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# Microstructural and mechanical properties of welded SSM356-T6 and SSM7075-T6 aluminum semi-solid sheets by friction stir welding

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**Abstract**

Friction stir welding (FSW) is a welding process applied in this research to join different grades of alloy sheets consisting of semi-solid metal (SSM) 356-T6 and 7075-T6. The test pieces had dimensions of 50 mm × 100 mm × 4 mm. The effect of the tool rotational speed on metallurgy, and mechanical properties of the weld was investigated. Dissimilar butt joints were produced using a cylindrical pin with different tool rotation (710, 1,000 and 1,400 rpm) and welding speeds (80, 112 and 160 mm/min). The weld microstructures showed three different areas including a base metal, stir zone and thermo mechanical affected zone, which were directly affected by the rotation speed of the tool. A butt joint rotation speed of 1,000 rpm provided an average maximum tensile strength of 246.33 MPa. This rotational speed allowed material to flow from the front to the rear of the tool. The heat generated from friction lead to microstructural changes and promoted good mixing and adhesion of both materials.

**Keywords:** Friction stir welding, Dissimilar joined, Aluminum alloy, Semi-solid

## 1. Introduction

The aluminum alloy produced by the semi-solid metal casting process has one of the major problems in welding semi-solid metal by using fusion method, that is the constraint to maintain mechanical properties of joints as close to the base metal as possible. Because the welding by using fusion method not only generate pits, but also cause metallurgical changes. These affect the welded region, including the area of Heat Affected Zone (HAZ) changed and ultimately may lead to other parts damage or work inefficiently.

Friction Stir Welding is a solid state welding, which was founded by The Welding Institute (TWI) of England. This method was applied to weld materials that difficult for fusion welding processes such as aluminum alloys [1-3]. The Friction Stir Welding lead to the fine grain of the welded structure, increasing in strength which cannot be obtained from the molten welding method [4]. The solid state process is suitable for no fusion welding. Also there is no solidification. Therefore, it is suitable in welding semisolid cast al alloy.

Recently, Some welding experiments were produced welding butt joint dissimilar materials between rolled aluminum and cast aluminum. This welding method is widely used for joint materials in many applications, such as aircraft parts, aircraft structures (Airframe) and missile parts. An example of stir welding aluminums alloys are as follow. A356 and AA6061 [5] have shown that the mechanical properties of the welded region largely depend on the material at retreating (RS) side because the structure of the welded region is mostly composed of material at the retreating side. A356-T6 and AA 6061-T651 [6] found that the tensile strength of the welded region was low as a result of new structure emergence at stir zone, and there was the silicon particle distribution along the length of welded region. As a result, intergranular fracture was the beginning of the draw. It was also indicated that rotation speed and welding speed affected the microstructure of the welded region of A356 and AA6061-T6 [7] have suggested that changing rotation speed and welding speed directly affected the microstructure of the welded region significantly. SSM 356-T6 and AA6061-T651 [8] were found that modification of the rotation speed and welding speed directly affected to the microstructure and the mechanical properties of the welded region significantly. However, friction stir welding for different types of aluminum alloy derived from semi-solid casting process between SSM 356-T6 and SSM 7075-T6, Lack of research and investigation in welding between SSM alloys.

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**Table 1** Chemical c compositions of experimental materials (%wt)

| Elements | Si | Fe | Cu | Mn | Mg | Zn | Ti | Cr | Ni | Al |
|---|---|---|---|---|---|---|---|---|---|---|
| SSM 356-T6 | 7.50 | 0.2 | 0.2 | 0.1 | 0.45 | 0.1 | 0.2 | 0.02 | 0.01 | Balance |
| SSM 7075-T6 | 0.4 | 0.5 | 2.00 | 0.3 | 2.90 | 6.10 | 0.2 | 0.28 | - | Balance |

The research aimed to study factors affected to the welds, including rotation speed and welding speed factors. These factors affected the metallurgical properties (micro and macro structure) and mechanical properties of weld metal as well as thermo mechanical affected zone (TMAZ). The goals of the research were to find out the proper micro and macrostructure including mechanical properties and to use the study results for selecting and improving the proper welding process in both research and industrial sector.

## 2. Materials and methods

### *2.1 Materials and friction stir welding process*

The materials used in the experiment were aluminum alloy produced from semi-solid casting process SSM 356-T6 and SSM 7075-T6. Their chemical compositions were shown in Table 1. This the size of both materials thick ness of 4 mm, length of 100 mm and 50 mm in width.

