FRICTION STIR WELDING TOOL

Friction Stir Welding tools consist of a shoulder and a probe which can be integral with the shoulder or as a separate insert possibly of a different material. The design of the shoulder and of the probe is very important for the quality of the weld. The tool has two primary functions: (a) Localized heating and (b) Material flow.[10]

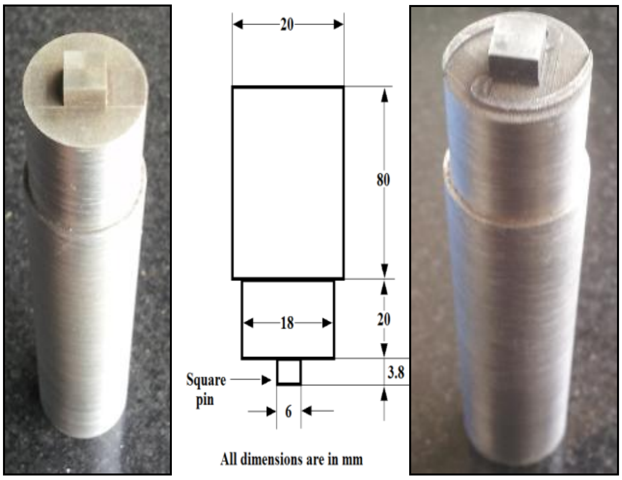


Fig. 3 Friction stir welding tool dimensions and geometry (H-13 die steel)[6]

5. EXPERIMENTATION

Friction Stir Welding of aluminium alloy plates have been carried out on FSW set-up prepared on CNC Milling Machine (CMO 1060). FSW process is considered for this experimental study of a Square pin profile tool without shoulder geometry and with scrolled geometry. The welds are developed in butt joint configuration. The aluminium alloy plates of 4 mm thickness, AA6082 were cut into the required size (300 mm x 75 mm) by CNC milling machine. The butt joint configuration (300 mm x 150 mm) was prepared to fabricate FSW joints. The welds are developed at different tool rotational speeds i.e. 600, 800 and 1000 rpm at a different feed rate of 30, 40, and 50 mm/min and total 26 trials have been carried out.[11] Tool is positioned perpendicular to the welding surface during the joining process as shown in fig.3

5.1 Surface Appearance of weld zone

Surface appearance of FS welded plate at tool rotation speed of 800 rpm at a feed rate of 30 mm/min using TOOL (a Square pin profile tool without shoulder geometry) is presented in fig.3

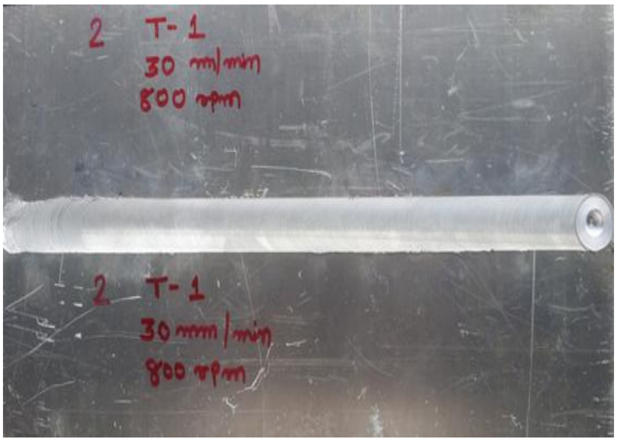


Fig 3: Surface appearance of Friction stir welded plates[12]

5.2 Measurement of Tensile Strength

As prescribed by the design matrix 26 joints were fabricated. The tensile tests were conducted using Universal Testing Machine (AI-UTM-40T). Tensile specimens were fabricated perpendicular to the weld zone line as per the American Society for Testing of Materials (ASTM E8M-11) standards by abrasive water jet cutting machine and the tensile tests were conducted using Universal Testing Machine[13]

