Production of Hypo-eutectic Al-Si Alloy Based Metal Matrix Composite with Thixomoulding Processing

Hasan Aztekin[a], Dursun Özyürek[b*], and Kerim Çetinkaya[a]

[a]*Karabuk University, Technical Education Faculty, Departman of Machine Edu. 078100 Karabük, Turkey*
[b]*Karabuk University, Technical Education Faculty, Departman of Metal Edu. 078100 Karabük, Turkey*

(Received May 4, 2010; final form May 11, 2010)

ABSTRACT

In this study, hypo-eutectic A356/SiC_p metal matrix composite production was made with thixomoulding. For this purpose, A356 (Al-Si) alloy was put in the form of powder in ≤50 μm level produced using gas atomization method. 5%, 10%, 15% and 20% SiC_p reinforcement was added and they were mixed in a mixer for 30 minutes. Then, the mixed powders were pressed for 1 min under 20 kN force at 823 K mould and 863 and 873 K process temperatures. Optical and scanning electron microscopy (SEM) investigation and sphericity, grain size and micro hardness measurements were carried out on the produced composites. It was observed that thixomoulding resulted in spherical grain structure rather than dendritic structure. The most ideal sphericity was obtained for the specimens produced at 823 mould and 863 K process temperatures. Increasing SiC_p reinforcement decreased % sphericity rate and increased grain size and hardness.

Keywords: Thixomoulding, Al/ SiC Composite materials

*Corresponding author:
Tel: +90 370 4338200, Fax: +90 370 4338204,
E-mail:dozyurek@karabuk.edu.tr

1. INTRODUCTION

When semi solid processing is compared with classical production methods, it is observed that it has many advantages such as less micro segregations and solidification shrinkages and low forming temperature less porosity /1-5/. Another characteristic of materials produced with this method is the micro structural superiorities that they enable /6-10/. As known, traditional materials are produced with casting methods and the materials produced with this method have dendritic morphology /11-13/. During solidification, micro pores formed between dendrite arms affect the mechanical characteristics of materials in a negative way /14/. Moreover, stress accumulations forming at the upper parts of dendrites also affect the characteristics of the materials. For this reason, one method preferred in eliminating these problems is the use of different processes in production.

Hypo-eutectic Al-Si alloys such as A356 are widely used in automotive sector /15-17/. One of the methods preferred in the improvement of physical and mechanical characteristics of these materials is their use as matrix material for composite material production. Aluminum matrix composite materials (AMK) are preferred thanks to their characteristics such as high melting temperature, hardness and elasticity modules and low thermal expansion and density. Reinforcement rate, size and type also have an effect in the characteristics of these materials. The studies show that SiC and Al_2O_3 reinforcements are very important material group, for the improvement of AMK materials' wear resistance /18-21/.

In this study, what is aimed is the production of Al/SiC reinforced composite material with semi solid processing (thixomoulding) technique which is used in automotive and electronic industry for component production. As matrix material, Al-Si (A356) alloy and reinforcement SiC reinforcement were preferred. As a result of the literature studies, it has been observed that it is possible to obtain spherical microstructures with semi solid processing techniques in metal and alloys, but it isn't possible to obtain desired spherical grain structures in composite materials. For this purpose, the main aim of this study is the production of Al/SiC composite materials which have spherical grain morphology and can be obtained with thixomoulding processing in metal and alloys and the determination of the optimum production parameters.

2. EXPERIMENTAL PROCEDURE

In this study, Al-Si based SiC particles reinforced metal matrix composite materials were produced by thixomoulding method. In the experimental studies, 5%, 10%, 15% and 20% (vol %) SiC were incorporated to the Al-Si matrix. In thixomoulding the mould temperature was 823 K, process temperature was 863 K and 873 K, pressing force was 20 kN and pressing time was 1 minute. The chemical composition (mass %) of Al-Si alloy ingot used as starting material is given in **Table 1**. Al-Si ingot alloy was transformed into powder by gas atomizing. In the atomizing process, argon gas was used at 32 atmospheric pressure. The average size of produced powders was nearly about ≤50 µm. Al and SiC powders that will be produced with thixomoulding at four different SiC amounts (5%, 10%, 15% and 20%) were mixed in a mixer for 30 minutes.

