The Effect of Chamfer Angle Variations on the Quality of Friction Welding Results of AZ-31B Magnesium

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Abstract

Friction welding is one of the solid-state welding types. Friction welding is a joining process whose application melts the material itself by using the heat generated between the surfaces through a combination of rotational motion and the application of compressive loads. The use of magnesium alloys is widely used in various industrial fields, examples of magnesium alloy applications include coating materials from iron and steel as a means of protecting against corrosion. The use of AZ-31B series magnesium alloys has a high specific strength compared to other series such as AM. The purpose of this final project research is to determine the effect of the addition of chamfer angle on the tensile strength value and microstructure of AZ-31B magnesium friction welding results. From this research, the results obtained in tensile testing are that the addition of the chamfer angle to the surface of the weld specimen will increase the tensile strength value. The highest maximum stress value was obtained in the chamfer angle variation of 300 with an average of 228.525 MPa and the lowest maximum stress value was in the material that did not use the chamfer angle variation with an average of 105.722 MPa. Based on microstructure testing, it shows differences in α- Mg and β-Mg phase grains$_{17}$ Al$_{12}$ in each region, this is influenced by heat and also the melting generated from welding so that it changes its microstructure. This finding opens more possible application of magnesium, including for biomedical material as bone-bold implant material.

Keywords: *The friction welding, magnesium AZ-31B, visual test, tensile test, microstructure.*

I. INTRODUCTION

Magnesium (Mg) is a chemical element that has the symbol (Mg) with atomic number 12 and atomic weight 24.31 gr/mol. Magnesium is known to be lightweight, flammable and reacts easily with other metals. The use of AM and AZ series magnesium alloys (AM50A, AM60B and AZ91D) is a combination of alloys that is very well suited to the use of magnesium alloys. Both in terms of mechanical properties, corrosion resistance, and good castability. Especially the AZ series has a high specific strength [1]. The highly flammable magnesium material makes it difficult to weld using liquid welding. To overcome this, solid welding types such as friction welding or friction stir welding can be used depending on the shape of the material and the desired joint position.

Friction welding is a joining process whose application melts the material itself by using heat generated between the surfaces through a combination of rotational movement and the application of compressive loads [2]. In the scope of modern industry, welding processes are generally classified into two categories, namely: fusion welding and solid-state welding without fusion process. Friction welding is one of the *solid-state welding* process methods. In this friction welding method, heat is generated by changing mechanical energy into heat energy on the surface due to friction during rotary motion under pressure (friction). Some of the benefits of friction welding are such as not requiring filler metal and relatively fast time for joining two similar or different materials [3].

Parameters that need to be considered in friction welding include rotating speed, friction time, friction pressure, forging time, forging pressure, and chamfer type [4]. In this joining process, the plastic deformation process occurs due to *forging* pressure and the diffusion process occurs due to high heat, which leads to high joint quality between similar and different materials. It is stated in several studies that adding variations in *chamfer* angle to the material to be friction welded will increase the value of its tensile strength.

In the *friction* welding process is divided into 3 phases, including the initial *friction phase* (*friction phase*) where in this phase the torque increases after the start of the process, then the torque will decrease before reaching the second phase, namely the *braking phase*, at this stage it is hoped that the duration of time is carried out as quickly as possible so that the heat generated is not lost and the torque will decrease. Entering the third phase, namely the forging phase (*upset phase*), in this phase there is a change in frictional pressure to forging pressure which is carried out in the absence of rotational movement and in this phase the forging pressure is differentiated from the frictional pressure which is increased to strengthen the weld joint.

The principle of friction welding is simply described in figure 1.

