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Microstructure and Mechanical Properties of Friction Welding in SSM356 Aluminium Alloys

K. Boonseng[1], S. Chainarong [2], C. Meengam [3]
[1]Dept.of Engineering, Songkhla Rajabhat University, Thailand, Kulyuth.bo@skru.ac.th
[2]Dept.of Engineering, Songkhla Rajabhat University, Thailand, Suppachai.ch@skru.ac.th
[3]Dept.of Engineering, Songkhla Rajabhat University, Thailand, Chaiyoot.me@skru.ac.th

ABSTRACT

The purpose of this research is to study the friction welding in SSM356 aluminium alloys which was obtained from a rheocasting technique allowing the globular structure formation on base metal. The friction welding used parameters: rotation speeds at 1360, 1540 and 1750 rpm, burn of length at 1.8 and 3.2 mm, and welding time for 30 sec respectively. After friction welding, the results showed that the structure in weld zone conserves microstructure similar to the original structure of the base metal, which is fine structure. Due to the rotation speed and pressure, eutectic (Mg_2Si) phase fracture can be observed as well. It is also found that parameters as follows: rotational speed of 1540 rpm, burn of length of 3.2 mm and welding time of 30 sec provide maximum tensile strength which is 82.98 MPa. The results of the investigation have shown an average hardness in the range of 58.13 HV.

Keywords : Friction Welding, SSM356 aluminium alloys, Mechanical properties, Lathe computer numerical control machine (CNC).

1. INTRODUCTION

Friction welding (FW) method has been used extensively in the manufacturing methods because of the advantages, such as high material saving and strong welded joints produced, and used in many industries - aeronautical engineering, automobile engineering, submarine industry, and heavy industry. [1] Friction welding, 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. [2] These are the most important parameters for this joining process. The quality and the strength of the welds depend on the correct choice of these parameters. As the friction welding method shown in Figure. 1, semi-solid metal 356 (SSM 356) aluminiums have been receiving considerable attention due to its advantages for application in automotive and aircraft industries. [3] Using a new rheocasting technique named gas induced semi solid (GISS) process can lower the temperature of SSM processing than conventional casting and forms globular microstructure on the material. [4] In addition, conventional welding processes lead to the formation of porosity in weld as well as changes of microstructure and hot crack in weld. [5] The aim of the present studies is to examine whether such good welds can be produced by using rotary friction welding methods for SSM356 aluminium alloy.

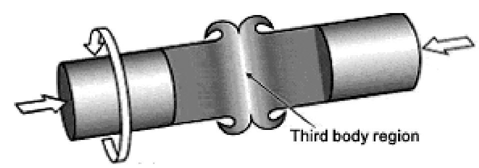

Figure 1 Shows the basic steps in friction welding [6]

In this research, the effect of joining parameters on the microstructure and mechanical properties of friction welding with butt-welded joints of SSM356 aluminium alloy was investigated. After friction welding, welded specimens were tested hardness and tensile strength and examine the microstructure by SEM respectively. The results were reported and discussed.

2. MATERIALS AND METHODS

In the experiment, semi-solid metals SSM356 aluminum materials were selected to form by semi-solid casting technique (gas induced semi solid) under casting temperature at 620 degree Celsius. After that, argon or nitrogen gas flow through via porous graphite by the time at quenching was obtained with the rheocasting time for 5 sec. Then, squeeze casting. Chemical compositions are shown in Table 1. The microhardness of SSM356 aluminium alloy is 60 HV on based. The dimensions of this cylindrical-shape specimen are 50 mm in length with 12 mm of outer diameter respectively. 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.
The setup used for the present work was methods of friction welding machine illustrated in Figure.2. The lathe computer numerical control machine (CNC) was specifically designed and modified for this experiment because of its stability and precise comparing to conventional lathe machine. The spindle is driven by an asynchronous servomotor and the maximum rotation speed is 5000 rounds per minute. Axial forces are controlled by a hydraulic servo valve. The specimen preparation was carried out by grinding surfaces with P320 grit SiC paper and cleaning in acetone for 30 sec;

Table 1 Shows chemical composition of SSM 356 aluminium alloy used.