Table 1
Chemical composition of Al-Si alloy (in mass %)

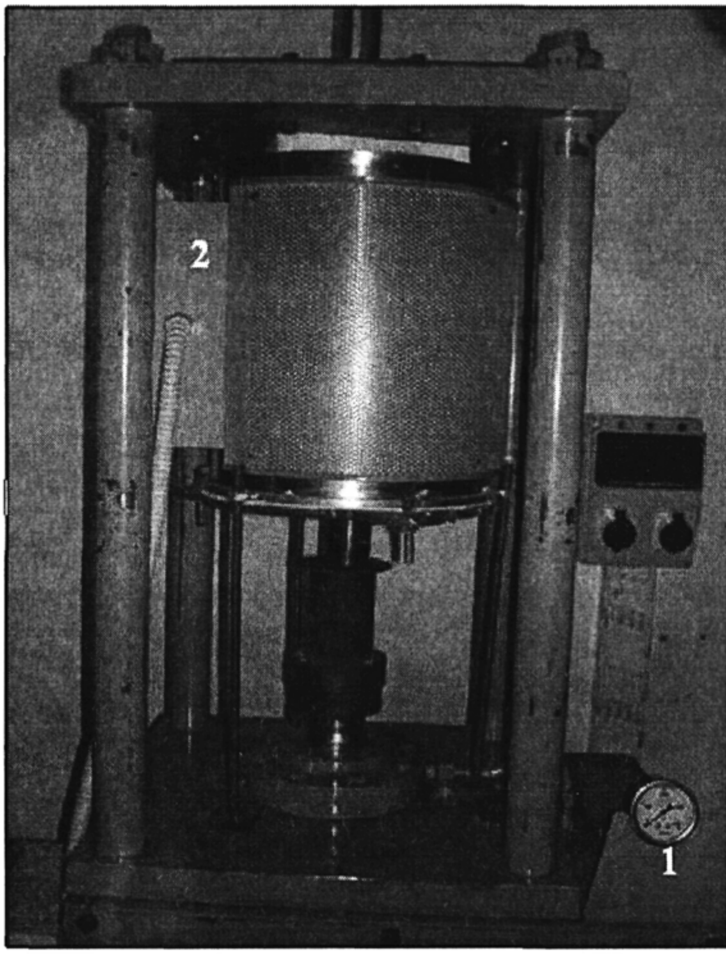
Material	Si	Fe	Cu	Mn	Mg	Zn	Ti	Pb	Al
A356	6,5	0,15	0,03	0,03	0,4	0,05	0,2	0,03	Balance

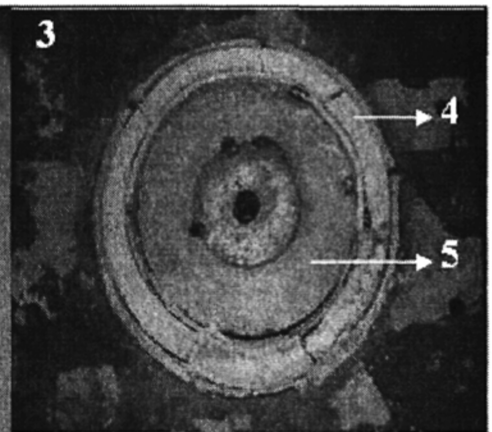
Al and SiC powder mixtures were preshaped with cold pressing (800 MPa) before the forming process with thixomoulding. To be able to shape the powders and take them out of the mould easily, 1% zinc stearat was used. The thixomoulding unit used in the experimental studies **(Figure 1)** consists of 5 main parts; press, furnace, mould, mould heating system and mould holder. A graphite was used in semi solid forming. For microstructural investigations, the produced Al/ SiC composite components were etched for 30 seconds in 90 ml H_2O, 5 ml HNO_3, 3 ml HCl, and 2 ml HF solutions after the standard metallographic processes. Optical and scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) investigations were made. Grain size measurements (ASTM E 112) and spherical shape condition measurements were made in MSQ Plus 6.5 image analyzer system, and hardness measurements were made in universal AFFRI hardness measurement equipment (HV5).

3. RESULTS AND DISCUSSION

3.1. Microstructure

As can be seen from **Figure 2**, Al-Si alloy used as starting material has a dendritic microstructure. As known, structure has influence on the mechanical characteristics of the material. Generally, in equiaxed and columnar micro-structured Al-Si alloys, grain size and form, and in dendritic micro-structured materials, the distance between dendrite arms and micro porosities between these arms are influential over mechanical characteristics.