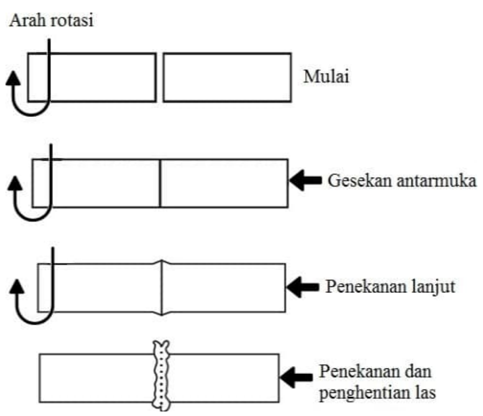


Figure 1. Working principle of friction welding

Pure magnesium and its alloys have been recognized as materials that are lightweight, flammable and react easily with other metals. The highly flammable nature of magnesium makes it difficult to weld using liquid welding. To overcome this, it can use solid welding types such as *friction welding* or *friction stir welding* depending on the shape of the material and the desired joint position [4]. Magnesium is usually mixed with other materials such as aluminum, manganese, and zinc to improve physical properties, but with several different percentages. Magnesium AZ31 is one example of magnesium alloyed with aluminum and zinc, where the percentage of each alloy is about 3% and 1%, respectively. The AM and AZ series magnesium alloys (AM50A, AM60B and AZ91D) are excellent alloy combinations in terms of mechanical properties, corrosion resistance, and good castability. Especially the AZ series has high specific strength. The friction welding process will produce *weld* structures such as: *base metal* (*BM*), *heat affected zone (HAZ)* and *weld zone* (*WZ)* or also identified as *stir zone* (*SZ)*. This study aims to examine the quality of friction welding joints on AZ-31B magnesium with the addition of *chamfer* angle variations using testing methods such as visual tests, tensile tests and microstructure tests.

II. Materials and Methods

The material used in the friction welding process in this study is AZ-31B magnesium and for the chemical composition of AZ-31B series magnesium materials to be welded is as shown in Table 1 below.

Table 1. Composition of AZ-31B Magnesium [5]

Elements	W_t (%)
Mg	Bal
Al	2,45
Zn	0,92
Mn	0,31
Cu	0,006
Ni	0,002
Si	0,07
Fe	0,023

This study uses several parameters that need to be considered such as specimen diameter of 20 mm, specimen length of 180 mm, rotational speed of 1750 rpm, friction time of 2 minutes, friction load of 3 kg, forging time of 30 seconds, forging load of 4 kg, as well as variations in *chamfer* angle used respectively 150, 300, 450 and also use specimens without angles for comparison of test results. The following is a sketch of the making of the *chamfer* angle on the specimen according to the specified parameters as described in Figure 2.

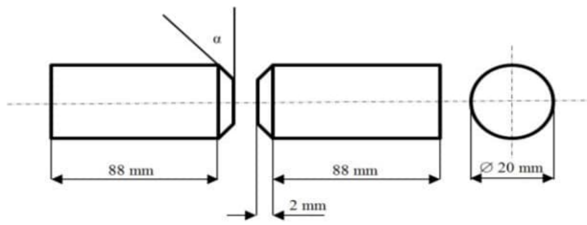


Figure 2. Specimen with *chamfer* angle

After the specimen is made, then enter the friction welding process stage, which is the first stage, preparing the friction welding tool and a set of electronics for the friction welding tool. The second stage is to check and calibrate the sensors used in the friction welding tool. The third stage is the installation of the specimen to be tested on the two recorders and ensuring that the two recorders have been locked firmly as well as installed in parallel. Then enter the welding process stage, namely the fourth stage starting with turning on and adjusting the *spindle* speed according to the required parameters, then bringing the specimen closer until it sticks.

Then wait for a while until the specimen is finished welding according to the specified time, after the welding time has been reached, then the forging process is carried out on the specimen. The fifth stage is the *finishing* process by stopping and releasing the specimen that has been welded on the friction welding tool. To determine the quality of friction welding results, it is necessary to test specimens such as visual tests, tensile tests and microstructure. In tensile testing, welding specimens need to be formed in advance according to ASTM E8 standards using a lathe and adjusting the dimensions. as described in figure 3 below.

