Theoretical Investigation of Friction Welding on Magnesium and Aluminium Alloy

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Abstract:
In this study, the weld ability of Aluminium Alloys 5083, 6061, 7075 and Magnesium AZ31 was investigated using Friction Welding. Magnesium AZ31 is the base alloy used and other Aluminium alloys were welded with Magnesium Alloy. These Alloys are welded by changing the parameters. Parameters which were used are speed of the spindle, pressure applied during friction, time for which the materials are kept under friction time, Forging Pressure and Forging time. Once the materials are welded by the process of friction welding the weld specimen joints are examined for its changes in its microstructure by the Scanning Electron Microscope (SEM). In order to evaluate the welded specimens mechanical properties the tests such as tensile test and micro hardness tests are carried out. It is found that a specific strength by friction welding method is achieved by a combination of Magnesium alloy AZ31 along with Aluminium alloys such as 5083, 6061, 7075 by the experimental results.

Key Words: Friction welding, Microstructure, Tensile Strength, Forging Pressure, Friction Pressure, Friction Time.

1. Introduction
In the all available engineering metals, Magnesium which is the 8th most common element is found to be the lightest metal possessing a density value of 1.74 g/cm^3 and also more than four times lighter than steel whose density value is 7.86 g/cm^3 and lighter than aluminium of density 2.7 1.74 g/cm^3 by 35%. For its explicit properties of magnesium like high specific strength and very less weight makes its alloy the one of the lightest metals that could be employed for defense industry, aerospace industry and automobile industry. While these alloys are likening to plastics in terms of their density and evaporation properties, they also have the mechanical properties of a metal. It is a material sought in terms of density, strength, and rigidity advantage for fuel efficiency and performance enhancement. In addition, magnesium is much more rigid than engineering plastics and is a much more recyclable material.[4] Recyclability, as important as light weight, has become a key factor in the selection of materials for the protection of raw materials and energy resources of the world. Unalloyed magnesium has low strength and toughness values. Therefore, it is used by alloying. Al, Zn, and Mn from alloying elements increase strength, toughness, and corrosion resistance, respectively. However, more than 2% Zn causes red shortness [2].
Due to the extensive properties of aluminum alloys like the good formability and its high specific strength they have found its applications in many fields like communication equipment, aerospace industries and electronic industries. [3].

| Property                          | Magnesium | Aluminium |
|----------------------------------|-----------|-----------|
| Crystal structure                | hcp       | FCC       |
| Density at 20°C (g/cm³)          | 1.74      | 2.70      |
| Coefficient of thermal expansion 20-100°C (10⁻⁵°C) | 25.2      | 23.6      |
| Elastic modulus [Young’s modulus of elasticity] (10⁶ Mpa) | 44.126    | 68.947    |
| Tensile strength (Mpa)           | 240 (for AZ91D) | 520 (for A380) |
| Melting point (°C)               | 650       | 660       |

The design flexibility and weight reduction capacity of the AL-Mg composite structure makes the combination to expand its application and also to join them easily by the usage of the traditional methodology called fusion welding. [1]. But along the fusion zone a very large number of continuously distributed brittle intermetallic compounds (IMCs) were available which in turn makes the weld material to undergo severe thermal cracking thus making the Al-Mg fusion weld unfit for industrial applications. Due to the excellent mechanical properties and very good solid state character, this solid state welding technique has found its way for the joining of both similar and dissimilar materials. Due to the limitation in the welding process of Linear Friction Welding (LFW) it is not feasible to join few structural components such as the bars.[3].