1	Press
2	Furnace
3	Mould Holder
4	Mould Heater
5	Graphite Mould

Fig. 1: The thixomoulding unit used in experimental studies

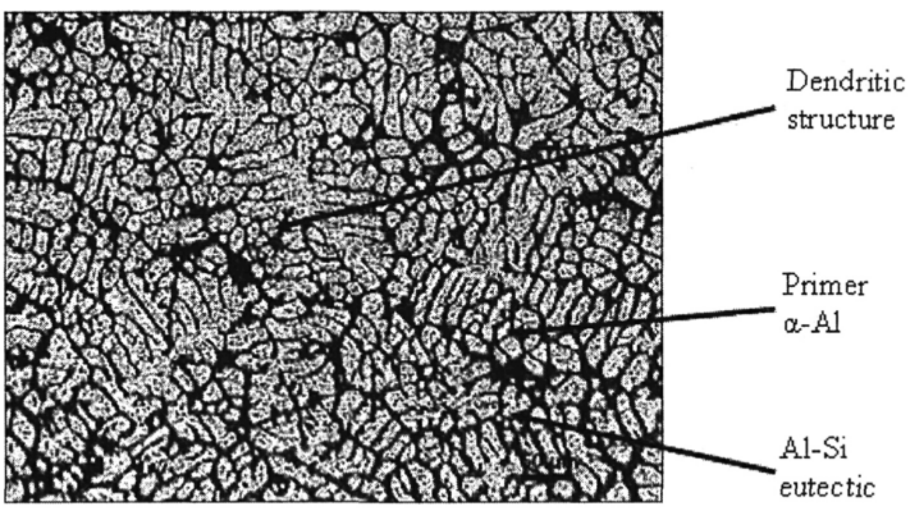


Fig. 2: Al-Si alloy used as starting material has a dendritic microstructure.

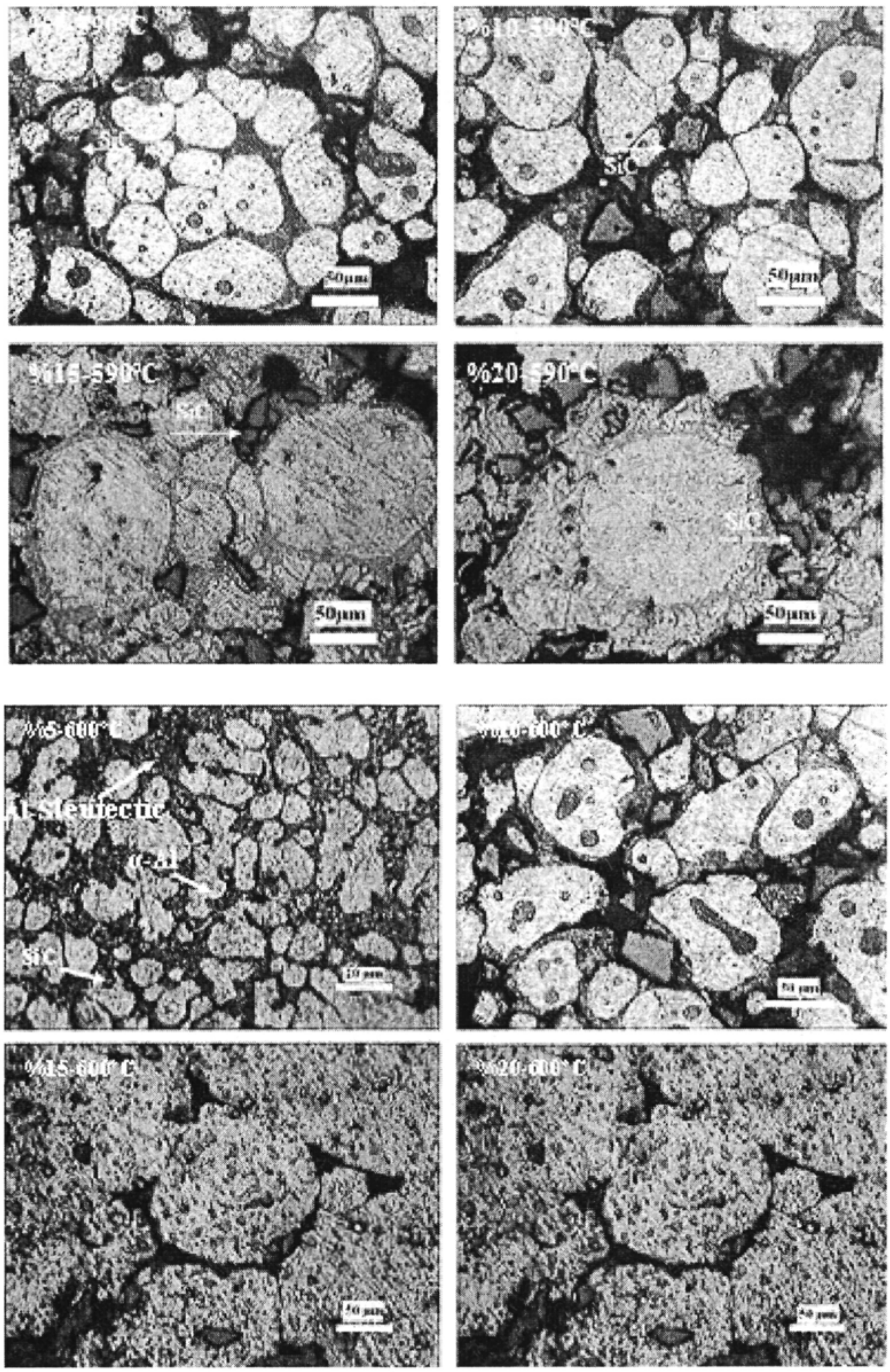


Fig. 3: Optical microscope images of 5%, 10%, 15% and 20% SiC reinforced aluminium composite materials produced at 863 K and 873 K temperatures

