Friction Welding of SSM356 with SSM7075 Aluminium Alloys

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ABSTRACT

The aim of this study is to joining parameters that affects microstructures and mechanical properties of friction welding technique in dissimilar joints of SSM356 with SSM7075 aluminium alloys. Friction welding methods were investigated the joining parameters as follows: rotation speed at 800, 1000, 1200, 1400 and 1600 rpm, burn of length of 1.8 mm and welding time 30 sec. Two pieces of sample were rotated. After experiments, the results of the investigation have shown that condition of rotation speed at 1400 rpm, burn of length of 1.8 mm, welding time 30 sec, and spinning SSM356 develop the most complete welding. The highest joint strength reaches to 121.24 MPa. The optimum hardness in weld zone was 157.0 HV. In weld zone, recrystallized structures turn from globular grains into fine structures, which is resulting from thermal. The size of new forming fine particles in weld zone is small about 2.250 μm long and about 2.144 μm wide due to mechanical force action.

INTRODUCTION

Recently, semi-solid metal (SSM) forming technology is continually evolving in order to increase mechanical properties of the material, reduce the cost of producing, and extend life of molds (J.Wannasin, 2006). Aluminium is another material that has been interested for forming through this process (J.Wannasin, 2008). SSM356 and SSM7075 are types of SSM, which are globular structures. The SSM356 and SSM7075 aluminium alloy have been receiving considerable attention due to its advantages for application in automotive and aircraft industries (D.V Dunford, 1985) because of their lightweight, and high strength properties. Joining these materials is important because conventional welding processes lead to the formation of porosity in weld as well as microstructure changes in weld, and hot crack (J.Q. Su, 2003). However, joining of dissimilar aluminium alloy is generally more challenging because of differences in the physical, chemical and metallurgical properties. Many highly efficient solid-state joining processes such as friction stir welding, friction welding, diffusion bonding, and cold roll welding are being developed to join dissimilar materials. Among these welding techniques, friction welding (FW) technique is most interesting because of characteristics of high reproducibility, sub-melting temperature, short weld time, low energy input, and negligible intermetallic formation. At the present, many dissimilar materials have been bonded by the FW, such as copper (Ahmet Z. Sahin, 1998), steel (M.Sahin, 2005), titanium (A. Vairis, 1998) and aluminum (M.N Ahmad Fauzi, 2010). FW, a solid state joining process, consists of parameters such as friction pressure, friction time, upset pressure, upset time, temperature measurement, burn off length, and rotational speed (A. Moarrezfazadeh, 2012). However, quality and the strength of the welds depend on the correct choice of these parameters. In this research, study on the effect of dissimilar joining parameters on the microstructure, tensile strength, and hardness properties of FW of SSM356 with SSM7075 aluminum alloy by both types of materials alternating spins. The microstructure used scanning electron microscopy (SEM) analysis of weld zone and nearly weld zone and, after welding joints.

MATERIALS AND METHODS

In the experiment, aluminium semi-solid metals SSM356 and SSM7075 materials were used. These materials were formed by semi-solid casting technique (gas induced semi solid) under casting temperature at 620 and 640 degree celsius respectively. Then, nitrogen gas flow with the rate of 5 liter per minute via porous graphite by time at quenching was obtained for the rheocasting time of 10 seconds following by squeeze casting.
Obtained chemical composition is shown in Table 1. The sample is cylindrical in shape of length 45 mm, and outer diameter is 12 mm. The parameters used for the present work to perform the friction welding are: rotation per minute (RPM), burn of length (mm), and welding time (sec) shown in Table 2.