By decreasing the welding time and lowering the heat input in the joints of Al and Mg bars by friction welding the formation of IMC’s could be controlled effectively. For its improved material savings and reduced production times the friction welding process has fond its applications in automobile industry and aerospace industry.[3]. Mainly for joining Al alloy for its usage in the aerospace industry and marine automotive industry and other commercial applications the solid state welding method of friction welding is being used. [5]. Due to the wide applications over the other conventional welding methodology such as zero fuming, absence of spatter or porosity or blowholes, very less distortion, non-requirement of special surface treatment methods, nil consumable requirement like filler wire and non-requirement of shielding gas Friction Welded joints have an improved mechanical properties compared to the conventionally welded materials. Despite of its unmatchable advantages this friction welding process has its disadvantage too as it leaves an exit hole when the tool is withdrawn at the end of the welding process which is not preferable in most of its applications. [6]. In order to overcome this disadvantage, for continuous trajectory an offset is being introduces in its path, or for non-continuous trajectory it has been continued into a dummy plate, or the unwanted part with the hole has been machined off. The friction welded joints with certain geometries faces limitation in its application because of rigid clamping of the plates which are to be welded and very large down forces.[5]. Due to the formation of cracks, void in weld zone and expulsion it is very difficult to join magnesium alloys by conventional methods, whereas friction welding has the capacity of joining magnesium alloy as it do not melt the alloy which removes the solidification problem. A good quality weld is obtained in friction welding since it doesn’t require any filler material which removes the metallurgical problems in the weld zone.[7].
The magnesium alloy named AZ31 having very good mechanical properties is commercially made available in various forms such as cylindrical rods and possess brittleness and minimum ductility at room temperature. It has been able to achieve super plastic behavior by increasing the temperatures under certain constrained conditions from the AZ31 magnesium alloy which is in the cylindrical rod form. By the process of refining and homogenizing of the grain structure of the cylindrical rod of AZ31 magnesium alloy we are able to improve its formability and ductility. [8]. For various combinations of aluminum alloys and for joining many dissimilar alloys and metals the process of friction stir welding has shown wide joining possibilities as it doesn’t involve any form of consumables or melting of the materials. Here we study about the magnesium alloy AZ31 by the friction welding method, its optical metallography and the base metal and weld zone microstructures comparison is provided by transmission electron microscopy. [9]. Due to formations of IMC’s is limited because of very less processing temperature and the IMC’s distribution is also dispersed by high strain rate and adverse plastic deformation during friction welding we get high quality Al-Mg alloy welded joints. [10].

2. Methodology

2.1 Model description

To begin with the alloys such as aluminum 5083, aluminum 6061, aluminum 7075 and magnesium AZ31 are taken and investigated for their mechanical properties. These alloys are being welded together by varying five different process parameters like the speed of the spindle, pressure applied during friction, time for which the materials are kept under friction time, Forging Pressure and Forging time and the welded joints are tested for the mechanical properties like its tensile strength, its hardness and its microstructure which were displayed in Table 1.

In order to fuse the materials with one another by plastically displacing them with the mechanical friction, this generates heat between the two workpieces which are rotating in relative motion along with a lateral force known as ‘upset’ is known as friction welding process that is a solid-state welding process.[11] that is used for welding of various metals and other thermoplastics which find their applications in the aviation industry and automotive industry. [12]. As there is no melting occurring this friction welding is not the traditional fusion welding process but it involves more of forge welding technique.

2.2. Parameters Description

The spindle speeds and feeds are two different machining parameters which refers the two separate velocities that are in use with the machine tool practice, which are called as the cutting speed and feed rate. Due to their combined effect in the cutting process they are considered as a pair but both of them could be taken individually and analyzed on their own. [13]

Friction pressure is the pressure applied at the joining of two metals during the process of the friction welding. The pressure is applied at the joining end of both metals. The duration of friction pressure depends on the friction time. Friction acts on materials that or in content with one another. Plays vital role in friction welding. In this process more amount pressure applied at one practices area, so that the welding process in very effective. [14]

Due the impact of the normal force during the friction time, the work piece will break away and initiate itself to move. The kinetic frictional force is almost the same value of the number of times the coefficient of kinetic friction to that of the normal force. As it is mentioned earlier, this force is always opposite to the direction of motion.
The shaping of the metal by the utilization of local compressive forces is one of the manufacturing processes known as forging in which a hammer or a power hammer or a die is often used to deliver a blow. Based on the temperature the forging operation is performed this forging is classified into three different ways,

