Investigation the Mechanical Properties of 2024AA of Friction Stir Processing

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Abstract: The 2024AA has good mechanical properties and used for many application, there was many research in the field of friction stir welding in past 20 years age, now many research focusing in the friction stir processing technology which has many advantage according to the mechanical properties investigation, in this paper comparing the 2024AA base metal with friction stir process 2024AA with different feed rate and rotation speed, the feed rate that has been used is (20, 35, 50 mm/min), although in the rotation speed ( 1400, 2000 rpm) where used. The mechanical properties has been investigate, the hardness has been tested in different location. The tensile strength in 2024AA has been found 460 MPa, as comparing with 35, 1400 friction stir processing the ultimate tensile stress found to be 420 MPa so that percentage of improving 9.5 %. The flexural stress in 2024AA has been found 828 MPa as comparing with 35, 1400 friction stir processing the flexural stress found to be 745 MPa so that percentage of improving 11.1 %.

Keyword: 2024AA, friction stir processing, aluminum, welding, tensile, hardness, bending.

1. Introduction

Background and numerical modeling of friction stir welding and friction stir processing, the welding steps, welding types and also the main influencing factors on these methods.

1.1 Weld ability of Aluminum Alloys

Aluminum alloy has been the material in this decade, must of steel alloy has strength to weight ratio is low compare to aluminum. The weight of aluminum alloy is roughly three time lighter in weight and has three times higher thermal coefficient and three time weaker than steel. The design necessary to enhanced to reduce the weight savings should frequently be compensated by improved design to prevent unnecessarilly weakening As compared to arc-weld, the oxide-layer has a higher thermal coefficient of protection. To prevent excessive thermal expansion, the oxide layer should be split and replaced, and
heat should be introduced quickly. These issues are resolved with the use of friction stir welding. [1].

The properties of various alloys are determined by a number of variables, including the hardening process and heat transfer. The properties of various alloys within each category vary, making it impossible to categorize the properties of each group.

![Diagram of Aluminium Composition and Weldability](image)

**Figure (1):** Weldability of various aluminum alloys [1]

AA2024 Aluminum It is a lightweight, high-strength aluminum alloy. Because of its high strength-to-weight ratio, it, its ancestors, and similar versions have been widely used in aircraft manufacturing for several years. Despite this, it is also used in the manufacturing of aircraft. The microstructure of AA2024 is one of the most complex of any Al alloy.

Literature survey

**M. ILANGOVAN,** et al. 2015 [2] investigated the joints between two different type of aluminum alloys, an effort has been made to join non-heat treatable (AA 5086) with heat treatable (AA 6061) aluminum alloys by friction stir welding (FSW) by using three tool pin profiles which are consist of (taper cylindrical, straight cylindrical and threaded cylindrical).

**Sunny Mehra,** et al. 2012 [3] investigated the tool geometry effect on the experimental results of FSW for AA19000-H12 aluminum alloy plates, with thickness of 6 mm. The tools Material that used high carbon steel with dimensions of 17 mm diameter of tool head and 50mm length. This work included four different tool pin profiles (square, triangular, straight cylindrical and threaded) and two types of joint fabrications (single pass friction stir welding and double pass friction stir welding ). The tool traverse and tool rotation speeds kept constant at 25 mm/min and 3000 rpm. Tensile test of welded specimens are prepared according to (ASTME8) to found the percentage of elongation, Ultimate tensile strength and joint efficiency.
2. Theoretical Consideration

2.1 Friction Stir Processing

The surface modification of friction stir processing FSP as compare with friction stir welding FSW has best result. There is friction stir processing and between friction stir welding is that them doing have dissimilar purposes in applied applications. The main goal of friction stir welding is to join to plates of alloy together rather friction stir processing is to modify the welding process. As can saw that misconstruction of the material is improve in friction stir processing achieved plastic deformation, the microstructure of material has been modify so that the structure of friction stir welding which has fine crystalline structure as comparing with friction stir processing the crystalline structure has stress relief and smaller crystalline structure. [4][5] as shown in figure 2.

Figure (2): Principles of the friction stir weld process.

