

# Fatigue Life Evaluation of Friction Stir Welded 7075-T651 Aluminum Alloy Joints

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**Abstract:** Aluminium 7075- T651 alloys are widely used in the production of light weight structures requiring a high strength to weight ratio and high corrosion resistance. The effect of processing parameters on fatigue life of 7075-T651 aluminium joints produced by friction stir welding was investigated in the present study. Welding samples were made by employing rotating tool speed of 770, 900 and 1200 r.p.m, welding speeds of 70, 75 and 80 mm/min. After welding process, mechanical properties of samples were evaluated by means of fatigue testing machine at room temperature. Results clearly illustrated that as the tool speed decreases, fatigue life decreases. The highest fatigue life was obtained with 80mm/min welding feed and weld speed of 1200 r.p.m.

**Keywords:** AL 7075-T651, Friction Stir Welding, Fatigue Life, Welding Parameters

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## 1 INTRODUCTION

Friction stir welding (FSW) is a solid state joining process developed and patented by the Welding Institute [1] and has emerged as a welding technique used in high strength alloys (2xxx, 6xxx, 7xxx and 8xxx series) for aerospace, automotive and marine applications which otherwise were difficult to join with conventional techniques. This technique is applicable for joining high strength aluminium alloys since there is far lower heat input during the process compared with conventional welding methods such as TIG or MIG. This solid state process leads to minimal micro-structural changes and better mechanical properties than conventional welding [2], [3].

The process was developed initially for aluminium alloys, but since then, FSW was found suitable for joining a large range of materials. Conventional fusion welding of aluminium alloys often produces a weld which suffers from defects, such as porosity developed as a consequence of entrapped gas not being able to escape from the weld pool during solidification. In contrast, with FSW, the interaction of a non-consumable tool rotating and traversing along the joint line creates a welded joint through viscoplastic deformation and consequent heat dissipation resulting in temperatures below the melting temperature of the materials being joined.

Other interesting benefits of FSW compared to fusion processes are low distortion, excellent mechanical properties in the weld zone, execution without a shielding gas, and suitability to weld all aluminium alloys [4]. Some authors analyzed the influence of the tool rotation speed [5], [6], welding speed [7], [8] and both parameters simultaneously on the microstructure and mechanical properties of 6XXX welds [9], [10]. Recently, experimental work has been carried out for welding of tube to tube plate by using FSW process and investigated numerically. These works enhance the difficulty in evaluating the dependence of the thermal and mechanical properties on weld parameters. In this investigation, an attempt has been made to understand the effect of tool pin profiles and different welding speed on the weld quality of AA6082-O aluminium using FSW process [11].

Tri-flute and taper screw thread pin are used as tool pin profiles in this research. The pin traveled longitudinally at different welding speeds (mm/min) and the tool rotation speed was held constant at 1200 rpm in all experiments.

Consequently, the appearance of the weld for different welding speed has been examined by using X-ray radiography technique and the impact of the stress as a function of strain and the effect of different welding speeds and pin profiles on yield strength and elongation are analyzed.

## 2 FRICTION STIR WELDING

Friction stir welding, a process invented at TWI, Cambridge, involves the joining of metals without fusion or filler materials. It is used already in routine, as well as critical applications, for joining the structural components made of aluminum and its alloys. Indeed, it has been convincingly demonstrated that the process results in strong and ductile joints, sometimes in systems which have proved difficult using conventional welding techniques. The process is most suitable for components which are flat and long (plates and sheets) but can be adapted for pipes, hollow sections and positional welding. The welds are created by the combined action of frictional heating and mechanical deformation due to a rotating tool. The maximum temperature reached is of the order of 0.8 of the melting temperature [4].