Materials	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Ni	Al
SSM 356	7.74	0.57	0.05	0.06	0.32	0.01	0.05	0.02	0.01	Bal.

Table 2 Shows parameters used for the present work.

Number of Experiments	Parameter		
	Rotational Speed (rpm)	Burn of Length (mm)	Weld Time (second)
1	1360	1.8	30
2	1360	3.2	
3	1540	1.8	
4	1540	3.2	
5	1750	1.8	
6	1750	3.2	

thus, this led to the friction welding. Heat was generated due to the friction between two materials during applying friction force into specimens bonded together. After friction welding, the welded specimens were sectioned at the weld-joint to study the microstructure. Specimens were polished by grinding on various grades with emery paper and then etched with Keller's solution. Vickers hardness test were conducted across the interface of the welded joints at the center of the specimens by Vicker's microhardness tester HWDM-3 Type A at a load of 100 gf on the diamond indenter for 10 seconds respectively. All the experiments were varied by three levels of rotation speed and two levels of burn of length. And the weld time was kept constant. Heat was generated due to the friction between the materials while the friction force and the direction of clockwise rotation were applied. [7] Totally, six experiments were performed respectively.

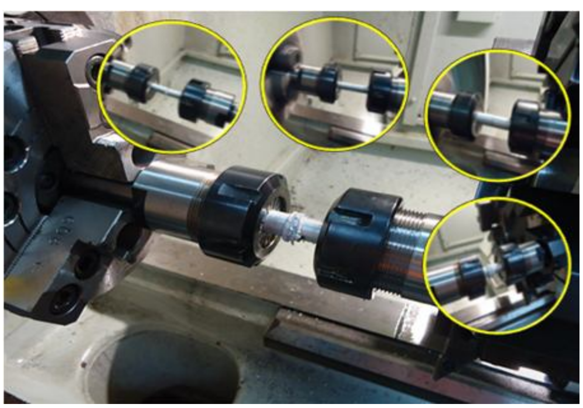

Figure 2 Shows frictional welding for SSM356 aluminium alloy

3. RESULTS AND DISCUSIONS

3.1 Influence of parameters that affect structures

The microstructures of the welded joints, taken at 50X, are shown in Figure. 3, Figure. 4 and Figure. 5. For the rotation speed at 1360 rpm, it is generally observed in weld joints, the Thermo Mechanical Affected Zone (TMAZ) represents a distinct area between the globular structures and fine structures (Figure. 3 a, c) because the heat caused by friction, resulting in a globular structure deformation.

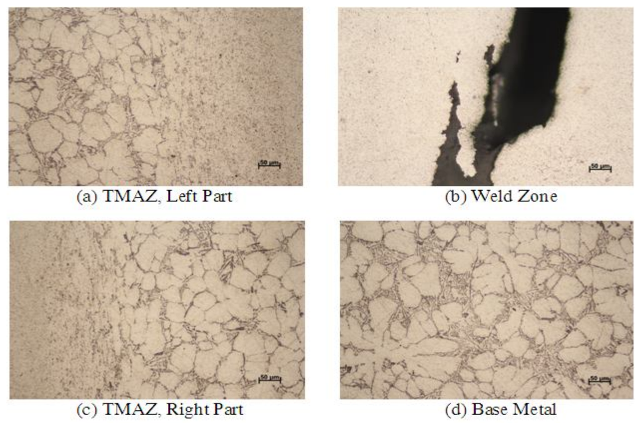

Figure 3 Shows interface of specimen welded at 1360 rpm

Weld zone (WZ) has formed more refined grain structures. However, after friction welding process, voids can be found when the rotation speed was low enough to make void formation in the weld zone as shown in Figure. 3 (b). This is due to the frictional heat from the process. The microstructures on base metal (BM) did not change because they were not influenced by the heat of welding as shown in Figure. 3 (d). The effects of burn of length make the grains compressed in the direction of rotation. However, the softened area is decreased with an increase in upset pressure because the softened material was adjacent to the weld interfaces [8].

