OPEN ACCESS

International Journal Of Modern Engineering Research (IJMER)

Diffusion Bonding of Semi-Solid (SSM 356) Cast Aluminum Alloy

Chaiyoot Meengam[1], Prapas Muangjunburee[2], Jessada Wannasin[3]

[1, 2, 3]*Department of Mining and Materials Engineering, Faculty of Engineering, Prince of Songkla University, Hat Yai, Songkhla, Thailand, 90112*

Abstract: *A new technique to achieve the globular weld structure of SSM 356 aluminum alloy was conducted. The effect of joining parameters on the microstructure and mechanical properties of diffusion bonding butt joints of semi-solid SSM 356 aluminum alloy was investigated by conditions as follows: compressive pressure at 0.4, 0.9, 1.8, 2.4 and 2.7 MPa, with holding time 3 hours and temperature at 495^{o}C under argon atmosphere at 4 liters per minute. The results showed that the compressive pressure 1.8 MPa, with holding time 3 hours and temperature 495^{o}C, under argon atmosphere provided the highest joint strength to 124.48 MPa. In addition, the results of the investigation have shown that the joint efficiency was 72 percent compared with base metal and microstructure in weld zone (WZ) after welding becomes globular structure. This microstructure, similar to the original structure of the base material, is a globular structure but the grain size can grow at a higher temperature.*

Keywords: *SSM 356 Aluminium alloy, Diffusion Bonding, Bond line, Semi-Solid Metal*

I. INTRODUCTION

Semi-solid metals (SSM) have been receiving considerable attention due to its advantages for application in automotive and aircraft industries. SSM processing exhibits distinctive advantages such as components are near net shape, the temperature of SSM processing is lower than conventional casting and its globular microstructure is shown in Fig 1 [1]. It was clear that the joint of SSM aluminum alloys have expanded in the usage of casting components. Joining of SSM aluminum alloys has been carried out with a variety of fusion and solid state welding processes. Conventional welding processes lead to the formation of porosities in weld as well as change in weld microstructure [2]. Therefore, a suitable joining technique is required to overcome these problems. These difficulties have led to joining in solid state by diffusion bonding. In this study, SSM 356 aluminum alloy was obtained from a new rheocasting technique, named gas induced semi solid (GISS) process.

Diffusion bonding is a solid state joining process, which consists of three main parameters such as time, temperature and pressure. In this method, mating materials are brought into contact under a pressure far below the yield strengths of the base materials, and generally the bonding temperature is chosen between 0:5-0:8*T*m, where Tm is the melting point of the base materials [3]. Diffusion bonding of aluminum alloys faces some problems due to its protective oxide film (Al_2O_3). This oxide has great stability and tenacity at high temperatures and to hinder diffusion of atom [4]. However, problems from oxide film can be avoided by joining in a vacuum or under atmospheric shielding gas [5].

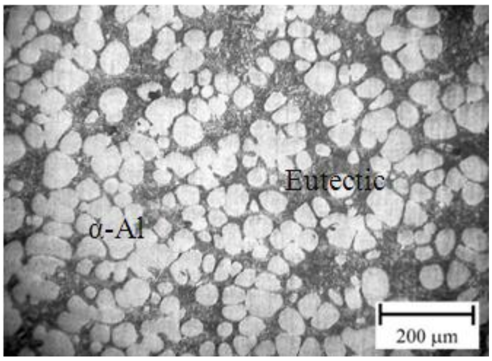


Fig: 1 Microstructure of base materials SSM 356 [6]

In this research, systematic study on the effect of joining parameters on the microstructure and mechanical properties of diffusion bonding butt-welded joints of SSM 356 aluminum alloy was investigated and the results were reported and discussed.

II. MATERIALS AND METHODS

The material used in this study was aluminum semi-solid metal SSM 356 with chemical composition shown in table 1. The mechanical properties of SSM 356 are as follows; ultimate tensile strength (UTS) is 168 MPa, yield strength (YS) 137 MPa and elongation (E) 9.7 percent

Table 1: The chemical compositions of SSM 356 (% weight) [7].

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.