**Table 1:** Chemical composition of SSM356 and SSM7075 aluminium alloy used.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Zn</th>
<th>Ti</th>
<th>Cr</th>
<th>Ni</th>
<th>Others</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSM356</td>
<td>7.74</td>
<td>0.57</td>
<td>0.05</td>
<td>0.06</td>
<td>0.32</td>
<td>0.01</td>
<td>0.05</td>
<td>0.02</td>
<td>0.01</td>
<td>-</td>
<td>Bal.</td>
</tr>
<tr>
<td>SSM7075</td>
<td>-</td>
<td>0.46</td>
<td>1.93</td>
<td>-</td>
<td>2.5</td>
<td>6.08</td>
<td>-</td>
<td>0.19</td>
<td>-</td>
<td>0.45</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

The setup used for the present work was principals/principles of friction welding machine shown in the Figure 1. The lathe computer numerical control machine (CNC) was designed by modifying used because its stability and precision comparing to conventional lathe machine. The spindle is driven by an asynchronous servomotor, and maximum rotation speed is 5000 rounds per minute. Axial forces are controlled by a hydraulic servo valve. The sample preparation was carried out by grinding surfaces with P180 grit SiC paper and cleaning with acetone for 30 sec to eliminate oxide film for the thermal induction in friction welding. Heat was generated by the friction between the materials while applying friction forces into samples to bond together as clockwise direction. All the experiments were done at three different rotation speed and two different burn of length, but the welding time was kept constant. After friction welding, the samples were polished by grinding on various grades of emery paper. Then, they were etched with Keller’s reagent: 190 ml H2O, 5 ml HNO3, 3 ml HCl, and 2 ml HF. In order to study the grain structure of the weld zone and other areas, the microstructure tester by scanning electron microscopy (SEM) with back-scattered electron image mode (FEI-Quanta, Japan; model: 400), allocated in the Scientific Equipment Center, Prince of Songkla University. Vickers hardness test was conducted across the interface of the welded joints at the center of the specimens by Zwick/Roell Vicker’s microhardness tester (model: ZHU). The samples were measured on the cross-section at every 0.5 mm intervals away from the center of weld zone at 10 HV on the diamond indenter for 10 sec, respectively.

**Table 2:** Parameters used for the present work.

<table>
<thead>
<tr>
<th>Number of Experiments</th>
<th>Spinning (Clockwise)</th>
<th>Rotational Speed (rpm)</th>
<th>Burn of Length (mm)</th>
<th>Weld Time (sec)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>1000</td>
<td>1.8</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>800</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1200</td>
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<td></td>
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<tr>
<td>4</td>
<td>1400</td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td>1600</td>
<td></td>
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<tr>
<td>6</td>
<td>800</td>
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<td>7</td>
<td>1000</td>
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<tr>
<td>8</td>
<td>1200</td>
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<td>9</td>
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<td></td>
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<tr>
<td>10</td>
<td>1800</td>
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</table>

All the experiments were varied in five levels of rotation speed and alternating to rotate the sample of the process and the weld time with burn of length was kept constant. Heat was generated from the friction between the materials while applying friction force and the direction of rotation was clockwise.

![Fig. 1: Friction welding for SSM356 with SSM7075 aluminum alloy.](image-url)
RESULTS AND DISCUSSION

For this experiment, the best conditions were examined in both microstructure and mechanical properties. Different parameters of conditions result in the tensile strength values. The best parameters are rotation speed at 1400 rpm, burn of length at 1.8 mm, welding time 30 sec, and SSM356 aluminium alloys is spinning.

Characteristics of Welding Samples after FW:

Figure 2. shows the photograph of samples in all conditions by SSM356 aluminium alloys is top side and SSM7075 aluminium alloys is bottom side. As you can see, after FW, most samples were completely bonded. Except, rotation speed at 800, 1000 rpm, and spinning SSM7075 aluminium alloys, the samples were not bonded shown in Figure 2. (f, g) because the heat generated during welding was too low, causing the weak weld zone. It is also observed that at low rotation speed, instead of causing the molten materials, contributes to the impact and loss of the surface materials during FW. Then, some parts of materials’ surfaces were damaged or broken as shown in the Figure 2. (g). However, spinning SSM356 aluminium alloys lead to good adhesion in the samples shown in the Figure 2. (a, b, c, d, e) with no defect.

Fig. 2: Sample morphology of SSM356 spinning at (a) 800 rpm, (b) 1000 rpm, (c) 1200 rpm, (d) 1400 rpm, (e) 1600 rpm and SSM7075 spinning at (f) 800 rpm, (g) 1000 rpm, (h) 1200 rpm, (i) 1400 rpm, (j) 1600 rpm.

