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Study of Dissimilar Welding AA6061 Aluminium Alloy and AZ31B Magnesium Alloy with ER5356 Filler Using Friction Stir Welding

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Abstract. This paper is to study of dissimilar welding AA6061 aluminium alloy and AZ31B magnesium alloy with ER5356 filler using friction stir welding. 2 mm thick plates of aluminium and magnesium were used. Friction stir welding operations were performed at different rotation and travel speeds and used the fixed tilt angle which is 3°. The rotation speeds varied from 800 to 1100 rpm, and the travel speed varied from 80 to 100 mm/min. In the range rotation speed of 800 to 1000 rpm and welding speed of 80 to 100 mm/min there are no defect at the weld. Tensile test show the higher tensile strength is 198 MPa and the welding efficiency is about 76%.

1. Introduction

Magnesium alloys do not have enough strength to apply as a structural material although it is lightweight, combination of aluminium alloy and magnesium alloy can be a good structure. However, conventional fusion welding between aluminium alloy and magnesium alloy is unable because large coefficient of expansion of $Mg_{12}Al_{17}$ intermetallic compound formation in the fusion zone [1]. The use of conventional arc welding is unable because it will produce large HAZ because of melting of the base metal. It will produce defect due to high heat input and slow cooling rate and difficult to joint dissimilar material because of different chemical composition such as melting point. To overcome the disadvantages, Friction Stir Welding is an alternative method. Friction Stir Welding is a method process occurs below than the melting point of the alloys that is solid state joining.

Friction stir welding is one of the solid state welding. This method uses a cylindrical shouldered tool with a profiled pin. The pin is rotating while in the line of the two joining work piece that clamped at the backing plate [2].it use thermal heating by mechanical stirring by the rotational tool [3]. This welding is not achieving melting temperature of base metal. It is advances in aerospace, automotive and ship building industrial. Besides, multiple aspects of robotic friction stir welding are covered, including sensing, control and joint tracking [4]. The advantages in production by FSW are energy efficient, environment friendly and versatile. Then, FSW can be used to joining high strength aerospace aluminium alloys and other metallic alloy that are hard to weld by conventional fusion welding [3]. FSW produce the weld which joint metal without melting the base metal, improve in strength, ductility, fatigue and fracture toughness. In addition, weld by FSW achieved 80% yield strength of base metal and good appearance weld and low distortion [5]. This method uses a cylindrical shouldered tool with a profiled pin. The pin is rotating while in the line of the two joining work piece that clamped at the backing plate.it use thermal heating by mechanical stirring by the rotational tool. This welding is not achieving melting temperature of base metal [6].

Then, intermetallic compound layer in the stir zone is lower than that in the fusion zone of fusion welding [7]. Friction Stir welding can control the brittle intermetallic compound. There are some of researchers that conduct the experiment of dissimilar FSW between AZ31B and AA6061. Malarvizhi and Balasubramanian 2012 has conducted FSW between AZ31B and AA6061 joints were evaluated using tools with different shoulder diameters, the joint fabricated with a tool shoulder diameter of 21 mm (3.5 times the plate thickness) yielded maximum tensile strength of 192 MPa and the joint efficiency is 89% [8]. Other, Masoudian, Tahaei et al. 2014 has also conducted Tensile strength of the welded specimen was about 76% of that of AZ31 Mg alloy and AA6061 Al alloy, and the welded specimen failed through brittle-mode fracture [9]. Then, Morishige, Kawaguchi et al. 2008, conducted the dissimilar FSW joint between A5052-H aluminium alloy and AZ31B magnesium alloy was able to join and the joint efficiency was achieved to 61% [1].

The improvement on efficiency by enhance intermetallic compound by using filler. Then, to study what is effect of joining using filler because no study uses filler in FSW. Lack of studies observed in joining dissimilar AZ31B magnesium alloy and aluminium AA6061. It is difficult to obtain the optimum parameter such as tool rotational speed and transverse speed make the reason to run the experiment.

2. Experimental Procedure

The materials that are used are AA6061 and AZ31B with thickness 2 mm. Then, it cut into 100mm x 60mm dimension. Table 1 and table 2 show the chemical compositions of both materials.

Table 1.

Material	Mg	Si	Fe	Cr	Cu	Mn	Al
AA6061	0.89	0.53	0.20	0.20	0.30	0.02	Balance

Chemical composition (wt. %) of AA6061 aluminium alloy.

