Literature review on friction stir welding of magnesium alloys

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Abstract. Friction stir welding is a new solid-state joining process which is used to join the soft material. It is using a specially designed tool that rotates and traverses along the joint line, creating frictional heating that softens a column of material underneath the tool. The softened material flows around the tool through extensive plastic deformation and is consolidated behind the tool to form a solid state continuous joint. The friction stir welding of magnesium alloys and composite material has many engineering applications in industries such as marine, railway, aerospace, Shipbuilding, land transportation. In this review article the basic principle of friction stir welding and several aspects of friction stir welding, effects of varying welding parameter of Magnesium alloy is referred and discussed.

1. Introduction

Friction stir welding is an innovative solid-state welding process which is used to join metallic alloys and composite. It is used many manufacturing applications. The advantages of friction stir welding are abatement need for human skill, enhance mechanical and metallurgically properties. The friction stir welding method is influential in compare with conventional fusion welding method [1]. Friction stir welding is a newly developed which has high energy efficiency and flexibility since it is establish in 1991 by The Welding Institute (TWI). The need of Al alloy and Mg alloy for many engineering in recent year. These materials are arduous to weld by fusion welding [2]. The Mg density is lighter than aluminium. In recently introduced more than magnesium alloy.

Figure 1. Basic principle FSW [7].
1.1. Magnesium alloy
The AZ Magnesium alloys are mostly used in engineering application. The consists of aluminium and Zinc as large amount in their chemical composition [3]. Friction stir welding is a solid-state joining process which has welded similar and dissimilar material [4]. An important feature of friction stir welding is high gradients of temperature [5]. The mixing of Al and Mg one of the hybrid structure. This structure of material to use many engineering applications and saving weight. To join of these materials in fusion welding to occurs formation of brittle intermetallic compounds, thermal cracks and oxidative impurities.[6].

2. Working principle FSW
The friction stir welding tool is rotating on the workpiece and the tool is moving at constant speed to join the workpiece material as shown in Fig 1. The friction stir welding tool probe is smaller than the welding workpiece material thickness and tool are rotating on the workpiece surface. The heat is produced between tool and workpiece. This heat is produced by mechanical blending process in material [7].

3. FSW Tools

![Tool pin shapes](image)

**Figure 2.** Tool pin shapes [8]. (a) Tapered pin threaded shape, (b) Tool pin Triangular shape, (c) Tool pin Square shape (d) Tool pin Four-flute square shape, (e) Tool pin Four-flute square.

3.1. TiAIN coated tool
Numerous basic segments are associated with FSW and clearly tool is generally basic among them to the accomplishments of the process. High speed steel was chosen as the device material to set up the instrument material thickness of 4 microns utilizing physical vapour deposition (PVD) technique. The coated tool is shown in Figure 3.
4. The Function of Tool
The consists of friction stir welding tool is pin and shoulder. The pin plunges into the work piece to produced frictional and deformational heat [10]

| Working materials | Tool material | Tool shape                  |
|-------------------|---------------|-----------------------------|
| AA6061-T6         | H13 steel     | SS: concave PS: SCT         |
| AA6111-T4         | H13 steel     | SS: flat with square        |
| AA7020-T6         | HC steel      | SS: concave PS: SC          |
| AA6082-T6         | HC steel      | SS: scroll, cavity fillet PS:SC |
| AA7075-T7351      | H13 steel     | SS: flat with scrolls       |

PD: Pin diameter; PL: Pin length; PS: Pin shape; SC: Straight circular; SCT: Straight circular threaded. PL: Pin length; SS: Shoulder

| Working materials | Tool material | Tool shape                                      |
|-------------------|---------------|------------------------------------------------|
| AZ31 Mg           | H13 steel     | PS: SCT 3F with M4 Threads                     |
| AZ31B-H24 Mg alloy| H13 steel     | PS: SC, LHT, RHT                               |
| AZ31 Mg, 46–48 HRC| H13 steel,   | PS: SCT, and Threaded and unthreaded 3F         |

| Working materials | Tool material | Tool shape                                      |
|-------------------|---------------|------------------------------------------------|
|                   |               |                                                |

PL: pin length; PS: pin shape; SC: straight circular; SCT: straight circular threaded; PD: pin diameter; LHT (RHT): left (right) handed thread; TC: tapered circular; 3F: 3 flat

5. Welding Parameter FSW
There is a consensus that the most important welding parameter is the rotation speed, but that the transverse speed and plunge depth are also very significant.

5.1. Welding feed
In this process welding is done by producing friction between tool pin profile and plate. The tool is rotating on the workpiece at the same time frictional heat produced. Rotational speed of the tool is increase or decrease when weld quality will liable to increase or decrease as needs be [11].

5.2. Welding feed
Temperature diminishes when there is a welding feed speed up the temperature at inside position. Though, when there is moderate feed speed the temperature will be increase.
5.3. Axial force
There is an expansion in axial force when the material thickness is expanded.

