An Investigation of the Friction Stir Scribe Welding for Lap Joint of Dissimilar Materials AA6022-AZ31B

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Abstract
Friction stir welding (FSW) has emerged as a versatile solid-state joining technique for metals. However, joining dissimilar materials with significantly different melting points and material properties remains a challenge. Friction stir scribe (FSS) welding, a variant of FSW, offers a promising solution for lap joints of such materials. This technique modifies a conventional FSW tool by incorporating a small offset scribe at the tip of the welding pin. This research investigates the feasibility of FSS welding for lap joints between AA6022 aluminum alloy and AZ31B magnesium alloy. The focus of this study is to understand the influence of scribe and Different Lap configuration on the microstructure and mechanical properties of the lap joint. The investigation will involve FSS welding of AA6022 and AZ31B plates under various configurations, with the scribe and the plates arranged in different position (AA6022 on top or AZ31B on top). Microstructural characterization will be conducted to examine the formation of the material phases within the weld zone. Additionally, fracture load testing will be performed to evaluate the joint strength and identify the failure modes.

This research aims to contribute to the development of FSS welding for dissimilar material joining. By analyzing the impact of scribe and plate arrangement on the microstructure and mechanical behavior, valuable insights can be gained for optimizing the FSS process to create high-integrity lap joints of AA6022-AZ31B and potentially other dissimilar material combinations.

Keywords: Friction stir scribe welding, dissimilar materials (AA6022 aluminum alloy, AZ31B magnesium alloy), microstructure, mechanical properties, lap joint strength.

1. Introduction

As a solid-state joining technique, friction stir welding (FSW) has received a lot of praise. It offers many benefits over conventional fusion welding techniques, such as better mechanical qualities, less distortion, and fewer solidification flaws. [1]. However, effectively joining dissimilar materials with disparate melting points, thermal properties, and material behaviors remains a formidable challenge in FSW [2].

Such dissimilar material combinations often give rise to the formation of intermetallic compounds and other metallurgical complexities during welding, thereby compromising the integrity and performance of the joints [3].

To address these challenges, researchers have explored various modifications and adaptations of the FSW process. One such adaptation is friction stir scribe (FSS) welding, which integrates a small offset scribe at the tip of the welding pin [4]. This modification aims to enhance material mixing and interlocking at the joint interface, thereby improving weld quality and integrity, especially for dissimilar material combinations [5].

Despite the potential benefits of FSS welding, the current body of literature exhibits a noticeable dearth of studies focusing on its application to dissimilar material joints. Specifically, there is a scarcity of research concerning the optimization of FSS welding parameters and the characterization of resulting microstructures and mechanical properties, particularly for dissimilar material combinations such as aluminum and magnesium alloys [6].

The present study endeavors to bridge this gap by investigating the feasibility and optimization of FSS welding for lap joints comprising dissimilar materials, specifically the AA6022 aluminum alloy and AZ31B magnesium alloy. By means of a methodical investigation of variables such plate orientation, scribe orientation, and other relevant process parameters, the study seeks to clarify the impact of these factors on the mechanical properties and microstructure of FSS-welded joints. By combining knowledge from several research publications [7]-[16], the study seeks to advance the understanding of FSS welding as a viable joining technique for dissimilar material combinations.

2. Literature Review

Friction stir lap welding (FSW), specifically focusing on its application in joining aluminum and polymer materials through scribe technology. FSW offers a solid-state joining solution for dissimilar materials, overcoming challenges posed by traditional fusion welding methods. The integration of scribe technology involves pre-machining a groove along the joint line, facilitating material mixing and enhancing interlocking during welding.[1] Microstructural characterization techniques, including microscopy and XRD, alongside mechanical testing, provide insights into the weld zone morphology and strength. The implications span across industries, with potential applications ranging from lightweight vehicle construction to composite structure fabrication in aerospace and electronics sectors. The study contributes to the advancement of manufacturing processes by addressing challenges in joining dissimilar materials and offering potential solutions for enhancing efficiency and performance.

Performance of joints between AZ31 magnesium and uncoated DP590 steel utilizing friction stir-assisted scribe technique. This innovative approach combines experimental investigations with modeling to comprehensively understand the welding process and resulting joint characteristics. The research holds significant implications for industries requiring the joining of magnesium and steel, such as automotive and aerospace sectors. By offering insights into the performance of friction stir-assisted scribe technique, the study contributes to advancing manufacturing processes and enhancing the efficiency and reliability of joint formations between dissimilar materials. [2]

The study conducted by Curtis et al. at the Advanced Materials Processing and Joining Laboratory, South Dakota School of Mines and Technology, explores friction stir scribe welding of dissimilar aluminum to steel lap joints. This innovative technique combines friction stir welding with scribe technology to overcome challenges associated with joining dissimilar materials, particularly aluminum and steel. By pre-machining a groove along the joint line, the scribe technique enhances material mixing and interlocking, facilitating the formation of robust joints. The research encompasses experimental investigations and possibly numerical modeling to characterize the weld quality, microstructure, and mechanical properties of the joints. Understanding the effects of process parameters on joint performance and optimizing these parameters are central to the study. The findings hold significant implications for industries requiring the joining of aluminum and steel, offering potential solutions to improve the efficiency and reliability of such joints in various applications. [3]