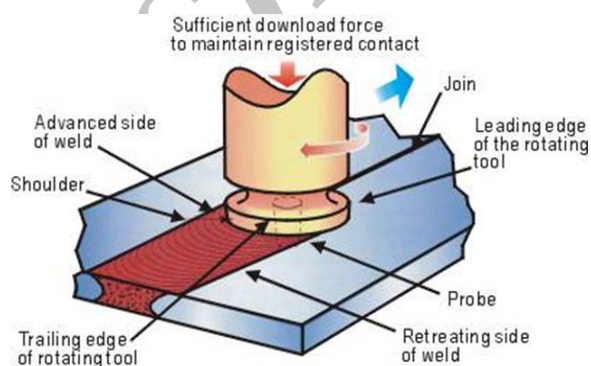


Fig. 1 Friction stir welding process

The tool has a circular section except at the end where there is a threaded probe or more complicated flute; the junction between the cylindrical portion and the probe is known as the shoulder, as shown in Fig. 1. The probe penetrates the work piece whereas the shoulder rubs with the top surface. The heat is generated primarily by friction between a rotating-translating tool, the shoulder of which rubs against the work piece. There is a volumetric contribution to heat generation from the adiabatic heating due to deformation near the pin. The welding parameters have to be adjusted so that the ratio of frictional to volumetric deformation, induced heating decreases as the work piece becomes thicker.

This is in order to ensure a sufficient heat input per unit length. The micro structure of friction stir welding depends in detail on the tool design, the rotation and translation speeds, the applied pressure and the characteristics of the material being joined. There are a number of zones. The heat-affected zone (HAZ) is as in conventional welds. The central nugget region containing the onion-ring flow-pattern is the most severely deformed region, although it frequently seems

to dynamically recrystallize, so that the detailed microstructure may consist of equated grains. The layered (onion-ring) structure is a consequence of the way in which a threaded tool deposits material from the front to the back of the weld. It seems that cylindrical sheets of material are extruded during each rotation of the tool, which on a weld cross-section gives the characteristic onion-rings.

The thermo mechanically-affected zone lies between the HAZ and nugget; the grains of the original microstructure are retained in this region, but in a deformed state (Fig. 2). The top surface of the weld has a different microstructure, a consequence of the shearing induced by the rotating tool-shoulder.

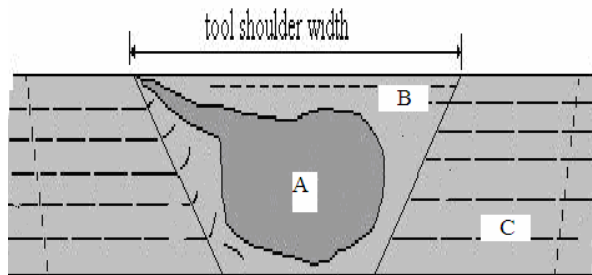


Fig. 2 Heat affected zone

### 3 EXPERIMENTAL PROCEDURE

#### 2.1. Selection of base material

##### 2.1.1. Material: Aluminium 7075-T651

##### 2.1.2. Chemical Composition:

Chemical composition of aluminum 7075-T651 is presented in Table 1.

Table 1 Chemical composition of AL 7075-T651

Alloy	Chemical Composition % weight								
	%Cr	%Cu	%Fe	%Mg	%Mn	%Si	%Ti	%Zn	%Al
Al 7075	0.18-0.28	1.2-2	0.5 max	2.1-2.9	0.3 max	0.4 max	0.2 max	5.1-5.6	Rest

#### 2.2. Tool Details

2.2.1. Tool Material: High speed steel (Wc-Co) is the selected tool which is shown in Fig. 3.



Fig. 3 High steel steel tool

2.2.2. Tool Dimensions: High speed tool geometry and dimension is shown in Fig. 4.

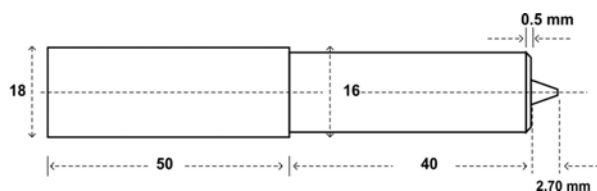


Fig. 4 Tool dimension of the designed tool

### 3 SAMPLE PREPARATION

Rolled plates of 6mm in thickness were cut into the required size (120mm x 60mm x 6mm) by power hacksaw cutting and milling. The experiments were conducted on the aluminum alloy IS 64430, where the results are shown in Table 2. Before friction welding, the weld surface of the base material was cleaned. Plate edges to be weld were also prepared so that they are fully parallel to each other.