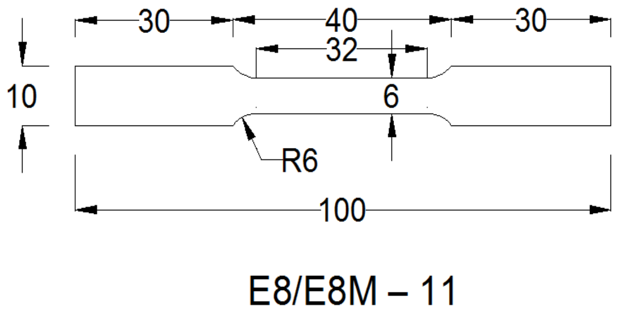
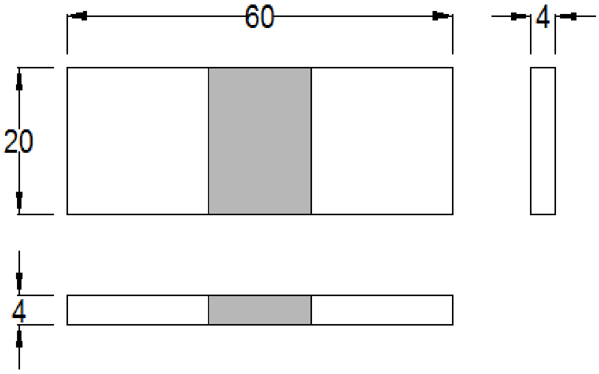


Fig 4: Schematic illustration of the tensile test samples.[14]

Fig 5: Tensile test specimens [14]

5.3 Measurement of Hardness

Hardness is the property of a material that enables to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting. Three point's average hardness is considered on the cross section of weld zone along the weld line for FSW welded specimen by Vickers hardness tester. Total 26 hardness specimens were fabricated perpendicular to the weld zone line with required size.[15]



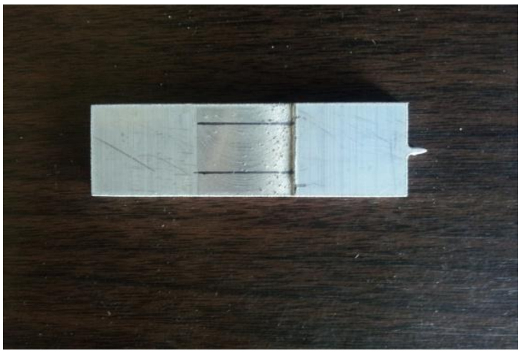


Fig 6: Hardness test specimens [15]

Experimental results of tensile strength & hardness

Table 2: Tensile strength & Hardness of the FSW joints evaluated by Tool no 1 (shoulder without Geometry)

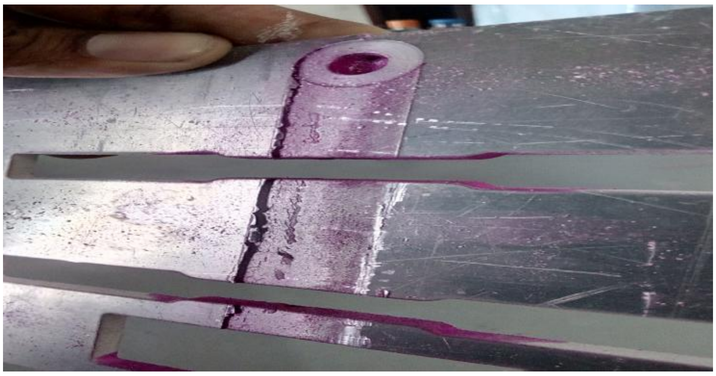
SR No	Rotational speed	Traverse speed (mm/min)	U.T.S-1 (N/mm²)	AVG of U.T.S	Vicker Hardness (HV 5) at 5Kg Load		
					PM	HAZ	WELD
1	600	30	124	115	67	61	63
2			109				
3			111				
4	800	30	141	139	61	57	59
5			137				
6			138				
7	1000	30	168	161	62	58	57
8			154				
9			160				
10	600	40	108	110	63	60	61
11			108				
12			113				
13	800	40	116	117	60	53	54
14			111				
15			124				
16	800	40	125	122	62	50	52
17			118				
18			122				
19	800	40	128	124	63	52	53
20			122				
21			123				
22	800	40	114	114	59	51	51
23			111				
24			116				
25	800	40	115	120	61	52	54
26			125				
27			119				
28	1000	40	123	125	56	48	52
29			133				
30			120				
31	600	50	108	105	62	59	61
32			103				
33			102				
34	800	50	119	110	61	46	48
35			125				
36			115				
37	1000	50	137	120	63	43	46
38			112				
39			111				

