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# Impact of Tool Rotating Speeds on The Mechanical Characteristics of Dissimilar Friction Stir-Welded AZ80A-Mg – AA6061-Al Joints

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**Abstract**

*In this investigation, separate AA6061-Al and AZ80A-Mg alloy plates were effectively joined through stir welding with friction. We looked closely at the weld joints' characteristics, especially their mechanical aspects. In the experiment, here were multiple tool rotating rates (rpm) of 800, 1000, 1200, 1400, and 1600 used. A cylindrical pin-equipped tool featuring a tapered profile was utilized, inserted into the AA6061 alloy plate is offset by 0.5 mm, while maintaining a 30 mm/min constant traverse speed. The experimental findings indicated that optimal levels of frictional heat were achieved when 1200 rpm was the rotational speed of the tool. As a result, this specific joint exhibited a notable tensile strength of 225 MPa, representing approximately 77.76% of AZ80A's tensile strength and 72.25% of AA6061 alloy. These results underscore the significance of rotating speed of the tool in influencing the mechanical performance of stir-welded friction joints between distinct aluminum and magnesium alloys.*

**Keywords:** Friction stir-weld, tensile test, tool speed, traverse rate, aluminum and magnesium alloys

## INTRODUCTION

Modern times have brought more attention to environmental and global resource concerns, which has led to a major emphasis on lightening the weight of aircraft parts, automobile bodies, and fast-moving passenger and freight cars. Enhancing fuel efficiency and lessening the negative effects of greenhouse gas emissions caused by human activity are the main goals [1–3]. Stakeholders in the aerospace and automotive industries are facing immediate pressure to reduce the weight of their vehicles in order to comply with the standards of international climate change accords. Alternative lightweight materials with improved characteristics have become more popular as a result of this necessity [4].

The transportation industry has witnessed a significant increase in the creation and application of magnesium (Mg) alloys that are incredibly lightweight. Their excellent strength-to-weight ratio, reduced density, remarkable damping properties, and ease of recycling are the reasons for this trend [5–6]. Concurrently, because of its remarkable ability to combine strength and low

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weight, aluminium (Al) alloys have long been preferred by producers of automotive and aerospace components [7]. Aluminium and magnesium alloys must be fused since these two distinct metal groups are utilized concurrently in the production of transportation vehicles. The challenge is to do this while utilizing the special benefits of both metals without compromising the efficiency and security of passenger cars [8–10].

Simultaneously, welding alloys containing magnesium and aluminium utilizing fusion and standard welding methods poses a considerable difficulty due to the different crystal structures inherent in these alloys [11–13]. Furthermore, the production of intermetallic mixes when these alloys are welded using conventional methods poses a significant problem since it leads to the development of brittle joints that are more fragile [14–15]. To minimize the volume portion of these intermetallic combinations, connecting these alloys involves the adoption of welding methods that generate low heat [16].

Among the many noteworthy benefits of Friction Stir Welding (FSW), are its minimum distortion, low energy consumption, and less generation of residual stress. The FSW technique has the unique capacity to fuse magnesium and aluminium alloys together because materials are connected efficiently even before they melt [17–19]. Consequently, by combining temperature, mechanics, metallurgy, and interactions, FSW emerges as a sophisticated solid-state welding process. Its manufacturing of high-quality joints, environmental friendliness, and energy efficiency are its revolutionary qualities [20–21].

The fusing of various magnesium and aluminium alloys using the FSW process has been the subject of numerous examinations carried out in the years prior [22–26]. For instance, the experiment conducted by Kwon et al [22]. focused on the use of the FSW technique to weld 5052 Al alloy and AZ31B-Mg alloy plates that were 2 mm thick. rotational rates between 850 and 1550 rpm were used to maintain a constant speed of traversal: 300 mm/min. It was possible to obtain perfect joints at 1400, 1200, and 1000 rpm with AZ31B-Mg and 5052 Al. The peak joint's tensile strength formed at 1000 rpm was around 134 MPa, that is roughly comparable to 65% of the 5052 Al alloy’s tensile strength. Additionally, there was about 2% elongation in the joints.

Jayaraj et al [24]. looked on the enhanced corrosion resistance of FSWed joints made of Alloys AZ31B-Mg and AA6061-Al. In this experiment, a device with a threaded taper cylindrical pin was used; AA6061-Al and AZ31B-Mg plates, respectively, were used to mark the sides of the tool that advance and retract. A systematic study established a correlation to determine the corrosion rate of the manufactured magnesium and aluminium alloy joints. As the exposure period grew, the results demonstrated that the corrosion rate decreased, suggesting that the early corrosion products acted as a barrier to stop the corrosion medium and protect the metal substrates.