The base material for diffusion bonding was supplied in the form of cylindrical shape of dimensions 11 mm. in diameter and 40 mm in length. The specimen preparation was carried out by grinding surfaces with P180 grit SiC paper and cleaning in acetone for 30 s. just before diffusion bonding. Bonding was performed in argon atmosphere at 4 liters per minute in a high temperature chamber attached to a testomatic tensile testing/compression testing machine. The temperature of the chamber was set at 495°C. Bonding pressure were 0.4, 0.9, 1.8, 2.4 and 2.7 MPa and heating holding time of 3 hours. The variables used in this experiment are summarized below:

1. Diffusion bonding temperature: 495 °C
2. Applied pressure: 0.4, 0.9, 1.8, 2.4 and 2.7 MPa
3. Heating holding time of 3 hours.

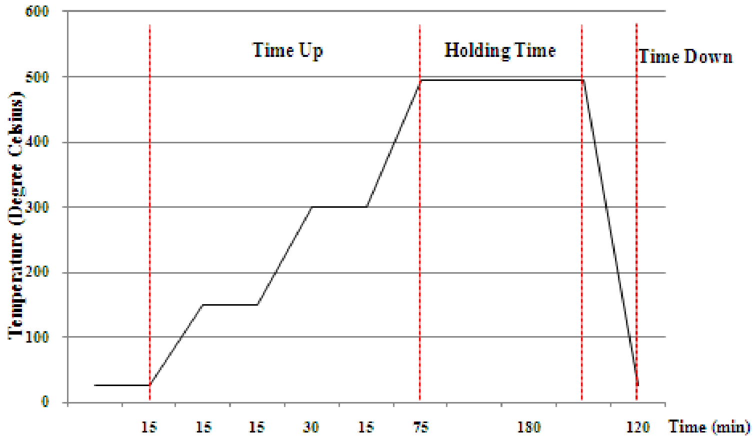


Fig: 2 temperature cycle time

Total time of heating cycle is 7 hours 45 minutes as shown in Fig 2. Finally desired compression force and all of which are controlled under the oven shown in Fig 3.

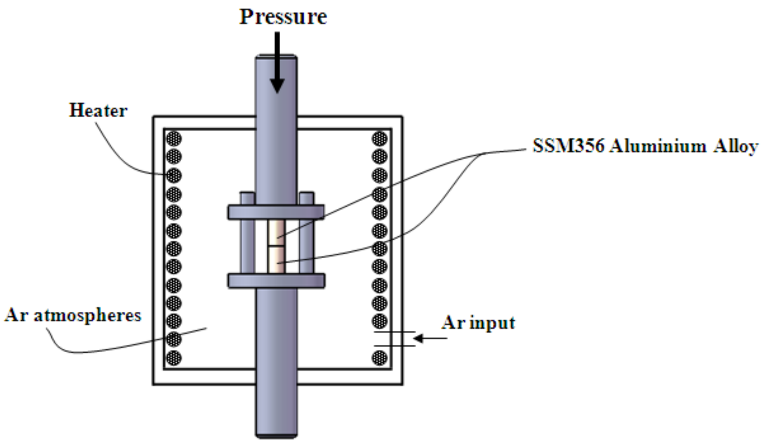


Fig: 3 Set-up used for bonding.

III. Results And Discussion

3.1 Metallography

Fig 4(a) shows the cross section macrograph of the diffusion bond line. It can be seen that no macro defects were observed, in addition, two base materials were sound bonded. Fig 4(b), 4(c), 4(d), 4(e), and 4(f) show the microstructure along the bond line from top to bottom. The results have indicated that only one void was observed in the bond interface obtained from Fig 4(d). This elongated void located at the center of the bond line to this is due to the elimination of the interfacial voids was nearly completed. It is generally considered that a sound bond was achieved despite little evidence of the bond line. Bond line was part of the specimens where microstructure is not changed due to heating cycles, and microstructure in bond line zone has globular structure which is similar to base structure SSM 356 but different in sizes – the size of bond line grain is about 12-15 μm but the size of base structure grown about 19-22 μm. Fig 4(b)-4(f) also reveals smaller grain size at the interface compared with base materials away from the interface. Microstructure at and near the interface was influenced by temperature, time and pressure resulting in changes to the shape and size of grains. [8] Fig 4(a) and 4(b) suggest a small misalignment at the top and bottom during bonding process.