The results of the friction stir scribe welding method for combining aluminium and galvanised steel dissimilarly are presented in the research paper [4]. This method, which pre-machines a groove along the joint line to improve material mixing and interlocking, combines scribe technology and friction stir welding to address the difficulties involved in combining different materials. The study investigates the assessment of joint properties, such as microstructure and mechanical performance, and the optimization of process parameters in order to ascertain the feasibility and effectiveness of this welding approach. Additionally, Das and associates.[5] contribute to our understanding of material interactions in dissimilar material junctions by examining the interfacial reactivity during friction stir-assisted scribe welding of an immiscible Fe and Mg alloy system. The interfacial layer for friction stir scribe welded aluminium to steel joints is further investigated by Wang et al. [6], providing insight into the mechanisms controlling the bonding between these materials.[7]

Evaluates the intermetallic compound layer at the aluminum/steel interface connected by friction stir scribe method. The procedure and ramifications of utilizing the friction stir scribe technique to join dissimilar materials are covered [8]. In order to establish a connection between structure and process in the friction stir scribe joining of different materials, Gupta et al. use a computational method backed by experimental data [9]. In other Research investigate how friction stir scribe technology can be used to enable different material joining. They work with multiple institutions to address multiple facets of this research [10].

The literature review reveals gaps prompting the formulation of objectives for investigating Friction stir scribe welding for lap joint of dissimilar materials AA6022-AZ31B. Which include comparing tensile strength with traditional methods, analyzing microstructures, optimizing process parameters, characterizing joint properties. This research aims to enhance understanding of friction stir scribe welding's feasibility, mechanical behavior for dissimilar material lap joints.

3. Experimental setup and Methodology

The FSS setup was implemented using a vertical milling machine in the Workshop at the Welding Lab. This setup facilitated precise machining and assembly of components crucial for the experiment's performance, ensuring accurate control over parameters like shoulder geometry and tool alignment.

Figure 1 Vertical milling machine - Workshop -Welding laboratory, PDEU

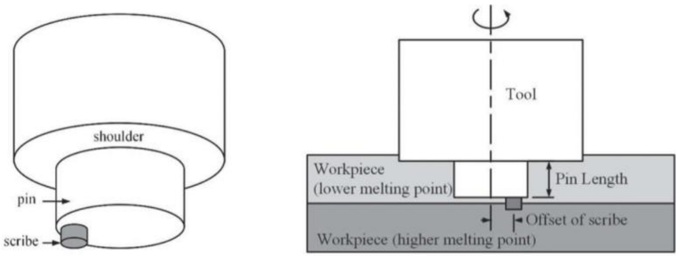


Figure 2 Geometrical Information of tool used for the welding with tilted scribe

In this investigation, a lap arrangement was used, where a 100 mm x 100 mm magnesium alloy sheet was overlapped on top of a 100 mm x 75 mm aluminium alloy sheet with a 3 mm thickness and clamped into place. In FSS, the scribe creates a tiny, continuous incision on the surface of the material with a higher melting point below, while the regular part of the FSW tool plastically deforms and "stirs" the upper layer with a lower melting point.

The FSS tool, which has a cutter scribe attached offset from the axis of rotation, is a standard FSW tool. H13 tool steel that had been heat-treated was used to make the scriber and FSS tool. The tool is positioned so that the bottom material is only penetrated by the scribe. The scribe functions to produce a mechanical interlocking characteristic between the different materials that resembles a rivet. The tapered pin, cylindrical scriber, and cylindrical shoulder made up the FSS tool. Table 1 provides the tool specification.

3.1 Tool Design

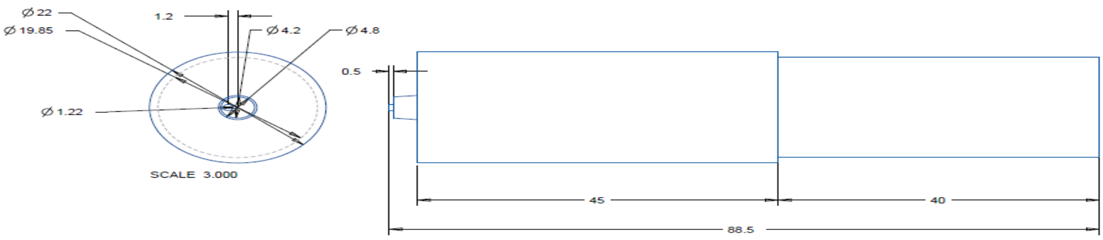


Figure 3 Dimensional Drawing of the FSS tool

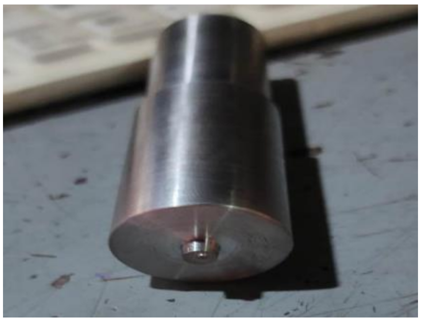


Figure 4 FSS Tool used in Experiment

Figure 5 Tool View from Different Angels

Figure 2 present schematic of tool geometry, Figure 3 Present Dimension of FSS Tool in millimeter and in Figure 4 and 5 Visualize actual FSS Tool Used I Experiment as per Table 1 Mentioned dimensions and material Selectin for tool as per Table 2.