Material	Al	Zn	Mn	Si	Cu	Ca	Mg
AZ31B	3.0	1.00	0.34	0.02	0.02	0.003	Balance

Table 2. Chemical composition (wt. %) of AZ31B magnesium alloy.

In this friction stir welding process. The plates were cleaned with a sand paper to remove surface oxides. Then, the plates cleaned with acetone to cleaning the surface of the plate. Unthreaded tapered tool made from H13 hardened tool steel with a shoulder of 10 mm in diameter an, a pin of 2 mm in diameter and 1.7 mm in length, and a tilt angle of 3° was used during the welding. Aluminium rod is used in this experimental which is ER5356 aluminium filler. Aluminium rod filler was knocked into flat 2mm × 0.3mm size by using hammer to require the dimension. In this experiment, the parameters used are 800rpm-100rpm rotation speed and 80 mm/min-100 mm/min welding speed. The two plates of AA6061 and AZ31B were butt welded to each other by FSW. AA6061 is placed at the advancing side and AZ31B is placed at the retreating side. The specimens for tensile test are prepared using ASTM E8. Figure 1 show ASTM E8 design. Then use electrical discharge machine (EDM). The tensile test carried out using Instron test machine using strain rate of 1 mm/min.

Figure 1. ASTM E8 design.

In the microstructural observation, etching is used to reveal the microstructure feature and remove dust or any small metal at the surface during polishing. The etching process was conducted by applying the etchants to the specimen and let it dry for few seconds. The process was conducted in fume hood to limit exposure of chemical liquid to air and dust. Microhardness of the specimen measured by using Vickers hardness using 300 kgf load and dwell time of 10s.

3. Results and Discussion

3.1. Weld Appearance

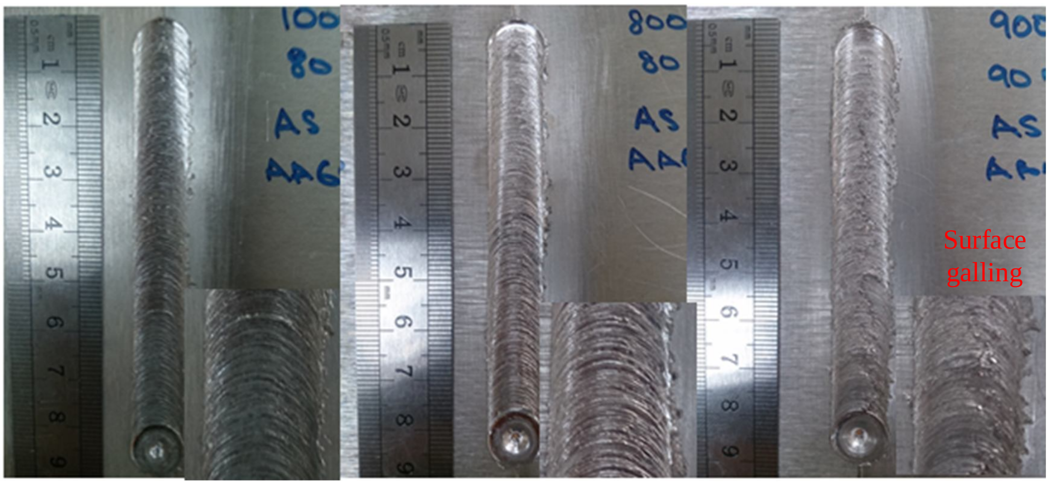


Figure 2. Weld appearance of FSW between AA6061 and AZ31B (a) Sample 2 (b) Sample 1 (c) Sample 9.

Figure 2 (a) is the sample 2 of FSW plate by using parameter 1000 rpm, 80 mm/min while Figure 2 (b) is the sample 1 of FSW plate by using 800 rpm and 80 mm/min. Both of these plates are free from defects. Sample 2 has a higher joint strength compared to sample 1 and sample 9 because it has enough heat during FSW process. Figure 2 (c) is the sample 9 of FSW plate by using 900 rpm and 90 mm/min. This plate is using the different heat input compare to sample 2 and sample 1 because of the different rotational speed and welding speed. Table 3 show the heat input of the plate of specimen 2, specimen 1 and specimen 9 during FSW process. The highest heat input is from the specimen 2 which is 0.4575KJ/mm. This show that specimen 2 receive enough heat input compare to specimen 9 which is affect the highest tensile strength. However, sample 9 shows the surface galling surface defect. It because it has less heat input from the sample 2 and inaccurate FSW parameter and affect from sticking metal from previous welding tool pin. Surface galling occur due to sticking of metal to the tool during welding causes the material on weld surface tearing up [10].