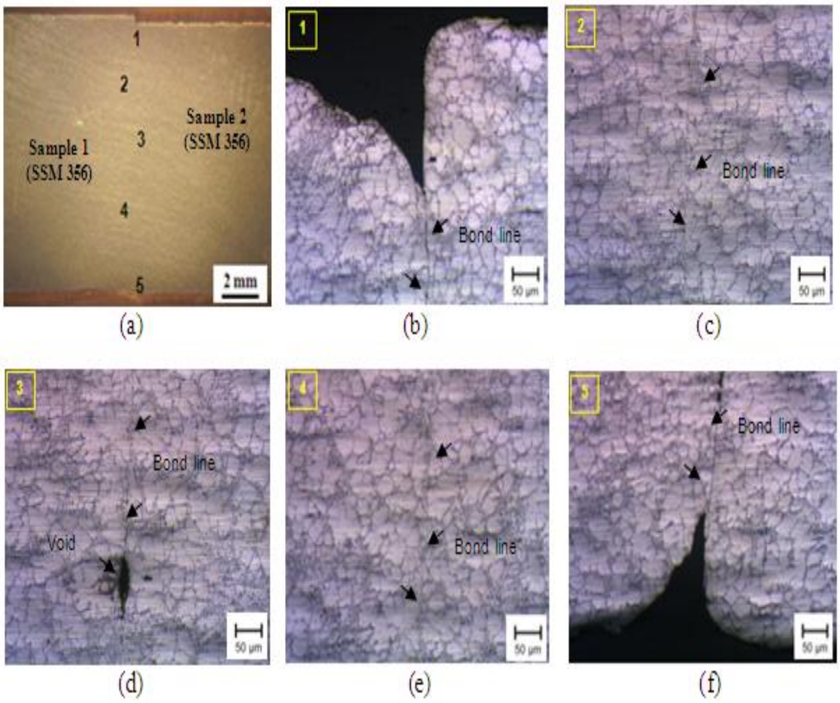


Fig: 4 Macro-Microstructure of interface for SSM 356. After diffusion bonding method (a) macrostructure at the interface, (b) on the top edge, (c) top, (d) medium, (e) bottom and (f) on the bottom edge.

Fig 5 shows microstructure revealed by scanning electron microscopy (SEM) with joining parameters at temperature 495 ^{o}C, pressure 1.8 MPa and time 3 hours. Fig 5 (a) reveals aluminums matrix phase (α-Al) and void. A small voids was obtained in the bond interface. In addition, broken silicon particles were also obtained at and near the bond interface. The void along the top to the bottom is very small. Silicon particles were broken by pressure and the influence of heat; then, the silicon and magnesium as combination of Mg_2Si have formed as shapes of the plates and rods [9]. Mg_2Si from shaped plate is grown about 4 μm and about 10-15 μm long, and Mg_2Si from rods-like-shape particle is about 1.5 μm wide and about 10-30 μm in length. Based materials on silicon from rods-like-shape particle is about 1.5 μm wide and plates-like-shape particle is 2.5 μm in length. For both rods-like-shape particle and plates-like-shape particle is about 15-20 μm wide. It is obvious that Mg_2si phase are arrangement parallel along the bond lines show in Fig 5 (b). Heating the silicon particles diffusion into bond line at the right time result in complete diffusion show in Fig 5 (c, d) and Mg_2Si are distributed throughout the aluminum matrix. Although Mg_2Si particle is smaller in size, this promotes material strength. Small voids were observed in the bond interface. In addition, some broken silicon were also observed at and near the bond line.

