

**FRICION STIRWELDED HIGH STRENGTH ALUMINUM ALLOYS: A
MECHANICAL AND MICROSTRUCTURAL STUDY**

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ABSTRACT:

Friction stir welding (FSW) is a solid-state joining technique that joins two facing work parts without melting the material by using a non-consumable tool. It has several benefits, including improved mechanical qualities, and the samples made using this method are strongly advised for a variety of uses, including robots, computers, aircraft, automotive, shipbuilding, and rolling stock in railroads. Therefore, two types of high strength aluminum alloys, AA2024 and AA7075, were chosen for this experiment, and FSW was carried out using certain parameters. SEM, EDS, hardness, and UTM are used to further characterize the manufactured samples in order to assess their mechanical and microstructural qualities. The development of mechanical characteristics was shown to be caused by weld portions with limited porosity and refined grain structures.

Keywords:

Friction Stir Welding, Microstructure, UTS, Hardness, SEM

1 INTRODUCTION

Friction stir welding (FSW) is a solid-state joining method for a range of materials, including metals and metal alloys [1]. It is currently expanded to include a variety of material combinations, both similar and different, for applications needing a lot of structure [2, 3]. One of the key characteristics of FSW is the cylindrical rotating tool that creates the welded junction and mechanically goes through the materials. The frictional surface between the work piece materials and the FSW tool [shoulder-pin] produces heat. The Aluminum series 2xxx and 7xxx are a significant class of alloys that are widely used in the aircraft sector, where the manufacturing of airframe structural components requires advanced weight reduction techniques. The AA7xxx series alloys are typically chosen due to their exceptional strength. Conversely, the alloys of the AA2xxx family are typically employed in applications where fatigue is a significant issue and high service temperatures are feasible. It was found that using traditional fusion welding techniques to join the Al alloy was prone to mistakes. Finding a different and efficient way to join these aviation-grade aluminum components is therefore essential, as are the effects of factors on FSW and the mechanical and metallurgical analysis of the welded joint. though AA7075 and AA2024 have many separate applications, the two alloys are used in situations where merging these high-strength aircraft aluminum alloys became essential in a variety of demanding applications [7].

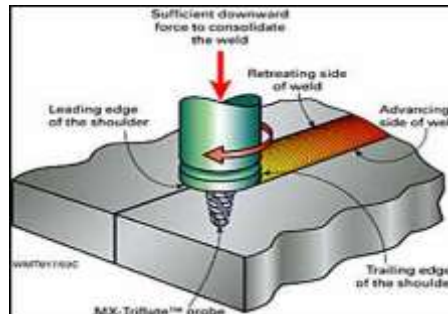


Fig. 1. Principle Diagram of friction Stir Welding

FSW has revolutionized low joint efficiency and other solidification-related issues. According to Heidarzadeha [8], the friction stir welding process produced joints with up to 100% efficiency in some metals. The second significant feature that FSW has introduced is the blending of various metals. Because of this, FSW is being utilized more frequently in applications that require the joining of dissimilar materials, particularly those with drastically differing mechanical, physical, and chemical properties as well as those where the weld zone contains brittle intermetallic phases. Furthermore, research is being done to completely use FSW with significant benefits for other high-temperature materials, such as titanium alloys and steel [9,10]. The mechanical qualities of other welded joints are also included in the advantages of FSW.

Table: 1. Chemical composition of AA2024

Material	Si	Fe	Cu	Mn	Mg	Zn	Al
AA2024	0.103	0.136	4.416	0.535	1.646	0.011	Remainder

Table: 2. Chemical composition of AA7075

Material	Si	Fe	Cu	Mn	Mg	Zn	Cr	Al
AA7075	0.062	0.186	1.445	0.019	2.55	5.602	0.195	Remainder

