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Process Parameter Optimization of Friction Stir Welded Aluminium Alloy 7075-T6

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Abstract: In addition to predicting the mechanical and thermal properties of the weld joint created by FSW through suitable modeling, this study attempts to establish a relationship between the critical process parameters of FSW and the weld characteristics. The Taguchi technique was used to identify the parameters that will provide the 7075 T-6 Aluminium Alloy with good weld tensile strength. The regression equation was developed using the most important parameters, their interactions, and the zone of heat effect. In a particular work, it was examined how the tensile strength and microstructural behavior of AA7075 vary depending on the process parameters used to butt weld two pieces with dimensions of 100 mm by 50 mm by 6 mm. These parameters included axial pressure force, welding traverse speed, and rpm of the FSW tool. Because friction stir welding (FSW) produces no harmful radiation, toxic fumes, or melt pieces, it is considered an environmentally friendly method of welding and was chosen over traditional methods to achieve the desired results. Because of its environmentally friendly nature, it can be widely used in the aviation, marine, automotive, and railway industries. Wings and fuselages are two examples of aircraft structures made of AA7075.

Keywords: Friction stir Welding (FSW), Aluminium alloy AA7075-T6, Advancing side (AS), Retarding sides (RS), Tensile strength, Microhardness.

1. INTRODUCTION

A variety of materials can be joined below their melting point using a solid-state joining technique called friction stir welding. Friction stir welding (FSW) was developed in 1991 by The Welding Institute (TWI) [1].

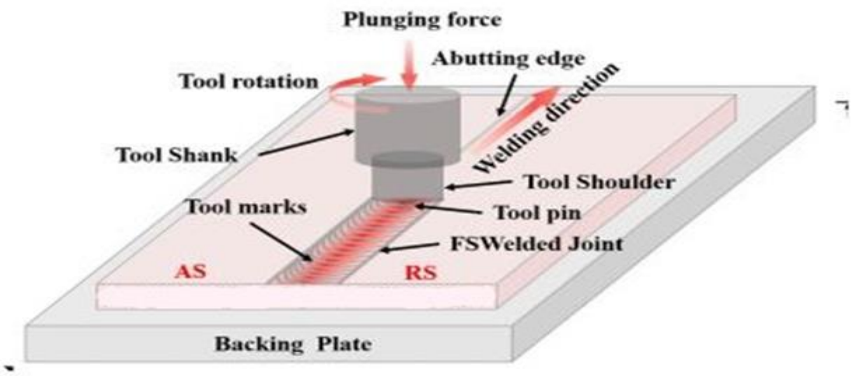

Fig. 1 Schematic Diagram of Friction stir welding

Based on multiple findings, it is evident that the conventional welding process has several disadvantages, including significant distortion, large residual strains, hydrogen cracking, welding fumes, and microstructural embrittlement caused by strong thermal gradients after welding. However, solid state techniques can minimize these drawbacks because they weld below the melting temperature. Because friction stir welding doesn't require filler material during the welding process, it has the advantage of saving extra weight gain in the final product. In friction stir welding, heat is produced by friction between the rotating tool and the work piece rather than by an external heat source as in conventional welding [2]. The two work pieces mechanically intermix in FSW as a result of the forging pressure that the tool shoulder and its rotational and translational motion apply to the metal pieces.

At first, friction stir welding was primarily created for aluminum alloys, however, these days; it is utilized for materials with great strength, such as titanium, SS alloys, etc. Zinc serves as the main alloying element in the aluminum alloy 7075. The aerospace industry uses a lot of 7075 aluminum alloys because of their strength, high density, thermal characteristics, and high strength precipitation hardening [3]. It is less corrosion resistant than many other Al alloys, but it has good fatigue strength and average machinability. The microstructural flaws stated above are minimized since the metals are not heated. The metal is able to maintain its material qualities due to its limited heat-affected zone (HAZ) and lack of melting. Joining dissimilar metals is also possible, even though friction welding of similar metals of AA7075-T6 [4] has been documented for the effects of process parameters on microstructure, hardness, and tensile properties. Finding the best possible combination of process parameters is the aim of maximizing the efficiency of the welded samples [5]. Because of its high strength to weight ratio and natural aging properties, this alloy is attractive for a range of aircraft structural applications [6]. Stir welding has several benefits when utilized for joining aluminum alloys and other challenging-to-weld materials. Further important parameters are the tool pin diameter and taper, flute design (number, depth, and taper angle), and pitch of any thread form on the pin, in addition to the tool rotation speed (TRS), weld speed (traverse speed/WS), and axial force (F).