Both material sheets were fastened and assembled to butt joints, and the material sheets were fixed on the fixture that was installed on the platform of vertical milling machine. The workpiece moved along the length of the weld.

Material orientation SSM 356-T6 posed onto retreating side (RS), and SSM 7075-T6 posed onto advancing side (AS) as shown in Figure 1.

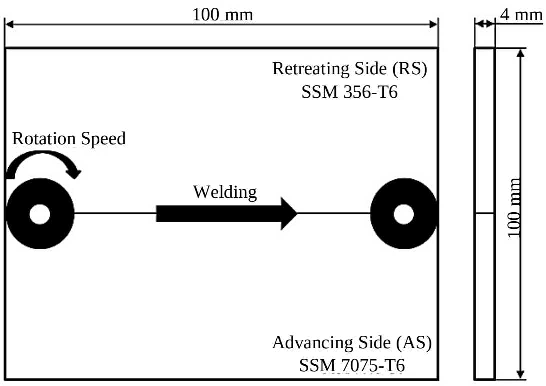


**Figure 1** The positioning of welding

In the experiments, experimental levels shown in Table 2 and variable used in these experiments shown the details in Table 3. Welding experiment was conducted by using a vertical milling machine. In this process, a pin was inserted into the middle of the welds away from the edge of work piece 10 mm until the depth and shoulders of the stir contacting with the surface. The pin stir has rotated at the origin continuously for 45 seconds to distribute the heat through the specimen, and then the welding process was started onto the test piece as defined parameters automatically. When the weld arrived at the rear of welding region, the weld pin stir was rotated for 10 seconds before lifted off from the weld. The levels of factors were adopted from the experiments of Kim. Et al. [9], and also they conform to the machinery capabilities.

**Table 2** Experimental levels in this experiments

| Process parameters | Values | repeats |
|---|---|---|
| Tool rotation speed (rpm) | 710, 1000 and 1400 | 3 |
| Welding speed (mm/min) | 80, 112 and 160 | 3 |

**Table 3** Variable used in this experiments

| Process parameters | Values |
|---|---|
| Axial force (N) | 450 |
| Tool tilt angle (°) | 3 |
| Tool shoulder diameter (mm) | 20 |
| Pin diameter (mm) | 5 |
| Pin length (mm) | 3.2 |
| Pin profile | Cylindrical |
| Tool material | SKD 11 |

**Table 4** Tensile strength of the materials used in this experiment

| Materials | Tensile Strength (MPa) | Yield Strength (MPa) | (% Elongation) |
|---|---|---|---|
| SSM 356-T6 | 295 | 236 | 9 |
| SSM 7075-T6 | 420 | 336 | 13 |

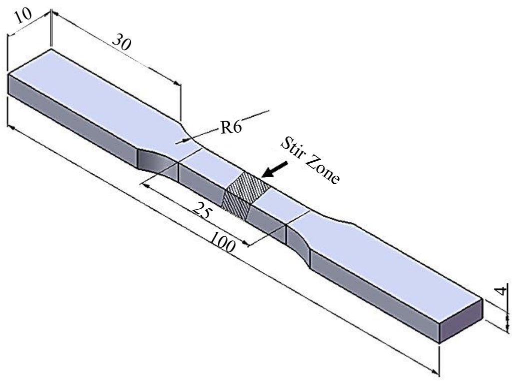


**Figure 2** Specimens for tensile test according to ASTM-E8M

### *2.2 Metallurgical structure investigation*

After the specimen was completely welded, the test piece was cut perpendicular against the region, and it was and polished. After that the test piece was etched by Keller's Reagent. The test piece was subjected to the optical microscope to view the micro and macro structure including

