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The influence of friction stir welding tool shape on quality of AZ31 Magnesium welding product

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Abstract

Magnesium is one type of material that can be used as a base metal in welding. Magnesium has superior properties, including low density, good ductility, medium strength and excellent corrosion resistance. Because of its properties, the metal is widely used, ranging from household goods to aircraft components. These base metals are categorised as mild when viewed from the specific gravity of magnesium (1.74 g/cm^3 and 1.83 g/cm^3). Welding is the process of merging two or more base metals which are merged at the contact surface with or without additives or fillers. Welding is divided into two main categories, Liquid and Solid-State Welding. Friction Stir Welding (FSW) is an example of Solid-State Welding (Non-Fusion Welding). FSW is a friction welding process that twists the tool by utilising heat energy and pressing without additives or fillers until the base metal is in a phase change. The welding process in this study used the cone and spiral shape with a tool rotation at 2000 rpm and a welding speed of 16 mm/min. The tests carried out are tensile and hardness testing. This study found that the tool shape, tool rotation, and welding speed significantly affect the mechanical properties of the welded AZ31 magnesium. The spiral shape will make the welding area wider. Although the cone shape will have a small area, the weld will look perfect with good tensile strength, while the hardness values for the two tool shapes are almost the same, but the cone shape is better.

Keywords: Magnesium, friction stir welding, welding tool, cone shape, changing spiral form

Introduction

Magnesium is a type of material used as a base metal in FSW because magnesium has better properties, including low density, good ductility, medium strength, and excellent corrosion resistance [1,2]. This base metal is in the mild group when viewed from the specific gravity of magnesium (1.74 g/cm3). In addition, magnesium can be used as an alloying element in various forms while improving the mechanical properties of other metals such as aluminum [3]. It is used primarily as an alloying material in various forms, including cast, forged, extruded, rolled to sheet, and plate. The main problems encountered in welding magnesium alloys are porosity and the emission of large amounts of non-toxic smoke in arc welding. The FSW is environmentally friendly because there is no smoke, spark, and arc glare on the fusion. This welding process does not require much money because it does not use filler metal. It only requires low energy input and the TMAZ (thermo-mechanically affected zone) area is smaller than arc welding [4].

Based on other previous research conducted, the welding products were not optimal because the bottom of the plate was not mixed during the welding process, there was a lot of surface tearing [5,6].

Hence, the hardness value in the welding area decreased as well as the stress-strain value, and this was due to variations in the tool shape is only one. Therefore, this study aims to see the best quality of the tool shape and mechanical properties of AZ31 magnesium base metal by varying the tool shapes: cone and spiral shape, while the rotation speed of the tool shape is 2000 rpm. Then the welding products will be tested: tensile test (E8/E8M-09) and hardness test for AZ31 magnesium with FSW.

The Earth's crust is one of the places where magnesium is found, which is about 2.7%. Magnesium is not found in the metallic form but exists in nature as a carbonate, dolomite, and magnesium carbonate. The primary source of magnesium is in seawater [7,8].

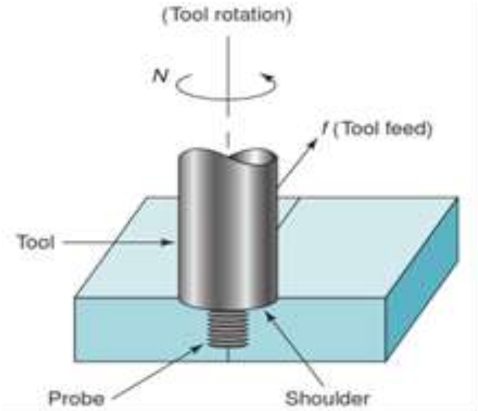
However, magnesium and its' alloys have some drawbacks, they are mainly the flashpoint of magnesium is lower than its melting point. This causes magnesium tends to flammable at high temperatures, which makes the material difficult to weld.

Those main problems may be encountered in welding magnesium alloys are porosity and the emission of large amounts of non-toxic smoke in arc welding [9-11]. This problem can be solved by FSW welding. FSW is a friction welding process that twists the tool by utilizing heat energy and pressure without additives or fillers until a phase change occurs in the base metal, requiring at least one part to be merged along the required cross-section and the base metal commonly used is in the form of a plate [12,13].

