Mechanical Properties of Friction Stir Welded Joints of Aa6061-T6 Aluminium Alloys

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***Abstract* - Friction stir welding (FSW) is an advanced friction welding process. The conventional friction welding is done by moving the parts to be joined relative to each other along a common interface also applying compressive forces across the joint. The frictional heat generated at the interface due to rubbing softens the metal and the soft metal gets extruded due to the compressive forces and the joint forms in the clear material, the relative motion is stopped and compressive forces are increased to form a sound weld before the weld is allowed to cool. In present work is to join the aluminum alloy of 6061-T6 of 2.5 mm thick by FSW using conventional milling machine. It was found that joints with rotational speed of 1000 rpm showed maximum tensile strength (UTS). Also joint strength shows an increase with respect to welding speed.**

Keywords: FSW, tool geometry, welding speed, axial force, tensile strength

1. INTRODUCTION

Friction stir welding (FSW) was invented and experimentally proven at The Welding Institute (TWI) in the UK in December 1991. TWI held patents on the process, the first being the most descriptive. FSW is a solid-state joining process that uses a non-consumable tool to join two facing workpieces without melting the workpiece material. Heat is generated by friction between the rotating tool and the workpiece material, which leads to a softened region near the FSW tool. While the tool is traversed along the joint line, it mechanically intermixes the two pieces of metal, and forges the hot and softened metal by the mechanical pressure, which is applied by the tool, much like joining clay, or dough. It is primarily used on wrought or extruded aluminium and particularly for structures which need very high weld strength. FSW is also found in modern shipbuilding, trains, and aerospace applications.

1.1 Friction Stir Welding Process:

A rotating cylindrical tool with a profiled probe is fed into a butt joint between two clamped workpieces, until the shoulder, which has a larger diameter than the pin, touches the surface of the workpieces.The probe is slightly shorter than the weld depth required, with the tool shoulder riding atop the work surface. After a short dwell time, the tool is moved forward along the joint line at the pre-set welding speed.

Frictional heat is generated between the wear-resistant tool and the work pieces as shown in Fig.1 and Fig.1.1. This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting. As the tool is moved forward, a special profile on the probe forces plasticised material from the leading face to the rear, where the high forces assist in a forged consolidation of the weld. This process of the tool traversing along the weld line in a plasticised tubular shaft of metal results in severe solid state deformation involving dynamic recrystallization of the base material.

