TECHNICAL ARTICLE

Production of Metal Matrix Composites by the Vortex Method and Investigation of the Effect of Changing Casting Temperature on Particles Ratio of Product-Composite

K. Ozdin

Mechanical Engineering Department, Hitit University, Çorum, Turkey

Keywords
Metal Matrix Composites, Vortex Method, Casting Temperatures, Particle Ratio

Correspondence
K. Ozdin, Mechanical Engineering Department, Hitit University, Çorum, Turkey
Email: k.ozdin38@yahoo.com

Received: August 3, 2011; accepted: April 29, 2012

doi:10.1111/j.1747-1567.2012.00840.x

Abstract

In this study, Al-2011 alloyed and Al_2O_3 particle-reinforced metal matrix composite (MMCs) were produced by using the Vortex method. Immediately after pouring composite to the mold and before full solidification, the porosity inside composite has decreased to accepted values by applied pressure. Product-composites were produced with approximately 8, 16, and 24 vol% Al_2O_3 particles. The effects of casting temperature were investigated on production of MMCs at targeted particle ratios. In addition, the effects of increased particle ratio to hardness were tested. According to the results of experiments, when casting temperature changes, the particle ratio of product-composite and rest-composite (the composite that remains at the bottom of pot after casting) also changes. As the difference between casting temperature and proper casting temperature grows, the difference between those rates increases. Moreover, it can be clearly seen that the increasement at composite's particle ratio also cause to an increase at hardness.

Introduction

Production of MMCs by the Vortex method

At present, conventional materials cannot meet the superior engineering material necessities of rapidly developing technologies. As a result of recent studies, there is a great demand on composite materials due to developments on their properties.[1,2] After these studies, a lot of improvement has been achieved on composite materials' many properties such as tensile strength, elastic modulus, toughness, creep, fatigue, and wear.[3,4] The production of composite materials is based on the combination of different materials' superior properties depending on requirements. When the low density, ductility, and toughness of alloy and high strength, elastic modulus, and hardness properties of ceramics such as Al_2O_3 or SiC are combined in a composite material, extremely important engineering materials that have tribological properties, which also includes abrasive wear, were produced.[5,6]

In comparison, as a reinforcing material, fibers are more expensive than particles and show anisotropic properties. Therefore, the usage of particles on developing composite materials has increased and generally Al_2O_3 and SiC ceramic particles are being used.[7] Al alloys are preferred as matrix because of their chemical and physical suitabilities with these particles.[8] However, due to some problems encountered in the production of particle-reinforced MMCs, the production method is still under development.[9] The most suitable one of many production methods is the Vortex method that is obtained by mixing ceramic particles into molten metal as supplement material as shown in Fig. 1. This method is one of the most common methods that is used in the production of MMCs.[10] In order to produce superior MMCs with the Vortex method, parameters such as mixing ability, reinforcing speed, mixing time, mixing temperature, and casting temperature must be determined precisely. Parameter errors cause problems such as high porosity, particle flocculence, and particle

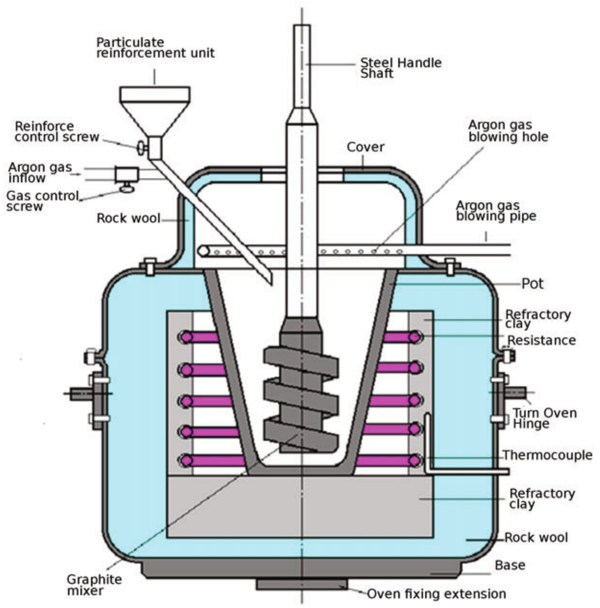

Figure 1 The view of composite material production oven which is used for the Vortex Method.