In the welded structure produced at the rotation speed of 1540 rpm, the grains were fine and there is a marked distinction between the structures of the two welded pieces as shown in Figure. 4 (a, c). Likewise, weld zone has fine grain and eutectic phase (Mg_2Si) was mixed with aluminium phase (α) by eutectic phase dispersing throughout the weld zone as shown in Figure. 4 (b). This is because the rotation speed makes these two phases mixed together very well. Figure. 4 (d) reveals aluminium matrix phase (α-Al); the microstructures shows globular shape grain. The friction heat was sufficiently generated and the softened area was extended in the friction stage due to large friction pressure and high friction speed [9].

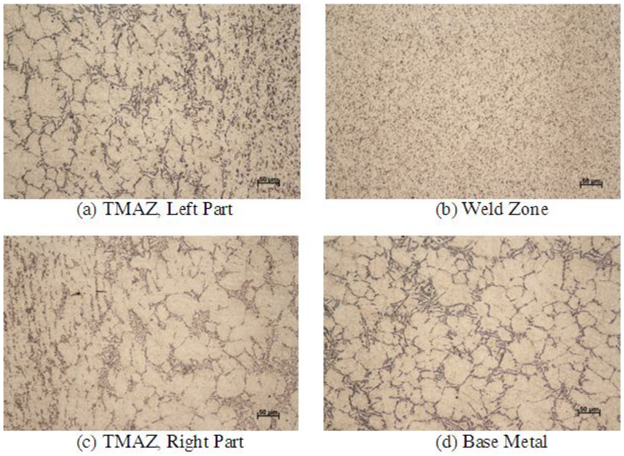

Figure 4 Shows interface of specimen welded at 1540 rpm

Figure. 5 shows microstructure produced at 1750 rpm. The microstructure of the weld zone and grain refining is observed. There is also a region of very fine grains in weld zone (Figure. 5 b). The high rotation speeds lead to high thermal during friction welding. This is because the material at the interface was heated to a high temperature and subsequently cooled at a faster rate due to the temperature gradient between the weld interface and base metal. [10] The microstructure near interface changes globular structure shape (Figure. 5 a, c).

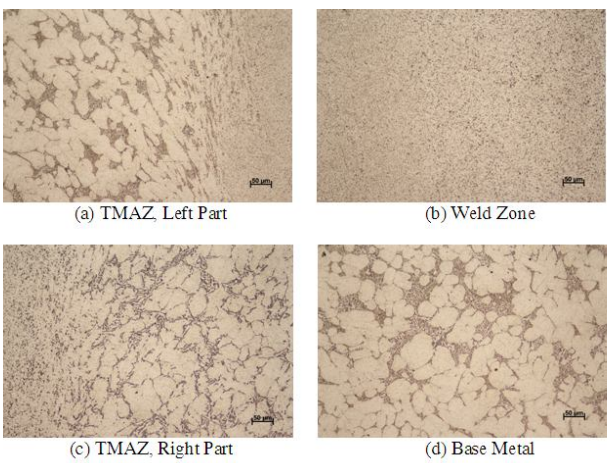

Figure 5 Shows interface of specimen welded at 1750 rpm

For the rotation speed at 1750 rpm, the microstructure on base metal is similar to the microstructure with the rotation speed at 1360 rpm and 1540 rpm as shown in Figure. 5 (d). At the high rotation speed, there were no voids, cracks, or other weld defects. Moreover, it enhances the plasticity of the material allowing the material to soften easily. On the other hand, at the low rotation speed, the material is still hard, difficult to be welded, and risk being an incomplete welding. Influence of temperature and plastic deformation induced by the friction action causes the recrystallized structure of SSM 356 aluminium alloy [11]. The main effect of each rotation speed is significant. But this may indicate that the burn off length do not have significant effect on the weld properties. The higher burn of length is, the more number of flash is occurred. So, the specimens will become shorter. Finally, parameters are important which affect the microstructure and lead to different mechanical properties.