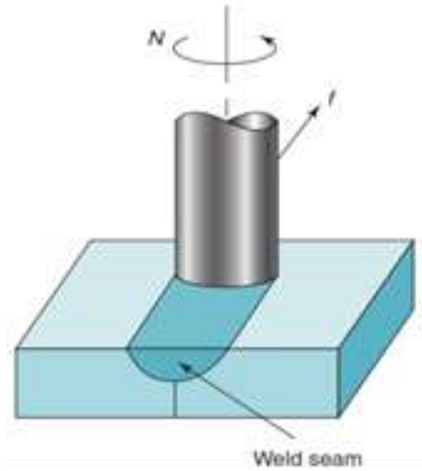
Materials and Methods

Magnesium Alloy AZ31 has been purchased and in the form of bulk casting as an industry grade. AZ31 has the main alloy of 3% Aluminum and 1% of Zinc 1%. The welding process in this study is using a universal milling machine VHF three axis.

Parameters of this study are cone and spiral tool shapes with tool rotation in 2000 rpm and welding rate in 16 mm/min. The three parameters were carried out simultaneously on three samples. Illustration of the FSW process is presented on Figure 1 [14].



(a) Rotate dan Plunge



(b) Weld, pull of dan finish

Figure 1. FSW processing steps [14].

Following Figure 1, the FSW welding process has several steps. The first step is preparing and installing the tool shape on the drill chuck and gripping shoulder.

After that, constant rotation was given gradually up to 2000 rpm. Then lower the shoulder until it is perpendicular to the gripped plate and place the indenter on the weld line at the boundary of the two plates.

The next step, provide heat input for 5 mins, starting when the tool shape has rubbed against the surface of the plate. The next step is the welding process after the characteristics have begun to transition phase on the plate surface and sufficient heat to reach a temperature of about 0.8 of the magnesium alloy's melting point. The FSW working temperature was assume around 560^{0}C.

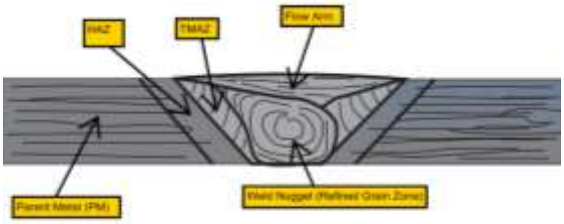


Figure 2. Microstructure profile of FSW.

The mixing or stirring of the molten metal base (stir zone) is at the highest stress and strain rate and high temperatures. This combination causes this section to be dynamically recrystallized [15]. Microstructure of this part of the welding area is very dependent on the shape of the welding tool, the rotational and translational speed, the pressure, and the characteristics of the material to be added.

Besides, this part is also a deformed part. In the thermomechanical affected zone, there is coarsening of the precipitate reinforcement but no evidence of dynamic recrystallisation. While the welding process, during the heat released on the heat-affected zone, the welding only grows grains [16,17].

Results and Discussions

The general view of samples after FSW process is presented on Table 1. It shows that the FSW process has been successfully covered all welding area.

The mechanical testing to determine the value of tensile strength and hardness. Tensile strength testing is carried out using a universal tensile testing machine and Figure 3 is the result of a tensile test.

Based on the results of the tensile test, there are differences in the ultimate tensile and yield stress values [13,16]. Rotation tool and welding speed do not show a significant differences.

Both types of welding tools, i.e., cone shape and changing spiral form that used in this study have significant affect the welding quality. The cone shape is better in the penetration process and the appearance of the welding products.

Table 1. Results of the FSW process.

No	a. Samples of cone shape tool	
1		
2		
3		
No	**b. Samples of spiral shape tool**	
1		
2		
3		

During the holding time process, the tool shape tends to be difficult to conduct heat due to the small surface area of the tool shape and the welding area is smaller, while the spiral shape has a larger area of welding than the cone shape and the initial heat application process is easier and more. The proper section area of welding using spiral shape is showing a better appearance of the welding results, presented on Table 1 and Figure 3.

(a)

(b)

Figure 3. UTS test specimens: (a) before and (b) after tensile test

The highest ultimate stress value with a cone shape is 58.55 MPa while the lowest ultimate stress value uses a spiral shape is 40.88 MPa, as well as the highest yield strength is 31.3 MPa with a cone shape while the lowest yield strength value using a spiral shape is 28 MPa.

When viewed from the fracture results there are cavities in the welding products and less penetration, in the second and third welding processes the quality of the tool shape has decreased and the shoulder has been exposed to heat due to the first welding.