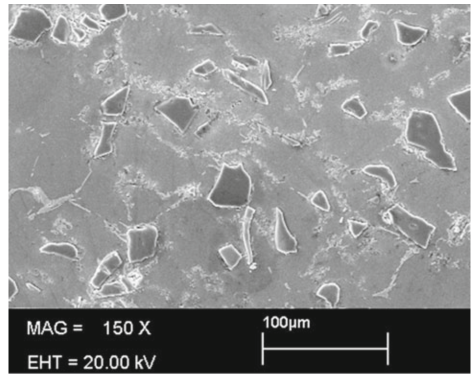

Figure 2 The SEM picture of composite that have Al-2011 matrix and 16% Al_2O_3 particles.

sedimentation.[10,11] One of the most important problems encountered in the production of MMC is that ceramic particles are not heated enough with the use of liquid metal.[12] Another problem is the tendency of particles to remain on the surface of liquid metal or sinking to the bottom depending on the value of density difference for liquid metal and particles.[8] To improve wettability, some methods such as coating particle surface, increasing the heat of liquid metal, or oxidation of particles with heat treatment are used.[9] To reduce density difference, the densities of matrix and particles are approximated to each other by adjusting the casting temperature. At the same time, this provides a more homogeneous distribution of particles inside the liquid matrix by causing a difference in viscosity of molten metal.

In this study, MMCs were produced by reinforcing Al_2O_3 particles inside Al-2011 alloy at 8, 16, and 24 vol% Al_2O_3-32 µm particle size by using the Vortex method (Fig. 1). The composite that has 16% Al_2O_3 can be seen in Fig. 2.

Soon after pouring the composite to the mold, porosity values are reduced to acceptable values by applying pressure with press before the composite completely solidifies. Also, the rest-composite, which remained at the bottom of pot, was produced by pouring on the mold.

Determination of casting temperature

One of the most important parameters for production of MMCs with the Vortex method is casting temperature. It is not possible to produce proper MMCs when the casting temperature is not suitable for production. After obtaining homogeneous distribution of mixing particles inside melted alloy, the particles precipitate to the bottom of pot because of the difference of density during the casting process to the mold. When the casting temperature deviates from appropriate values, the average density difference between product-composite and rest-composite increases. In order to decrease the density differences between produced composite and the ones that remain at the bottom of the pot, the most suitable casting temperature must be defined to produce MMCs that contain particles at the targeted ratio. Correctly defined casting temperature makes the density of matrix and particles more close because of the difference of thermal expansion coefficient. At the same time, by causing changes on viscosity of molten metal, particles' precipitation could be measured at the bottom inside liquid matrix or at least this can decrease the precipitation speed of particles at the bottom of the pot. This situation can give the opportunity to produce MMCs composite at aimed ratio of particles by decreasing the density differences of product-composite and the composite that remain at the bottom of the pot.

Determination of hardness values

Brinell hardness measurements of MMCs, which is Al_2O_3 particle reinforced at different volume ratios and Al-2011 alloys, were done by using 2.5-mm-diameter ball and 187.5 kg applied load. Eight different treatments were tested for each sample, and their average was taken as hardness value.

Table 1 Density values of composites that is produced at different casting temperatures

Materials	d_{teo}	Casting temperature, 680°C		Casting temperature, 690°C		Casting temperature, 700°C	
		d_{pc}	d_{pbc}	d_{pc}	d_{pbc}	d_{pc}	d_{pbc}
8% Al_2O_3	2.84416	2.818367	2.848964	2.816761	2.853769	2.817406	2.85185
16% Al_2O_3	2.94032	2.877772	2.949933	2.874562	2.959548	2.875847	2.955705
24% Al_2O_3	3.03648	2.907574	3.066702	2.908029	3.065326	2.909951	3.059554

Results and Discussion

The effect of changing casting temperature on particles ratio of product-composite

In this study, 8, 16, and 24 vol% Al-2011 alloyed Al_2O_3 particle-reinforced MMCs were produced for 680, 685, and 690°C casting temperatures at 500°C molding temperature. Theoretically, product-composite and the composite that remained at the bottom of the pot densities of alloys and composites are given at Table 1 for each casting temperature.