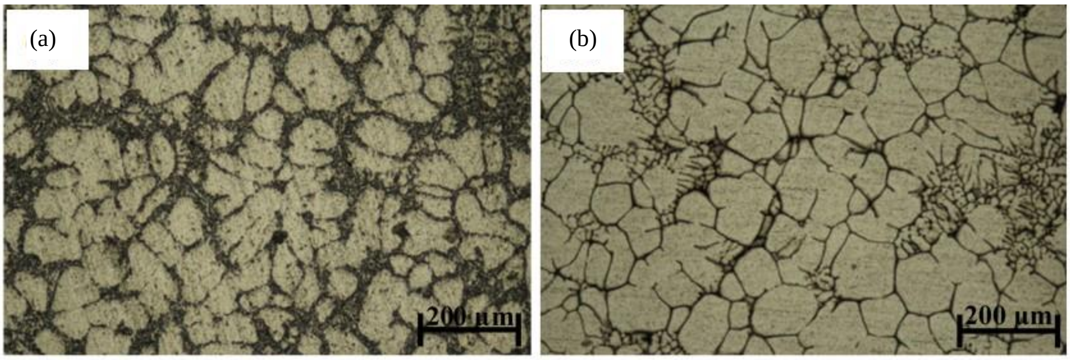


**Figure 3** Metallurgic structure of the base metal (a) SSM 356-T6 and (b) SSM 7075-T6

shape and size of grains weld at the jointed region after stirred friction welding process.

*2.3 Tensile strength test*

The test piece was tested its strength to determine the mechanical properties of the weld. The test piece was cut perpendicular to the welding direction, and the welded region located at the center of the specimens. Pulling speed rate was 1 mm/min, and the size and shape of the specimens were shown as Figure 2, which was according to the ASTM-E8M standard. Mechanical properties the strengths of the metal were shown in Table 4.

*2.4 Hardness test*

Welded region hardness test, Micro Vickers hardness tester was used to perform onto the cross-sectional area of the weld, which was divided into three rows: upper, middle and lower rows, respectively. Then, the hardness test data was collected and computed to find mean values for welded region hardness. The compression started from center to the end of welded region. The distance between indentation/compression points was 1.0 mm, and the measuring points were away from the center of welded region 14 mm on each side. Testing load and time were 100 gram and 10 seconds, respectively.

**3. Results and discussion**

This research aimed to study metallurgical and mechanical properties of friction stir welding of semi-solid aluminum alloys between SSM 356-T6 and SSM 7075-T6. In this research, rotational speed of the pin was set at 710, 1000 and 1400 rpm, and welding speed was 80, 112 and 160 mm per minute. The results of this experiment were as followed:

*3.1 Structural metallurgy characteristics of the base metal*

The microstructure of metallurgy on original phase was shown in Figure 3. Figure 3(a) showed that the Si and Mg phase aggregated on α – Al phase as a granular [8] on SSM 7075-T6. Figure 3(b) α – Al phase revealed granular with Zn, Mg, and Cu [10].

*3.2 Structural metallurgy characteristics of the weld*

Metallurgical structures were analyzed in three different characteristics including the surface above the welded region, macrostructure and microstructure as shown in Figure 4-6, which all three characteristics. The results of the experiment showed in an individual rotational speed. In the speed corridor welding it exhibited the same in all three levels. At the top view surface of the weld was a not smooth bump. It exhibited fish scales-liked arising from the fall of the surface attached to the shoulder of the tool. In comparison of three rotation speeds, it was found that the lowest rotation speed (710 rpm) lead to very smooth surface due to the proper frictional heat accumulating in aluminum matter easily circulated in plastic condition. However, when rotation speed increased from 1000 to 1400 rpm, several bumps appeared in the welded region. Therefore, the welded region looked not beautiful because the accumulated heat in the welded region was not adequate to allow plastic flow of aluminum plastic condition at welding start. This effect hindered the aluminum flow on the welded region [11] and also caused a fin slightly on the retreating side along the welded region of all three experimental conditions.

Macrostructure of friction stir welding was shown as in Figure 4(a), 5(a) and 6(a) aluminum weld derived from the combination of sides aluminum. The stirred welding area has no defect, and the welds were well coordinated both pieces. The frictional heat accumulated in the welds generated the plastic condition, then circulation appeared around the head pin [11]. When the aluminum was solidization, it appeared sketch layers in the gap between aluminum SSM 7075-T6 and SSM 356-T6. In this case, it could be seen aluminum SSM 356-T6 obviously penetrated into metal texture of SSM 7075-T6. According to the agitation of the head pin [11-13] due to the positioning welding material in the SSM 356-T6 retreating side stir swirl texture aluminum heads that were in plastic pine centrifugal rotary speed connection to shore. Advancing side by side, the positioning of the material support SSM 7075-T6 served to shock and push the material side of the SSM 7075-T6 to side of SSM 356-T6 more [11-15].