2 Experimental procedure

Commercial tempered grade aluminum alloy square plates measuring 100 X 100 X 4 mm was the material utilized in the studies. The compositions of each alloying element present in each grade of aluminum alloy are shown in [Table 1](#) and [Table 2](#). Aeroplane building is one of the many uses for high-strength aluminum alloys, such as those in the 2xxx and 7xxx families. Because of their dissimilar welding, these alloys are especially helpful [12,13]. FSW is a innovative solid-state welding technique that combines high-strength aluminum alloys from the 2xxx and 7xx families with various benefits over conventional fusion welding. The automotive, aerospace, and military sectors are the main users of the 2xxx and 7xxx series of high-intensity, heat-treatable/age-hardenable aluminum alloys [14,15]. The AA2xxx series is used for most interior components, such as frames, wing stringers, and lower wing skins. These materials are frequently utilized in applications that need outstanding fracture toughness and minimal weight. The AA7xxxx series was used to make aerospace parts that required exceptional strength, such as upper wing skins, vertical and horizontal stabilizers, and wing stringers. For the current study, aluminum alloys AA2024 and AA 7075 were used [16].

2.2 FSW process setup

Table: 3. FSW process parameters utilized in this work

Process Parameter set	1	2	3	4
Tool Rotational Speed(rpm)	500	700	900	1100
Weld Speed(mm/min)	30	30	30	30

2.3 Testing and characterization

The ultimate tensile strength, yield strength, % of elongation and micro-hardness tests are used for mechanical properties analysis, SEM and EDS are used for surface microstructural analysis.

2.4 Scanning Electron Microscopy (SEM) Analysis

Scanning Electron Microscopy is a widely used analytical technique that allows scientists to examine the composition of a wide variety of materials at high magnifications and resolutions. A popular analytical method that enables researchers to study the makeup of a broad range of materials at high magnifications and resolutions is scanning electron microscopy. The end effect is a picture that clearly displays surface characteristics. Directing an electron beam onto a sample's surface using an electron gun is the fundamental idea behind SEM. Using electromagnetic lenses, this beam is concentrated into a precise area and then re-exposed in a methodical pattern throughout the surface. Different signals are released as the electron beam interacts with the specimen's surface atoms. Since they offer comprehensive details about the sample's topography, secondary electrons are the most often utilized of them for imaging.

2.5. Energy Dispersive Spectroscopy

Energy Dispersive Spectroscopy (EDS), often referred to as Energy Dispersive X-ray Analysis (EDX), is commonly employed in combination with Scanning Electron Microscopy (SEM). In addition to producing secondary electrons for imaging, the electron beam in a scanning electron microscope (SEM) also causes the material's atoms to emit distinctive X-rays. The energy of these X-rays are unique to the elements they come from. The energy and intensity of these X-rays are measured by EDS detectors, which generate a spectrum that shows the elements and their relative abundance. EDS is particularly helpful for elemental mapping throughout the sample's surface, detecting contaminants, confirming the existence of particular elements, and identifying unknown compounds.

3 Results and discussion**3.1 Tensile Test Analysis**

The tensile properties of the welded joints were evaluated, and key metrics are summarized in [Table 4](#).

Table: 4. Tensile Test results

Sample ID	Tensile Strength (MPa)	Yield Strength (MPa)	% Elongation
1	191.21	174.75	6.16
2	167.42	167.42	4.72
3	218.56	211.82	6.48
4	88.84	61.27	6.48

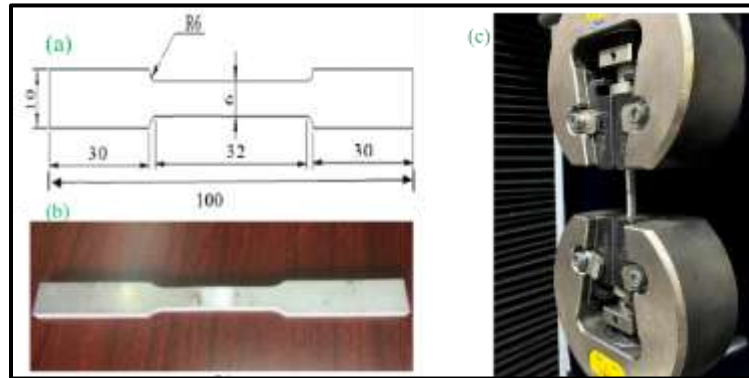


Fig. 3. Schematic diagram of the ASTM E8 standard tensile test specimen (a), Photograph of FSWed tensile specimen (b), UTM arrangement(c)