Malarvizhi et al [26]. conducted an investigation utilizing tools featuring five distinct diameters of the shoulders (24, 21, 18, 15, and 12 mm) and tapered pin profiles. The primary objective was to analyze the influence the plate's thickness to-tool shoulder diameter ratio regarding the tensile characteristics of AA6061-Al and AZ31B-Mg welds produced through the Friction Stir Welding (FSW) method. The remaining FSW parameters, namely 400 rpm for tool rotation speed, 12 kN for axial force, and 0.33 mm/sec for traverse speed, were held constant. The welding connection formed with a 21 mm in shoulder diameter, corresponding to 3.5 times the material's thickness welded plate, exhibited a 191 MPa maximum tensile strength. This strength represented approximately 88% of the tensile strength found in the parent magnesium alloy. These findings emphasize the significance of the plate's thickness to-tool shoulder diameter ratio in determining the FSW's tensile characteristics -welded joints.

While several researchers have successfully fused magnesium and aluminium alloys together using the FSW process, in-depth investigations of the microstructure evolution within the nugget area of the resulting magnesium-aluminium alloy welds are still missing. Moreover, a survey of the available research indicates that an lack of experimental investigation to comprehend the consequences of important FSW parameters, including traverse speed and tool rotation speed, in the welding of different Mg-Al alloys. During the welding process, the nugget area of Mg-Al alloy joints experiences considerable structural modifications. One of the main influences regards to the mechanical properties of stir-welded magnesium-aluminium alloy joints is the dimension's dispersion of these modified grain structures. Thus, in order to increase the mechanical Mg-Al alloy's strength FSW joints, it becomes crucial to investigate how these modified grain structures are produced in the nugget zone and how to manage their distribution by modifying important FSW process parameters.

In this study's experimental analysis, FSW was used to join wrought base magnesium alloy AZ80A, which is frequently used in the construction of car supercharger components and aircraft engine parts, with one of the strongest aluminium alloys, AA6061, which is widely used in the construction of various aircraft structures (such as fuselages, wings, car chassis, helicopter rotor components, etc.). The purpose of this work is to get a deeper comprehension of the connection between the mechanical properties of the AZ80A-Mg – AA6061-Al FSWed joints and the microstructural transitions that take place in the welded joints, particularly in the nugget zone, as influenced by the tool's rotation speed.

## PARENT METALS AND METHODOLOGY

Using a 410 x 800 mm work surface and a 7 kW spindle motor, a semi-automatic FSW machine was used in this study to build unique junctions using the alloys AA6061-Al and AZ80A-Mg. To produce butt joint configurations, rectangular plates of AZ80A-Mg and AA6061, with dimensions of 100 mm in length, 50 mm in width, and 6 mm in thickness, were placed on a specially built apparatus. Table 1 lists the specific chemical compositions and pertinent mechanical characteristics of the metals examined in this experimental investigation.

**Table 1.** Outlines the chemical compositions and mechanical properties of the metals under investigation.

| **Parent Metal** | **Mg** | **Si** | **Mn** | **Fe** | **Cu** | **Cr** | **Zn** | **Al** | **Tensile Strength, MPa** | **Yield Strength Mpa** | **% of elongation** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AA6061 alloy | 0.91 | 0.68 | 0.09 | 0.42 | 0.3 | 0.21 | 0.04 | Remaining | 309 | 275 | 12 |
| Parent Metal | Al | Cu | Mn | Fe | Ni | Si | Zn | Mg | Tensile Strength, MPa | Yield Strength, Mpa | % of elongation |
| AZ80 A Mg alloy | 8.24 | 0.049 | 0.14 | 0.005 | 0.0048 | 0.1 | 0.54 | Remaining | 288 | 196 | 6 |

In this experiment, a device with a tapered-profile cylindrical pin was employed. One of the tool's inner shoulders had a dimension of 15 mm for a shorter length of 10 mm, and an outer shoulder with a stepped cylinder structure that measured 20 mm in diameter for a length of 50 mm. A 5.85 mm long pin with a tapering diameter of 4 mm to 7 mm was also included with the tool. A detailed explanation of the tool's specifications is given in Figure 1d, and Figures 1a–c display images of various tool components used in this experiment. This experiment's primary objective is to examine the effects of the FSW parameter, or the tool's rotational speed. However, other variables were also considered, such as the traversal speed and the applied axial force, which were both maintained at 30 mm/min and 6 kN, respectively.

