# Effects of friction stir welding on mechanical properties and microstructure of aluminum alloy

**Mohammed F.Alkandari, Sayed.A.Abdallah, S.S.Mohamed**

***Abstract*— The objective of this work is to demonstrate the feasibility of friction stir welding (FSW) for Aluminum 6061. The rotational speeds, 1800 r.p.m and transverse speeds 16 mm/min were examined. Metallographic examinations of friction stir welded plates were carried out using optical and scanning electron microscopy.**

**Hardness profiles of weld joints were measured using Rockwell hardness testing machine. The hardness profile at transfer cross sections showed marked decrease in hardness values depending on welding conditions and position of hardness measurements. The FSW welds exhibited higher joint efficiencies relative to conventional techniques.**

***Index Terms*—FSW, Aluminum, welding.**

## I. INTRODUCTION

In recent years, there has been a strong demand for lightweight transport equipments. The use of aluminum alloys to substitute ferrous alloys in transport equipments is most effective in reducing the weight of automobiles and aerospace vehicles. Considerable tonnages of aluminum alloys are used in the transport industries. With that respect, the strength to weight ratios of aluminum alloys has thus been a dominant design consideration. Several strengthening mechanisms have been used in the last 30 years to develop new aluminum alloys with high strength to weight ratios [I ]. Dispersion hardening, precipitation hardening, and refinements of grain structure provide efficient strengthening mechanisms.

Nowadays, aluminum alloys are used in many applications in which the combination of high strength and low weight is desired. Ship building is one of the fields at which the low weight can be one of significant value. In fact, the first aluminum boat was built in 1891 and the first welded aluminum ship is formed in 1953 [6].

Friction stir welding (FSW) technique was recently developed to overcome such difficulties and eliminate the needs for special surface preparation or cleaning prior to weld aluminum alloys. Friction stir welding FSW is a solid state welding technique developed by The Welding Institute (TWI), for joining non weld able metals or metals difficult to be welded such as precipitation hardened alloys, cold worked, dissimilar metals, composites, and new materials [6-45].
The characteristics of FSW process make it desired for advanced applications such as aerospace, automotive and shipbuilding. FSW technique has the potentiality to avoid significant changes in microstructure and mechanical properties [7,9-11].

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## II. EXPERIMENTAL PROCEDURE

Aluminum 1050 plates were firstly milled to nominal thickness of 5,10,15,17 mm, 75 mm width, and 300 mm length.

**Table 1.** Typical chemical composition for aluminum alloy 6061

| Element | % Present |
|---|---|
| Cu | 0.05% |
| Mg | 0.05% |
| Si | 0.25% |
| Fe | 0.4% |
| Mn | 0.05% |
| Zn | 0.07% |
| Ti | 0.05% |
| Al | Balance |

Table (2): Mechanical Properties of Al 6061 /composites

| Temper | AL |
|---|---|
| Proof Stress 0.2% (MPa) | 35 |
| Tensile Strength (MPa) | 80 |
| Shear Strength (MPa) | 50 |
| Elongation EL (%) | 42 |
| Hardness Vickers (HV) | 60 |

The two pieces to be welded are brought into contact placed on a steel back plate and tightly clamped with holding fixtures to the traverse table of conventional milling machine. Fig.1. shows a schematic representation of the FSW process. The plate has been welded along the plate rolling direction. The welding tool was rotated in the clockwise direction and the parts which tightly fixed at the backing plate were traveled.

At first the rotating tool pin was inserted in the pilot hole and exerted compression and rubbing forces on the work piece under the probe shoulder. The tool pin rotates firstly without traversing for the first few seconds to initiate enough frictional heat to plasticize the welded material under the probe shoulder. After that, the table which hold the specimen was traversed with constant speed under the rotating pin.

Friction stir welding has many welding parameters, such as tool (including shoulder and screw- like probe ) materials, tool rotation speed, welding speed and angle of the tool. In this study, rotational speeds, 1800 r.p.m and traverse speeds 16mm/min were examined.

The Vickers hardness profile near the welding zone was measured on a cross section and perpendicular to the welding direction with a 100kg load for 10s. The test was performed in the mid thickness of the specimens. The readings were plotted as a function of distance.

The tensile test was carried out at room temperature using an Instron (?) –type testing machine with crosshead speed of 1.9 x$10^{-2}$ mm/s. To determine the tensile strength of stir zone, tensile test specimens were sectioned in the longitudinal direction to the weld line by an EDM (electrical discharge machine).

Microstructural changes from the welding zone to the unaffected base metal were examined with Optical Microscope and SEM (scanning electron Microscope).

Optical metallographic was performed on the metal to compare the grain structure. Metallographic specimens were extracted from the S-T plane of the base metal sheet. All of the weld metal metallographic was performed on a plane perpendicular to the welding direction at the weld centerline and mid-thickness.