ASTM E8 standard tensile test specimen (*Standard Test for Tension Testing of Metallic),* as presented in Figure 3 there are several descriptions of the dimensions described in Table 2.

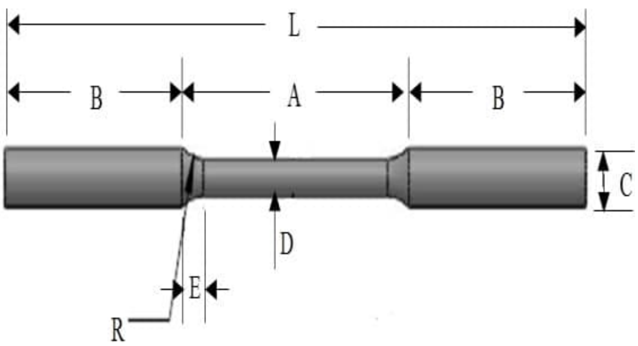


Figure 3. Dimensions of The ASTM E8 standard tensile test specimens

Table 2. Dimensions of ASTM E8 standard tensile test specimens

Description	Value
D - Centre diameter	6 ± 0.1 mm
C - *Grip* diameter	12.5 mm
A - Centre length	32 mm
B - *Grip* length	60 mm
L - Overall length	160 mm
R - Radius	6 mm
E - Radius width	5 mm

After the tensile testing process is carried out on all specimens, data is obtained in the form of maximum *tensile strength* (*ultimate tensile strength*), *yield stress* (*yield* stress) and modulus of elasticity which data is used to analyse the quality of specimens that have been friction welded. Furthermore, microstructure testing was carried out on 2 specimens that had been tensile tested, namely those with the highest and lowest tensile strength values to see changes in the structure contained in AZ-31B magnesium material.

III. Results and Discussions

After the friction welding process is carried out on the specimen with the specified parameters, then conduct a visual analysis of the welding results in accordance with applicable standards, such as testing carried out in adequate lighting conditions, position or angle of view and equipment when conducting visual tests also need to be considered in order to get good visual test results. To support the results of visual testing, equipment such as a caliper is needed to measure the dimensions of the *flash* produced on each specimen that has been welded and visual tests are carried out using the sense of sight with a maximum viewing distance of 40 cm with an angle of inclination. ^{300}. Visual images of AZ-31B magnesium welding results were obtained as specimen photos in Figure 4.

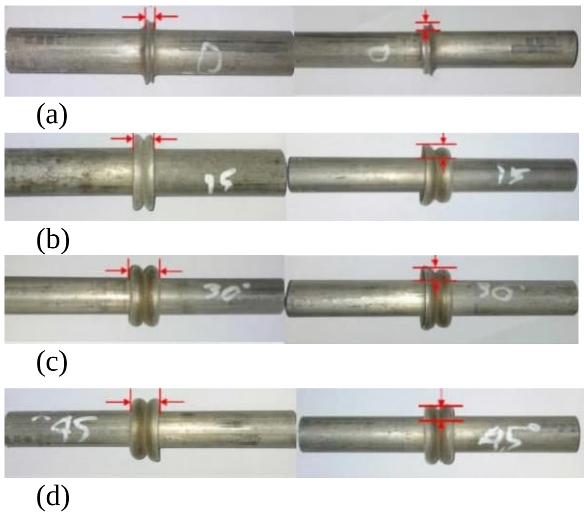


Figure 4. Friction welding results without angle (a) and with *chamfer* angle variations of 150 (b), 300 (c), and 400 (d)

Based on the visual testing that has been done, the difference in results is obtained especially in the *flash volume of* each specimen, seen in Figure 4 above in specimens without angles only produces a small *flash volume* and insignificant material shortening. Unlike the case with specimens that use *chamfer* angle variations that produce a variety of *flash volumes* and experience significant shortening of the material when compared to specimens without angles. The difference in *flash* conditions produced is due to the groove formed by the *chamfer* angle will be a place to fill the liquid metal with a more homogeneous mixing without any part of the metal being wasted out when compared to specimens without chamfer angles [5].