The joining process involved the combination of aluminum (Al) and magnesium (Mg) alloys, specifically AZ80A and AA6061. Specific tool rotational rates were employed, with the rotational rates set at 1600, 1400, 1200, 1000, and 800 rpm for AZ80A and AA6061 alloys, respectively. The positioning of the alloys during Friction Stir Welding (FSW) was deliberate, with the aluminum alloy

 

AA6061 located on the tool's advancement side and the AZ80A-Mg alloy on the retreatment side. This arrangement was designed to optimize the characteristics of each alloy in the welding process. The harder material (AA6061) on the advancement side was chosen to generate higher heat, facilitating thermoplasticization. On the retreatment side, the AZ80A-Mg alloy, known for its better fluidity, was positioned. This strategic placement aimed to take advantage of the differing properties of the alloys, enhancing the overall effectiveness of FSW for dissimilar metal joining [27]. Throughout the whole experiment, a tool offsets range of 0.5 mm to the exterior of AA6061 alloy remained intact. An overview of the experiment's parameters may be found in Table 2.

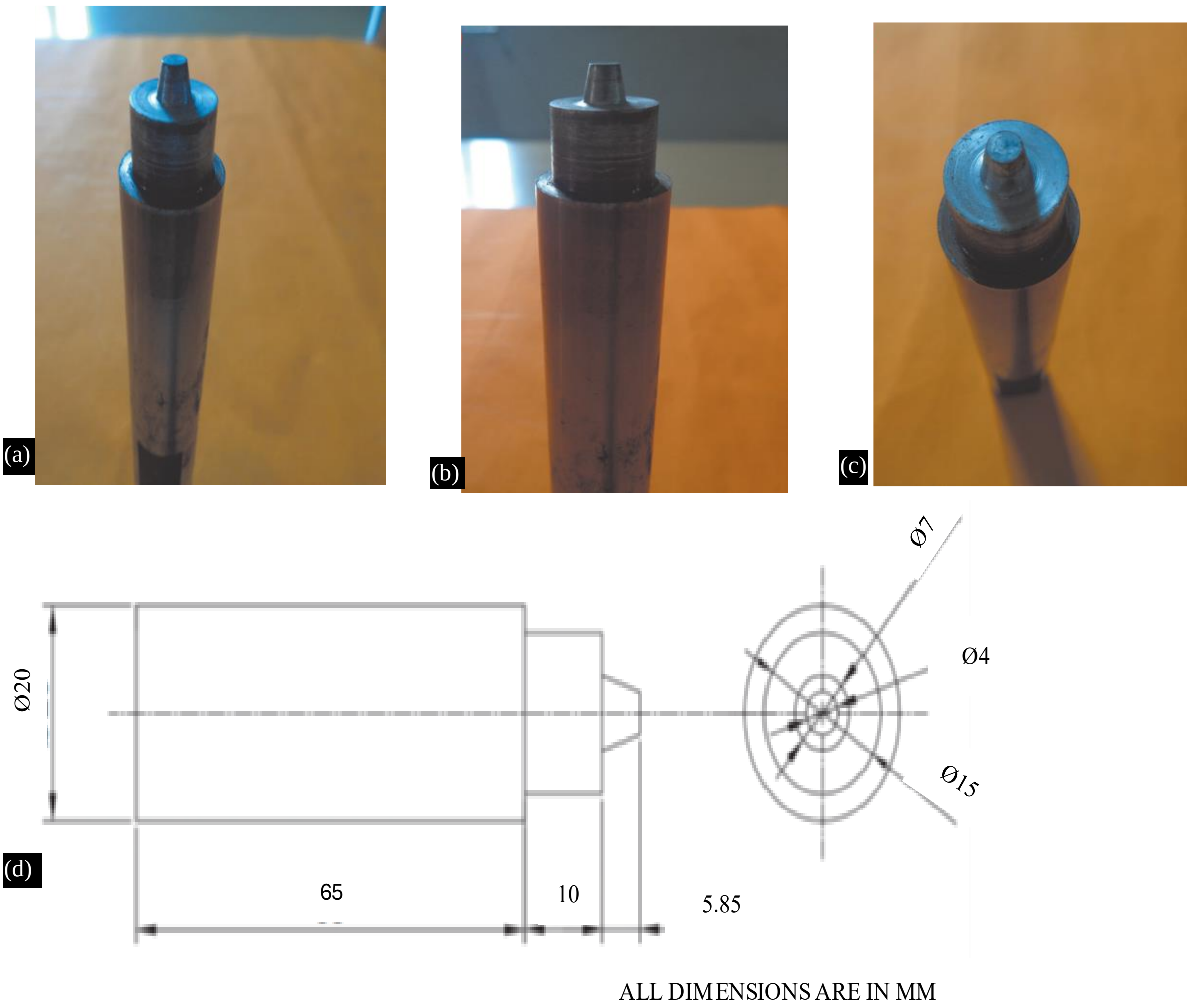


**Figure 1.** (a-d): Displays a–c) Various camera angles of the instrument, and d) Details of the instrument used in the present study.