Table 1 Tool Dimension Used in Experiment

Diameter of Stationary Holder (mm)	Diameter of Pin (mm)	Length of Pin (mm)	Scriber Diameter (mm)	Scribe Height (mm)
20	4.2 - 4.8	3	1.22	0.5

This tool is made from a tough material called H13 steel, known for being really strong and resistant to wear and heat. It has a shoulder that's 20 mm wide, giving it stability when it's being used. The shoulder is shaped like a cylinder, which helps it stay steady. There are pins on the Tapered tool that are 4.2 mm and 4.8 mm thick, and they're shaped like cones to make accurate marks. The tool also has a part called a scribe, which is offset by 1.2 mm for precise marking. The scribe Diameter is 1.22 mm and 0.5 mm long.

3.2 Work piece Material Selection

The selection of appropriate work piece materials is a critical aspect of friction stir Scrib welding (FSSW) experiments, particularly when dealing with dissimilar material joints. In the context of this research, the chosen work piece materials are AA6022 aluminum alloy and AZ31B magnesium alloy.

The AA 6022 aluminum alloy offers several desirable characteristics for FSW experiments. With dimensions of 100mm x 75mm x 3mm, this alloy provides a suitable platform for conducting FSW trials. AA 6022 is renowned for its excellent formability, corrosion resistance, and weldability, making it an ideal candidate for joining applications [1]. its composition, which includes elements such as silicon and magnesium, contributes to enhanced mechanical properties and weldability [2]. The choice of AA 6022 aluminum alloy aligns with the objectives of this research, which aims to explore the feasibility and optimization of FSW for dissimilar material joints.

With dimensions of 100 x 100 x 3 mm, the AZ31B magnesium alloy complements the AA 6022 aluminum alloy. Since AZ31B is lightweight and has a good strength-to-weight ratio, it is widely used in several industries, including aerospace and automotive [3]. Additionally, AZ31B has good formability and weld ability, which makes it ideal for joining applications involving dissimilar materials and favorable for FSW studies [4]. This research intends to assess the opportunities and difficulties related to combining different metal combinations, advancing FSW technology by integrating AZ31B magnesium alloy into the FSW tests. The AZ31B magnesium alloy and AA 6022 aluminum alloy were chosen as the work piece materials for the FSW studies highlights their applicability in dissimilar material joining scenarios. These materials support the goals of the study to look at the viability and optimization of FSW for dissimilar material joints by providing a balance of mechanical characteristics, weld ability, and formability. The mechanical properties and chemical composition of the magnesium alloy AZ31B and the aluminum alloy AA 6022 are shown in Tables 2 and 3, respectively.

Table 2 Mechanical Property

Mechanical Property	AZ31B magnesium alloy Value	AA 6022 aluminum Alloy Value
Yield Strength	140 MPa - 260 MPa	130 MPa - 210 MPa
Tensile Strength	215 MPa - 290 MPa	200 MPa - 270 MPa
Elongation	12% - 20%	10% - 15%
Hardness (Brinell)	45 HB - 75 HB	60 HB - 75 HB
Hardness (Rockwell)	40 HRB - 60 HRB	45 HRB - 55 HRB
Modulus of Elasticity	~68 GPa (~9,900 ksi)	~45 GPa (~6,500 ksi)

Table 3 Chemical Composition

Element	AZ31B Magnesium Alloy Composition (%)	AA 6022 aluminum Alloy
Aluminum (Al)	2.5 - 3.5	97.8
Zinc (Zn)	0.6 - 1.4	0.1
Manganese (Mn)	0.2 - 1.0	0.3
Magnesium (Mg)	Balance	0.25-0.60
Other Elements	< 0.3	< 0.5

The figures included in the research paper provide essential visual aids to enhance understanding of the experiment's setup and results. Figure 5 depicts the FSS tool utilized in the experiment, showcasing its design and features. Figure 6 illustrates the trial involving similar materials, while Figure 8 presents a macro image of trial 3, detailing the parameters of speed, feed, and tilt angle for a deeper insight into the experiment's outcomes. These figures collectively contribute to elucidating the methodology and findings of the research.