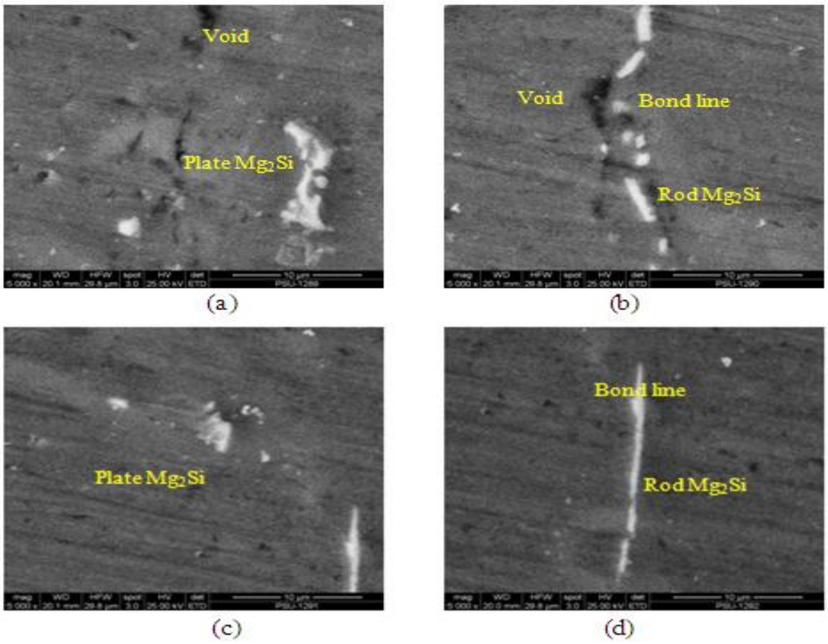
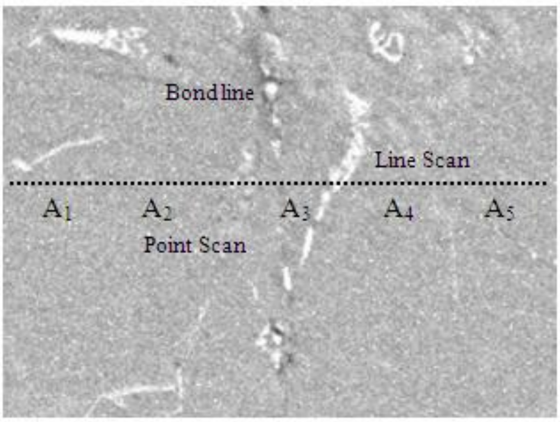


Fig: 5 Scanning Electron Microscopy of interface for SSM 356

Table 2: Chemical compositions of each zone in the bond line for 1.8 MPa at 495 ^{o}C (at.%)

Zone	Al	Si	Mg	Fe
A_1	72.55	25.74	1.27	0.44
A_2	79.80	16.57	2.65	0.98
A_3	59.12	38.71	1.26	0.91
A_4	75.52	22.51	1.38	0.61
A_5	83.82	14.11	1.61	0.46

Fig 6 shows an inspection of line scan and point analysis by energy-dispersive x-ray (EDX) analyze diffusion elements to bond line. It is found that the microstructures along bond line have silicon particle (Si) distributing throughout the aluminum matrix which forms a combination of magnesium and silicon into solid solution Mg_2Si where is nearby bond line. In addition, the maximums amount of silicon is located at the center because the interface zone has the same behavior as grain boundary which assists atoms to diffuse easily on interface grain. The chemical compositions of each zone in the bond line for 495 ^{o}C, pressure 1.8 MPa and time 3 hours by EDX shown in Table 2. According to the table, the silicon phase maximum diagram and the morphologies of A_3 have 38.71 percent.