**Table 2.** Description of the parameter values employed in this experiment.

| **Description of parameters** | **Values of the used parameters** |
|---|---|
| Tool rotational speed, measured in revolutions per minute (rpm) | 800, 1000, 1200, 1400 and 1600 |
| Speed of traverse, mm/min | 30 |
| Axial force, kN | 6 |
| Offset distance, mm | 0.5 mm in the direction of the alloy AA6061 |
| Advancing side | AA6061-Al alloy |
| Retreating side | AZ80A-Mg alloy |

 

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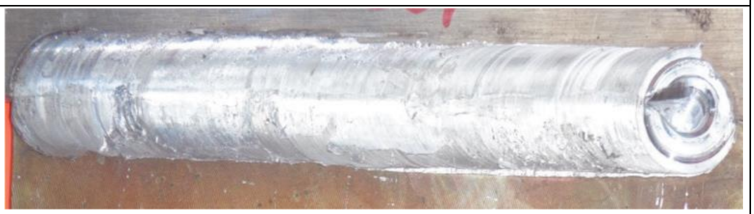
## EXPERIMENTAL FINDINGS

### Visual Characteristics of Produced Joints

Table 3 displays the appearance of the bonded surfaces of the FSW alloy joints AA6061-Al and AZ80A-Mg. These were completed while keeping a steady traverse speed of 30 mm/min at different FSW tool rotation rates (i.e., 800, 1000, 1200, 1400, and 1500 rpm). Further investigation of these welded surfaces reveals that rpms of 800, 1000, and 1200 were successful in achieving successful welding between the AZ80A-Mg and AA6061-Al alloys. However, there seem to be some macroscopic flaws on the surfaces of the welds made at 1400 and 1600 rpm. For example, the joint's weld surface, which was produced at 1400 rpm, exhibits tunnel flaws. Similarly, at 1600 rpm, a crack spreads across the joint's whole weld surface.

**Table 3.** surface appearances of the AZ80A-Mg and AA6061-Al alloy joints achieved at five distinct rotational speeds.

| Joint No | Speeds of rotation of the FSW tool, rpm | Surface appearances of the friction stir welded AZ80A-Mg and AA6061-Al alloy joints |
|---|---|---|
| 1 | 800 |  |
| 2 | 1000 |  |
| 3 | 1200 |  |
| 4 | 1400 |  |
| 5 | 1600 |  |

### *Determination of Tensile Strength*

To assess the mechanical properties of the friction stir-welded joint between AZ80A-Mg and AA6061-Al alloys formed at a rotational speed of 1200 rpm, specimens for tensile testing were extracted from a flaw-free joint. The tensile tests were conducted employing the F-100 Model universal testing apparatus, equipped with servo control. Figure 2a provides an diagram showing the collected tensile specimen prior to the tensile test.

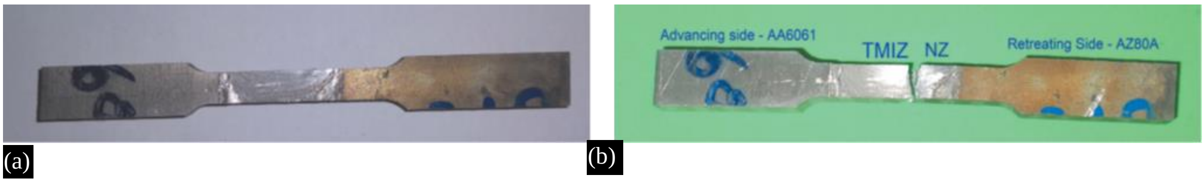



**Figure 2.** Exhibit images of the tensile specimen extracted from the AZ80A-Mg – AA6061-Al alloy joint obtained at 1200 rpm. Subfigure (a) displays the specimen before undergoing the tensile test, while subfigure (b) showcases the specimen after completion of the tensile test.

The juncture where the deformed structures fuse together—the thermomechanically impacted zone and the nugget zone on the retreat side—is where the tensile specimen from the weld obtained at 1200 rpm failed, as Figure 2b illustrates.