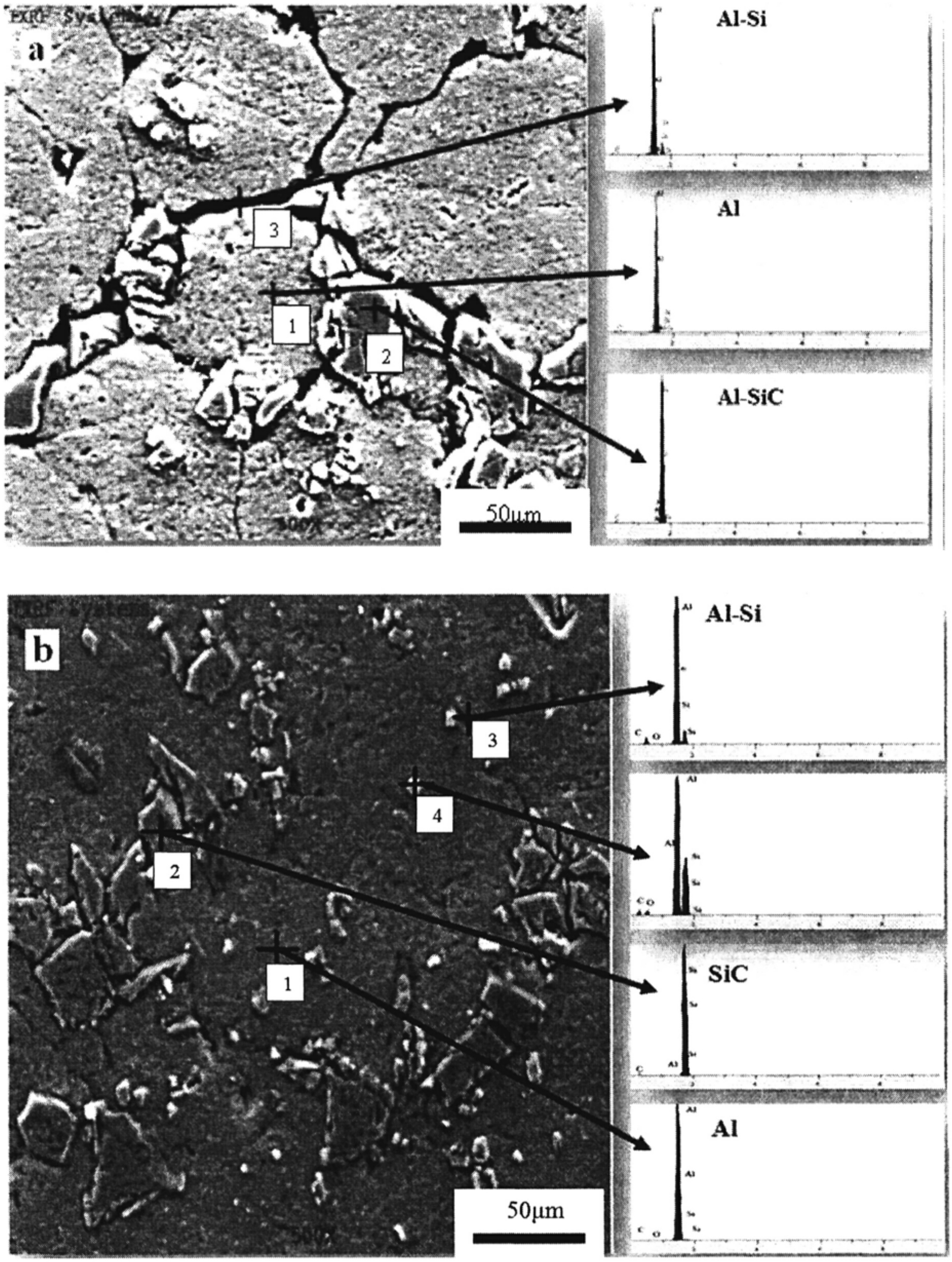


Fig. 4: Figure 4. SEM and EDS analysis results of 15% SiC reinforced aluminium composite materials produced at 863 K (a) and at 873 K (b) semi solid processing temperature

In the present study, optical microscope images of Al/ SiC composite materials produced with thixomoulding method at different SiC reinforcement rates and at 863 and 873 K temperatures are shown in **Figure 3**.

As can be seen from **Figure 3**, SiC particles added to Al matrix exhibit a homogeneous distribution in the structure. Reinforcement phase, with thixomoulding in Al-SiC composite production, was placed in liquid eutectic. SiC intensifies in dark areas which surround α-Al grains and are rich in terms of Si (Al-Si eutectic). SiC particles which intensify in these liquid characteristic type areas during semi solid process increase the viscosity of semi solid material. Furthermore, in optical microscope images shown in Figure 2, inter surface forming is observed between the matrix and SiC. This situation is also reported Lee et al /22/.