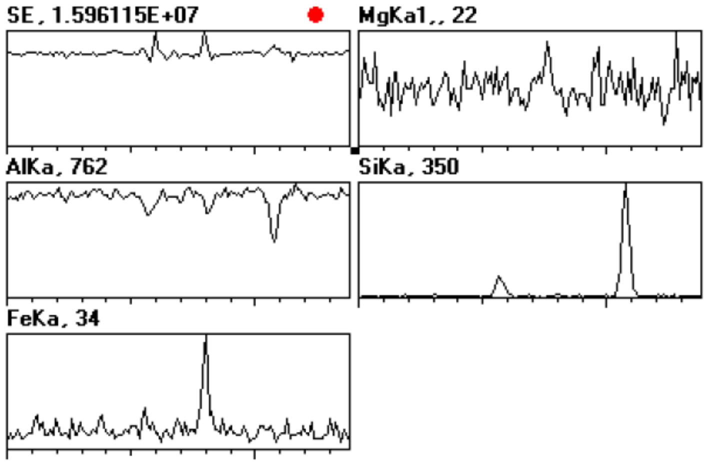


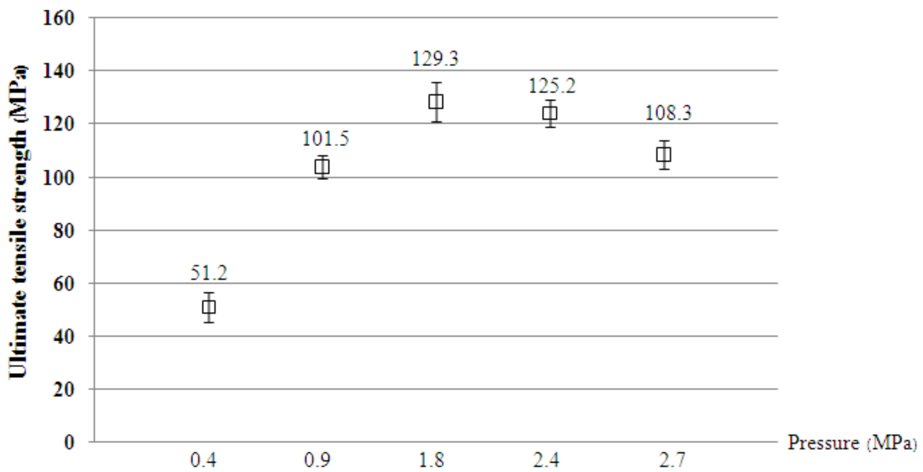
Fig: 6 Energy-Dispersive X-ray of interface for SSM 356

3.2 Tensile Strength of Joints

The tensile properties and fracture locations of joints welded at different welding condition are show in Fig 7. From investigation, the increase in the contact pressure leads to increase in the tensile strength, a maximum average value tensile strength of 129.3 MPa was achieved by the joint parameter at contact pressure 1.8 MPa, holding time 3 hours. temperature 495^{o}C, under argon atmosphere flow 4 l/min. Compared with the base material is around 76.96 percent of efficiency joints by base material aluminums SSM 356 is 168 MPa. Joint efficiency can be measured by the percentage of bonded area [4]. The equation used to calculate the joint efficiency is given as:

$$\text{Joint efficiency} = \frac{\text{UTS of bonded specimen}}{\text{UTS of SSM 356 specimen}} \times 100$$

From Fig 7, it shows that if the contact pressure is too low, the tensile strength and the bonding surface is small too. In contrast, the more pressure increase, the more tensile strength increases, respectively. But if the pressure is too high, the tensile strength will be decreased and the specimen will be deformed. The pressure variables 0.4 MPa for tensile strength is very low 51.1 MPa because contact the surface of the sample is very little to diffusion of atoms together is difficult. Increasing pressure is 0.9 MPa, the tensile strength was increased to 101.5 MPa. Likewise, the pressure is 1.8 MPa while contributing to the higher tensile strength to value of 129.3 MPa this phenomenon as a result of right pressure. Recovery time is the compression of the grain in compression at high or too low.



Joint Efficiency (%)	30.35	60.41	76.96	74.40	64.46

Fig: 7 Tensile properties of SSM 356 diffusion bonding

Increasing pressure is too high resulting in a decrease in tensile strength as a result of grain surface area is compressed by the massive force stress at the interface lead to use of energy higher in the release of stress [4]. The high pressure causes the recovery longer described by variable pressure 2.4 and 2.7 MPa is 125.2 and 108.3 MPa respectively. In experiments, the pressure that directly affect the tensile strength and the deformation of the sample after welding. The variable temperature and time it is also important could result in a change in metallurgy. Therefore, the variables right is important for the diffusion bonding. Another reason for the high strength specimen of the bonded as well due to the amount of void is interface zone has minimal.

3.3 Hardness Test

The microhardness distributions on the transverses cross-section of joints welded at all welding condition the data is summarized in Fig.8 It is observed that the bond lines with a hardness higher than other areas descriptive by bond line have Mg_2Si phase, The influence of temperature resulting in particles together and specimen by diffusion bonding through all regions were slightly decreased in comparison with the base materials [10]. Base materials have average hardness in the range 67 HV but after the experimental specimen average hardness increases is 93 HV which comes from the heat in due movement of the atoms from Mg_2Si phase. The average hardness is 35.48 percent. Heat during welding support to specimen with the hardness increases. Finally, diffusion bonding processes help increase of the hardness of the specimen after welding.