3. Experimental work

3.1 Tool Design and Manufacturing

The tool is a very necessary and crucial aspect of FSP process. The method consists of a concentric pin and a shoulder. The tool used in this work is made of steel tool X38, chemical composition is presented in Table (1).

Table (1) Composition of welding tool steel T30102 A2 standard (ASTMA 681 – 94).
The tool material is available in rod, this rod is shaped to produce tool. The tool geometry was processed on central turning machine according to the specific dimensions as they showing in Figure (3). Table (2) present the dimension of the manufactured tool. Figure (4) present the fabrication process of the used tool by a turning machine.

**Table (2):** tool dimensions details

| Parameter              | Value |
|------------------------|-------|
| Shoulder diameter (D)  | 15 mm |
| Pin diameter (d)       | 5 mm  |
| Pin length (L)         | 2.8 mm|
| D/d ratio              | 3     |

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**3.2 FSP Procedure**

The welding process curried out by using the HARTFORD CNC milling machine.

**3.3 Mechanical Tests**

There are several tests available to assess the different mechanical properties of components, all of which are standardized. In this work the mechanical testing is detailed below as follow;
3.3.1 Tensile Test

A specimen for tensile test was done using a tensile testing device, at a speed of 1 mm/min to the test specimens of 2024-T3 aluminum alloy were prepared following the ASTM standard[6]. During this test was used the “Testometric Universal Testing Machine (Type: DBBMTCL-2500kg-1.5-000. Serial No:20199” testing machine. Figure (5) present the result of tensile testing on a sample.

Figure (5) present the tensile specimen after testing at different parameters for FSP

3.3.2 Bending Test

Bending test specimens prepared according to ASTM-E290 three-point bending standard [7] with dimension 10mm x200 mm. The bending test using bending tester device (Testometric) which is the same the device for tensile testing but with replacing the head to preform bending test. Figure (6) present the bending test on one of the specimens, while Figure (7) shows specimen after and before bending test.
4. Result and discussion

The experimental results are presented graphically. The examinations carried out for 2024-T3 aluminum alloy welded by FSP will be presented.

4.1 Tensile Results

Figure (8) present the tensile test results for FSP at rotating speeds of 1400 and 2000 RPM and welding speed of 20, 35, and 50 mm/min respectively. The presented results in the tensile testing were the average of three identical specimens, which is done to obtain more reliable data from the testing and minimize the chances of error in the reading. The base metal stress was 455.2 Mpa. However, the FSP stress max of the has been 421.7 MPa with improving reach to 92.64%. Earlier researches mentioned the temperature of peak temperature with friction stir processing with this can related to welding speed and rotation speed, the heat introduce to the system input with rotation speed. Can saw that defect and 2000 RPM because of tool sticking. The defect at 1400 RPM has lower defect as comparing with 2000 RPM with recrystallized grains as effected with thermo-mechanical affected zone, which has lower rotation speed corresponds to lower heat input throughout FSP, that resulted in finer recrystallized grains within the stirred zone and thermo-mechanically affected zone. When the rotation speed grew, so did the joint diameter. As a result, as the rotating speed was reduced, the strength and stiffness of the weld joints improved. [8] [9]. For more detailed information about the tensile obtained results, FSP welding achieved the best strain (27.28 %) and best ultimate stress 421.736 MPa) as shown in Table (3).
Figure (8): Tensile results of specimens with FSP processes

Table (3): summary of the tensile testing results

| #    | Rotation speed (RPM) | Feed speed (mm/min) | ULT Stress (Mpa) | Peak Strain (%) | Efficiency (%) |
|------|----------------------|---------------------|------------------|-----------------|----------------|
| B.M  | -                    | -                   | 455.2            | 28.863          | 100            |
| Case 1| 1400                 | 20                  | 392.1            | 19.01           | 86.142         |
| Case 2| 1400                 | 35                  | 421.7            | 27.28           | 92.64          |
| Case 3| 1400                 | 50                  | 390.1            | 19.79           | 85.72          |
| Case 4| 2000                 | 20                  | 356.1            | 18.34           | 78.24          |
| Case 5| 2000                 | 35                  | 382              | 21.87           | 83.94          |
| Case 6| 2000                 | 50                  | 410.1            | 24.19           | 90.1           |