Table 3: Tensile strength & Hardness of the FSW joints evaluated by Tool no.2 (Shoulder with scrolled Geometry)

SR No	Rotational Speed	Traverse speed (mm/min)	U.T.S-2 (N/mm²)	AVG of U.T.S	Vicker Hardness (HV 5) at 5kg Load		
					PM	HAZ	WELD
1	600	30	119	119	56	48	60
2			119				
3			120				
4	800	30	138	141	53	46	55
5			144				
6			141				
7	1000	30	167	172	57	47	49
8			170				
9			179				
10	600	40	116	116	59	45	54
11			117				
12			114				
13	800	40	119	121	60	48	51
14			125				
15			119				
16	800	40	123	128	58	46	48
17			128				
18			133				
19	800	40	129	123	61	49	50
20			122				
21			118				
22	800	40	124	117	57	51	52
23			115				
24			111				
25	800	40	129	125	58	45	49
26			125				
27			120				
28	1000	40	128	132	56	46	48
29			133				
30			135				
31	600	50	115	114	57	48	53
32			116				
33			110				
34	800	50	113	116	60	49	51
35			124				
36			111				
37	1000	50	123	120	56	45	51
38			116				
39			121				

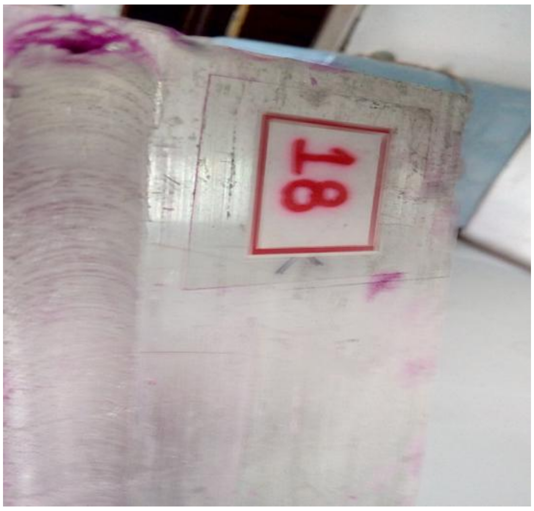
6. Non destructive testing

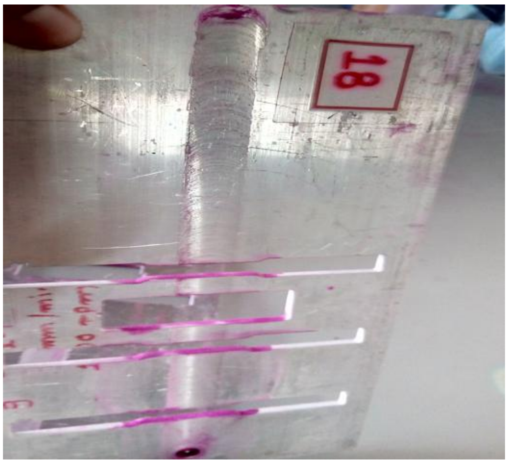
- Liquid penetrant testing report has given some defects in weld areas of both type of plates welded by Tool-1 and Tool-2.
- Thus it confirms that change in shoulder geometry of same welding tool material (H-13 Die Steel) with same pin profile (Square pin profile) reacts (while friction stir welding) in different manner to same material (AA 6082) and results in different quality of weld.
- Figures shown below also represents the visible discontinuity in plate no 1 & 5 more in comparison to the plate no 18.
- Overall defects found in plate no 1 to 13 is higher than plate no 14 to 26.