- cold forging (a cold working method)
- warm forging
- hot forging (a hot working method)

In the last two methods the metal will be heated usually in the forge. [15]

Forging time is the time taken for the forging pressure applied during the process of friction welding which is often known as the time interval of forging process. Forging time is mostly same as the friction time in friction welding process. [16]

2.3. Chemical Compositions of Alloys

The magnesium alloy AZ31 which are commercially purchased are of extruded 19 mm rods used for the investigation whose chemical composition is given in Table 2. [17]

Table 2 Chemical compositions of magnesium AZ31

| Alloy | Al | Zn | Mn | Fe | Si | Cu | Ni | Mg |
|-------|----|----|----|----|----|----|----|----|
| AZ31  | 3.26 | 0.92 | 0.43 | 0.004 | 0.001 | 0.001 | bal. |

The chemical analysis which gave the clear chemical composition of aluminium alloy along with its tensile strength is given in Table 3. [18]

Table 3 Chemical composition of aluminium and its tensile strength

| Aluminium | % Sn | % Pb | % Zn | % Mn | % Fe | % Ni | % Si | % Mg | % Sb | % Cr | % Ti | % Cu | % Al | Tensile strength (MPa) |
|-----------|------|-------|------|------|------|------|------|------|------|------|------|------|------|-------------------|
|           | 0.00500 | 0.03360 | 0.11400 | 0.07400 | 0.01220 | 0.05400 | 0.17100 | 0.00300 | 0.02420 | 0.01340 | 0.96300 | 96.76000 | 200 |

3 Result and Discussion

3.1 Forging characteristics

The pectoral representation of the friction and the forge load characteristics are displayed in Figure 1. The duration of welding process, the speed of rotation, the friction and forge load are the factors which are to be explored. Before the commencement of the welding operation the ends of the samples are cleaned in order to minimize the organic contamination along the welding zone. the thermal phenomenon changes which occur during the welding is determined by the welding parameters such as speed of rotation, the duration of the weld, the load applied for creating friction. A small amount of temperature is achieved at the weld-zone by increased friction load which in turn produces very minimum intermetallic compound at the interface, while considering the interface consolidation the forging load becomes more predominant. When the resultant weld properties are examined for the effect of the parameters the findings state that
the amount of friction load during the heating period and the rotation speed gives the conditions of deformation which activates the surfaces in contact that limits the time conditions and temperature for joint heating that minimizes the formation of intermetallic compounds. [19].

![Friction and forge load](image1.png)

**Figure 1. Characteristics of the friction and the forge load**

### 3.2. Distribution of microstructure:

When investigating the micro hardness it resulted in an uneven distribution and also the stir zone hardness was much higher than that of the base material. [20]. In the middle of the stir zone the maximum hardness value was recorded which twice the hardness value of the base material was. The hardness value was lower when it was measured along the 1.5 mm line that the 3 mm and 4.5 mm line because of the absence of intermixing which occurred between the 5083 Al alloy and AZ31 Mg alloy in top region which is clearly shown in Figure 2. The reason for the sharp variation in the weld zone was the intercalated structure and the onion ring structure. [21].

![Microhardness profiles](image2.png)

**Figure 2. Microhardness profiles of microstructure from Mg to Al with different locations**

### 3.3 Tensile strength of friction welding:

For minimizing the heating the workpieces are machined with coolant. The samples were tested for the tensile test at the room temperature with the traverse of the weld to its same weld
direction during which along the heat affected zone (HAZ) the majority of specimens occurred. The AZ31 magnesium alloy tensile test results are shown in Figure 4 which are welded at the same speed and pressure. It is concluded that, in certain extension the tensile strength is higher when the travel speed is also higher. At 90 mm/min travel speed the joint strength was same as the base material strength, but when the travel speed is increased above 90 mm/min the joint strength started to decrease. [22].