Furthermore, mechanical testing was carried out to determine the quality of the welded joints in the form of tensile tests and metallographic tests (microstructure). Tensile strength testing was carried out using a tensile testing machine *Universal Testing Machine* brand MTS *Landmark* with a capacity of 100 kN and before testing the specimen was formed using a lathe to adjust the dimensions according to ASTM E8 standards as shown in Figure 5 as follows.

Figure 5. Shape of the tensile test specimen Based on the results of the tensile test that has been done

The results of this study are presented in Table 3, which shows the values of *ultimate* stress, *yield stress* and modulus of elasticity as well as information on the position of the fracture in the specimen.

Table 3. Tensile Test Result Data

No.	Angles *Chamfer* (degree)	*Ultimate Stress* (MPa)	*Yield stress* (MPa)	Elastic Modulus (GPa)	Broken position
1	0^0	83,722	68,849	43,6	*Weld zone*
2		127,722	85,07	44,8	*Weld zone*
3	15^0	154,051	94,463	44,9	*Weld zone*
4		147,499	96,48	44,1	*Weld zone*
5	30^0	211,175	91,362	43,1	HAZ
6		245,875	95,484	44,9	HAZ
7	45^0	196,076	97,65	44,8	HAZ
8		197,714	95,545	45,2	HAZ

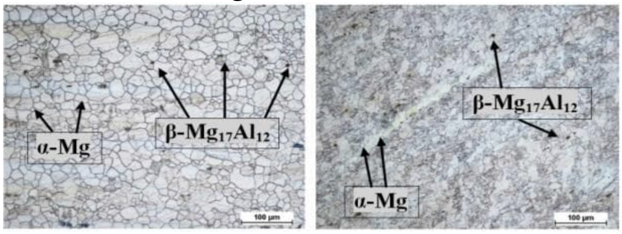
Based on the results of tensile testing that has been carried out on AZ-31B Magnesium, it is concluded that the specimens that have the highest tensile strength values are at variations in angle 30^0 compared to other specimens, this is shown in the maximum stress value obtained in specimen 6 which is 245.875 MPa. And the one with the lowest tensile strength value is specimen 1, which is not the same as the other specimens.
using a *chamfer* angle with a maximum stress value of 83.722 MPa. This shows that the addition of *chamfer* angle variations on the surface of the welded specimen will increase the value of its tensile strength.

Based on the results of tensile testing that has been done, it can be explained that by giving the *chamfer angle to the* material can affect the value of its tensile strength, where as it is known that the greater the *chamfer* angle, the smaller the cross-sectional area that rubs to produce the h e a t required (*heat input*) for the friction welding connection process on AZ-31B magnesium.

The difference in cross-sectional area is also what causes the difference in the tensile test value of the material that has been welded, because the smaller the rubbing cross-sectional area will increase the frictional pressure during the welding process and make the *heat input* conditions higher which causes a stronger bond due to higher frictional pressure plus the area of the bonded area is also wider [6]. In the research that has been done that the higher the angle of the *chamfer* contained in the material will increase the tensile strength value, but there is a difference in the material that has the highest angle, namely 450 which has a decrease in the tensile strength value when compared to the angle 300 , this happens because the angle 450 has a smaller cross-sectional area than the others, this is related to the smaller the rubbing cross-sectional area will increase friction pressure during the welding process and make the *heat input* conditions excess or higher so that it softens and makes the tensile strength value decrease.