Al-Si alloys are one of the mostly-used materials in aluminum matrix composite production. However, some brittle phases are formed when producing SiC particle reinforced Al-Si alloy matrix composite in the particle-matrix interface due to Si decomposition. These brittle phases, in turn, result in decrease in the mechanical properties.

In this study, for the purpose of determining the structure of produced samples and the resulting morphology, SEM and EDS analyses were made. In **Figure 4** a, SEM and EDS analysis results of 15% SiC reinforced aluminum composite materials produced at 863 K semi solid process temperature and in Figure 4 b, those produced at 873 K are given.

In EDS analysis taken from three different points shown in the SEM image given in **Figure 4a**, Si rate was observed as 0.53 (1), 75.52 (2) and 18.75 (3). Si rate in Al-Si eutectic around α-Al grain boundary shows an increase. As stated before, Selvaduray et al. reported precipitation of Al_4C_3 around grain boundaries due to the decomposition of SiC at high temperatures. In addition to this, it can obviously be seen that the microscopic structure of sample produced at 863 K temperature is in a more spherical form. Moreover, in EDS analyses no oxygen was observed. As can also be understood from the SEM and EDS results given in **Figure 3b**, the fraction of perfect sphere decreases with increasing thixomoulding temperature. This case can be seen better in spherical shape condition results given in **Figure 4**. In EDS analyses taken to determine the structure, oxidation problems were observed. From the measurement taken from matrix, O_2 amount was observed to be 3.24% (1) and from the one taken from grain boundary, O_2 amount was observed to be 22.6%. In this region, C existence at the rate of 37.5% was also observed. While an increase in semi solid process temperature causes oxidation, SiC decomposes with the reaction that occurs in parallel with temperature increase. As stated in the studies made by Lee et al /22/, an increase of 1% Si content of the alloy was observed (under solidus temperature in matrix) at temperatures especially between 853 and 893 K. As the increase in Si content prevents the reaction between matrix and SiC reinforcement phase, an interface is formed around SiC reinforcement phase. As the presence of interface forming affects the strength, toughness and wear characteristics in negative way in composite materials, temperature should be given enough importance in Al/SiC composite materials production process.

3.2. Fraction of perfect sphere and grain size

Figure 5 shows the fraction of perfect sphere of Al/ SiC composite materials produced with thixomoulding at 863 K (a) and 873 K (b), respectively. In the diagram given in **Figure 4a**, the fraction of perfect sphere in the 5% SiC reinforced composite material is observed to be 82%. Based on the increase in reinforcement rate, a steady decrease in the fraction of perfect sphere is observed. The same situation can be seen in composite materials produced at 873 K temperature (**Figure 4b**). The fraction of perfect sphere in the 5% SiC reinforced composite material was observed to be 79% at 873 K case. This situation can be explained by the increasing viscosity with increasing reinforcement rate, when producing metal matrix composite by thixomoulding. That is because, reinforcement particles intensity around the liquid eutectic areas when the reinforcement rate is increased.

Grain sizes of specimens produced by adding SiC at different levels are shown in **Figure 6**. In parallel to the increase in reinforcement rate in Al/ SiC composite materials produced with thixomoulding process, an