On the contrary, the heat from spinning SSM7075 aluminium alloys is difficult resulting in poor adhesion of the samples (M.B. Uday, 2012) shown in the Figure 2. (f, g, h, i, j). Moreover, different rotation speeds cause an unequal amount of flash. For example, when increasing rotation speed 800 to 1600 rpm of spinning SSM356 aluminium alloys results the increase of flash. Likewise, at higher rotation speed of spinning SSM7075 aluminium alloys easily make flash. Therefore, high rotation speeds lead to high thermal during FW to soften materials and cause good adhesion. However, when a rotation speed is too high, it may result in the loss of heat from the cooling action of rotation speed itself.

Influence of Parameters that Affect Microstructure:

Figure 3. shows the microstructures of spinning SSM356 aluminium alloys around the welded joints in weld zone (centre of samples) from optical microscopy (OM) at taken at 200X. It is noteworthy that the increase of rotation speed contributes to the reduction of the voids shown in the Figure 3. (a, b, c). Observed that, the presence of voids are in Thermo Mechanical Affected Zone (TMAZ) shown in the Figure 3. (a) because the thermo-mechanical affected zone is the area of thermal differences between the weld zone and base materials. For the rotation speed at 1400 rpm, no void and other defect shown in the Figure 3. (d). In weld zone, changes of the structure from globular structure to fine structures were observed due to frictional heat, resulting in a globular structural deformation. Fine structure in weld zone is the area of the two-phase mixture between Mg2Si phases of SSM356 aluminium alloys and MgZn2 phases of SSM7075 aluminium alloys (Y.B. Yan, 2010). Both phase have smaller structures than the original structures and dispersed throughout the weld zone due to rotating mechanical force. It was also found that both types of aluminum phase (α) were mixture together. Likewise, in weld zone, they formed fine structures similar to all conditions, and the flows of material are in the same direction as the direction of rotation. However, for the welded structure produced at 1600 rpm, which the rotation speed was extremely high leading to the loss of heat during the welding, it causes the presence of many small voids in the weld zone as shown in the Figure 3. (e). Although frictional heat will cause structural changes, it happens just only in welded zone. However, base metal is still a globular structure because it did not receive thermal energy from the rotating mechanical force.
Figure 3: Microstructure on weld zone of SSM356 spinning at (a) 800 rpm, (b) 1000 rpm, (c) 1200 rpm, (d) 1400 rpm, (e) 1600 rpm.

Figure 4. shows the microstructures of spinning SSM7075 aluminium alloys around the welded joints in weld zone (center of samples) from optical microscopy (OM) at taken at 200X. The rotating SSM7075 aluminium alloys cause lower frictional heat comparing with spinning SSM356 aluminium alloys because of low heat input during FW. The lower heat input generates, the more difficult the samples to be welded. For example, for rotation speeds at 800 and 1000 rpm, samples do not adhered very well as shown in the Figure 4. (a, b). However, increase rotation speed leads to the increase frictional heat, which makes welding to be more easily successful. The welded microstructure produced at 1200 rpm shows large void resulting from insufficient heat while welding shown in the Figure 3. (c). In addition, when rotation speeds were increased to 1200 and 1600 rpm, the number of voids clearly reduced as shown in the Figure 4. (c, d, e). In weld zone, for the rotation speed 1600 rpm, there were the smallest amount of voids. Fine grains of microstructures in weld zone were observed because influence of temperature and plastic deformation induced by the friction causing the recrystallized structure of SSM356 and SSM7075 aluminium alloys. Two types of aluminium alloys were mixed the materials together as a result of the heat from the friction from the surface of the samples (Kulyuth Boonseng, 2014). These alloying elements are mechanically forced until the particles broken leading to an increase in the hardness of the weld zone. Likewise, microstructure near interface changes from globular structures to fine structures influenced by rotation speed and other parameters. In addition, workpiece preparation before welding is very important; especially, the removal step of the oxide on the surface, which hindered to procreate the heat input leading incomplete welding.