3.2 Influence of parameters that affect distribution of particles in welded zone

Figure. 6 is a photograph from scanning electron microscopy (SEM), taken at 100X. It showed weld zone with rotation speed 1540 rpm, burn of length of 3.2 mm, and welding time of 30 sec. Observed micro void is very small and very little volume. The shape of eutectic is elongated and plate-like as a typical eutectic structure shown in Figure. 6 (b) which shows that eutectic phase consists of Silicon (Si), Magnesium (Mg), Steel (Fe) and other at combination from Mg_2Si phase [12]. The base particles size of Mg_2Si phase is about 7.746 µm long and 1.143 µm wide. However, rotation speed and pressure resulting Mg_2Si phase broken into particles. After friction welding, particles size is around 1.518 µm long and 1.140 µm wide shown in Figure. 6 (a). It was also found that distribution of particles in welded zone forms better, which leads to increased hardness. The heat generated during the welding allows Mg_2Si phase to be occurred due to softening led the material brake easily. However, although Mg_2Si phase provides higher hardness property, they are brittle as well.

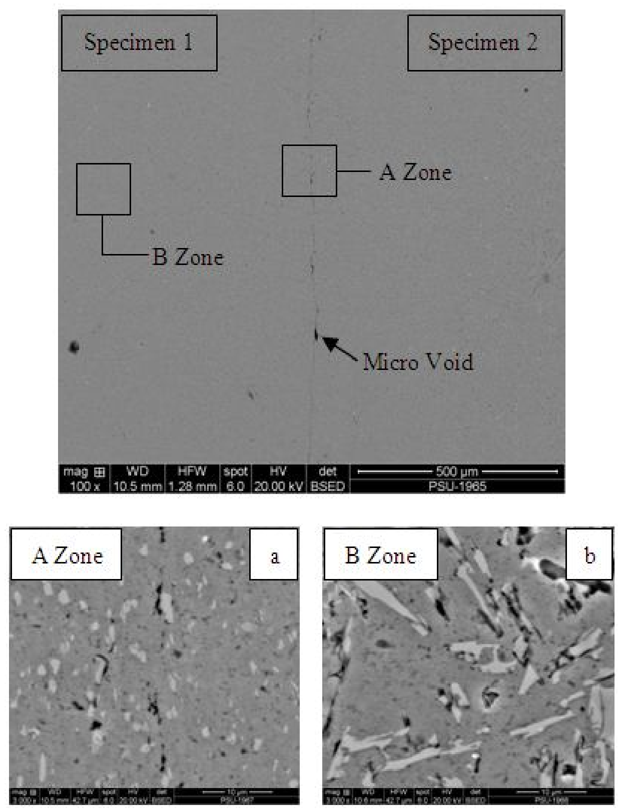

Figure 6 Shows photography of distribution of particles in welded zone of rotation speeds 1540 rpm, burn of length of 3.2 mm and welding time of 30 sec

3.3 Tensile strength of the joint welded by friction welding

The result of tensile strengths is shown in Figure. 7. The rotation speeds and burn of length directly affect the tensile strength of the joints, which an increase of burn of length from 1.8 to 3.2 mm leads tensile strengths increase. For example, at rotation speed 1540 rpm and burn of length at 1.8 mm, it can provide maximum tensile strengths at 68.13 MPa. In addition, burn of length at 3.2 mm can generate maximum tensile strengths for 82.98 MPa. Because the higher burn of length is, the higher density weld zone can be. Likewise, the increasing rotation speeds form 1360 to 1540 rpm lead to higher tensile strengths at joint area. For example, at burn of length 3.2 mm and rotation speed 1360 rpm, the maximum tensile strength is 59.68 MPa. When rotation speed increases to 1540 rpm, the maximum tensile strengths of the joints is 82.98 MPa. However, when compared with the base metal (168 MPa), tensile strengths of all conditions are still around 50 % less. Perhaps, this causes from less number of bonded area. The higher rotation speeds led to high heat in put during friction welding can lead to soften the material easily. However, when rotation speed is extremely high, such as at 1750 rpm, the strength of the materials cannot be increased because texture of materials is pushed into the flash. Therefore, the selection of the appropriate of parameters is important for applications.