(A) Plate-1, Tool-1(600rpm,30mm/min)

(B)Plate-5, Tool-1(800rpm, 40mm/min)





(C)Plate-18, Tool-2(800rpm, 30mm/min) (D) Plate-18, Tool-2(800rpm, 30mm/min)

Figure 6.1(A, B, C, D) Comparison of weld area between Plate No.-1,5,18

- It may be possible that due to better frictional area provided by the scrolled geometry at weld zone has significant effect on the quality of weld.
- In few cases tool no 1 also has performed well but against it we are getting poor UTS and hardness for that particular no. of plate.

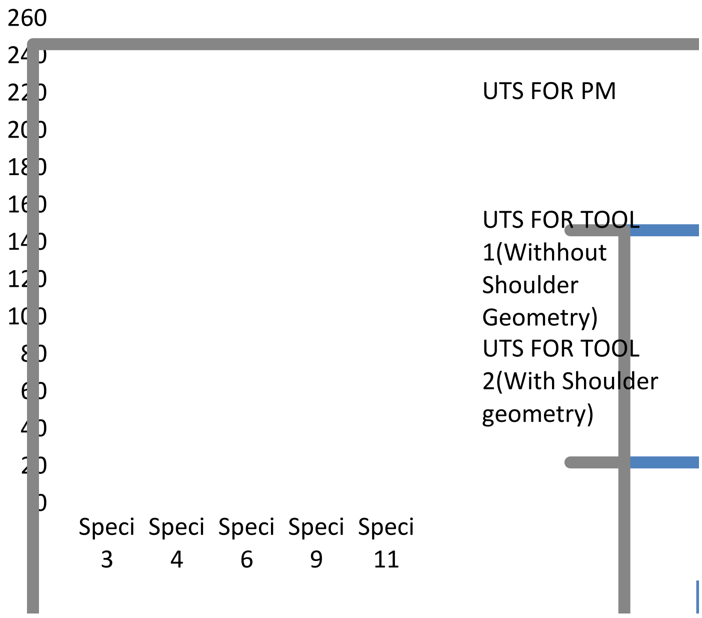
7. CONCLUSION, ANALYSIS & FUTURE SCOPE

In this study, the Ultimate tensile strength in FSW process was analyzed through response surface methodology (RSM). From this investigation, the following important conclusions are derived.

The analysis shows that the developed model can be effectively used to predict the UTS and Hardness of the joints at 95% confidence level.

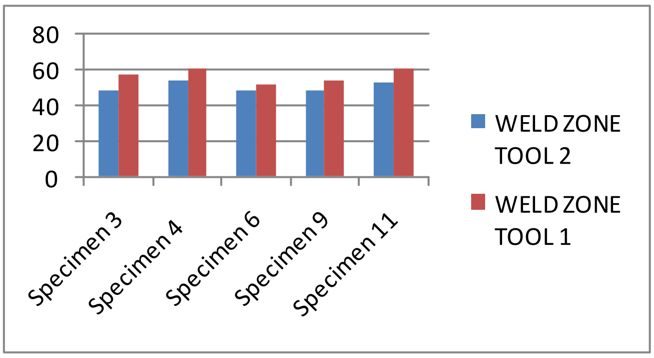
UTS of the FS welded joints increased with the increase of tool rotational speed at a constant welding speed.

Samples with welded by tool no. 2(square with scrolled shoulder) have performed better than Tool no.1(square with flat shoulder)



Above graph clearly says that the UTS possessed by random specimens joined by means of FSW with Tool-2(With scrolled shoulder geometry) represent better tensile strength.

The maximum tensile strength of the FSW joints is almost 73 to 75% of that of its base metal at 1000rpm at welding speed 30mm/min using the square tool pin profile with scrolled shoulder geometry.



Above graph represents that when you are choosing five different specimens randomly and compare the hardness at their weld zone, Hardness possessed by plates which are welded by means of tool-2 are having low hardness. According to that we are also getting better values of UTS for same specimens.

Non destructive testing performed on all of 26 plates has resulted in discontinuities in welded plates, among them plates welded with the help of tool-1 has comparatively more defects then plates welded by tool-2.

This Present study can be extended by studying of micro-structural analysis, to change pin profiles and shoulder geometries, to change D/d (shoulder dia. to pin dia.) ratio of the tool to use Hybrid Friction Stir Welding Techniques (e.g., FSW assisted by arc, high frequency induction heating or by electrical heating)

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