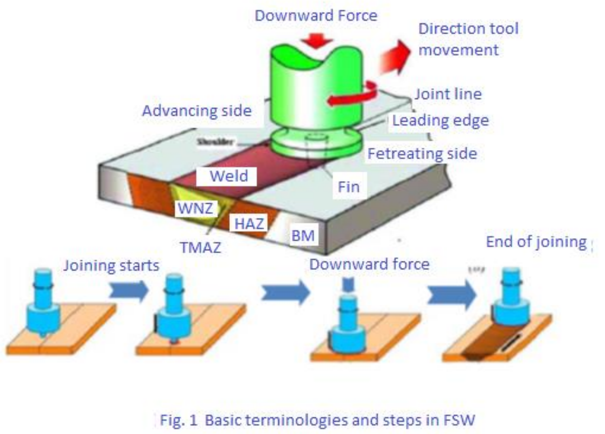


Fig 1: Friction stir welding (FSW) process

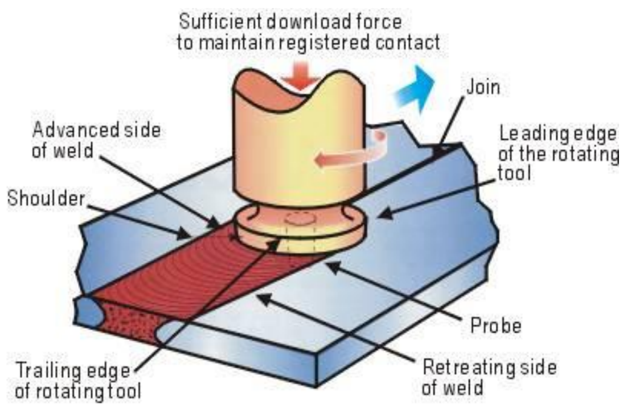


Fig. 1.1 Working Principle of FSW

2. EXPERIMENTAL METHODOLOGY

Conventional Milling machine (Fig.2) is the machining process of using rotary cutters to remove material from a workpiece by advancing in a direction at an angle with the axis of the tool. It covers a wide variety of different operations and machines, on scales from small individual parts to large, heavy-duty gang milling operations. It is one of the most commonly used processes in industry and machine shops today for machining parts to precise sizes and shapes.

Fig 2: Universal Milling Machine

2.1Preparation of work material

The work piece material selected in the present work is aluminum alloy AA6061-T6 plate of size 300x75x2.5 thick. Table 1 shows the chemical composition of AA6061-T6 aluminum alloy material.

Thermo-mechanical characterization of aluminum and its alloys of Al (AA6xxx series) present good mechanical properties with respect to high strength, welding performance, good corrosion resistance. These alloys are used in aircraft industries, automobile industries etc. It is very difficult to join dissimilar alloys than joining similar alloys due to the difference of their compositions. Joining of these alloys haveprospective market for Gas cylinders, Battery car body and structures, ladders, trolleys, domestic and office furniture etc. These are generally done by the small entrepreneurs. Further study will prove its applicability in real life. Keeping all these points in mind, the present investigation was carried out.

TABLE 1:CHEMICAL COMPOSITION OF AA6061-T6 ALLOY MATERIAL (IN WEIGHT PERCENT)

Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
95.8-98.6	0.04-0.35	0.15-0.4	Max 0.7	0.8-0.12	Max 0.15	0.4-0.8	Max 0.15	Max 0.25

2.2 Preparation of FSW Tool

The D-series of the cold-work class of tool steels, which originally included types D2, D3, D6, and D7, contains between 10% and 13% chromium (which is unusually high) as shown in Table 2. These steels retain their hardness up to a temperature of 425 °C (797 °F). Common applications for these tool steels include forging dies, die-casting die blocks, and drawing dies. Due to their high chromium content, certain D-type tool steels are often considered stainless or semi-stainless, however their corrosion resistance is very limited due to the precipitation of the majority of their chromium and carbon constituents as carbide. Fig. 3 shows HCHCR tool be used for the FSW joints.

Fig.3: HCHCR FSW tool

TABLE 2: CHEMICAL COMPOSITION OF HCHCR TOOL MATERIAL (IN WEIGHT PERCENT)

C	Cr	Si	P	Mo	Mn	V	S
1.5	11-13	0.3	0.03	0.9	0.45	1	0.03

A fixture is work-holding or support device used in the manufacturing industry. Fixtures are used to securely locate (position in a specific location or orientation) and support the work, ensuring that all parts produced using the fixture will maintain conformity and interchangeability. Using a fixture improves the economy of production by allowing smooth operation and quick transition from part to part, reducing the requirement for skilled labor by simplifying how work pieces are mounted, and increasing conformity across a production run as shown in Fig. 4.

Fig 4: Pneumatic fixture for FSW joint

2.3 Preparation of Welded joint

Two work-piece material plates were rigidly clamped on the bed of conventional Milling machine using specially designed mechanical fixture with axial force sensor mounted on it. Welded joints were prepared using Universal Milling Machine (Make:BFW, Model: UF1, shown in Fig. 2) after conducting trial studies to attain range of FSW process parameters. The range of FSW parameter selected weretable traverse speed are 80 to 100 mm/min, tool rotational speed are 710 to 1000 rpm and tool plunge depth 2.35 to 2.40 mm. The details of process parameters selected within the range as shown in Table 3.

Digital X-ray radiography techniques are used for evaluation of the quality of the friction stir welded aluminum butt joints as shown in Fig 5.