Table 3. Equation value for the power consumed and heat inputs for FSW [11].

Specimen	RPM	T	P	f_1	V
Specimen 1	800 rpm	1220 Nm	32533 W	0.9	80 mm/min
Specimen 2	1000 rpm	1220 Nm	40666 W	0.9	80 mm/min
Specimen 9	900 rpm	1220 Nm	36600 W	0.9	90 mm/min

3.2. Tensile Test

Table 4 show the tensile properties of the base materials and the weld specimen. The tensile result of the welded specimen is 76% of AZ31B. Figure 3 show the welded specimen failed at the centre joining weld and the friction stir welded specimen failed through brittle-mode fracture. Table 4 show the comparison of FSW with filler and without filler. FSW with filler is the highest tensile strength and joining efficiency which is 198 MPa and 76 % and FSW without filler is 175 MPa and 67 %. This result shows the joining efficiency increase from 67 % to 76 %. It is increase about 9 % of joining efficiency.

Table 4. Tensile test result of AA6061, AZ31B and FSW of AA6061 and AZ31B with no filler.

Material	Tensile strength (MPa)
Base metal AA6061	310
Base metal AZ31B	260
WELD	198
FSW of AA6061 and AZ31B with no filler	175

Table 5. Comparison of joining efficiency between types of FSW materials.

Type of FSW material	Joining efficiency
With filler	76 %
Without filler	67%

Figure 3 illustrates the tensile test data. The graph shows the Specimen 2 with the parameter of 1000 rpm, 80 mm/min and 3° of tilt angle has the highest tensile strength which is 198.216 MPa. Specimen 1 with the parameter of 800 rpm, 80 mm/min and 3° of tilt angle has the tensile strength of 165.616 MPa. The third highest tensile strength is 155.941 MPa was obtained by Specimen 4 with the parameter of 1000 rpm, 100 mm/min and 3° of tilt angle. Figure 4 show the tensile test comparisons between FSW welding with filler that is 198 MPa and without filler that is 175 MPa. It shows FSW with filler has higher tensile value.

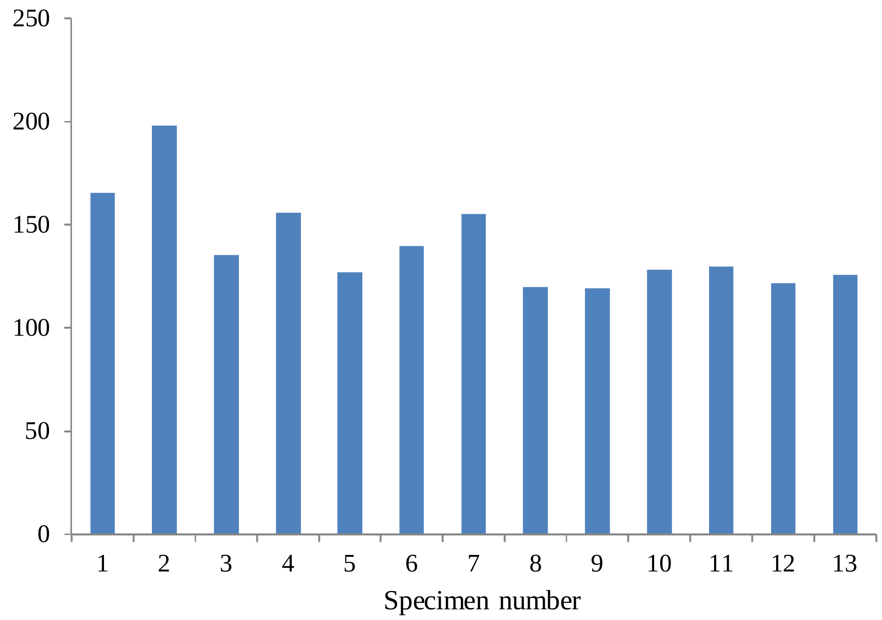
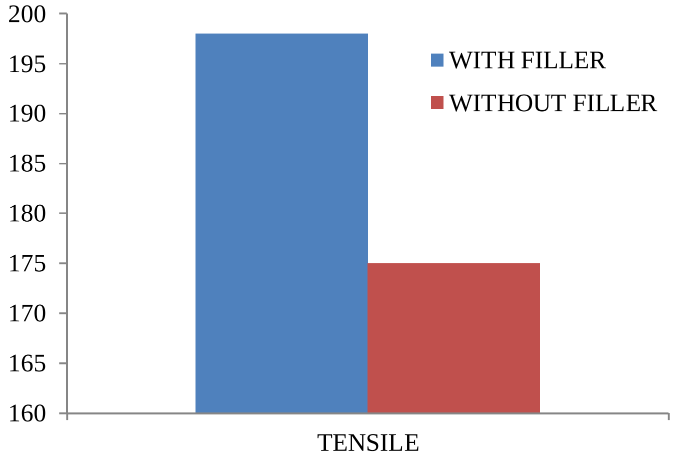