Sample-3 (AA 7075) exhibits the highest tensile strength (218.56 MPa) and yield strength (211.82 MPa), indicating its superior mechanical performance. This can be attributed to the alloy's heat treatment condition and higher content of zinc, which significantly enhances strength. Sample-1 also shows a strong mechanical profile, with tensile and yield strengths of 191.21 MPa and 174.75 MPa respectively, likely corresponding to AA 2024 alloy in a heat-treated condition. Sample-2 displays equal tensile and yield strength (167.42 MPa), indicating little to no plastic deformation before failure. This could point to an over-aged or annealed condition where the yield and tensile values converge. Sample 4 has the lowest values of tensile strength (88.84 MPa) and yield strength (61.27 MPa), possibly representing an as-cast or untreated alloy with a more ductile and less strong microstructure. Sample 4 showed significantly lower strength (88.84 MPa), likely due to defects like porosity or incomplete penetration due to defects like porosity or incomplete. % Elongation was consistent (~6%) except for Sample 2 (4.72%), indicating brittle behaviour in that joint.

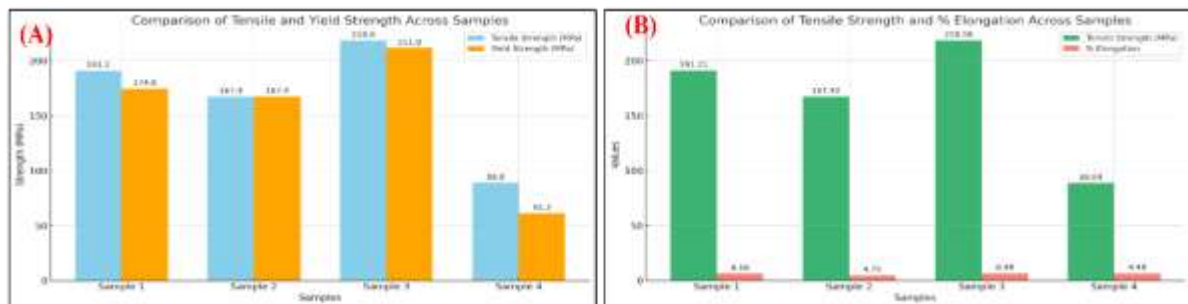


Fig. 4. (a) comparison of tensile strength and yield strength and (b) comparison of tensile strength and percentage elongation.

3.1.1 Comparison Tensile strength, yield Strength and % Elongation:

The comparison of tensile strength, yield strength, and percentage elongation across the samples highlights significant variations in mechanical properties. Sample 3 (AA 7075) showed the highest tensile (218.56 MPa) and yield strength (211.82 MPa) with good elongation (6.48%), indicating excellent strength and ductility. Sample 1 (AA 2024) followed with strong tensile (191.21 MPa) and yield (174.75 MPa) values and moderate elongation (6.16%). Sample 2 had equal tensile and yield strength (167.42 MPa) with the lowest elongation (4.72%), suggesting limited ductility. Sample 4 had the lowest strength but decent elongation (6.48%), indicating a more ductile but weaker material.

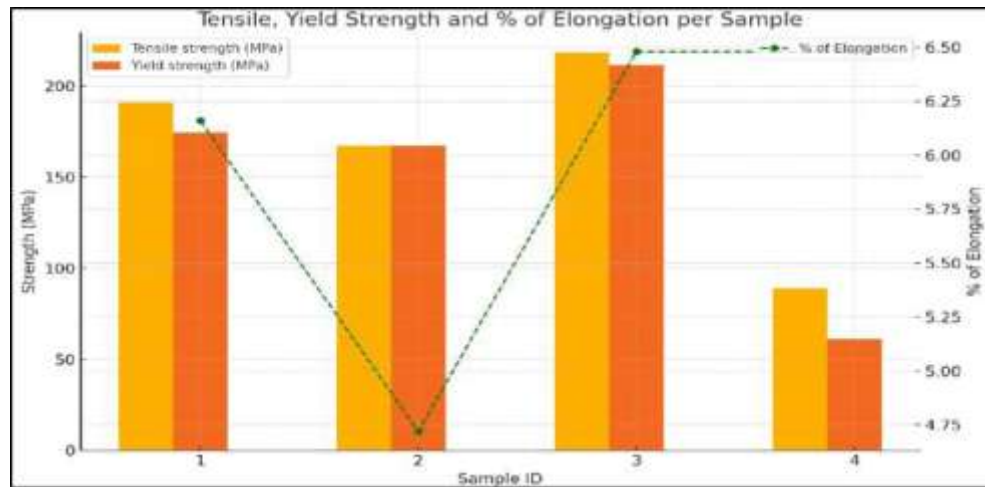


Fig. 5. Comparison of tensile properties (Tensile strength, Yield Strength and % Elongation).