3.3 Experiment with similar material

Figure 6 Similar material 3 trial (AA 6022-AA 6022)

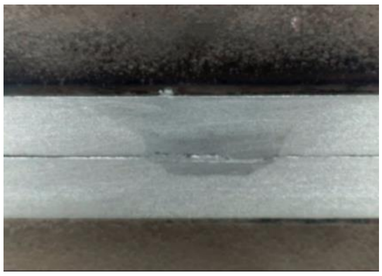
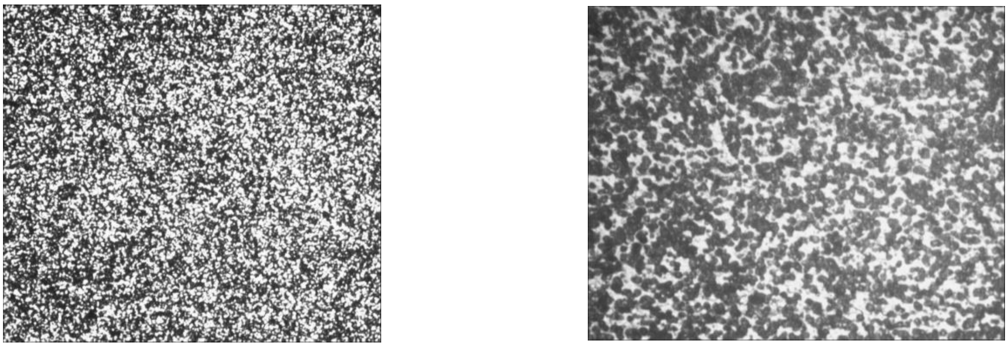


Figure 7 Macro image of which parameter 1070 rpm, 31.5 mm/min and 0 degree - in form of speed, feed and tilt angle.

Table 4 List of Process Parameter

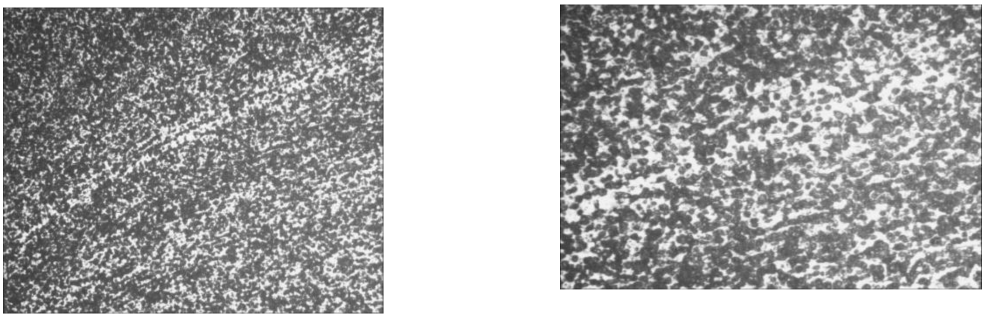
SPEED (RPM)	545	765	1070
FEED (MM/MIN)	20	50	31.5
TILT ANGLE (DEGREE)	1	2	0

The provided figures showcase the microstructures of AA6022 aluminum alloy at different regions affected by welding. Figure 8 (a), (b) displays the parent metal microstructure at magnifications of 100X and 200X, offering insights into its initial state. Figure 9 (a), (b) focuses on the TMAZ (Thermal-Mechanically Affected Zone) at 200X and 400X.



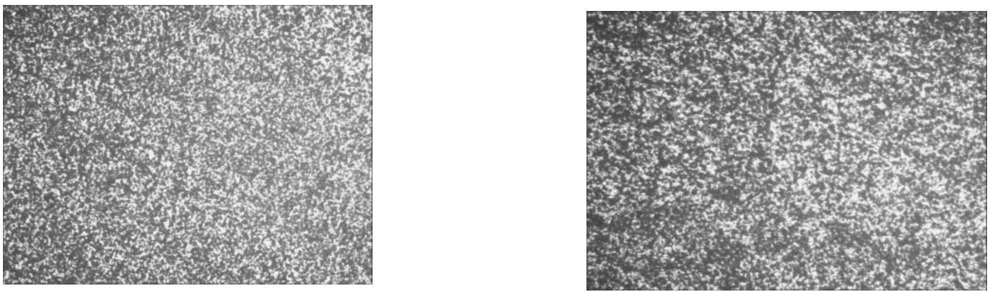
(a) 100X **(b) 200X**

Figure 8 Microstructure of AA6022 (parent metal)



(a) 200X **(b) 400X**

Figure 9 Microstructure of AA6022 (TMAZ)



(a) 200X (bottom) **(b) 200X (top)**

Figure 10 Microstructure of AA6022(SZ/nugget)

Figure 10 (a), (b) presents the microstructure of the SZ (Stir Zone) or nugget at 200X and Figure 11(a), (b) presents Microstructure of AA6022nugget at 400X, highlighting changes in the alloy's structure post-welding. These figures aid in understanding the metallurgical changes occurring during the welding process and their implications on the material properties.

(a) 400X (bottom) (b) 400X (top)

Figure 11 Microstructure of AA6022(SZ/nugget)

3.4 Experiment with dissimilar material

The experiment involves friction stir scribe welding of dissimilar materials, specifically AA 6022 aluminum alloy and AZ31B magnesium alloy. The dimensions of the work pieces are standardized for consistency: AA 6022 plates measure 100mm x 75mm x 3mm, while AZ31B plates measure 100mm x 100mm x 3mm.