4.2 Bending Results

Figure (9) illustrate the obtained results for the bending tests of the specimens. Bend tests were used as an important tool to understand the ductility and toughness of friction stir welds. As FSP samples passed bend test. Most of the welds presented good ductility, especially in case 9 where the maximum deflection reached to 29.534 mm with efficiency of about 90% compared to the base metal. The specimens that welded using double pass friction stir welding (FSP) [10]. The immediate growth in force that appear in Figure (13) at about 20 mm deflection came from some slipping occurred between bending specimens and device jaw so that slipping didn’t affected on the total results because that shifting occurred in all specimens and the comparison between base metal and welded specimens stilled in the same values.
Table (4): summary of the Bending testing results

| #    | Rotation speed (RPM) | feed speed (mm/min) | FORCE PEAK (N) | Moment | BENDING STRESS (MPa) AVE | Deflection Peak (mm) | Efficiency (%) |
|------|----------------------|---------------------|----------------|--------|--------------------------|----------------------|----------------|
| B.M  | -                    | -                   | 994.5          | 828.8  | 38.933                   | 100                  |
| Case 8 | 1400                | 20                  | 731            | 9655   | 609.1                    | 21.895               | 73.5           |
| Case 9 | 1400                | 35                  | 895            | 11912  | 745.9                    | 29.534               | 90             |
| Case 10 | 1400                | 50                  | 825.4          | 10952  | 687.9                    | 22.991               | 83             |
| Case 11 | 2000                | 20                  | 865.2          | 13747  | 721.3                    | 25.038               | 87             |
| Case 12 | 2000                | 35                  | 885.1          | 13980  | 737.6                    | 27.874               | 89             |
| Case 13 | 2000                | 50                  | 706            | 9317   | 588.4                    | 23.13                | 71             |

4.3 Hardness Results

The high heat generation during FSP increased temperatures that resulted in refinement grain size and thermal improvements in the weld zone, as well as a shift in distributed phases, resulting in a difference in microhardness across the weld zone. Each fourteen specimen were tested by dividing it into regions each point took 15 second then the reading was recorded and five points on each side of the center was measured. The observed variations in microstructure were taken. There is drop in hardness were perceived in the welding region. The soft in the region has affected zone as effect from the welding
process. The failure in the zone is effected as the tensile test in specific location [11]. This figure 10 show that micro hardness result with different weld feed and rotational speed. In center of welding zone area the hardness is larger than other location with high cooling rate as compare with other area so that can led to low toughness in this specific area. The hardness profile shows the deformation zone (nugget zone) has greater hardness as compare with other zones, as saw that the nugget zone the hardness decreases as it which reaches its minimum value at edge of the deformation zone (heat affected zone) and then increases again. Double pass friction stir welding (FSP) area has ahiger Vickers hardness value than single pass friction stir welded of FSP is caused to grain refinement and according to the Hall-Petch relationship the hardness increases as the grain size decreases.

Microhardness results at the nugget recorded in table (4) according to the process type and welding conditions.

![Microhardness profile](image)

**Figure (10):** Hardness for similar FSP (2024-T3) at different rotating and welding speeds.

| Case No. | NZ hardness (HV) |
|----------|------------------|
| Case 1   | 118.9            |
| Case 2   | 128.9            |
| Case 3   | 137.1            |
| Case 4   | 109.7            |
| Case 5   | 122.8            |
| Case 6   | 134.4            |

**Table (5):** FSP microhardness of specimens welded
5. Conclusion

1. The best efficiency of joints of the used parameters of FSP AA 2024-T3 is found at 35 mm/min weld speed and 1400 RPM rotation speed, it reaches efficiency of 92.64% of the tensile strain of the base metal for FSP.
2. The joint width was increased with the increasing rotation speed. Therefore, both the strength and hardness of the weld joints increased with the decreasing of rotation speed.
3. Most of the welded specimens presented good ductility, especially in case 9 where the maximum deflection reached to 29.534 mm with efficiency of about 90% compared to the base metal.
4. Hardness drops in the weld region. The softening was mostly evident in the heat affected zone on the advancing side of the welds.
5. FSP at 1400 RPM-35mm/min (case 9) shown to be the optimal speed for welding of 2024-T3, based on the done tests for this case specimen.

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