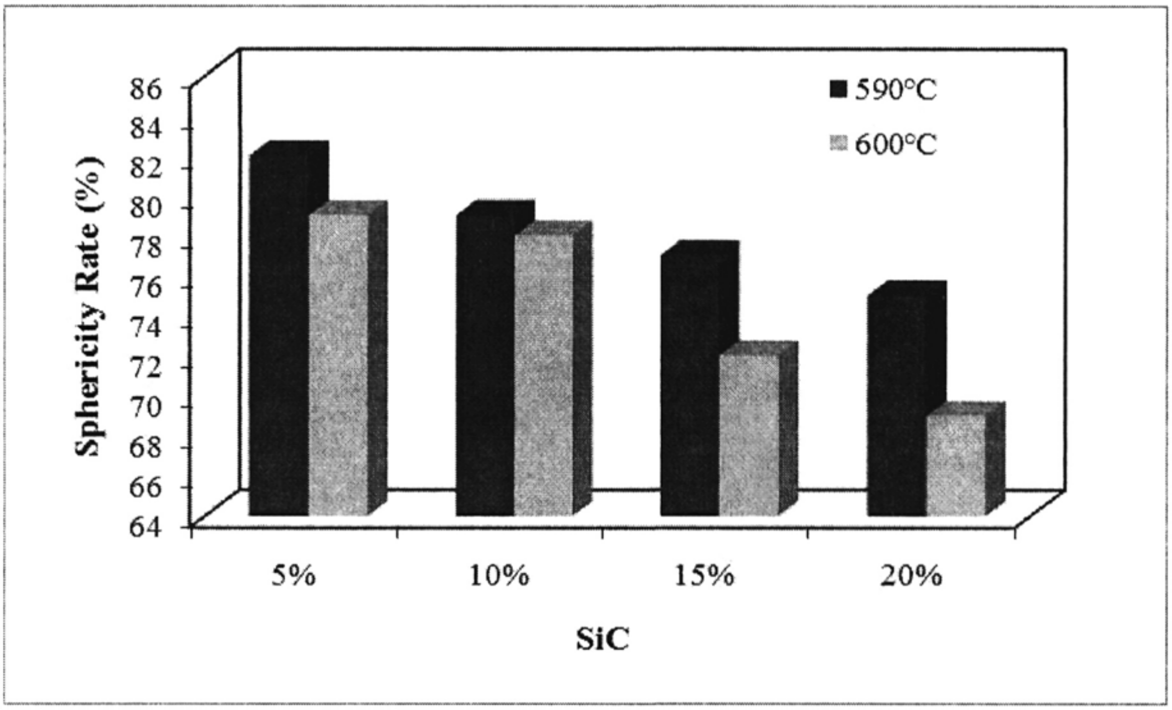


Fig. 5: The fraction of perfect sphere rates of Al/ SiC composite materials produced with thixomoulding at 863 K (a) and at 873 K

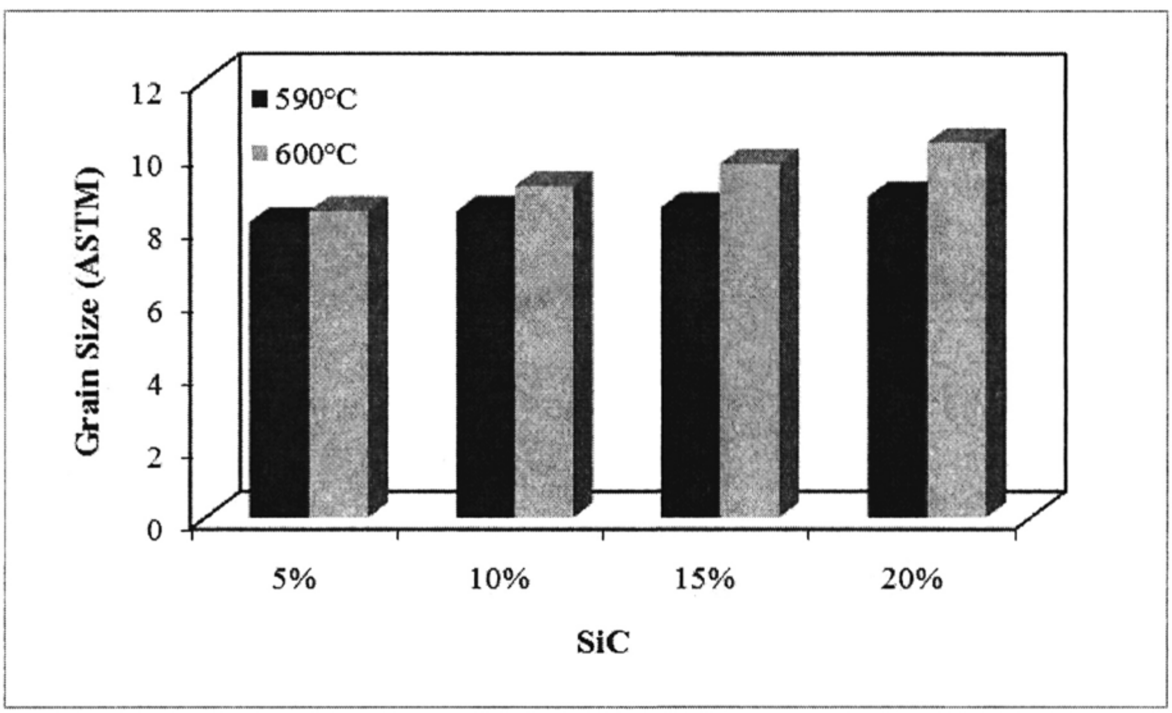


Fig. 6: Grain sizes of Al/ SiC composite materials produced with thixomoulding at 863 K (a) and 873 K (b)