3.2 Scanning Electron Microscopy (SEM) Analysis

Important information about the microstructural characteristics of the aluminum alloy samples is revealed by the Scanning Electron Microscopy (SEM) images. A fine-grained, dendritic structure, characteristic of precipitation-hardened alloys, is evident in the SEM micrographs of the AA 7075 and AA 2024 alloys. Micro voids and tiny intergranular fissures are seen in some places, which could be signs of wear and tear or corrosion under mechanical stress. Moreover, precipitates and second-phase particles are clearly visible at the grain boundaries, especially in samples that have undergone heat treatment. These characteristics are typical of T6 aging treatments, where the material's increased strength is caused by precipitates like as MgZn (in 7075) and Al₂Cu (in 2024).

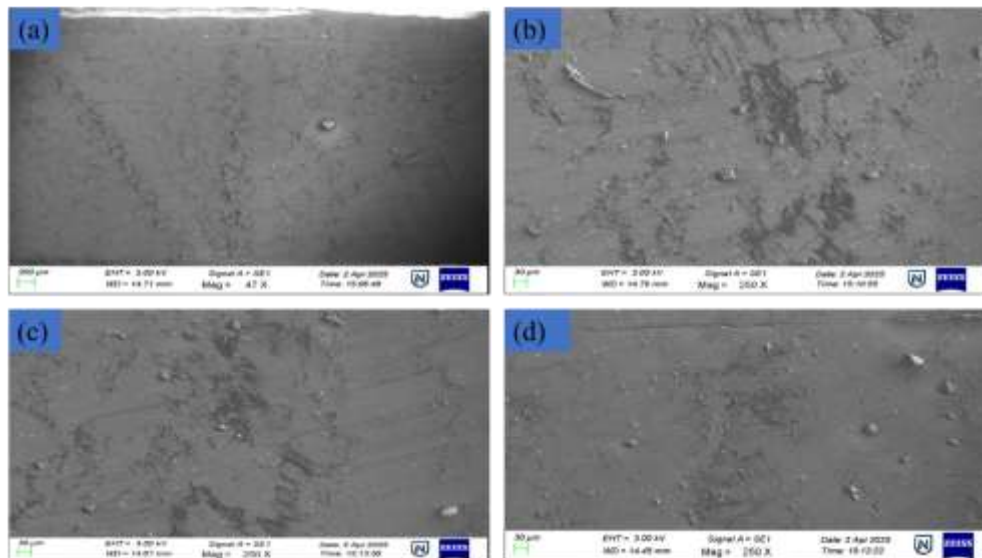


Fig. 6. Microscopic images of friction stir welded aluminium parts at cross section

The SEM and EDS investigations provided important details about the elemental and microstructural characteristics of the aluminum alloys under study. The SEM pictures, which displayed a heterogeneous microstructure with second-phase particles and precipitates, verified the effects of alloying and heat treatment on grain strengthening and

refinement. Particularly in heat-treated regions, notable features of alloys like AA 7075 and AA 2024 were observed, including fine grain boundaries, intermetallic dispersions, and occasional micro voids. **4 Conclusion**
The impact of FSW parameters on the mechanical properties of various aluminum alloys, AA2024-AA7075, has been investigated in this work. The investigation's findings led to the following important conclusions. The lower ultimate tensile strength was caused by the lowest welding and rotational rates. At RS 900 rpm and WS 30 mm/min, the maximum ultimate tensile strength of 218.56 MPa and yield strength of 211.82 MPa were discovered. At RS 1100 rpm and WS 30 mm/min, the lower ultimate tensile strength of 88.84 MPa and yield strength of 611.27 MPa were attained.

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