To support the results of the research conducted, it is necessary to have a comparison or comparison on AZ31B magnesium with no treatment (*raw material*). Based on research entitled *Low Cycle Fatigue Properties of Extruded Magnesium AZ31B*, it is stated that the average value of the maximum tensile strength of magnesium AZ31B (*raw*) is 269.62 MPa and in the research that has been done, the highest maximum tensile strength value is obtained, namely the variation of the *chamfer* angle 300 of 245.875 MPa. This shows that the value of tensile strength in *raw* specimens is still higher when compared to the results of friction welding on specimens added with angle variations [7].

After conducting tensile testing, the maximum and minimum tensile strength of several specimens carried out tensile testing, after obtaining the maximum and minimum value of the tensile strength, two specimens were taken for microstructure testing, the purpose of conducting microstructure testing to see changes in the structure contained in AZ-31B Magnesium material, before further observation, specimens that will be seen need to be prepared including framing (*mounting*), sanding, *polishing* (*polishing*) and *etching* (*etching*). In microstructure testing that will be seen is in the *weld zone*, HAZ (*heat affected zone*) and *base metal*. The first to identify whether there is a structural change or not is to look at the structure of the *base metal* and HAZ area as shown in Figure 6 below.



(a) (b)

Figure 6. Microstructure of the (a) *base metal* and (b) HAZ regions of AZ-31B magnesium

Figure 6 above shows a picture of the microstructure in the *base metal area* (*base metal*) and the HAZ area of the AZ-31B magnesium sample that has been prepared, seen in the picture is dominated by the α-Mg phase and also seen some Mg_{17} Al_{12} deposits scattered in the grain boundary area, in this phase is formed directly from the parent phase with an almost homogeneous distribution [8]. Also, in Figure 6 (b) in the HAZ area shows the difference in the α-Mg phase which previously in the *base metal* area was large and not tightly packed turned into small and tight grains. Likewise, the β-Mg $phase_{17}$ Al_{12} has changed, which initially in the *base metal* looks quite clear and spreads at each grain boundary, while in the HAZ area it becomes faint and less in number. This is due to the influence of heat that occurs in the welding area, so that it changes its microstructure and mechanical characteristics due to the distribution of heat generated in the weld area so that it changes the shape of the microstructure, as also presented elsewhere [9].

To complete the analysis of the microstructure of AZ-31B magnesium, the final step is to analyze the microstructure test results in the fault area as shown in Figure 7.

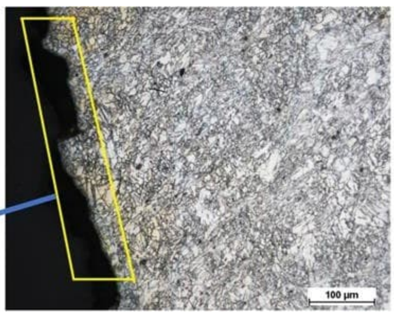


Figure 7. Microstructure of AZ-31B magnesium fault region

Figure 7 shows the α-Mg phase which tends to be irregular in the welding area, this is influenced by the heat and also the melting generated from welding so that it changes the microstructure which initially α-Mg is large to be small and also tight, and there is a change in the phase β-Mg_{17} Al_{12} which is tends to be increasingly invisible and merges with the grain boundaries in the fault section, and in the microstructure image it is still dominated by the α-Mg phase.

IV. Conclusions

Based on the data and discussion of the results of tensile testing and microstructure tests on AZ-31B magnesium which has been carried out the friction welding process with variations in *chamfer angle*, it is concluded that the difference in tensile strength values is quite significant in specimens without angles with those using *chamfer angles*, the highest tensile strength value is in specimens with a *chamfer* angle variation of 300 with a maximum stress value of 245.875 MPa. While the lowest tensile strength value is in the specimen without using the *chamfer* angle with a maximum stress of 83.722 MPa. And from the results of microstructure testing, it shows changes in phase and grain shape, especially in the fault area which is clearly different from the base metal. The phase changes that occur and also the grain size are caused by the influence of heat generated from the friction of the two materials when welding.

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