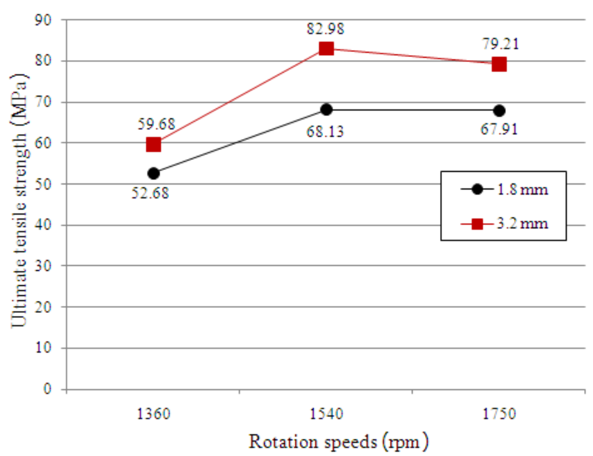

Figure 7 Shows tensile strength of the joints

3.4 Influence of parameters that affect hardness

Microhardness distribution data on the horizontal distance of joints are shown in Figure.8. It can be seen that the hardness of SSM356 aluminium alloy was reduced slightly around the interface (TMAZ). Softening is noted throughout the weld zone in the SSM356 aluminium alloy and its average value increased when rotations speed increased. Hardness in the WZ and TMAZ regions was lower in comparison with the base materials [13]. This is due to the WZ and TMAZ regions recrystallized structure. However, slight decrease in the hardness of the WZ regions is observed. Base metal have average hardness in the range 59.4 HV; however, after that, the experimental specimen hardness increases to 58.31 HV with rotation speed at 1750 rpm and burn of length at 3.2 mm. In addition, low rotation speeds at 1360 rpm and low burn of length at 1.8 mm generates less heat input and makes less hardness. Finally, hardness values of the specimen in all condition after friction welding processes are relatively closed.

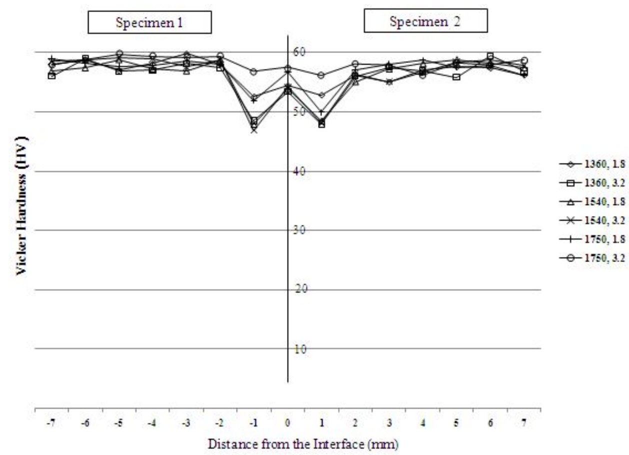

Figure 8 Shows hardness profiles across the weld region

4. CONCUSION

In the present study, the similar joints of SSM356 aluminium alloys were welded successfully by friction welding process using three different rotational speeds and burn of length. Following conclusions can be drawn;

1. The TMAZ changed from globular structures to fine structures, and microstructures in WZ are fine and homogeneous structures as a result of thermal during frictions welding.
2. The Mg_2Si phase particles were broken after friction welding. Particles size is about 1.518 µm long and about 1.140 µm wide.
3. The maximum tensile strengths are 82.98 MPa for condition with rotation speed at 1540 rpm, burn of length at 3.2 mm, and welding time for 30 sec.
4. The vickers hardness of the weldment is 58.31 of base metal; therefore, its hardness is closed to the hardness of base metal due to heating.

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