Figure 3. The tensile data.

Figure 5 shows the tensile fractured location. All joints fail at the stir zone of the weld. This is because stir zone at the center is the location which has the highest hardness value will cause the fractured brittle mode. Every dissimilar welding will occur fracture brittle mode [12]. During tensile testing, fracture occurred along the brittle and weak intermetallic layers. The resultant fracture surface shows the cleavage-type brittle fracture, as is shown in the SEM image in Figure 6 (b) [13]. This fracture is distinctly different from the microvoid type ductile fracture in the similar metal weld of 6061 Al in Figure 6 (a). It can be observed that the fractured surface was characterized with distribution of dissimilar size dimples [14]. These fine dimples indicate ductile behaviour of the aluminium alloy before the failure occurred.



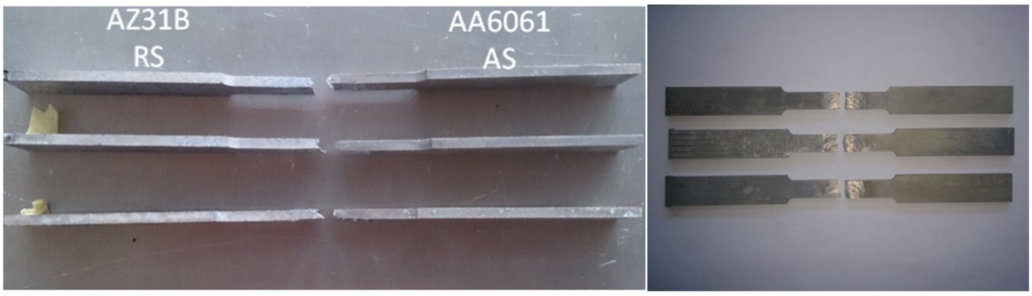


Figure 4. Tensile test comparisons between FSW welding with filler and without filler.

Figure 5. The tensile fractured location.

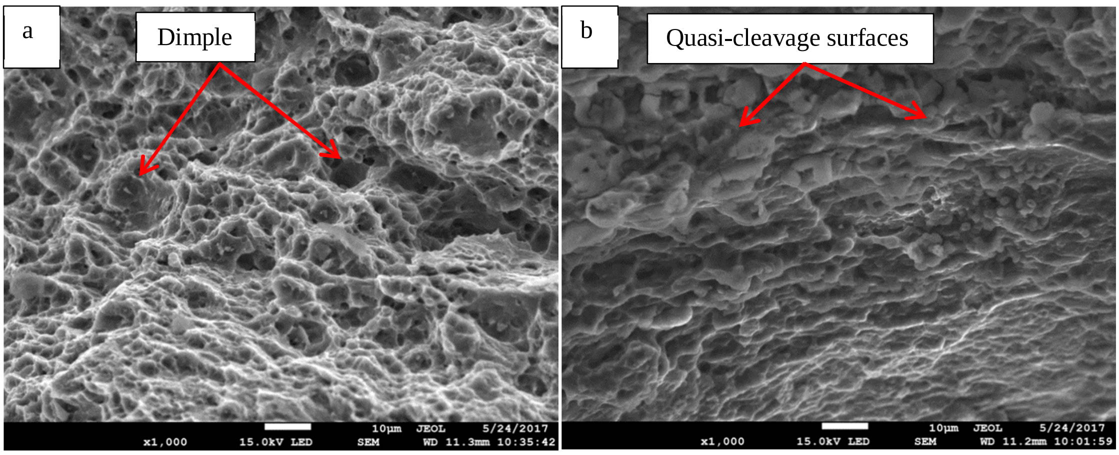


Figure 6. (a) SEM images of fracture surface on AA6061 (b) SEM images of fracture surface on AZ31B.