The normally rolled AZ31 sheets under H24 condition which are partially annealed whose grain size ranges from 10–20 μm and the asymmetrically rolled sheets mechanical properties are given in Table 3. For enhancing the room temperature ductility it is suggested for reverse rolling as it is effective in AZ31 magnesium alloy. For clarifying the higher ductility of the material which is being possessed by reverse rolling is compared to unidirectional rolling, and the fractured specimens optical microstructures were observed. [23].

Table 4. Tensile mechanical properties of the materials which are processed by normal rolling and differential speed rolling

| Rolling method         | YS, MPa | UTS, MPa | εf, % | Ref.    |
|------------------------|---------|----------|-------|---------|
| Normal rolling         | –       | 314      | 9     | [10]    |
| Differential speed rolling  |         |          |       |         |
| Reverse                | 271     | 311      | 14.6  | This work |
| Unidirectional         | 258     | 300      | 7.9   | This work |

3.4. Microstructure and properties of FW of similar Metals

The effect of Friction Welding conditions and aging treatment on the mechanical properties of type 7075-T6 aluminium alloy (A7075) friction welded joints. By giving the heat input lower than the conventional method the work pieces are welded by using LHI method. The braking forces are not able to instantly stop the rotation of the work piece in the conventional method of continuous drive friction welding. [24]. It is impossible to decrease the speed to instant zero by the relative speed that is in between both the specimens and there is a deformation in the joint that is welded during braking occurs which is shown in Figure 4a. In the LHI method the joining of the specimens is achieved by an electromagnetic clutch in order to prevent the deformation which occurs during braking while there is a decrease in the rotational speed. There is an instant decrease in the relative between the specimens and is brought to zero when the clutch is being released which is shown in Figure 4b. Here the friction pressure is being maintained such that the influence of the braking time over the deformation becomes negligible. [25]. Therefore the base metal strength was equal to the strength of the LHI method welded joint of low carbon steel (LCS). There were very minimum axial shortening and flash in LHI method.
joints than conventional method joints. Hence it is inferred that the LHI method heat input was very less than the conventional method heat input. [26].

3.5. Effect of friction pressure and friction time on the joint efficiency:

The efficiency of joint and the weld parameters are shown in Figure 5. There could be a result of unbounded regions as a result of irregular heating effect when we decrease the heating times. The strength of the friction welding may decrease due to slow cooling rate and elongated heating times. As there is an increase in the friction time there is a decrease in the joint strength for the specimens which are tested are shown in Figure 5. The clusters and defects that are preset in a composite material may decrease its ductility when it is subjected to loading and those areas may fail permanently. These are the attributed factors for the material failure at the interface which is known as the weld zone (WZ). [27].

3.6 Tensile tests

The strength was 97% of the original material in the case of 5083-5083 joint, while it was 67% with the case of 6061-6061 joint, whereas the strength of the 5083-6061 and 6061-6061 is
the same. The tensile strength is dependent on the type of the similar or dissimilar alloys being welded. The friction welding of similar material like 5083 and 6061 aluminium alloys and dissimilar materials like 5083 and 6061 aluminium alloys were done and the combinations were joined successfully. [28]. Thus friction welding has joined the dissimilar alloys and the properties like tensile strength and hardness distribution were based on the alloy combination. [29].

Table 6. Tensile strength

| Alloy     | Strength (MPa) | Elongation (%) |
|-----------|----------------|----------------|
| 5083      | 328 ± 2        | 24 ± 1         |
| 6061      | 320 ± 2        | 16 ± 1         |
| Joint     | 318 ± 2        | 21 ± 3         |
| 6061-6061 | 199 ± 6        | 11 ± 1         |
| 6061-5083 | 202 ± 3        | 7 ± 1          |