However, significant challenges emerged to accomplish these goals, either separately or in combination. The primary factor taken into account in this work is the change in properties in response to changes in tool geometry, rotational speed, axial force, and weld speed. [7, 8]

The literature review mentioned above made it evident that while a great deal of research has been done on the FSW technique for welding aluminum alloys, there is a dearth of information regarding the FSW of AA7075 alloys and their microstructural behavior analysis. Thus, an attempt was made to FSW AA7075 alloy in this research work by adjusting the feed, tilt angle, speed, and axial load as input variables. The obtained experimental results are examined. [9, 10] There isn't as much literature on how tool profiles affect the formation of the friction stir zone. Various pin profiles are created and produced. The joints that are produced with different tool profiles and different process parameters are examined.

2 EXPERIMENTATION

2.1 Problem Formulation

Construction of aircraft structures, such as wings and fuselages is used for AA7075-T6 material. Analyzing the joint's microhardness and tensile strength after joining through friction stir welding of aluminum alloy 7075-T6 presents a problem.

2.2 Research Objectives

1) To determine and evaluate the AA7075-T6 joint's tensile strength using FSW.
2) To determine and evaluate the AA7075-T6 joint's microhardness using FSW.

2.3 Material, Tool, and FSW Parameters

The basic metal in this experiment was AA7075-T6 alloy with dimensions of 100mm x 50 mm x 6 mm, Tables 1 and 2 demonstrate the chemical compositions and mechanical properties of AA7075-T6 alloy respectively.

Table 1. Chemical compositions (wt. %)

Material	Cu	Mg	Mn	Cr	Fe	Sn	Zn	Ti	A1	
AA 7075	1.5	2.3	0.1	0.25	0.3	0.2	5.6	0.05	Bal.	

Table 2. Material properties

Name of material	Yield Strength, YS (MPa)	Ultimate Tensile Strength, UTS (MPa)	Elongation, e (%)	Micro hardness (H_V)
AA7075	**503**	**572**	**11**	**175**

Both advancing and retreating sides were of AA7075-T6 alloy, the advancing side is the side on which the tool rotates and travels in the same direction. The term "retreating side" refers to when they are moving in the other direction. Proper clamping were provided on CNC vertical milling machine (HMT CNC) The machine's Info, are as follows: –
Device Name: HMT CNC vertical milling machine
Axis Limit: x = 560, y = 450, z = 450
Rotation: 30-6000 rev/min
Weight recommended: 2800 kg
In FSW avoid any misalignment and distortion of any kind due to large forces that apply during this process, and this way welding was done in single tool travel means single pass welding. Prior research determined that the best tool profile for producing all butt welded joints was a pin-profiled high speed steel (HSS) tool with dimensions of 15 mm for the shoulder, 6 mm for the pin, and 5.8 mm for the pin length [11]. The axial stress was kept constant during the welding process, allowing the tool pin's tip to remain continuously 0.2 mm above the base metal's lower surface. Accuracy of 6 microns was achieved in the welding process by using a 3-axis computer-controlled friction stir machine. The parameters chosen for friction stir welding were the welding speed, shoulder diameter, and tool rotation speed. Because of this, the welding settings used in this study are selected to achieve a suitable joint efficiency [12, 13]

2.4 **Analysis and Testing**

Mechanical and metallurgical testing was performed on each specimen after friction stir welding. Tensile, bending, and hardness tests were used to characterize the mechanical properties of each weld. A mechanical circular saw machine was used to cut tensile specimens perpendicular to the weld direction, as per ASTM standards, respectively (Fig. 2). A computer-controlled universal testing machine (ASTM E8M-04) was used to conduct the tests. During the first welding trials, the TRS, WS, and SD were adjusted to investigate the effects of these parameters on the microstructure and mechanical properties of the friction stir welded joints. To determine the practical working limits of the FSW process parameters, FSW trial runs were conducted using rolled plates of AA7075 that were 6 mm thick.