While the spiral shape when viewed at the fracture location is at the bottom, so it will reduce the yield of the tensile strength. In the second and third welding samples, the decrease in tensile strength is caused by the welding not reaching the bottom and the penetration process was too fast, so that the heat distribution was uneven, but when viewed thoroughly, FSW must be carried out in accordance with the standard clearance, so that the results of the tensile test can be maximum, as highlighted by others [17,18].

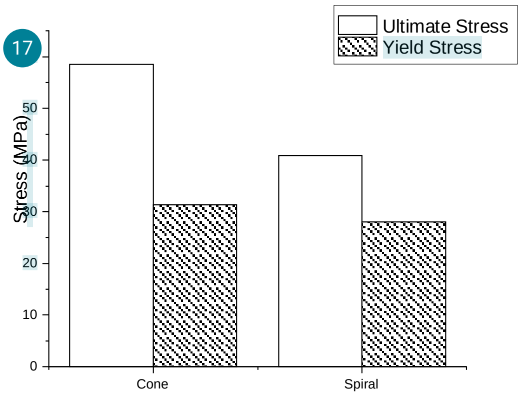


Figure 4. Tensile Test Results

Parameters that affect the reduced value of tensile strength were defects such as: surface breaks, the welding does not reach the bottom surface, porosity, grooves and weld waves.

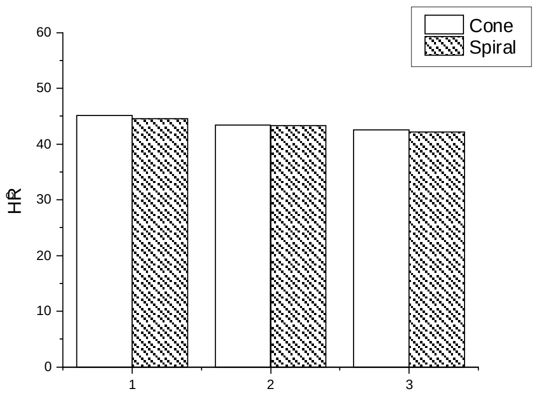


Figure 5. Hardness Test Result

The biggest influence on the hardness test results above is due to tool rotation and welding speed, especially in the tool shape and temperature. Especially the two tool shapes used have very significant differences, the cone shape is better in the penetration process and the appearance of the welding products.

During the holding time process, this tool shape tends to be difficult to conduct heat due to the small surface area of the tool shape and the welding area is smaller, while the spiral shape has a larger area of welding than the cone shape and the initial heat application process is easier and more even because of the proper section area, however, the appearance of the welding product is not good enough [18].

Then in each welding session using the same tool shape and resulting in a decrease in the quality of the tool shape in the second and third welding, this is also supported by the temperature acting on the tool shape, especially on the shoulder which continuously receives heat from the friction of the plate and also the stir welding products were uneven due to the absence of threads in the tool shape, indeed the cone shape has a better surface of the welding product [19].

The welding parameters of AZ31 magnesium with the FSW method is the cone and spiral shape have a tool rotation in 2000 rpm and a welding speed in 16 mm/min, also holding time is 5 mins, calculated when the tool shape touches the plate surface and when the plate has started to enter transition phase, the it can be welded.

The thermal cycle that occurs is also influenced by the high rotation of the tool and the welding speed at the time of welding, the higher the rotation of the tool and the welding speed, the faster the welding process, and vice versa, the welding time will be longer when the tool rotation and welding speed are low.

Based on the results above, the better shape between the cone and spiral is the cone shape, this is caused by a more perfect weld appearance and the grooves contained in the weld are more even so that the hardness of welding product surface increases, but the welding area of the cone shape is smaller compared to the spiral shape. The harness test of the FSW samples show the highest hardness value was on the cone shape is 43,68 while the lowest hardness value on spiral shape was 43,35.

Based on the results of the two tool shapes, which is better in terms of quality is the cone shape, but during the third welding process there are cold cracks in the weld area and the ductility decreases, when viewed visually the cone shape is better than the spiral shape, the surface of the product is smoother and the grooves look even, which are in a good agreement with others [16,19].

Conclusion

Based on the data and discussion of the tensile and hardness test results on the AZ31 magnesium welding products, there is a significant effect between the cone and spiral shape. The cone shape produces a better weld appearance, and the penetration process is much easier. While the spiral shape welds appearance is not good enough but the heat distribution is better. Also, the stirring area is wider than the cone shape. The hardness test results, the ultimate stress value, and the yield strength value of the cone shape are better.

Acknowledgment

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