This is to ensure that there is no uneven gap between the plates which may not result in sound welding. Secondly surface preparation was also done so that the surfaces of both plates are of equal level and footing. The FSW process is shown in Fig. 5.

Table 2 Friction stir welding experiment results conducted on aluminum alloy IS 64430

Specimen No	Welding speed (mm/min)	Rotational Speed (r.p.m)
1	70	770
2	75	900
3	80	1200

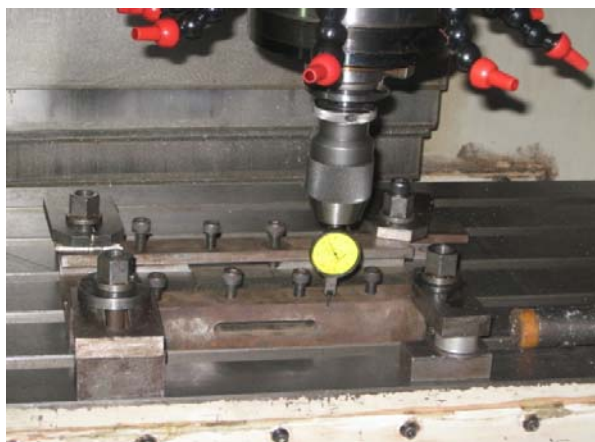


Fig. 5 FSW Processing set-up

#### 4 FATIGUE TESTING

To get proper specimens for the fatigue test, both sides of the welded plates were grinded. The specimens were made by cutting, and the final dimensions were given by grinding. The cross-section of the specimens was  $20.5 \times 1.25$  mm and they were unnotched, while the weld zone assured an inhomogeneous, and therefore a stress concentrating structure (Fig. 7).

##### 4.1. Fatigue Examination

To examine the fatigue properties of the welded joints, fatigue test was carried out. The specimens were tested with an MTS 810 servo hydraulic material testing equipment. The test was carried out with load control and sinusoidal tensile load, as a simplified cutting environmental load. The mean stress was 680 MPa, while the amplitude of the load was 400 MPa and the load frequency was 25 Hz. The measured parameter was the number of cycles to failure as shown in Fig. 6.

