The effect of pin probe length on the characteristic of dissimilar metal Al-CuZn lap joint using friction stir welding (FSW)

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Abstract. Dissimilar lap joint between aluminum 6061 and brass is performed by using friction stir welding (FSW) method where universal milling machine is used to implement this method. The parameters that use in welding are probe design with a varied length of pin probe 11.0 mm, 11.5 mm and 12.0 mm at 2000 rpm rotation of machine and feedrate 10 mm min⁻¹. The macrostructure result of pin probe length 11.0 mm better than of pin probe 11.5 mm and 12.0 mm. The mechanical properties results with a pin probe length 11.5 mm a higher mean hardness value of 104.26 VHN than a pin probe length 11.0 mm and 12.0 mm with hardness values of 98.93 VHN and 70.43 VHN. Shear stress result of 67.32 MPa with a pin probe length 12 mm, better than of pin probe length 11.0 mm and 11.5 mm shear values of 40.2 MPa and 42.14 MPa.

Keywords : friction stir welding, length of pin probe, feedrate.

1. Introduction
One of solid phase joining technique on fabrication industry is Friction Stir Welding (FSW) technique. It was discovered and patented in 1991 by The Welding Institute (TWI) and originally used to produce aluminum alloy butt joint [1]. FSW is a joining method of solid metals which also capable in joining two different metals (dissimilar metals) in plastic condition. The heat in FSW produces due to friction between the metals and the probe. The plastic condition reach when the stress due to thermal is higher than the yield stress of the materials. The joint occurs when two metals in this state is continuously stirring along the joint line. Similar to other joint technique such as bolt joint and riveted joint, FSW also able to perform lap, butt, and T joints. Figure 1 shows the schematic of FSW lap joint [2].
Many dissimilar metals joint study have been carried out by several researcher by using FSW method. Bisadi et. al. conducted a study of the effect of rotational and welding speeds on microstructures and mechanical properties of friction stir welded Al5083 and commercially pure copper sheets lap joints. The dimension of the specimen is 150mm x 100 mm and varies thickness of 2.5 mm and 3 mm. Huang et. al. investigated the material flow and mechanical properties of aluminum-to-steel self-riveting friction stir lap joints. The lower sheet is 6082-T6 aluminum alloy within dimension of 330 mm x 90 mm x 3 mm and the upper sheet is QSTE340TM steel within the dimension of 330 mm x 90 mm x 3 mm [4]. Previously, author have also studied the characteristic of lap joint carbon steel ST 37 and aluminum 6061 by using FSW method [5]. Another Aluminium and Copper joint study done by Zadeh et. al. They investigated the microstructural and mechanical properties of friction stir welded aluminum/copper lap joints including microstructure and the strength of materials [6].

Even though a lot of studies have been done but the investigation in dissimilar metals joining still need to understand deeply including aluminium and brass joint. Brass composed of copper (Cu) and zinc (Zn) where copper is the main component and usually classified as a copper alloy. Brass with a Zn content of 47.5% will form β crystals first at a temperature of 890°C, then there is a double phase (β + liquid) that is very small, and no segregation occurs. At temperatures of 880°C, the liquid will freeze completely to form homogeneous β crystals. This kind of brass is called brass β (beta) with hard and brittle mechanical properties [7]. The aim of this study is to investigate the effect of pin probe length on the characteristic of dissimilar metal Al-CuZn lap joint using Friction Stir Welding (FSW).

The Heat is generated in FSW due to friction between the tool and the sheet materials through on plastic deformation. The fraction of the plastic deformation energy is stored within the thermomechanically processed region in the form defect densities increment [8]. Probe spin at a certain speed then placed on a connection between two materials which no added material is needed. The friction of the two objects creates 0.8 Tm of sheet materials heat [9]. Figure 2 presents the heat zone that occurs in FSW method.
The stir zone has the highest stress and strain rate and high temperature, so this combination causes dynamic recrystallization. The microstructure of the mixture is very dependent on the shape of the welding tool, the speed of rotation and translation, the pressure and characteristics of the materials [11]. The shear stress in FSW results are increased by increasing in probe speed and and length that will initiate the high heat [12]. Heat is formed during the welding process in the section of the heat affected zone (HAZ) only grows in the grains. In addition, thermo-mechanical affected zone (TMAZ) occurs in between weld nugget and HAZ. Typically, the heat generated by FSW or solid welding is lower than fusion welding [13]. FSW can also be applied to similar or different materials with better results, whereas liquid welding can cause heat cracking, porosity, and distortion [14,15].

2. Methods and materials

Dissimilar joint between aluminum 6061 and brass is used in this study by performing a lap joint friction stir method. Each metal has dimension of 175 mm x 95 mm x 10 mm. Medium carbon steel
of EMS 45 is used as pin probe where the length is varies of 11.0 mm, 11.5 mm, and 12.0 mm. The variations is denoted by A, B, and C, respectively as shown in Figure 3. The research scheme of FSW can be seen in Figure 4. Table 1-3 summarized the chemical composition of the materials used in this study.

The engine speed and feed rate are controlled in 2000 rpm and 10 mm / min, respectively. Besides, the temperature is measured by utilizing several thermocouples as shown in Figure 5. The results will be obtained by using data logger and processed by using Microsoft excel software to visualize the temperature results as shown in Figure 6.