Microstructure characteristics shown as in Figure 4 (b-e), 5 (b-e) and 6 (b-e) the microstructure characteristics of the weld was obvious a combination of the two types of materials. There would be a sequence of alternating both materials at the weld center stir zone (SZ). In this case, the material texture was fine because the material was crushed and stirred, while stirring with the impact of the SSM 356-T6 grains appear as elongated grains. In the middle of the weld between the two kinds of the materials and grain was smaller than the original metal. Grains were very fine, especially SSM 7075-T6, which was on the top of the rotation line that there would be the metal texture mixed a lot because of blowing of the stirring while stirring [14]. The contact between the above surface and the shoulder of the tool, which was closer than the bottom let to the grains were

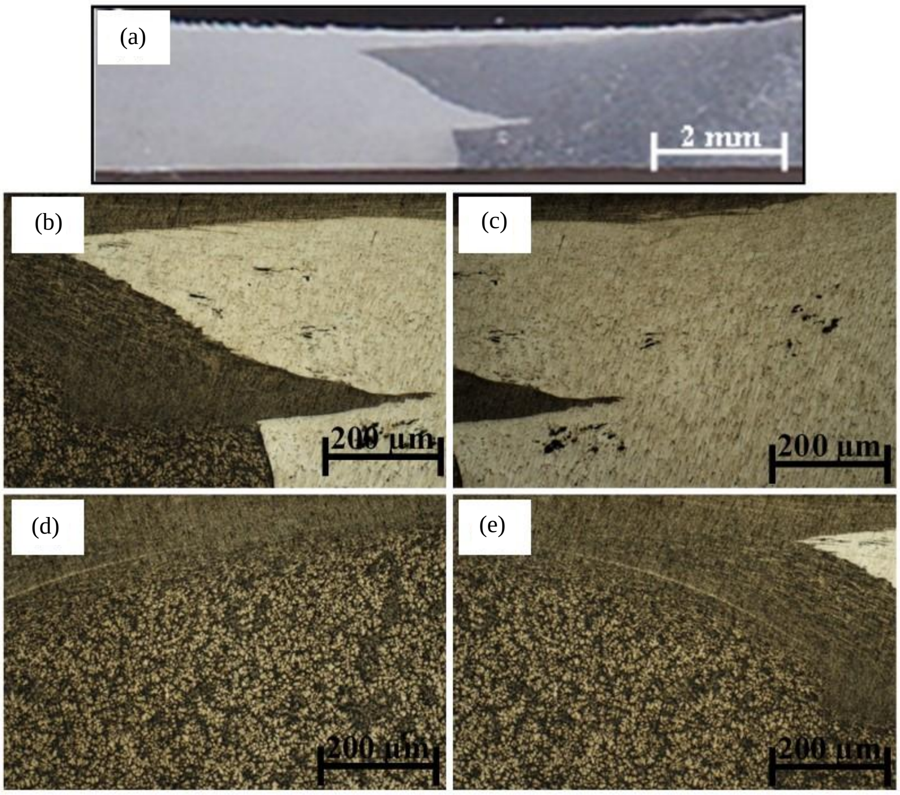


**Figure 4** Metallurgic structure of the weld at rotation speed 710 rpm (a) macrostructure, (b) SZ (AS), (c) SZ (RS), (d) TMAZ (AS) and (e) TMAZ (RS)