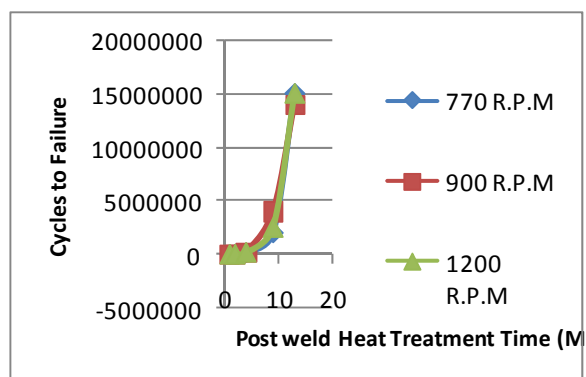


Fig. 6 Number of cycles to failure v/s Time

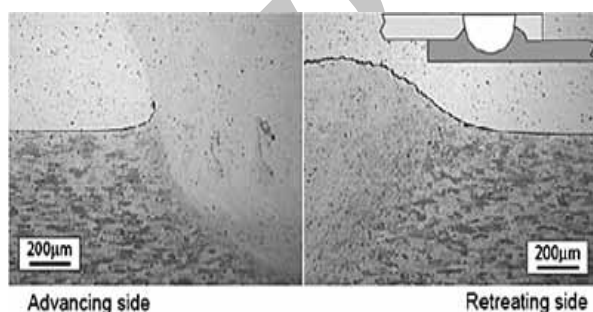


Fig. 7 Microstructure

#### 5 MICROSTRUCTURE ANALYSIS

The appearance of the crack was not observed, while the crack propagation and the failure went just a few cycles. The average cycles to failure for each test weld can be seen in Fig. 6. As it can be seen in Fig. 6, the most fatigue resistant structure evolves at the welded joint, when 13 minutes of PWHT is chosen. In the case of this PWHT duration, the place of cracks was the heat affected zone of weld.

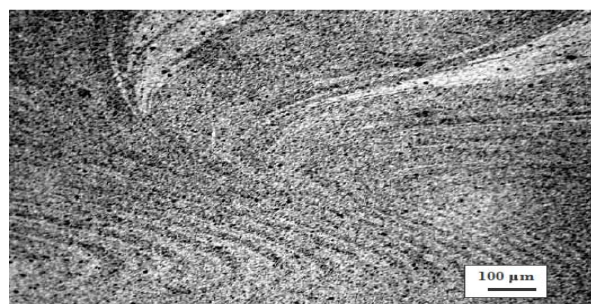


Fig. 8 Microstructure of Weld nugget of 7075-T651 Alloy

The surface analyses of the fractured specimens were carried out on the scanning electron microscope (SEM) Philips XL30. The characteristic surfaces of the fractures of Al 7075-T651 alloys welded of friction stirring weld's



material (FSW), after the fatigue tests are presented in Figure 8.

The fatigue zone has demonstrated cleavage fracture, which is turning into a plastic crack in the fracture zone that can be easily observed on the fractured faces of tested specimens. Fatigue strips are visible on the surface of the fatigue zone. In the fracture zone, in some points, some discontinuities caused by the welding process are visible.

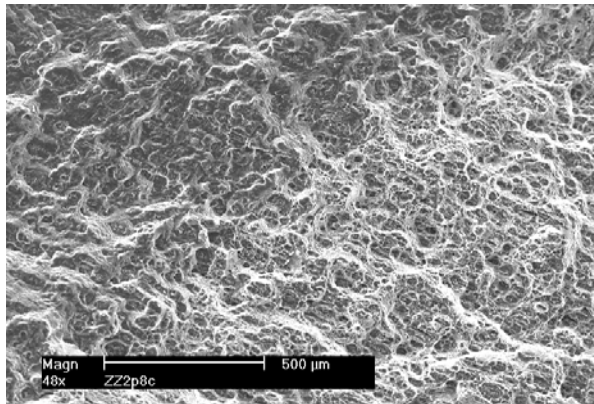


Fig. 9 SEM image of fractured surface



Fig. 10 Fracture surface

Some cracks, which start through disintegration of interphase borders–matrix/molecule, can be seen on the surface of the specimen. The cracks are initiated by the observed micro voids which arise around particles of the fragile intermetallic phases through their cracking. Fatigue cracking most often spreads in the weld's nugget. Fractured surface of the specimen and its SEM image is shown in Figs. 9 and 10.

## 6 CONCLUSION

1. The fatigue life of welded metal decreased clearly with decreasing speed of the tool.
2. No significant fatigue life changes occurred in the weld metal with change in the feed between 70mm/min to 75mm/min.

2. High surface finish is obtained at tool speed of 1200 rpm and weld speed of 80 mm/min which resulted in high fatigue strength.
3. Alignment of work piece welding line and tool is an important factor to be considered to obtain high fatigue strength. In experimental work, it has been observed that due to misalignment of welding line and tool, the fatigue strength is lower compared to the same work with proper alignment.
4. The minimal PWHT duration, at 425°C, as the fatigue test results indicate, is 12 minutes.

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