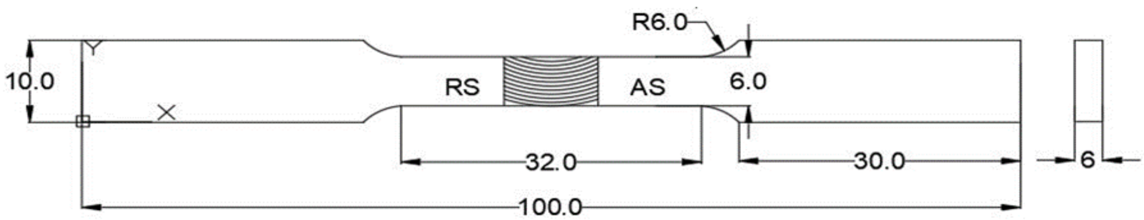

Fig. 2 Tensile sample (per ASTM E8M-04 standard)

2.4.1 Tensile Test

The work specimens generated in accordance with ASTM E8 standards are subjected to a tensile test utilizing the Universal testing machine. The specimens' tensile tests are displayed in the provided image. In comparison to the AA7075-T6 alloy, the tensile strength of the weld samples was lower. Similar behavior has also been observed using the yield strength values. It was noted that the sample fracture happened along the weld center line. The weld center is where the fracture occurs. Every sample had a ductile fracture.

At 1050 revolutions per minute, the samples show good mechanical properties. At 1200 rpm and 60 mm/min, the joints produced had the highest tensile strength, while those produced at 900 rpm and 20 mm/min had the lowest tensile strength. Specifically, the Manufacturing Universal Testing Machine specifications are –

Capacity – 25 KN

Maximum crosshead travel – 1200mm

Testing Speed range – 0.001 to 1000 mm/min

Maximum crosshead speed at 5kN – 550 mm/min

Fig. 3 Tinius Olsen Tensile Testing Machine

Fig. 4 Photograph: –Tensile specimen (after testing)

2.4.2 Microhardness

The important rupture surfaces have been individually prepared using standard metallographic methods and etched with Keller's reagent to examine the grain structure of the welded zones and facilitate optical microscopy characterization. The welded region's hardness was measured at various locations using Micro Vickers HV testers. Keller's Reagent (1 ml HF, 1.5 ml HCl, 2.5 ml HNO3, and 95 ml H2O) was used to etch the specimens after they had been polished. The specimens were etched for four minutes. After being etched, the samples were cleaned with water and allowed to dry. The CARL ZEISS optical microscope (AXIOVERT 25) depicted in Figure (a) was used to view the microstructures. A CCD camera (Moticam pro) is used to take the optical micrographs, and the images are then transferred to a PC. The specimens' traverse cross-section was used to examine the optical microstructures. Figure (b) illustrates the various regions present in the welded joint of AA7075 in FSW [14, 15].