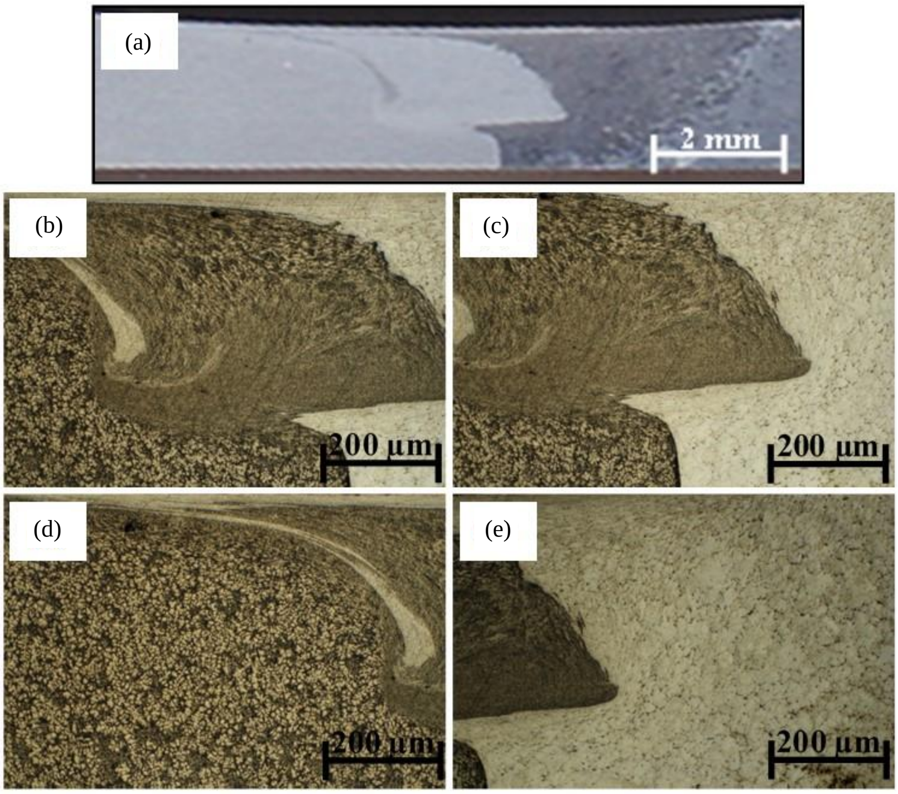


**Figure 5** Metallurgic structure of the weld at rotation speed 1000 rpm (a) macrostructure, (b) SZ (AS), (c) SZ (RS), (d) TMAZ (AS) and (e) TMAZ (RS)

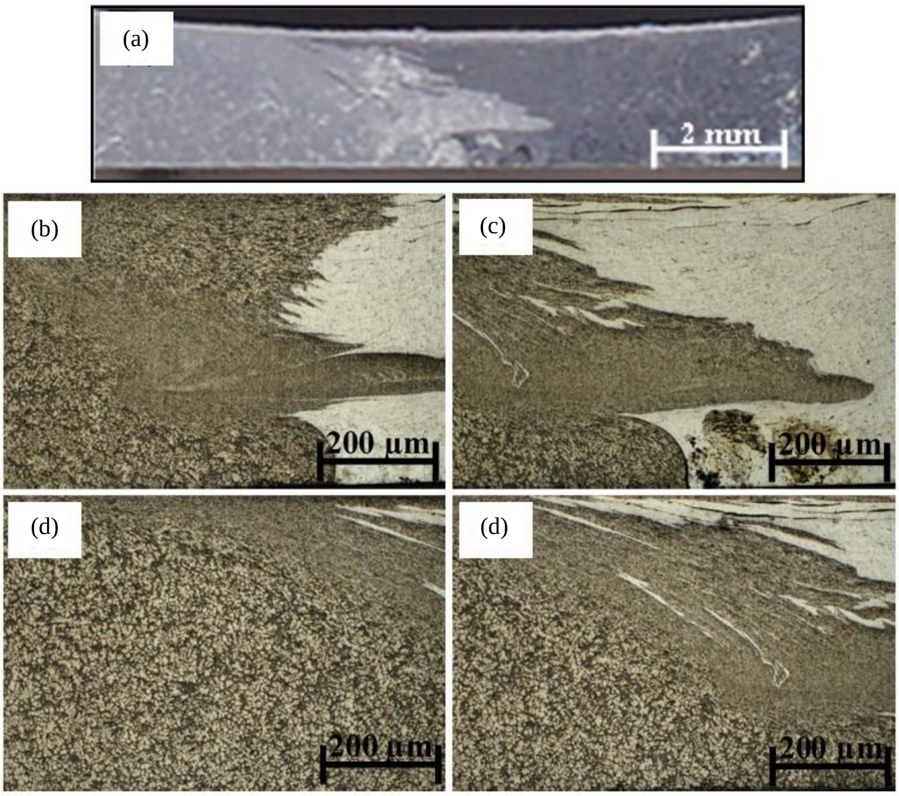


**Figure 6** Metallurgic Structure of the weld at rotation speed 1400 rpm (a) macrostructure, (b) SZ (AS), (c) SZ (RS), (d) TMAZ (AS) and (e) TMAZ (RS)

fine. Some of the material texture was arranged in alternating layers [15]. The rotations of agitation caused plastic deformation due to compression and pushed both materials to merge together. Especially in welding (SZ) both materials were plastic, compression and pressure conditions both materials continuously. Generally, Friction stir welding by a welding speed of rotation of the tool was an important factor that generated frictional heat. If the heat were not enough, the circulation of plastic condition would incomplete. As a result, weld defects would appear, then the low spread of the metal texture would affect to the material texture integration [15].