For the IMC layer observation in figure 7 (a) and figure 7 (b), it shows the FSW welding with filler have lower thickness of IMC layer than the FSW without filler IMC layer. The IMC layer for FSW without filler is 5.62 µm compare to IMC layer for FSW with filler that is 1.41 µm. The lower thickness of IMC layer will be resulting lower brittle of center of the welding. It also has lower hardness result for welding.

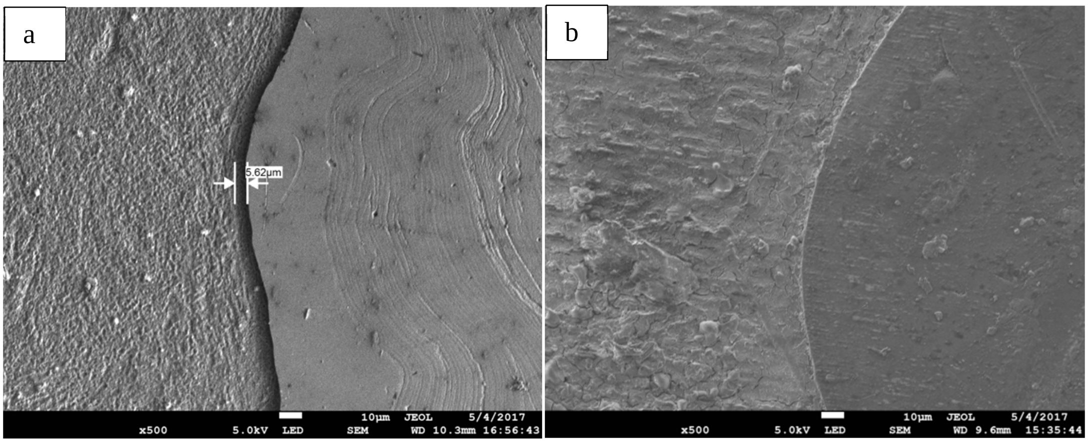


Figure 7. (a) SEM of IMC layer of FSW without filler (b) SEM of IMC layer of FSW with filler.

3.3. Microhardness

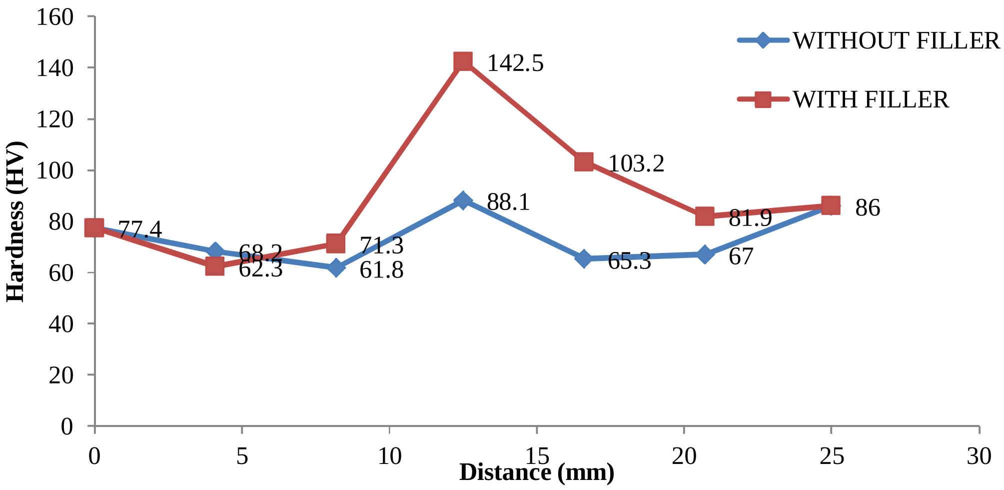


Figure 8. Vickers hardness comparisons between FSW with filler and without filler.