Case I Configuration: Al/Mg: TOP: AA 6022 plates BOTTOM: AZ31B

Figure 11 Parameter actual run Al/Mg

Key process parameters are established to ensure reproducibility and control during welding. The welding speed is set at 31.5 mm per minute, indicating the rate at which the welding tool traverses along the joint line. The rotation speed of the tool is fixed at 1070 RPM (Revolution per minute), determining the speed at which the tool rotates around its axis. Additionally, For this experiment, the tool's tilt angle, or the angle at which it is inclined with respect to the work piece surface, is adjusted at 0°.

Two different arrangements of materials in lap configuration are investigated to assess their influence on joint properties. In the first configuration, AA6022 aluminum alloy is positioned at the top, with AZ31B magnesium alloy at the bottom. Conversely, in the second configuration.

Case II Configuration: Mg/Al: TOP: AZ31B plates BOTTOM: AA 6022

Figure 12 Parameter actual run trial 1 Mg/Al

AZ31B is placed at the top, while AA6022 is positioned at the bottom. These configurations allow for comparisons between joints with different material sequences, providing insights into the effects of material arrangement on the resulting weld characteristics.

This experimental setup aims to explore the feasibility and optimize the friction stir scribe welding process for joining dissimilar AA 6022 and AZ31B alloys, considering various parameters and material arrangements Here in this Research paper, From Experiment Average Revolution Speed and Tilt angle 0° Represented.

Table 5 Work piece material dimension

Aspect	Dimension/Value (mm)
AA 6022	100 x 75 x 3
AZ31B	100 x 100 x 3

Table 6 Table Process parameters

Welding speed	31.5 mm per minute
Rotation speed	1070 RPM
Tilt angle	0°

3.5 Tensile Test Specimen Preparation

In Case I and II of the experiment, the work pieces consist of two different materials: AA 6022 aluminum alloy and AZ31B magnesium alloy and The dimensions of the work pieces are standardized to ensure consistency throughout the welding process. The AA 6022 plate measures 100mm x 75mm x 3mm, while the AZ31B plate measures 100mm x 100mm x 3mm as Mention in Table 7.

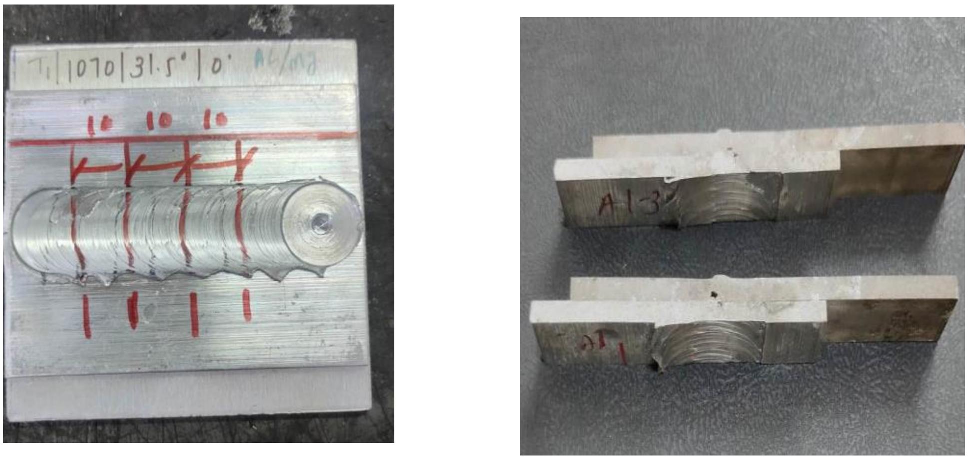


Figure 13 Preparation for Tensile testing (Al/Mg)

Table 7 Arrangement of materials in lap configuration

Case 1	AA6022 at top and AZ31B at bottom
Case 2	AZ31B at top and AA6022 at bottom

Several process parameters are established to control the welding conditions effectively. The rate at which the welding tool moves along the joint line is indicated by the welding speed, which is set at 31.5 mm per minute. The rotation speed of the tool is fixed at 1070 RPM, determining the speed at which the tool rotates around its axis. The tilt angle of the tool is set at 0°, indicating that the tool is positioned perpendicular to the work piece surface as Mention in Table 7..

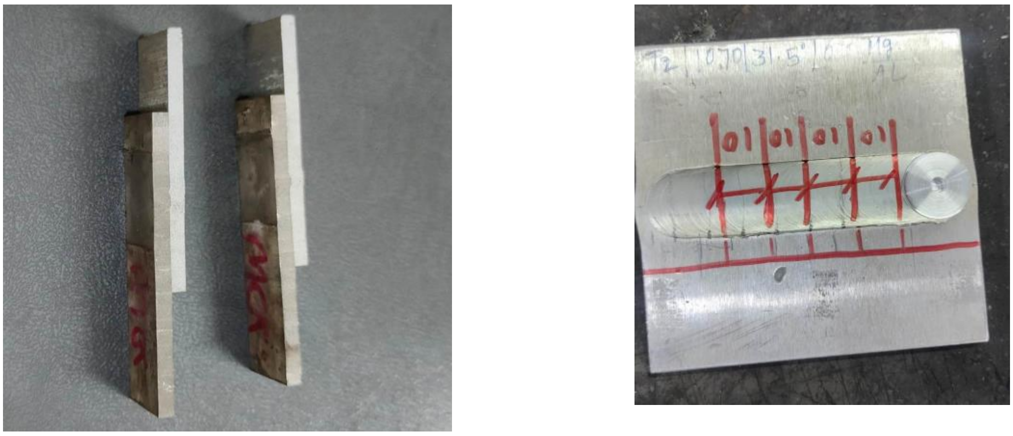


Figure 14 Figure Preparation for Tensile testing (Mg/Al)