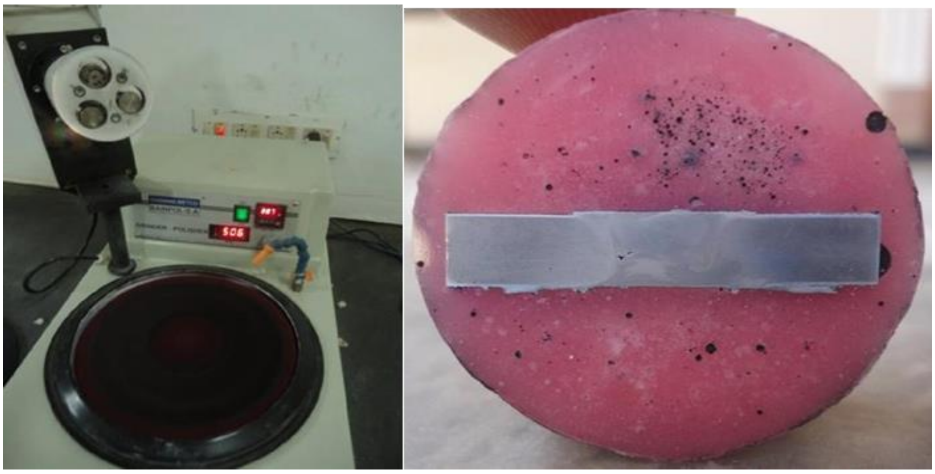

Fig. 5 Automatic disk polishing machine and Mounted specimen

3 RESULTS AND DISCUSSION

3.1 Taguchi Technique

The Taguchi technique was created in 1980 by Genichi Taguchi [16]. This is a simple yet efficient method for maximizing performance attributes within the constraints of a given set of process variables. To investigate how process parameters affect particle size and the best milling settings, Aykut Canakci et al. [17] used the Taguchi approach. Koilraj et al. [18] adjusted the welding settings using a Taguchi L16 orthogonal array to increase the tensile strength of the friction stir welded joints between the dissimilar plates.

Table 3. Welding parameters for Optimization.

Welding parameters	L1	L2	L3
a – speed, (rpm)	900	1050	1200
b– Feed, (mm/min)	20	40	60
c – shoulder diameter (mm)	15	20	25

3.2 **Testing Results**

The work specimens had multiple flaws, including holes and a rough surface, when they were first trail welded on a manual VMM at 900 rpm with manual feed. Fig 6 below shows the trial weld setup.

Fig. 6 Trial weld setup with cylindrical pin

Subsequently, the parameters were adjusted, producing sound welds with few faults. Tensile tests were performed on the specimens after they had been welded using a CNC VMM at varying RPM and feed rates. Fig 6 below shows CNC VMM and welded joints.

Fig. 7 CNC VMM and welded joints

The tensile test results are documented in the provided table 4.

Table 4: Depiction of Tensile Strength (MPa) at various parameters

Weld Joint No.	W(rpm)	V (mm/min.)	Shoulder Diameter(d)	UTS(MPa)
01	900	20	15	153
02	900	20	20	165
03	900	20	25	173
04	1050	40	15	255
05	1050	40	20	259
06	1050	40	25	273
07	1200	60	15	182
08	1200	60	20	185
09	1200	60	25	195

The fracture during tensile testing was observed to be inside the weld zone propagating almost along the weld centre line (Dimple type fracture), hence failure planes were within the weld zone making the joint weaker than the base metal AA7075-T6.

The tensile strength variation concerning speed and feed is displayed in the accompanying graph.

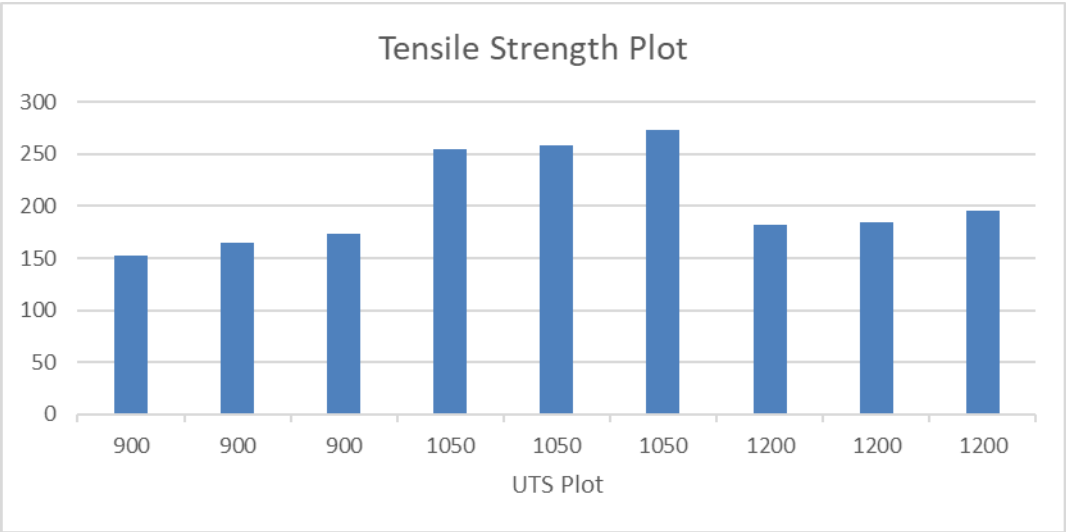

Fig. 8 Tensile Strength (in Graphical manner)