It can be seen that the variables affecting the mechanical properties and microstructures, especially the different types of materials by FW, are important to complete the welded zone. Therefore, the selection of the appropriate parameters is important for applications. We can see that welding of SSM356 with SSM7075 aluminium alloys by FW shows that rotating samples affect the heat transferring differently which leads to changes of microstructure and mechanical properties.

Influence of Parameters that Affect Distribution of Particles in Welded Zone:

The photograph of SEM taken at 200X with the parameters of spinning SSM356, rotation speed at 1400 rpm, burn of length at 1.8 mm, and welding time for 30 seconds are shown in Figure 5. The results show that the find micro voids are very small and very little volume located in the bottom area of the sample. These voids found near the thermo-mechanical affected zone in SSM356 aluminium alloy due to heat changes. Size of void is about 1.2 mm long and 0.2 mm wide as shown in Figure 5(a). However, within thermo-mechanical affected zone, coarse structures were detected. In weld zone, we found that eutectic phase, which is formed as a fine structure, consists of Silicon (Si), Magnesium (Mg), Steel (Fe) from SSM356 aluminium alloy and Zinc (Zn), Magnesium (Mg), Copper (Cu) from SSM7075 aluminium alloy. At the base particles, the size of Mg2Si phase is about 7.746 μm long and 1.143 μm wide. And the size of MgZn2 phase is about 14.566 μm long and 2.312 μm wide. However, in weld zone influenced by rotation speed and pressure, both Mg2Si and MgZn2 phases were broken. After FW, new forming particles size is about 2.250 μm long and 2.144 μm wide and the distribution of these new forming particles in welded zone is wider as shown in Figure 5(b). It is noteworthy that this new size of Mg2Si and MgZn2 phase mixture (also called “Mixture Zone”) is smaller which helped to
increase the hardness the weld zone leading to the good mechanical properties of the sample. In addition, texture material flow of both types depends on the direction of rotation, and the heat input can determine the width of weld zone. In contrast, the heat input at low rotation speed makes weld zone narrow causing poor mechanical properties. However, FW process for welding of different materials does not change structures in the weld zone back to their dendritic structure because the heat input during FW did not reach the melting point, which is the key for solid state welding.

Fig. 4: Microstructure on weld zone of SSM7075 spinning at (a) 800 rpm, (b) 1000 rpm, (c) 1200 rpm, (d) 1400 rpm, (e) 1600 rpm.

Fig. 5: Photographs of particle distribution in welded zone of spinning SSM356 with rotation speeds at 1400 rpm, burn of length of 1.8 mm, and welding time for 30 seconds.

Figure 5 (c) shows the microstructures on the top of the sample. It shows that the weld zone is nearly perfect with only a very small void. However, in base metal of both alloys, we found a globular structure because there was no mechanical action that can causes the structural changes and mechanical changes.

**Tensile Strength of the Joint Welded by Friction Welding:**

The result of tensile strengths is shown in Figure 6. It can be seen that the difference both rotation speeds and rotating materials result the difference of tensile strength of the joints. In the case of spinning SSM356 aluminium alloys, we found that when the rotation speeds increase from 800 to 1400 rpm, it also led tensile strengths to be increased. For example, at rotation speed 800, 1000 and 1200 rpm, tensile strengths is 33.14, 39.95 and 71.69 MPa respectively. On the other hand, an increase of rotation speed at 1400 rpm can develop
higher tensile strengths around 121.24 MPa. This is because the higher rotation speed makes weld zone gain higher heat input during FW. But, when rotation speeds increase to 1600 rpm, it cause lower tensile strengths of joint which is around 101.25 MPa due to the loss of heat from the rotation. Another reason that results less tensile strengths is the amount of voids (Shailesh K. Singh, 2014). Thus, higher tensile strengths are directly related to the complete bonded area. However, in the case of spinning SSM7075 aluminium alloys, tensile strengths were not very high even using identical parameters. For example, between the rotation speeds from 800 and 1000 rpm, the samples were not bonded as a result from low heat input. But when rotation speeds increase from 1200 to 1600 rpm, tensile strengths is 19.23, 58.46 and 97.7 MPa respectively. Although the tensile strength of the joints after FW is satisfactory, when compared with the base metal of SSM356 (tensile strength 168 MPa) and SSM7075 aluminium alloys (tensile strength 198 MPa), we found that the tensile strength is lower. In addition, for the condition of rotation speeds at 1400 rpm, burn of length at 1.8 mm, welding time 30 seconds, and spinning SSM356 aluminium alloys, efficiency of the weld joints is 85 percent compared with the base metal of SSM356 aluminium alloys and efficiency of the weld joints is 65 percent compared with the base metal of SSM7075 aluminium alloys.