6. Natural aspects of FSW
Today, there is a need to check new mechanical strategy with respect with its impact on the earth. Warily thought of HSE (Health, Safety, and Environment) issues at the workplace is of prime fundamental to any industry. It is standard for makers to screen the characteristic impact of any industry. Grinding Friction stir welding offers different environmental ideal conditions stood out from other joining strategies [11].

7. Macroscopic morphology of the cross section of the joint
Fig(a) shows the micrograph of the BM of AZ31B Mg along the cross-area opposite to the moving heading. The normal grainsize of the B Measured by the direct area technique is 18.05 ± 1.02 μm. Fig(b)– (d) shows the microstructures of the HAZ on the AS with current of 0 A, 100 A, and 200 A, respectively, which are mostly made out of unique grains and developed grains. when the current expanded to 200 A, the grain size of the HAZ further expanded, and the normal grain size is 21.09 ± 1.34μm [12].

8. Microstructures of FSW material
Fig (5) and Fig (6) shows the examples were set up for optical microscopy by cleaning and afterward carving with a corrosive arrangement of 20 mL HCl, 100 mL ethanol and 5 g FeCl3. The microstructures of the joints were contemplated utilizing optical microscopy (OM), examining electron microscopy (SEM) and transmission electron microscopy (TEM). The grain size of the α-stage in the metal SZ close to the interface was estimated utilizing the line-catch technique, where the mean grain widths of the α-stages on all the 10 lines drawn onto the SEM picture magnified by 3000 × for each welded joint are estimated [13].
Figure 5. cross-section of joints [13].

| Welding speed (mm/min) | Appearance | Cross section |
|------------------------|------------|--------------|
| Large burr             | 250        |              |
| Good lap joint         | 500        |              |
| Lap joint was not formed | 600      |              |

Figure 6. FSW welding Microstructure of sound joint [13].

8.1. Grain size evolution

Fig (7) and Fig (8) shows the microstructure of AZ31B magnesium alloy added with 0.5 wt. % Ce was mainly small dynamic recrystallization, and there were small amount of coarse grains and elongated grains. The microstructure in the weld nugget zone were uniform with small equiaxed grains. The grains in the heat-affected zone and the thermo-mechanical affected zone were coarser than those in the base metal zone and the weld nugget zone [14].
**Figure 7.** Grain size evolution with shoulder diameter for 1000 rpm, 200 mm min\(^{-1}\) butt FSW: (a–c) 13 mm shoulder diameter; (d–f) 10 mm shoulder diameter [14].
8.2. Microstructure of different regions
To investigate the local microstructural feature of the FSP material, the microstructures of the HAZ, TMAZ, and SZ of the two-pass condition were examined, as shown in fig. 9 (a)-(d). Different grain structure in the three zones can be attributed to the difference in frictional heat and material flow caused by FSP. Fig. (a) is a low-magnification micrograph that encompasses all of the above-mentioned zones [16].

Figure 8. Microstructure in the typical zones of FSW joint cross section of AZ31B magnesium alloy added with 0.5 wt.% Ce [15].

Figure 9. The microstructure of different regions after two passes of FSP [16].
8.2.1. Optical microstructure of the FSW. The optical microstructure of the FSW joints of different zone such as stir zone (SZ), thermomechanical affected zone (TMAZ) and heat affected zone (HAZ) have been observed shown in Fig. 10. The grains in the SZ were refined and recrystallised, while the grains in the TMAZ region of the joints were observed elongated and semi recrystallised. In the HAZ coarse grains were observed for all FSW joints. Reported that higher tool rotational speed produced the higher temperature due to friction as compared to the lower rotational speed. The SEM-BSE images of AlA—Cu joints are shown in Fig. 11. The layer wise intermetallic have been observed at the interface of the welded joint. The formation of intermetallic layer took place in the order from the copper side to aluminium side were as Al4Cu9, Al2Cu3, Al Cu, and Al2Cu respectively were confirmed from SEM-EDS analysis. The thickness of the intermetallic at the interface of AlA—Cu joints from 150 to 900 rpm was measured between 0.24 µm to 4.07 µm. The thickness of the intermetallic layer increased with the tool rotational speed [17].

![Figure 10 Optical micrographs of FSW joint.[17]](image1)

![Figure 11 SEM-BSE image interface region [17].](image2)

9. Tensile strength testing
The transverse elastic properties for the FSW joint are appeared in Fig. 15 Compared to the parent material, the FSW joint showed somewhat diminished extreme tractable and yield quality and extension to disappointment. The fracture happened in the HAZ on their treating side, which is
predictable with the most minimal hardness conveyance in the HAZ. Right now, transverse tensile and yield strength of the weld are those of the HAZ i.e. the most fragile zone in the entire weld. Consequently, in spite of the fact that the piece zone showed the most noteworthy hardness in the weld, marginally lessen malleable and yield strength were seen when the weld was tested along the transverse course [18]. It is a standard size of tensile strength specimen and results of the tension tests specimen [19].