**Table 1.** Chemical composition (wt.%) of 6061 aluminum alloy.

| Compositions | Mg | Si | Cu | Mn | Fe | Cr | Ti | Zn | Al |
|--------------|----|----|----|----|----|----|----|----|----|
| Contents     | 0.9| 0.6| 0.25| 0.086| 0.18| 0.1| 0.192| 0.01| Bal |

**Table 2.** Chemical composition (wt.%) of brass.

| Compositions | Cu | Zn |
|--------------|----|----|
| Contents     | 0.85| 0.15|

**Table 3.** Chemical composition (wt.%) of carbon steel EMS-45.

| Compositions | Mn | C   | Si  | Fe |
|--------------|----|-----|-----|----|
| Contents     | 0.486| 0.450| 0.156| Bal |

**Figure 4.** The research scheme of FSW

**Figure 5.** Thermocouple placement position
Figure 6. Data acquisition and to display graph.

3. Result and discussions

3.1. Macrostructure

Figure 7 shows the bonded dissimilar metal joint after FSW process. It’s classified into two side i.e. top side and bottom side and varied pin probe length of 11.0 mm (A), 11.5 mm (B), and 12.0 mm (C). To examine the quality of the joint, macrostructure analysis was performed. Figure 8 shows the macrostructure images that identify the weld nugget, Heat Affected Zone (HAZ), and Thermo Mechanically Affected Zone (TMAZ). It is clearly seen that by using pin probe length of 12 mm, wider weld nugget is reach due to the nugget is significantly formed on the advancing side and retreating side. Besides, a defect occurs along the weld path because of high heat energy which will cause a large compressive force and form a lot of plastic materials. For pin probe length of 11 mm and 11.5 mm, the weld nugget is not significantly formed on the advancing side and retreating side, so, no defects occur.

Figure 7. FSW Results for (A) pin probe length of 11.0 mm, (B) pin probe length of 11.5 mm, (C) pin probe length of 12.0 mm.
Figure 8. Macrostructure visualization for (A) pin probe length of 11.0 mm, (B) pin probe length of 11.5 mm, (C) pin probe length of 12.0 mm.

3.2 Temperature measurement

Figure 9 shows the welding temperature of FSW for different pin probe length of 11 mm, 11.5 mm, and 12 mm. As mentioned in methods section, this temperature measured by using thermocouples. It shows that the highest temperature of 600°C occurs when the pin probe length of 12 mm is used. Moreover, the lowest temperature of 500°C occurs when the pin probe length of 11 mm is applied. It is clearly seen that this phenomenon occurs due to the friction area effective is increased by increasing the pin probe length.
Figure 9. Welding Temperature for (A) pin probe length of 11.0 mm, (B) pin probe length of 11.5 mm, (C) pin probe length of 12.0 mm

3.3 Microstructure

Figure 10 shows the microstructure visualization for various pin probe length. Weld nuggets are areas that are affected by heat generated during welding, as well as deformed areas due to the process of mixing of pin probes. The grain refinement occurs in weld nugget area, which is an area that undergoes plastic deformation and during heating the FSW process resulting in recrystallization which produces fine grains in the stirring area. For the pin probe length of 11 mm, many oxides trapped in the material is formed, this is caused by the low compressive force of the probe during welding, resulting in low heat energy, and consequently imperfect plastic material formed. The defects that occur at pin probe length of 11.5 mm are might caused by scrap which is formed on the side of advancing and
retreating. A good weld connection occurs at 12 mm pin length, this can happen because the heat energy produced is high, so that it will form plastic material then stir it perfectly.

**Figure 10.** Microstructure visualization for (A) pin probe length of 11.0 mm, (B) pin probe length of 11.5 mm, (C) pin probe length of 12.0 mm

### 3.4 Micro hardness

Tests of hardness on the test specimens were carried out on the connection area between two different materials as shown in Figure 7. The point of indentation distributed into 20 points where 10 points to the right of the connection center and 10 points to the left of the connection center.

![Graph showing micro hardness Vickers number for different pin probe length](image)

**Figure 11.** Micro hardness Vickers number for different pin probe length

Figure 11 shows the micro hardness Vickers number for different pin probe length. It shows that the lowest hardness value of 75 VHN is in FSW within the pin probe length of 12 mm. Heat energy is too large because of the length of the pin, so it will produce a 600°C temperature, and cause a lot of plastic material to form. This will cause a lot of scrap on the side of advancing and retreating, and defects will occur. The micro Vickers hardness test values on 11mm and 11.5mm pins on average higher are 100 VHN. Causing the heat energy that occurs is lower than the pin length of 12 mm, so that little scrap is formed and no defects occur.
3.5 Shear strength

Figure 12. Shear test specimen preparation for (A) pin probe length of 11.0 mm, (B) pin probe length of 11.5 mm, (C) pin probe length of 12.0 mm.

The shear strength obtained by utilizing shear test. The shear test is carried out four times for each variation by using constant load. Figure 12 shows the shear test specimen preparation for pin probe length of 11.0 mm, 11.5 mm, 12.0 mm. While Figure 13 presents the shear strength results of the shear test. The average shear stress for 12 mm length of 65 MPa is higher than the 11mm and 11.5 mm. This is due to more even distribution of plastic material and more incoming pressure. Even though defects occur on the surface because a lot of plastic material is formed. The pin lengths of 11 mm and 11.5 mm of low shear stress values are 40-43 MPa. This is due to the distribution of a small amount of plastic material, heat energy and a small amount of plastered material.

Figure 13. Shear strength for different pin probe length.

4. Conclusions
Dissimilar joint between Aluminum 6061 and Brass material with parallel lap joint using the friction stir welding method have been carried out with pin probe length variations of 11.0 mm, 11.5 mm, and 12.0 mm. The following results are obtained that the parallel lap joint welding process, dissimilar metal aluminum 6061, and 6 mm thick brass with friction stir welding method can be done. Formed scrap on the side of advancing and retreating. High heat energy will produce a high temperature of 600°C which will produce low Vickers micro hardness of 75 VHN, but high shear stress of 65 MPa at 12 mm pin length.
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