From Figure 8, it can be observed that the base metal (BM), heat affected zone (HAZ), thermo-mechanically affected zone (TMAZ) and stir zone (SZ) region can be differentiated by analysing the hardness value. It can be observed that AA6061 have a higher hardness value compared to AZ31B which is 86 HV compare to 77.4 HV. For both AA6061 and AZ31, it can also be identified that the hardness value at HAZ region will decrease from the hardness value of BM region. The lowest hardness value in this specimen can be identified at the HAZ region of AZ31B where the hardness value is 62.3 HV. The microhardness value at TMAZ was slightly higher than the HAZ region for both AA6061 and AA7075. The maximum hardness value of 142.5 HV has been achieved at the center of the weld. The maximum hardness value of 142.5 HV has been achieved at the center of the weld. Figure 4.23 below show the comparison of Vickers hardness between FSW using filler and without filler. With using filler, the result shown it have higher hardness value that is 142.5 HV compare to FSW without filler that is just 88.1 HV at the stir zone. From the lower result of hardness of welding without filler, it is because it has worm hole defect at the stir zone and higher grain size cause lower hardness. Figure 9 show the grain size of FSW without filler is higher than FSW with filler. It shows the entire zone at FSW without filler have higher grain size compare to FSW with filler. Then, higher grain size will affect lower hardness value. At the all zone using filler have higher hardness value except at the heat affected zone (HAZ) of AZ31B. The higher hardness value of FSW using filler resulting the higher tensile strength compare the FSW without filler.

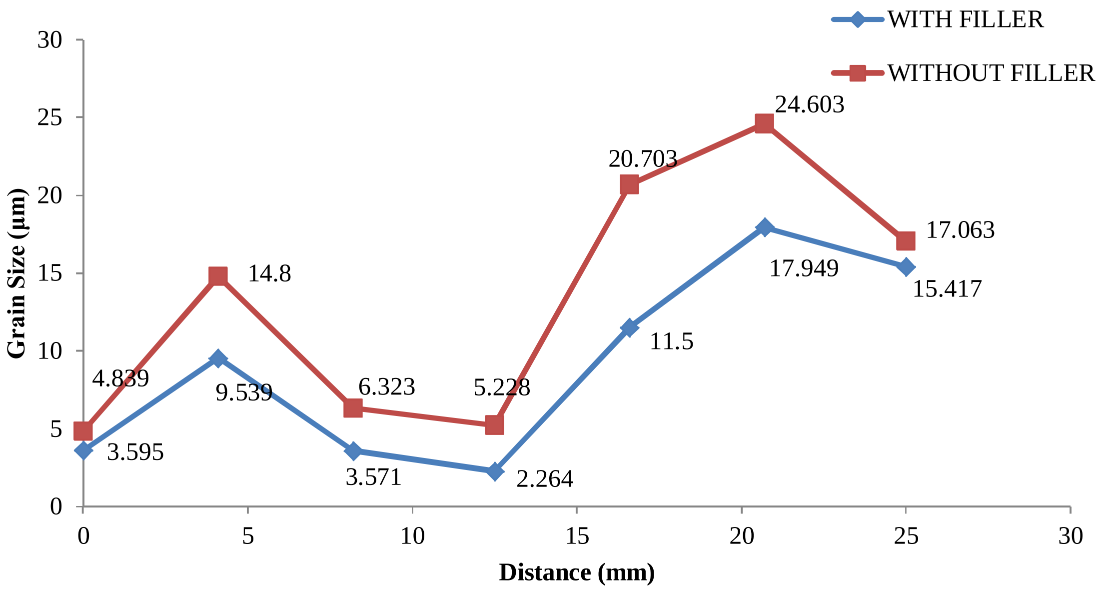


Figure 9. Grain size comparisons between FSW with filler and without filler.

4. Conclusion

- AZ31B magnesium alloy and AA6061 aluminium alloy with ER5356 filler can be join successfully by FSW.
- The optimum parameter for FSW between AA6061 and AZ31B using ER5356 which use response surface method (RSM) is when the rotational speed (RS) is 1000 rpm, welding speed (WS) is 80 mm/min and tilt angle is 3°. The tensile strength of the FSW by using the optimum parameter is 198 MPa and the highest hardness is 142.5 HV.
- The FSW microstructure change of welds using filler better than FSW without using filler because the grain is smaller and the IMC layer thickness is thinner which is 1.41 µm compare to IMC layer for FSW with filler that is 5.62 µm.
- The hardness profile shows that the center of the weld has the highest hardness value because brittle mode fractured.
- The joining efficiency of AZ31B magnesium alloy and AA6061 aluminium alloy use filler ER5356 is about 76% from lower base metal tensile strength. Then, the joining efficiency of AZ31B magnesium alloy and AA6061 aluminium alloy without using filler ER5356 is about 67%. This show FSW with filler is better about 9% increases of joining efficiency.

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