As a result of the calibration, the hardness tester provides the microhardness values exactly. Plotting the graph involved calculating the variation in hardness on each side away from the weld zone.

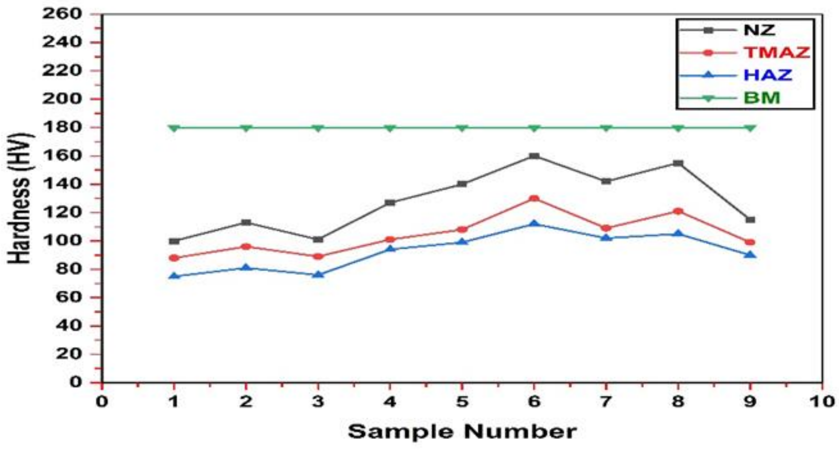

Fig. 9 Micro hardness Plot

One may observe the hardness distribution along the joint. This shows that the joint center line hardness values are higher than those of the advancing and retreating sides [19]. Because of the finer grains and stronger precipitates, the sample with the peak strength shows at the weld center (NZ) was produced by combining a higher rotating speed of 1050 rpm, a feed speed of 40 mm/min, and a shoulder diameter of 25 mm. Comparable degrees of hardness are seen on the approaching and receding sides [20]. The higher rotational speed results rise in temperature and causes the dissolution of precipitates which lowers the hardness and the lower rotational speed results in less heat generation at the tool-workpiece interface causing less refinement of grains which promotes a reduction in hardness and tensile strength. Consequently, during tensile testing, cracks along the weld center line occurred. The heat-affected zone (HAZ) has been determined to have the lowest hardness values; the softening of the heat-affected zone (HAZ) is the cause of this. Softening's prevalence is closely associated with the process of annealing. Consequently, the heat-affected zone was only affected by temperature change where all of the fractures happened [21, 22].

4 CONCLUSIONS

This study used the Taguchi technique to investigate the outcome of tool shoulder diameter, feed rate, and rotating speed during friction stir welding of AA7075-T6 alloy. At a Pin rotation speed of 1050 rpm, a traversing speed of 40 mm/min, and a shoulder diameter is 25 mm, a defect-free weld was observed with a tensile strength of 273 Mpa. The most crucial parameters for the output were found with the aid of the signal-to-noise ratio. The amount that each control variable contributed to the output factors was determined. Tensile strength and hardness were mostly determined by the speed at which the tool rotated. The TRS and WS were the most significant determinant in tensile strength and hardness. The greatest tensile and hardness was obtained with finer grains distributed uniformly, according to a microstructural study. Weld discontinuities and poor material mixing because of low TRS and WS reduce the tensile and hardness of the weld. So the process parameters were optimized and found to be 1050 rpm, 40 mm/min welding speed, and 25 mm shoulder diameter. The higher value of shoulder diameter enhances the better material flow. All of the fractures were found in the HAZ during tensile testing.

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