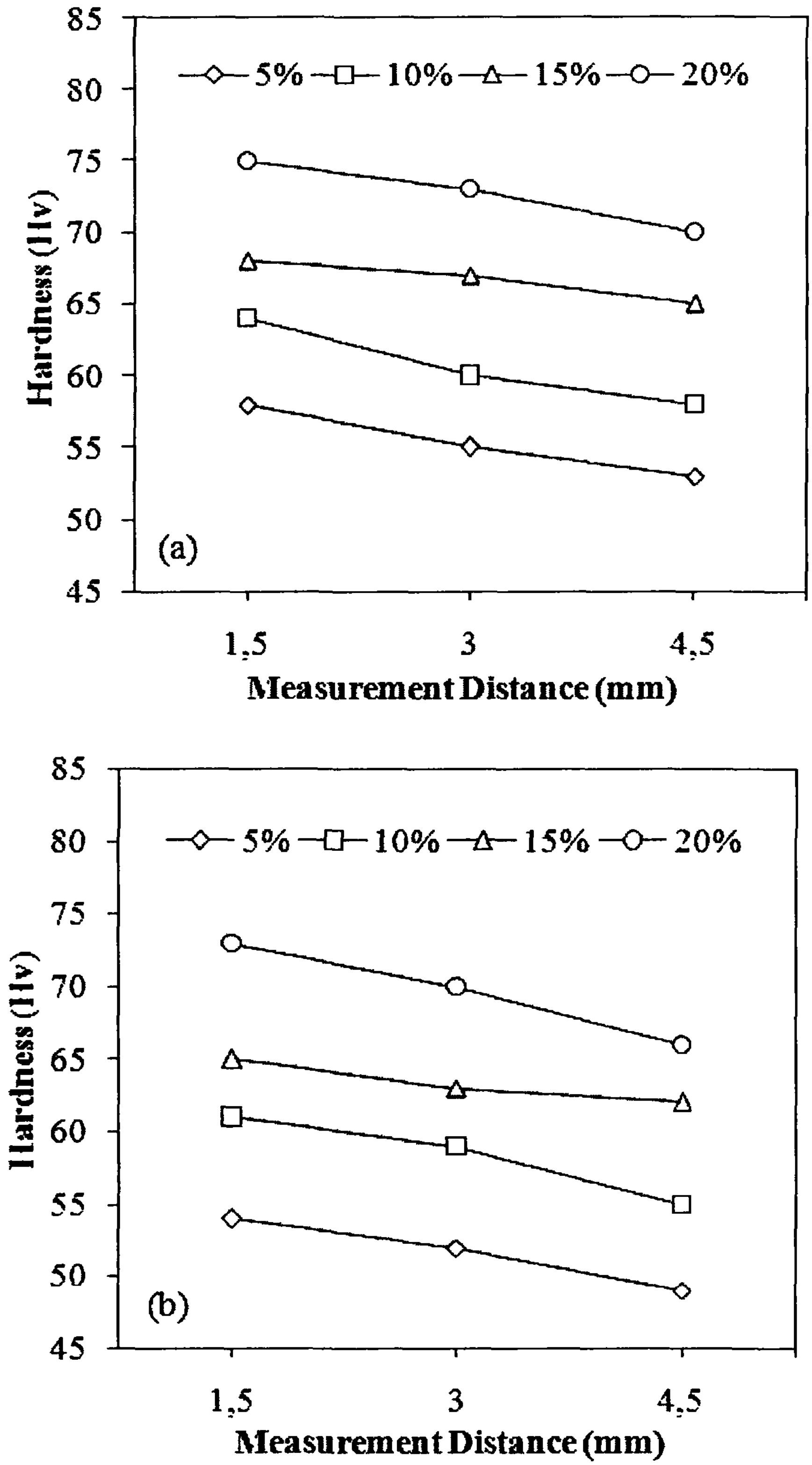


Fig. 7: Hardness changes from the outer surface to the centre in Al/SiC composite materials produced with thixomoulding at 863 K (a) and 873 K (b)

increasing tendency in grain size is observed. The grain sizes of aluminum composite materials produced at 863 K vary between 8.1 and 8.8 depending on reinforcement amount. (**Figure 6a**) When the semi solid process temperature is raised to 873 K, in parallel to the increase in reinforcement rate, grain size varies between 8.4 and 10.3 (**Figure 5b**) As known, as temperature increases, grain growth is observed in the microstructure. Moreover, it is understood from the results that the increase in reinforcement rate is also influential on grain growth. This is because, an increase in temperature increases liquid rate in material. With the effect of applied pressure, primer α-Al grains have more contact surface. With the influence of temperature, small grains combine more easily. In a previous study, it is also stated that semi solid process temperature is influential on material's grain size and spherical shape condition /5/.

3.3 Hardness investigations

In **Figure 7**, hardness values of Al/ SiC composite materials produced with thixomoulding at 863 K (a) and 873 K and taken from outer surface to the center are given. Hardness measurements were made with 1.5 mm distances. As a result of the measurements, the hardness of the composite materials produced both at 863 K and 873 K decreased from the outer surface to the center. In both types of materials, hardness values increase in parallel to the increase in reinforcement rate. The reason for the decrease in hardness from outer surface to the center is certainly related to the solidification conditions. As semi solid components formed with semi solid process are quenched, the outer surface of the produced material is harder compared to the center. Moreover, as liquid level in liquid- solid balance will increase because of the increase in process temperature, grain growth tendency in the structure will also increase. Because of this reason, the hardness measurements of composite materials produced at 863 K are expected to be higher than those produced at 873 K. Grain sizes given in **Figure 6** also support the hardness results.