Fig 5a

Fig 5b

Fig 5c

Fig 5: FSW joints of aluminium 6061-T6

TABLE 3: DETAILS OF WELDING PARAMETERS

3. RESULTS AND DISCUSSION

3.1 Preparation of Tensile Testing Specimen

Weld No.	Rotational Speed (rpm)	Traverse Speed (mm/min)	Plunge Depth (mm)
FSW - 1	1000	100	2.35
FSW - 2	710	80	2.40
FSW - 3	1000	80	2.35

ASTM E8/E 8M-08 standards method considered for specimen preparation. A tensile specimen is a standardized sample cross-section. It has two shoulders and a gage in between. The shoulders are large so they can be readily gripped, whereas the gauge section has a smaller cross-section so that the deformation and failure can occur in this area.

The shoulders of the test specimen can be manufactured in various ways to mate to various grips in the testing machine as shown in Fig 6. Threaded shoulders and grips also assure good alignment, but the technician must know to thread each shoulder into the grip at least one diameter's length, otherwise the threads can strip before the specimen fractures.

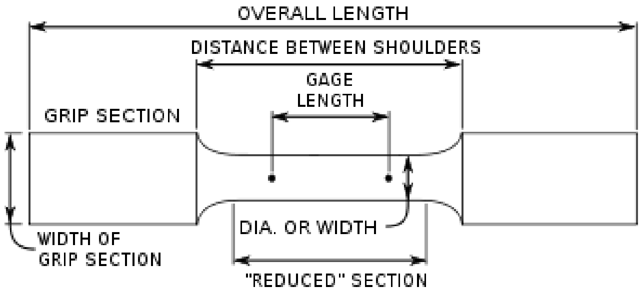


Fig. 6: Schematic diagram of tensile test specimen as per the ASTM-E8/E 8M-08 standard

3.2 Tensile testing of FSW joined thin sheets

Tensile testing is also known (Fig 7)as tension testing, is a fundamental materials science test in which a sample is subjected to a controlled tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area. From these measurements the following properties can also be determined. Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics (as shown in Fig 8, 9, 10 and 11). Uniaxial tensile testing is the most commonly used for obtaining the mechanical characteristics of materials.