3.7 Mechanical data

The samples tested for the initial strain rates from 3 × 10⁻⁵ to 10⁻² s⁻¹ for their variation in the nominal true stress with elongation which is shown in Figure 6. All the samples which were taken for the test failed except the sample which was tested at 3 × 10⁻⁵ s⁻¹ as the tensile pull was terminated while it was in the elongation of 50% anticipating the long test duration. [30]. Assuming uniform deformation and constant volume under the basis of the displacement of the load and the cross load the nominal true stress was calculated. [13]. Following a flow softening the flow stresses reached the peak at relatively low elongations are observed by the mechanical test results which indicate the strain hardening at very high strain rates. Before gradual flow softening the hardening values are going up to elongations of 50-100% at very low strain rates. A maximum elongation of 475% is observed at a strain rate of 10⁻⁴ s⁻¹ and at a high strain rate of 10⁻² s⁻¹ the elongation value decreased to 160%. The conditions that correspond to superplastic and non-superplastic flow the experiments were made on GBS and texture focused on strain rates of 10⁻⁴ and 10⁻² s⁻¹ are based on ductility value. The corresponding strain rate sensitivity and ductility are consistent with the observations which are made. [31].

3.8 Results and discussion:
Based on its excellent electrical conductivity than copper and 100% recyclable nature without losing its original characteristics and their very high strength to weight ratio aluminium alloys are considered best than magnesium alloys are inferred from the works.[32]. Aluminium oxide quickly resists corrosion and the resulting surface coat of aluminium oxides resists further corrosion, by air, water and Chemicals this protective coating is clear, colorless and non-staining. [33]. The strong aluminium alloys or the alloy steels are comparable with the strength-to-weight ratio of the precipitation hardened magnesium alloys. [34-36]. Low density, specific modulus, stand greater column loading per unit weight, high thermal conductivity that allows rapid heat dissipation are the properties of the magnesium alloys. When magnesium alloy compared with aluminium alloys they are very difficult to be deformed by cold working and they are also very costly but their efficiency do not match with the other materials of the range. [35-37]. Some aluminium alloys especially those in the 5xxx and 7xxx series (example 5083 and 7075) are so strong that they could be used in armour structures. Aluminium 5083 alloy cannot be heat treated and Aluminium 7075 alloy can be heat treated. [38].

Aluminium alloy majorly used in ship building vehicle bodies and pressure vessels etc. It is preferred majorly because of its lightweight and resistant to corrosion aluminium alloys maintains strength at high temperatures. Magnesium alloys also lightweight material and has high tensile yield strength. Both the materials all lightest of the commonly used alloys. [39-40]

4. Conclusion

This research paper investigates the process of collection of materials and completion of research through literature paper. The systematic studies that have been so far carried out and they are said to optimize parameters of the friction welding in order to attain better Mechanical properties in Magnesium and Aluminium dissimilar joints. With the knowledge of various research papers, we will further proceed to the welding process magnesium AZ31 is to be joined with aluminium 5083, aluminium 6061 and Aluminium 7075 after that various test will be carried out to evaluate their Mechanical properties like tensile strength, hardness and microstructure. Analyzation of the test results will take place after that all these processes

1. Keeping in mind the prime target of environmental conservation these magnesium alloys when implemented in automobile industry can be a key factor for weight reduction which will effect in the decrease of fuel consumption and CO2 emissions.

2. Taking the property of ductility the Al-condition weld by friction welding increases the strength of weld joint than the O-condition weld of parent material of all trials.

3. With the help of the spindle speed and the x-axis torque we may calculate the heat input in the Al-Mg friction weld and by placing the Al on advancing side and by offsetting the tool to Al, the heat input is increased and then decreased with the increase of traverse speed and rotation speed.
4. The reaction layer that was made with the IMCs layer and Mg solid solution layer. The thickness of IMCs layer in Al/Mg joints increased and the Mg solid solution has transformed the IMCs gradually as the friction time increased.

5. The Mg base material micro hardness was lower than the Al/Mg friction interface. As the friction time increased the thickness of the hardened layer on Mg side also increased, whereas on the Al alloy side, the micro hardness in the zone close to the friction interface was lower than that of the Al base material.

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