![Figure 12. Transverse tensile properties of PM and FSW joint [18].](image_url)
Figure 13. The geometrical dimensions of the tensile test specimens [19].

| Pin shape | Ts [Mm/min] | RS [rpm] | UTS [Mpa] | H |
|-----------|-------------|----------|-----------|---|
| TC 8      | 900         | 21.3     | 62.8      |   |
| TC 10     | 900         | 21.9     | 63.8      |   |
| TC 12.5   | 900         | 22.2     | 64.8      |   |
| TC 8      | 1860        | 23.7     | 63        |   |
| TC 10     | 1860        | 21.1     | 63.2      |   |
| TC 12.5   | 1860        | 21.3     | 68.6      |   |
| TC 8      | 2920        | 21.6     | 61.7      |   |
| TC 10     | 2920        | 19.7     | 61.9      |   |
| TC 12.5   | 2920        | 20.2     | 62.7      |   |
| S 8       | 900         | 19.7     | 102.6     |   |
| S 10      | 900         | 20.2     | 103       |   |
| S 12.5    | 900         | 20.8     | 102.3     |   |
| S 8       | 1860        | 20.3     | 103.2     |   |
| S 10      | 1860        | 21.2     | 102.2     |   |
| S 12.5    | 1860        | 20.7     | 103       |   |
| S 8       | 2920        | 21.2     | 101.8     |   |
| S 10      | 2920        | 19.7     | 102       |   |
| S 12.5    | 2920        | 20.2     | 103.1     |   |
| T 8       | 900         | 18.2     | 97.8      |   |
| T 10      | 900         | 18.6     | 98.5      |   |
| T 12.5    | 900         | 18.9     | 99.5      |   |
| T 8       | 1860        | 18.8     | 98.6      |   |
|     | TS   | RS   | UTS   | H    |
|-----|------|------|-------|------|
| T   | 10   | 1860 | 19.1  | 99.6 |
| T   | 12.5 | 1860 | 20.7  | 98.6 |
| T   | 8    | 2920 | 17.9  | 99.6 |
| T   | 10   | 2920 | 18.3  | 98.6 |
| T   | 12.5 | 2920 | 18.4  | 99.3 |
| SC  | 8    | 900  | 16.2  | 97.3 |
| SC  | 10   | 900  | 17.2  | 97.8 |
| SC  | 12.5 | 900  | 17.6  | 99.5 |
| SC  | 8    | 1860 | 18.6  | 94.2 |
| SC  | 10   | 1860 | 17.9  | 95.1 |
| SC  | 12.5 | 1860 | 16.9  | 98.6 |
| SC  | 8    | 2920 | 18.6  | 93   |
| SC  | 10   | 2920 | 17.9  | 93.1 |
| SC  | 12.5 | 2920 | 16.9  | 94   |

TS: Traverse speed, RS: Rotation speed, UTS: Ultimate Tensile Strength, e: Elongation, H: Hardness.

10. Hardness testing

Fig.14 shows the Vickers microhardness profiles measured along the mid-thickness line of the cross section. The Vickers test was done with 8-second at 100 g load and a 1 mm step. The three ranges are travel speed of 90, 75 and 37.5 mm/min at the same rotation speed 1500 rpm. It could be found that hardness value of FSZ is higher than that of BM. There are two main reasons for the improved hardness of FSZ. Firstly, since the grain size of FSZ is much finer than that of BM, grain refinement plays an important role in material strengthening [18]. The hardness estimation of FSW joints in the precipitation-solidifying Al composites is predominantly subject to the grain size, encourage conveyance and the kind of intermetallic mixes. The hardness esteem is conversely relative to the grain size as indicated by Hall-Petch equation. The tractable properties of the comparable AA7075 and AA2024 joints nearly remain consistent with a variety of rotational speed. In actuality, the change of rotational speed impacts the ductile properties of the divergent AA7075-2024 joints. With the expansion of rotational speed, the YS, UTS and TE of the divergent AA7075-2024 joints decline marginally after the pinnacle esteem. A decent mix of elastic properties (YS: 276.1 MPa, UTS: 412.9 MPa and TE: 7.63%) can be acquired at the rotational speed of 950 rpm [20]. The welded joints showed better performance based on whose tensile strength is higher than of the steel base material. Demonstrated that friction stir welded joints tend to fail in the region with the lowest hardness [21].
11. Conclusion

In this paper a study of friction stir welding process has been finished. It is uncovered that FSW can be utilized to weld delicate material like aluminium, copper, nickel, titanium, and so forth. Successfully, FSW is fundamentally influenced by different welding parameter like revolution speed, weld speed, and apparatus geometry and so on. Increasing in tool rotation and axial force resulted in decrease of percentage elongation. Hardness in UHAZ is higher NHAZ. In addition to aluminum alloys, friction stir welding has been successfully used to join other metallic materials, such as copper, titanium, steel, magnesium, and composites. Because of high melting point and low ductility, successful joining of high melting temperature materials by means of FSW was usually limited to a narrow range of FSW parameters. So, the attainment of this milestone is well within the reach of the welding community within the next ten years.

12. Reference

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