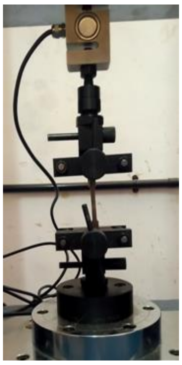


Fig 7: Tension Testing in Universal Testing Machine

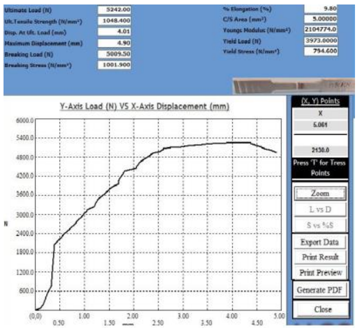


Fig. 8: Tensile test result of Base Metal with specimen

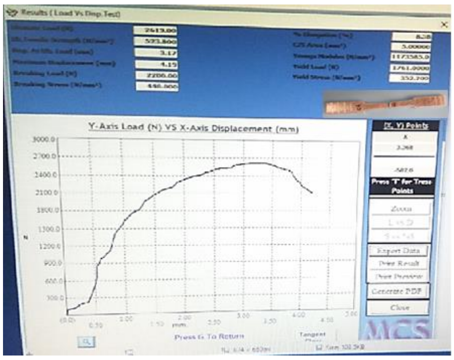


Fig. 9: Tensile test result of FSW1 specimen

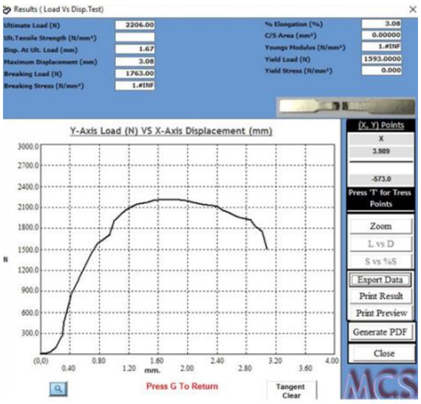


Fig. 10: Tensile test result of FSW2 with specimen

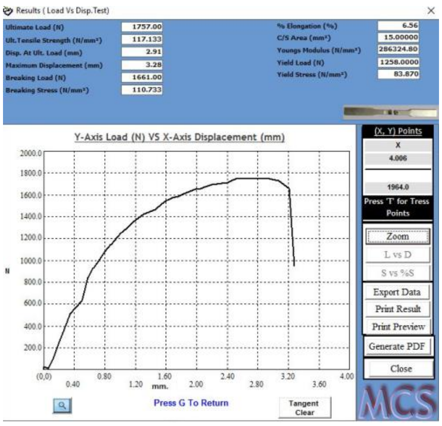


Fig. 11: Tensile test result of FSW3 with specimen

The tensile properties such as tensile strength, percentage of elongation tensile strength of 6061-T6 aluminum alloy joints were evaluated. Specimens were tested in MCS. The tensile strength of unwelded parent metal is 1048.4(N/mm2). However, tensile strength of FSW1 joint is 523.86 (N/mm2), FSW2 joint is 442.06(N/mm2) and117.13(N/mm2) respectively as shown in Table 4.

TABLE 4: TENSILE TEST RESULTS OF BASE MATERIAL AND FSW JOINTS

Weld No.	Base Material	FSW- 1	FSW- 2	FSW- 3
Ultimate Load (N)	5242	2613	2206	1757
Ultimate Tensile Strength (N/mm2)	1048.4	523.86	442.06	117.133
Displacement at Ultimate Load (mm)	4.01	3.17	1.67	2.91
Maximum Displacement (mm)	4.90	4.19	3.08	3.2
Breaking Stress (N/mm2)	1001.9	440.67	333.59	110.57

3.3 Axial force measurement

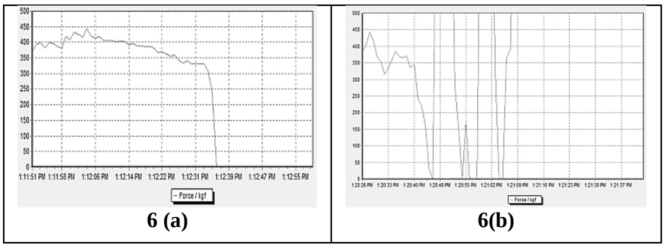
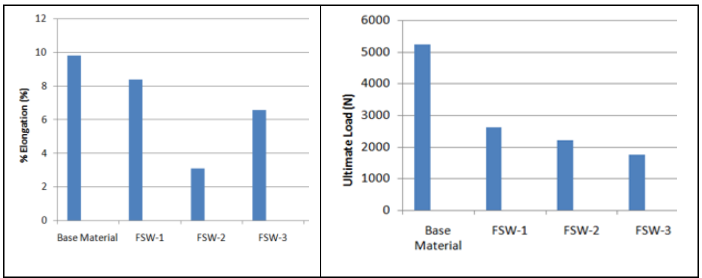


Fig.12:Variation of Force in z-direction during FSW process



Displacement v/s Joints	Ultimate tensile strength v/s Joints

Fig. 13: Strength and % Elongation of different FSW joints

4. CONCLUSION

- Aluminum alloy (6061-T6) is weldable using different (FSW) tool rotation speed.
- Increasing tool rotation speed with fixed other parameter causes increasing in mechanical properties of the welds joint.
- The tensile strength of welded joints can be increased using the FSW process.
- Hardness change in the welded material is affected by the amount of the heat input during the welding process.
- The test results and data analyzed here will help the design and production of aluminium fabricated panels from FSW.

5. REFFERENCES

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