Regarding the arrangement of materials in the lap configuration, the AA6022 aluminum alloy plate is positioned at the top, while the AZ31B magnesium alloy plate is positioned at the bottom. This configuration allows for the investigation of joint properties when AA6022 is the uppermost material and AZ31B is the lowermost material in the weld joint. In this Case I and Case II of the experiment aims to assess the feasibility and optimize the friction stir scribe welding process for joining dissimilar AA 6022 and AZ31B alloys under specific process parameters and material arrangements as mentioned in Table 8.

4. Result and Discussion

Based on the investigation and microstructure observations Figure 15 (a), (b), (c), (d) and Figure 16 (a),(b)(c),(d) Comparison, the comparison between the Al/Mg and Mg/Al configurations reveals significant differences. The Al/Mg configuration exhibits fewer distortions and damages in its microstructure compared to the Mg/Al configuration. This suggests that the welding process or conditions for Mg/Al may be stronger, leading to a more uniform and less compromised microstructure.

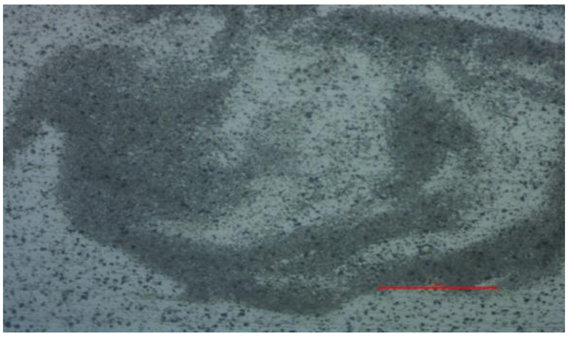
Investigation of Graph 1, 2 and 3 it’s observed that the Mg/Al configuration demonstrates higher tensile strength compared to Al/Mg. This could be attributed to several factors, including the inherent properties of magnesium and aluminum alloys, as well as the specific welding parameters used. The microstructure observations likely reveal finer grain structures, better intermetallic bonding, or fewer defects in the Mg/Al configuration, contributing to its superior tensile strength.

4.1 Micro Structure Examination Al/Mg Configuration

The Figure 12 and Figure 13 titled provide visual microstructure of the sample preparation process for conducting tensile tests on aluminum-magnesium (Al/Mg) alloys. These figures likely depict steps such as sample cutting, machining, and mounting to ensure standardized test specimens. The repetition of the figure title suggests that multiple images or angles of the sample preparation procedure may be included for comprehensive documentation.

(a) Macro

(b) Stir zone - 100X



(c) Stir zone - 500X

(d) TMA zone -200X

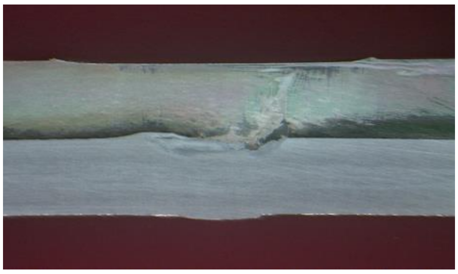
Figure 15 Figure Examination of Al / Mg

The Figure 15 titled "Examination of Al/Mg" presents a comprehensive visual analysis of various zones, Figure 15 (a) Macro: Provides an overview of the weld at a macroscopic level, Figure 15(b) Stir zone 100X - Offers a magnified view of the stir zone at 100X magnification, allowing for detailed examination. Figure 15 (c) Stir zone 500X Further magnifies the stir zone to 500X, providing even greater detail for analysis. Figure 15 (d) TMA zone 200X Focuses on the thermal-mechanically affected (TMA) zone at 200X magnification, highlighting its structural characteristic

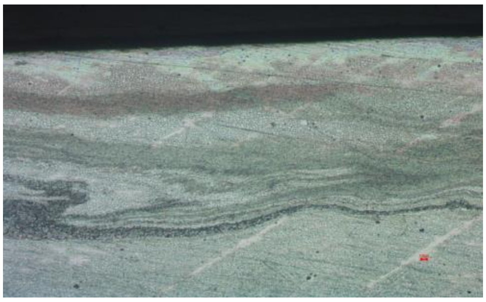
- of defects compared to the Mg/Al configuration.

These images collectively enable a thorough investigation of the microstructural features and properties of the Al/Mg weld.