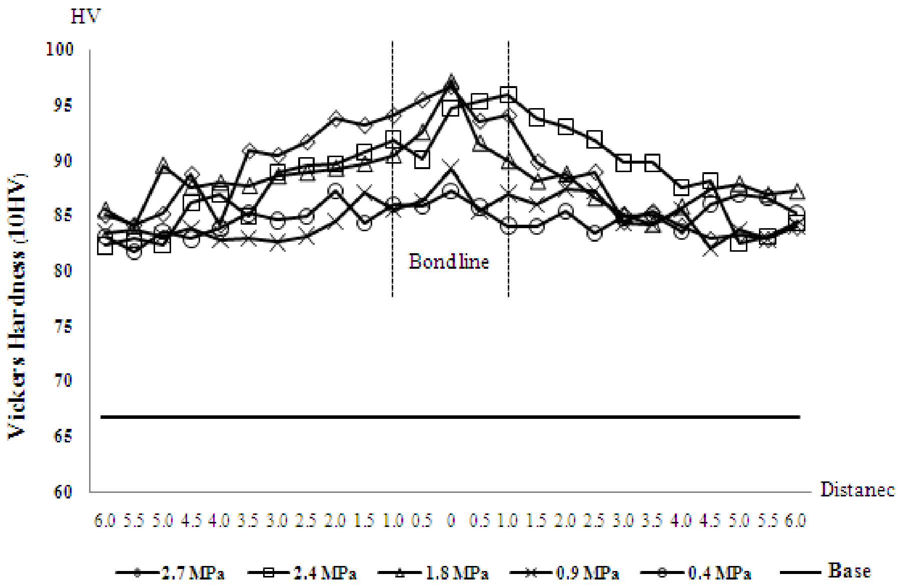


Fig: 8 Microhardness results for diffusion bonding.

IV. CONCLUSION

In the present study SSM 356 aluminum alloys were joined by diffusion bonding under contact pressure and holding time were investigated. Summarizing the mean features of the results, the following conclusions may be drawn:

1. The highest joint strength reaches 129.8 MPa when the specimen is bonded at pressure 1.8 MPa, holding time 3 hours. temperature 495^{o}C, under argon flow 4l/min.
2. Microstructure after welding is globular structure is the same as the original texture of the material but the grain size to grow at a higher temperature.
3. Silicon particles in formed fracture of the increasing pressure and at the influence of heat is diffusion to the bone line combined with magnesium form solid solution Mg_2si
4. Solid solution Mg_2si shaped plate is grown about 12 μm and a length of about 15-25 μm and shaped rods is about 3 μm in length and about 10-40 μm.

Acknowledgements

This work was supported by the Higher Education Research Promotion and National Research University Project of Thailand, Office of the Higher Education Commission. Researchers thank the Department of Mining and Materials Engineering, Faculty of Engineering, Prince of Songkla University in Thailand.

REFERENCES

[1] R.F. Tylecote, Diffusion bonding (Welding and Metal Fabrication, 1967).

[2] D.V. Dunford and P. G. Partridge, Proc. CIT Grandfield Con. on Super plasticity in Aerospace-Aluminum, UK, 1985, 252.

[3] N. Masahashi, Effect of Pressure Application by HIP on Microstructure Evolution during Diffusion Bonding, Materials Transactions, 46)7(, 2005, 1651-1655.

[4] C.S. Lee, H. Li and R.S. Chandel, Vacuum-free diffusion bonding of aluminium metal matrix composite, Journal of Materials Processing Technology, 89-90, 1999, 326-330.

[5] X-P. Zhang, L. Ye, and Y.W Mai, Investigation on diffusion bonding characteristics of SiC particulate reinforced aluminium metal matrix composites (Al/SiCp-MMC), International Journal of Composites: Part A, 30, 1999, 1415–1421.

[6] J. Wannasin, S. Junudom, T. Rattanochaikul, and M.C. Flemings, Development of the Gas Induced Semi-Solid Metal Process for Aluminum Die Casting Applications" Solid State Phenom, 141, 2008, 97-102.

[7] J. Wannasin, and S. Thanabumrungkul, Development of a semi-solid metal processing technique for aluminium casting applications, Songklanakarin Journal Science Technology, 30(2), 2008, 215-220.

[8] H. Moller, G. Govender and W.E. Stumpf, The T6 heat treatment of Semi-solid Metal Processed Alloy A356, The Open Materials Science Journal, 2, 2008, 6-10.

[9] A. Urena and J.M. Gomezde Salazar, Bonding of aluminium matrix composites for application in the transport industry, Journal de Physique Archives, 3, 1993, 1037-1042.

[10] S. Kuntongkam, S. Wisutmethangoon, T. Plookphol and J. Wannasin, Influence of Heat Treatment Processing Parameters on the Hardness and the Microstructure of Semi-Solid Aluminum Alloy A356, Journal of Metals, Materials and Minerals, 18)2(, 2008, 93-97.