4. CONCLUSIONS

In this study, in the production of SiC reinforced aluminium matrix composites by semi solid processing, the effects of reinforcement and process temperature on the fraction of perfect sphere rate and grain size were investigated. The following conclusions can be drawn from this study:

1. While a dendritic micro structure is observed in specimens obtained with traditional casting methods, a globular grain structure was observed in specimens produced with semi solid forming method.
2. It was observed that in Al-Si matrix 5%, 10%, 15% and 20% SiC reinforced composite material production, the ideal semi solid temperature was found to be 863 K.
3. Grain growth was observed depending on the increasing liquid rate. With changing percent solid-liquid rate at high temperature, 873 K.
4. Depending on the increasing in temperature, oxidation was observed in specimens produced at 873 K.
5. The fraction of perfect sphere rate was found to decrease with increasing SiC in the composite.
6. While hardness measurements of specimens produced with thixomoulding increase depending on the increase in SiC reinforcement, hardness measurements of specimens decrease from the outer surface to the centre.

ACKNOWLEDGEMENTS

This work has been supported by DPT (the State Planning Organization of Turkey) under project number 2003K121110. The authors are grateful to the DPT for financial support and Karabuk University for the provision of laboratory facilities.

REFERENCES

1. Q.D.Qin, Y.G.Zhao, P.J.Cong, W.Zhou and B.Xu, *Mater. Sci. Eng.* **A 444,** 99-103 (2007).
2. C.G.Kang, J.W.Bae and B.M.Kim, *J. Mater. Proces. Techno.,* **187-188,** 344-348 (2007).
3. D.Liu, H.V.Atkinson, P.Kapranos, W.Jirattiticharoean and H.Jones, *Mater. Sci. Eng.* **A 361,** 213-224 (2003).
4. S.Nafisi and R.Ghomashchi, *Mater. Sci. Eng.* **A 452/453,** 437-444 (2007).
5. D.Özyürek, N.Aktar and H.Aztekin, *Materials and Design,* **29,** 1070-1074 (2008).
6. H.K.Jung, H.G.Kim and C.G.Kang, *J. Mater. Proces. Techno.* **182,** 220-228 (2007).
7. H.K.Jung and C.G.Kang, *Key Eng. Mater.* **177/180,** 565-570 (2000).
8. P.J.Ward, H.V.Atkinson, P.R.G.Anderson, L.G.Elias, B.Garcia, L.Kahlen and J.M.R.Ibabe, *Acta Mater.* **44,** 1717-1727 (1996).
9. H.K.Jung, P.K.Seo and C.G.Kang, *J. Mater. Proces. Techno.* **113,** 568-573 (2001).
10. O.Lashkari, S.Nafisi, J.Langlais and R.Ghomashchi, *J. Mater. Proces. Techno.* **182,** 95-100 (2007).
11. P.K.Seo, D.U.Kim and C.G.Kang, *Mater. Sci. Eng.* **A 445/446,** 20-30(2007).
12. S.Naher, D.Brabazon and L.Looney, *Composites: Part A* **38,** 719-729 (2007).
13. M.R.Jafari, S.M.Zebarjad and F.Kolahan, *Mater. Sci. Eng.* **A 454/455**, 558-563(2007).
14. Q.Q.Zhang, Z.Y.Cao, Y.F.Zhang, G.H.Su and Y.B.Liu, *J. Mater. Proces. Techno.* **184,** 195-200 (2007).
15. K.Yasue, A.Radjai, K.Miwa and Y.Sakaguchi, *J. Mater. Sci.* **38,** 3591-3595 (2003).
16. E.M.R.Navas, J.B.Foragnolo, F.Valesco, J.M.R.Prieto and L.Froyen, *Composites: Part A* **37,** 2114-2120 (2006).
17. L.E.G.Cambronero, E.Sanchez, J.M.R.Roman and J.M.R.Prieto, *J. Mater. Proces. Techno.* **1437144,** 378-383 (2003).
18. J.M.Torralba, F.Valesco, C.E.Costa, I.Vergara and C.Caceres, *Composites: Part A* **33** 427-434 (2002).
19. D.C.Jia and Y.Zhou, *Mater. Sci. Eng.* **A 252,** 44-52 (1998).
20. L.Lu, M.O.Lai and C.W.Ng, *Mater. Sci. Eng.* **A 252,** 203-211 (1998).
21. J.K.M.Kwok and S.C.Lim, *Composites Science and Technology,* **59,** 65-75 (1999).
22. J.C Lee, H.K.Seok and H.I.Lee, *Materials Research Bulletin,* **34,** No.1, 35-42 (19999.