- Macro structural examination of the Al/Mg configuration reveals the presence of minor voids. Despite the meticulous analysis
- This observation highlights a potential limitation in the Al/Mg configuration, indicating that it may be more susceptible to the formation



(a) Macro



(b)Stir zone - 100X

(c) Stir zone - 500X

(d) TMA zone -200X

Figure 16 Figure Examination of Mg / Al

The Figure 16 represent the "Examination of M/Al" a comprehensive visual analysis of various zones, Figure 16 (a) Macro: Provides an overview of the weld at a macroscopic level, Figure 16 (b) Stir zone 100X - Offers a magnified view of the stir zone at 100X magnification, allowing for detailed examination. Figure 16 (c) Stir zone 500X Further magnifies the stir zone to 500X, providing even greater detail with no void , defect free macro structure .. Figure 16 (d) TMA zone 200X Focuses on the thermal-mechanically affected (TMA) zone at 200X magnification, highlighting its structural characteristic

These images collectively enable a thorough investigation of the microstructural features and properties of the Mg/Al weld.

- Within the 500X boundary, optimal microstructure examination reveals compelling evidence of defect-free welds in the Mg/Al configuration. This assertion is supported by meticulous analyses conducted within the specified parameters
- This achievement is particularly noteworthy given the inherent challenges associated with welding, emphasizing the robustness and reliability of the Mg/Al configuration in producing high-quality welds.

4.2 Tensile test data

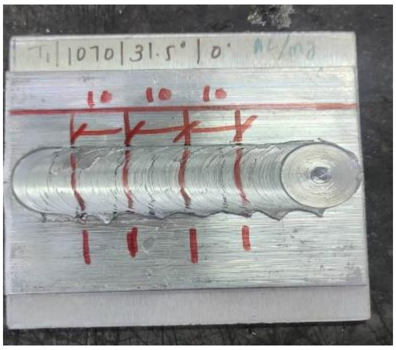
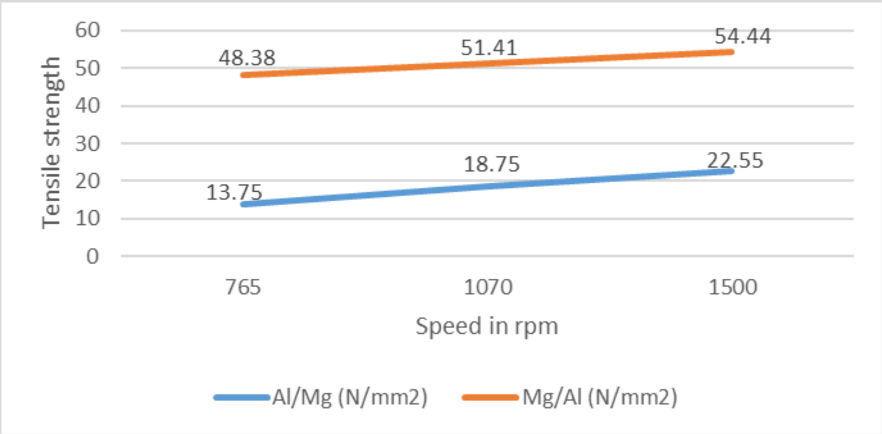


Table 9 Experiment Tensile Strength observation

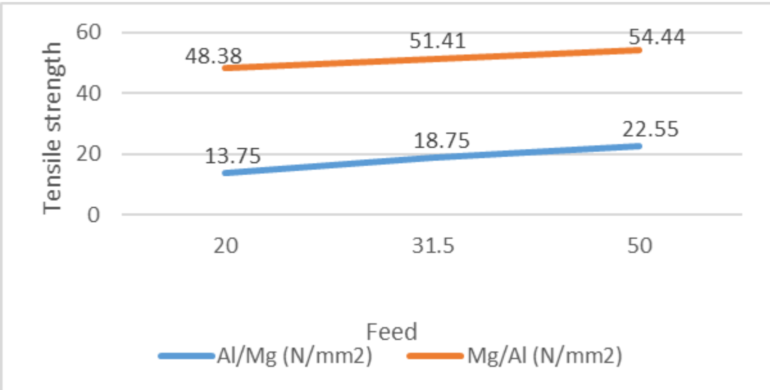
SPEED (RPM)	FEED (MM/MIN)	TILT ANGLE (DEGREE)	AL/MG TENSILE (N/MM^2)	MG/AL TENSILE (N/MM^2)
545	20	1	13.75	48.38
765	50	2	18.15	51.41
1070	31.5	0	22.55	54.44

The tensile strength (in N/mm2) of lap joints formed using the friction stir scribe (FSS) welding process between magnesium (Mg) and aluminum (Al) alloys is shown for various welding speeds in Table 9 Experimentally Observed data. The magnesium and aluminum plates are positioned alternately in two different configurations of the lap joints: Mg/Al and Al/Mg. Three distinct welding speeds are used to record the tensile strength data for each configuration: 765 mm/min, 1070 mm/min, and 1500 mm/min.