The SEM microstuctures of the welded region at head pin speed 1400 rpm was shown in Figure 7. The decisive phase of Zn, Cu, Mg and Si scattered throughout the area. In SZ welded area, the grain has more resolution than the area affected due to the TMAZ heat. Because the welded area was directly swirled by the welding head, the grain was fine and more resolution than the grain of the original metal texture. The effect was a direct result of rotation speed and welding speed [16-17].

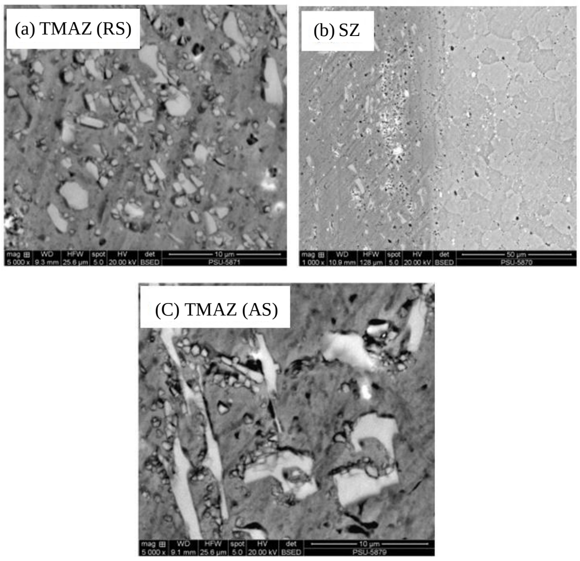


**Figure 7** SEM structure in the welded area (a) TMAZ (RS), (b) SZ and (c) TMAZ (AS)

*3.3 Tensile test of the weld*

The results of tensile tests was shown in Figure 7. The study found that rotation speed of the tool would push and shove the material to flow from the front to the back of the tool (engine) for heat generation from friction. The rotation speed affected the grain change and material texture combination. The proper friction heat lead to complete material texture mixture such as at rotation speed 1000 rpm. As a result, the strength was the highest value at 198.67 MPa. It was observed that the higher rotation speed of welding generated high frictional heat, but heat ventilation rate was low. This effect lead to grain decomposition [18-19], so the strength value was low. On the other hand, when the rotation speed was low, it generated improper material texture mixture, then the strength was low because of the low frictional heat [15].

When the strength was compared between original metal and existing metal SSM 7075-T6, it was found that the strength was lower about 12 percent, but in case of SSM 356-T6 it was higher about 9 percent at rotation speed 710 rpm. The highest average strength was 246.33 MPa at rotation

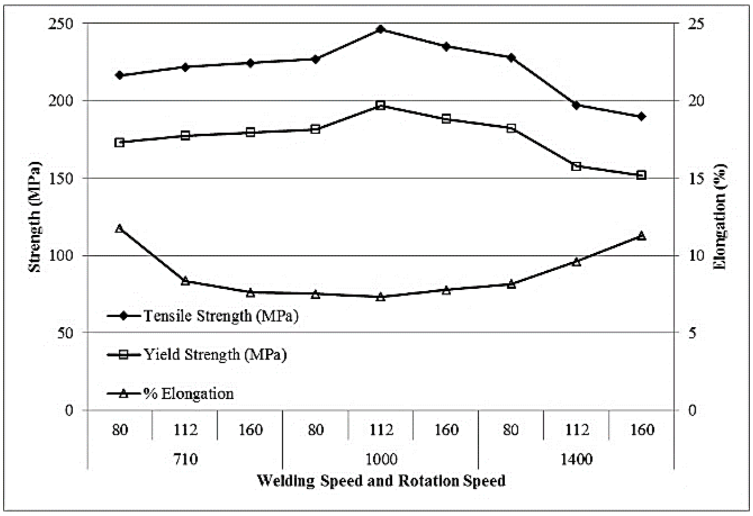


**Figure 7** Tensile strength, Yield strength and Elongation of the weld obtained at different welding speeds and rotation speeds