**Fig.1. Friction stir Welding process**

## III. Results and Discussion

### Macrostructure

Macroscopic examination of transverse and longitudinal cross section- showed defect free sound weldments, produced under all applied experimental conditions. It showed also the presence of concentric elliptical rings, as shown in Fig.( 2 ). This indicates the formation of ellipsoids in the stir zone, in most investigated specimens such ellipsoids characterize the macrostructure of FSW process [ 4-7 and 10]. They represent plastic deformation increments that developed as the rotating tool pin moved through the joint interface. The presence of such flow lines indicates that, during the FSW process, the material at the interface of abutting joint, i.e. at weld centerline was strongly stirred and mixed together, so that it can be considered as a viscous fluid, which makes swirl movements under the probe- shoulder. As the probe- pin moved in traverse direction, i.e., away from the weld centerline, the temperature decreased, the layer viscosity increased. The transverse diameter of inner ellipse decreased

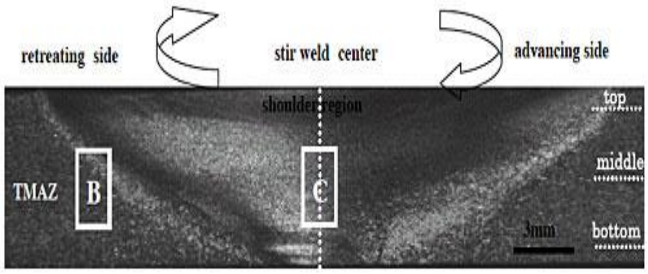


**Fig.2** Cross sectional microstructure of friction stir welded 6061 aluminum plate at a rotation speed of 800$m^{-1}$ and a travel speed of 38mm/min

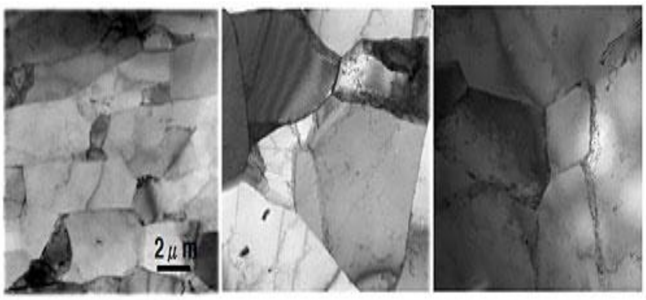


**Fig.2** TEM image of 6061 aluminum (a) base material, (b) TMAZ, (c) stir weld zone

### Hardness measurements

The hardness measurements in Fig. 3. represent the hardness profiles for specimens at 16mm/min- traverse speed, and rotational speeds of 1800 r.p.m. The hardness profiles were taken at three different locations across the weld nugget, i.e. near the weld-face, at midway through the weld nugget, and near the root of the FSW joint.

In general, the hardness decreases from the base metal towards the weld centerline. This is a typical hardness profile for some of friction stir welded aluminum alloys [5,10,15,17]. On the other hand, it decreases from the weld root towards the weld face. However, the hardness profile shows a more or less saddle pattern near the weld centerline especially near the weld face. Such softening phenomenon has been attributed to the dynamic recovery and dynamic recrystallization processes during FSW of aluminum alloys Fig.3. represents the decrease in hardness from base metal to the centerline of weld nugget at constant rotational speed, while Fig represents it at constant speed from the hardness profile in Fig.3 it could be concluded that the higher degree of strain hardening in weld nugget.

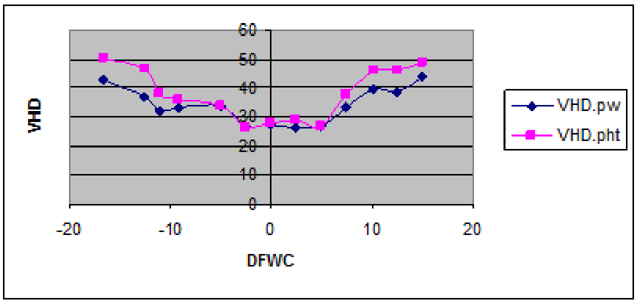


Fig. 3 Hardness profile measurement for FSW at speed 1800 r.p.m and feed16mmmin and thickness 17mm

The measurements of tensile strength and ductility for selected specimens are given in table 1.

Changes in tensile properties and hardness after FSW represent the sum of two different mechanisms i.e. the softening mechanism due to dynamic recrystallization as given in Fig.4 and 5 and extraordinary grain refining mechanism due to heavy plastic deformation of highly stable microstructure constituents. due to heavy plastic deformation of highly stable microstructure constituents.

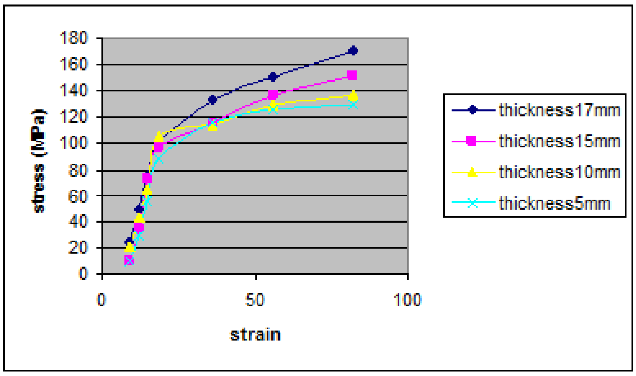


Fig.4 Relation between strees and strain

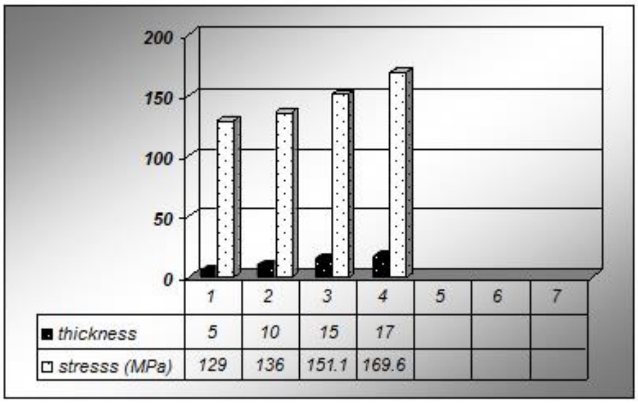


Fig.5 Relation between stress and thickness

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