Graph 1 Tensile Strength Vs Speed

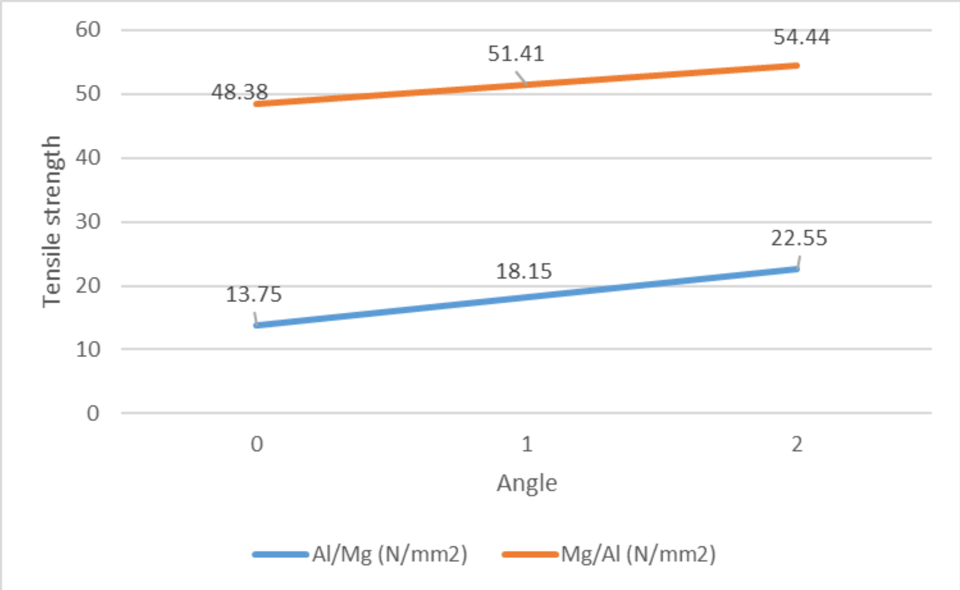
Graph 1: Observation Data The Mg/Al combination has a greater tensile strength of 48.38 N/mm², whereas the Al/Mg design shows a tensile strength of 13.75 N/mm², representing a welding speed of 765 mm/min. Tensile strength increases in both setups as the welding speed reaches 1070 mm/min. In particular, the Mg/Al combination has a marginally greater tensile strength of 51.41 N/mm², while the Al/Mg design has a tensile value of 18.75 N/mm². Lastly, additional improvements in tensile strength are noted for both configurations at a welding pace of 1500 mm/min. A tensile strength of 22.55 N/mm² is achieved by the Al/Mg arrangement, and a higher tensile strength of 54.44 N/mm² is reached by the Mg/Al structure.



Graph 2 Tensile Strength vs Feed

Experimentally Graph 2 observed data showcases the tensile strength (N/mm²) of lap joints formed through friction stir scribe (FSS) welding between aluminum (Al) and magnesium (Mg) alloys at varying feed rates (mm/min). Two configurations, Al/Mg and Mg/Al, are examined with alternating placement of aluminum and magnesium plates.

At lower feed rates (20 mm/min), the Mg/Al configuration consistently exhibits higher tensile strength (48.38 N/mm²) compared to the Al/Mg configuration (13.75 N/mm²). Increasing the feed rate to 31.5 mm/min enhances the tensile strength for both configurations, with the Mg/Al joint (51.41 N/mm²) still outperforming the Al/Mg joint (18.75 N/mm²). Further escalation of the feed rate to 50 mm/min results in continued improvement in tensile strength for both configurations. The Al/Mg joint achieves 22.55 N/mm², while the Mg/Al joint reaches 54.44 N/mm².



Graph 3 Tensile Strength vs Tilt Angle

At a tilt angle of 1 degree, the Al/Mg joint configuration exhibits a tensile strength of 18.15 N/mm², while the Mg/Al joint configuration shows a higher tensile strength of 51.41 N/mm².

As the tilt angle increases to 2 degrees, the tensile strength values for both configurations also increase. At this angle, the Al/Mg configuration shows a tensile strength of 22.55 N/mm², while the Mg/Al configuration demonstrates a higher tensile strength of 54.44 N/mm².

Overall, the data indicates that increasing the tilt angle leads to an improvement in the tensile strength of joints formed between aluminum and magnesium alloys, regardless of the sequence of layers in the joint configuration. Additionally, the Mg/Al configuration generally exhibits higher tensile strength values compared to the Al/Mg configuration at each tilt angle.

5 Conclusion

This Research study investigate the Macro structure examination and tensile test data exhibited by lap joints fabricated through friction stir scribe (FSS) welding, focusing on the dissimilar materials combination of aluminum (Al) and magnesium (Mg) alloys. The investigation entailed the evaluation of two distinct configurations: Al/Mg and Mg/Al.

- Macro structural examination revealed superior intermixing of molecules and mechanical interlocking in Mg/Al configuration compared to Al/Mg configuration.
- This strongly suggests that Mg/Al having a higher tensile strength compared to Al/Mg in this configuration. The data points reinforce this observation, with Mg/Al values 48.38 N/mm², 51.41 N/mm², 54.44 N/mm², consistently exceeding those of Al/Mg 13.75 N/mm², 18.75 N/mm², 22.55 N/mm². Macro structure examination further supports the strength superiority of Mg/Al joints over Al/Mg joints in FSS welding applications.
- These findings collectively support the feasibility and efficacy of lap joint fabrication using the FSS technique, highlighting its potential for enhancing mechanical properties and structural integrity in relevant applications.

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