![Fig. 6: The relationship between the tensile strength of the joints with rotation speed.](image)

**Influence of Parameters that Affect Hardness Properties:**

Hardness distribution data on the horizontal distance from joints are shown in Figure 7. It can be seen that, in weld zone (WZ), hardness is clearly higher than other areas because of distribution of particles in the weld zone, which are small particles broken by mechanical forces. This results the strength in the weld zone was increased when either the spinning of SSM356 aluminium alloys or SSM7075 aluminium alloys. The results were similar as shown in Figure 7 (a, b). However, spinning SSM7075 can provide maximum hardness in weld zone (157.0 HV) which is higher than the hardness values (143.6 HV) when spinning SSM356. This is because types of spinning material directly affect the heat input during FW. It can be noticed that, the higher the rotation speed is, the higher the hardness is. This causes from the higher heat input from higher rotation speed. For example, in the condition of spinning SSM356 and rotation speed at 800 rpm, hardness was 124.0 HV. However, when we increased the rotation speed to 1600 rpm, hardness soared to 143.6 HV. Anyhow, high hardness makes the samples be easily brittled and properties of toughness decreased. We also remark that hardness in weld zone was still high, when comparison with that of the base materials (73.5 HV of SSM356 and 113.7 HV of SSM7075 respectively). However, the hardness of TMAZ zone is lower than other areas because of the recrystallized structure and microstructural transformation caused by the thermal (M.B. Uday, 2012). For instance, in the condition of spinning SSM356 and rotation speed at 1000 rpm, hardness in TMAZ zone was 102.5 HV, which is still a little lower than the strength of base metal shown in Figure 7(a). The generated heat not only results a different hardness but also affects the adhesion of the samples. It is noticed that, from the condition of rotation speed at 800 and 1000 rpm with spinning SSM356, the sample did not bond together as shown in Figure 7(b) because the generated heat during welding was too low. So, the heat during the welding process is extremely important for FW because it allows the hardness in the weld zone to be increased. And, the other factor that results the hardness is different particle sizes and distribution (Kulyuth Boonseng, 2014). If the small particles disperse throughout in weld zone, it will increase the hardness value in weld zone.

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Conclusion:
In the present study, the dissimilar joints between SSM356 and SSM7075 aluminium alloys were welded successfully by friction welding process. The changing of rotational speeds, burn of length, welding time, and the type of rotating materials affect the microstructures and mechanical properties explicitly. Following conclusions can be drawn:
1. The type of rotating material affects the adhesion of the sample. When spinning SSM7075 aluminium alloys with rotation speed at 800 and 1000 rpm, the sample did not bonded together. In contrast, when spinning SSM356 aluminium alloys with rotation speed at 800 and 1000 rpm, the sample can be bonded together.
2. In weld zone, globular structures transformed to fine structures which Mg2Si and MgZn2 phase particles were broken and make homogeneous structures. Particle size in weld zone is about 2.250 μm long and about 2.144 μm wide.
3. The maximum tensile strengths are 121.24 MPa for condition with rotation speed at 1400 rpm, burn of length at 1.8 mm, welding time for 30 seconds, and spinning SSM356 aluminium alloys.
4. The vickers hardness of the welded zone (mixture zone) is 157.0 HV because small particles from mechanical action are dispersed throughout in weld zone.

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