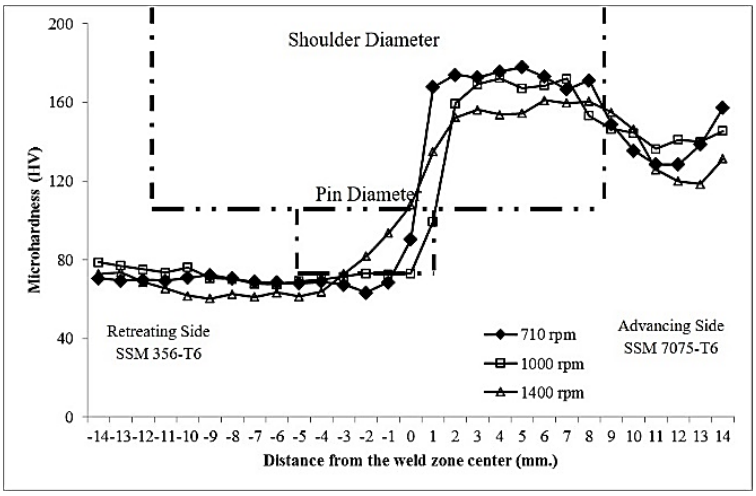


**Figure 8** hardness of the weld in welding speed 80 mm/min

speed 1000 rpm. On the other hand, the lowest average strength was 189.73 MPa at rotation speed 1400 rpm. However, the percentages of elongation were close proximity In other words, the all percentages of elongation were in the range of 5 – 10%.

*3.4 Hardness test of the weld*

The hardness of the weld base materials SSM 356-T6 had lower hardness than SSM 7075-T6 as showed in Figure 8. The lower hardness appeared in the area affected due to TMAZ on both sides of the weld. Softening of stiffness in this area due to precipitation of grain lost in the mixing area welding SZ that swept away by the pin causes welding was a solid increase. The hardness of the SSM 356-T6 began to move more than the original metal. This caused a swirl of metal mixed together in the SSM 7075-T6 return. The return was lower down, when it was compared to the original metal texture because it was made from soft material combinations in itself. It should be noted that the hardness of a rotation speed of 1000 rpm in SZ and TMAZ is higher the others speed. The increase in grain sediments in the welding is over along with the erection during the state of plastic, which is faster and better than making the hardness [17, 20]. The greatest value of 178.00 HV Obtained from the rotational speed 710 rpm, while the lowest value of 60 HV obtained from the rotational speed of 1400 rpm.

## 4. Conclusions

The research aimed to study the influence of parameters affected to the structures and mechanical properties of friction stir welding among different materials between SSM 7075-T6 and SSM 356-T6. The specimens were analyzed a microscope, strength test and hardness test. The results of this research were concluded as follows:

The rotation speed was important factor that affected and lead to combine of both types of material textures. The Cumulative heat together with axial force was generated from the friction between tool and materials into the welds lead to plastic deformation. As a results, the material texture flew around the head pin, which was sketch layers alternating shown in Figure 4 (b-e), 5 (b-e) and 6 (b-e) between aluminum texture of SSM 356-T6 and SSM 7075-T6.

The welded region was blended from two materials. The rotation and agitation caused the plastic deformation by compression and pushing of two material textures lead to mixing. Especially in welding SZ, both materials were transformed to plastic condition including continuous compression and pressure for both material textures. The rotation speed of the tool has pushed and pressed the material texture, and then the material textures flew from front to rear of the tool, then friction heat would be generated.

The optimal friction heat leading to well mixture was rotation speed of 1000 rpm. The strength value was highest 246.33 MPa. In the other hand, the lowest tensile strength value was 189.73 MPa at rotation speed 1400 rpm, and the percentage of elongation was in the range from 5% to 10%.

According to all welding, the low hardness has appeared in the area (region) affected from mechanical heat TMAZ, which was on both sides of the weld. Hardness softening in this area due to the softening mechanism by dissolution of precipitate phases and decreasing of dislocations. As a results, the weld hardness increased continuously. This research indicated that the greatest value of hardness was 178.00 HV at rotation speed 710 rpm, and the lowest hardness value was 60.00 HV at rotation speed 1400 rpm.

## 5. Acknowledgements

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