At a rotating speed of 1200 rpm, the tensile specimen removed from the AZ80A-AA6061 joint had noteworthy mechanical parameters, such as a 3.8% expansion, a tensile strength of 225 MPa, and a yield strength of 125 MPa. The mechanical properties of the flawless AZ80A-AA6061 alloy joint are graphically contrasted with those of each of its component metals in Figure 3. The joint performed well at 1200 rpm, attaining around 77.76% of the tensile strength of its parent metal, magnesium alloy AZ80A, and nearly 72.26% of that of its parent metal, aluminium alloy AA6061, as seen in the graph. This underscores the remarkable strength achievable through friction stir welding, especially when joining entirely different metal alloys [28].

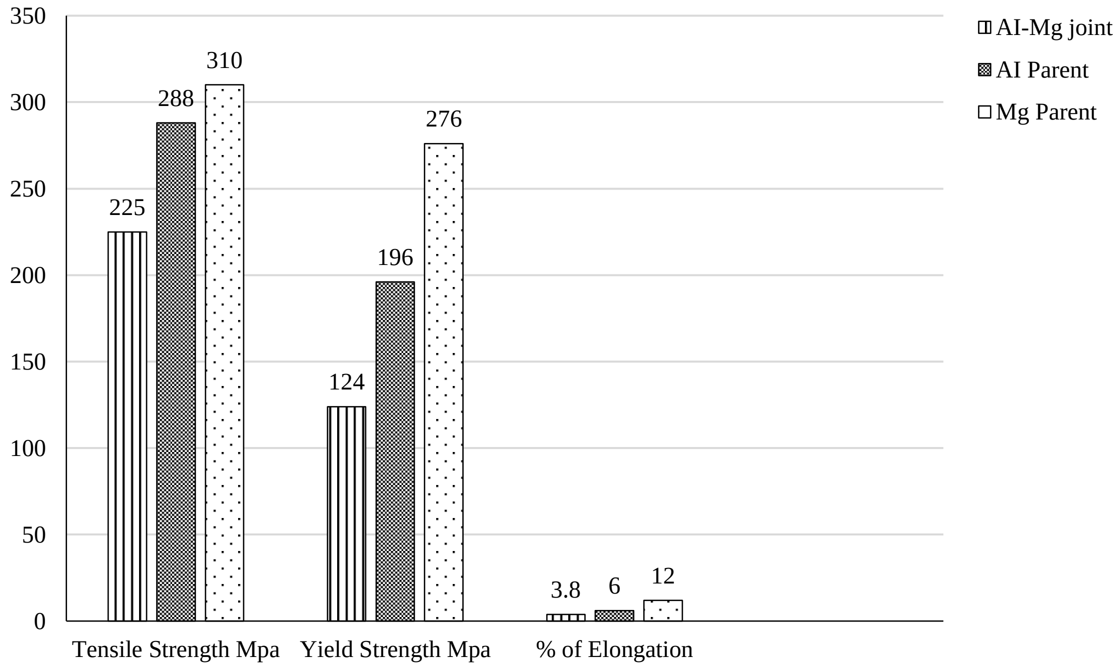



**Figure 3.** Mechanical characteristics of the AZ80A–AA6061 alloy junction, obtained at 1200 rpm, compare to the characteristics of its basic metals.

## CONCLUSIONS

The article outlines an experimental investigation aimed at welding various aluminum alloys, particularly the AA6061 alloy, with the fashioned magnesium alloy AZ80A through the process of stir welding by Friction. The experimental setup involved the use of a tapered cylindrical pin fitted into a tool, strategically positioned at a 0.5 mm offset from the side of the AA6061 alloy plate. The AZ80A-Mg and AA6061-Al alloys that were friction stir-welded were connected by the use of five distinct tool speeds of rotation (800, 1000, 1200, 1400, and 1600 rpm). The tool's traverse rate was kept at 30 mm/min and the applied axial force was kept at 6 kN throughout the welding operation. This systematic approach aimed to explore the impact of varying tool rotational speeds on the resulting welded joints, providing insights into the feasibility and mechanical characteristics of the fusion between these aluminum and magnesium alloys. The investigation's experimental findings are summarized as follows:

- The tool's 800 and 1000 rpm rotating speeds were insufficient to produce a sufficient amount of frictional heat. In a similar rotating speed of 1400 and 1600 rpm in tools have resulted in an increase in heat generation and the subsequent creation of defects. Defects are produced and the production of perfect, high-quality AA6061-Al and AZ80A-Mg alloy joints is hampered by higher and lower tool rotating speeds.
- The samples under tension for the AZ80A–AA6061 junction produced at 1200 revolutions per minute established a tensile strength of 225 MPa, which is 72.76% of the strength of the magnesium alloy and 72.25% of the strength of the aluminium alloy. 3.8% elongation and a yield strength of 124 MPa were also noted.

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