As can be seen from Fig. 3, when the casting temperature increases, the particle ratio of rest-composite also increases and each of them had more particle ratios than the targeted composite-particle ratio (8, 16, and 24%). It is thought that this reduction is due to the presence of composites that have less particle ratio at the top of the pot during the casting process, and this situation was caused by the increase of sedimentation rate at the bottom of pot as a result of the casting temperature. This difference was increased more when the casting temperature also increased. When the particle ratio of the composite that is desired increases, the difference between the particle ratio of rest-composite and targeted composite also increases. The reason for this increase is related to the increase in the number of precipitated particles per unit time depending on the targeted composite's particle ratio. Also, the route is thought to be increased during the precipitation of particles.

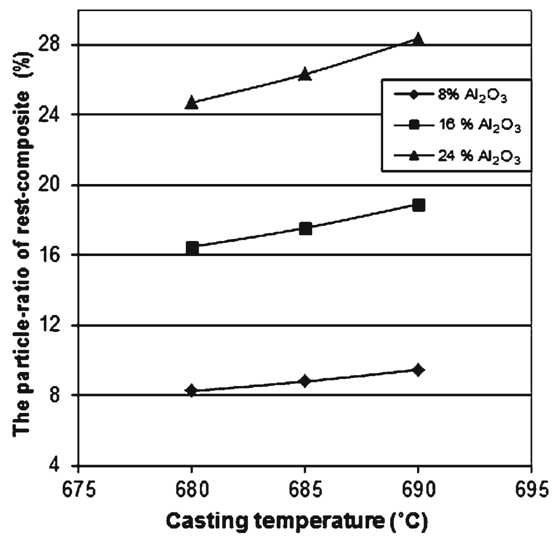

Figure 3 Particle ratios of produced rest-composites at different casting temperatures.

In Fig. 4 when the casting temperature is increased, ratios of particle are decreased. Each of particle ratios of product-composite is less than targeted ratio of composite (8, 16, and 24%). It is thought that this reduction is because of composites that have less particle ratio at the top of pot during casting process, and this was caused by the increase of sedimentation rate to the bottom of pot as a result of casting temperature. This difference has increased more according to the casting temperature's increasement.

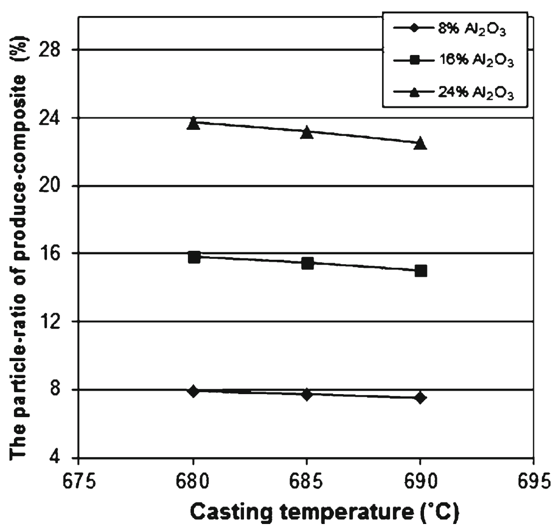

Figure 4 The particle ratios of product-composites that was produced at different casting temperatures.

Divergences of particle ratio of product-composite and rest-composite that belong to different composites are shown in Fig. 5 at various temperature.

Figure 5 shows that differences of between particle ratios of product-composite and rest-composite have been increased as long as the casting temperature

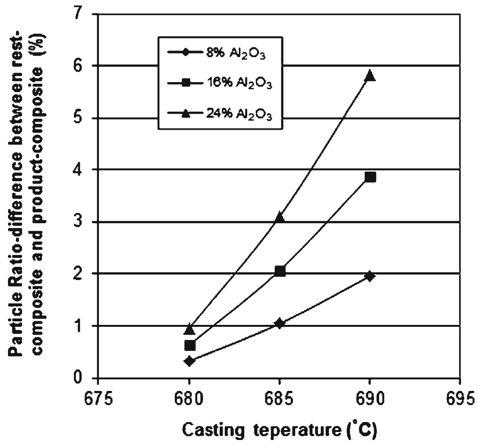

Figure 5 The particle ratio differences of composites, which is targeted to produce as rest-composite and product-composite at different temperatures and ratios.

is increased. For instance, differences between particle ratios of product-composite and rest-composite included 16% Al_2O_3 particle is approximately 0.3% at 680°C, 1.1% at 690°C, and 1.9% at 700°C. At the same time, when particle of the required production composite, differences of particle ratios of product-composite and rest-composite is increased. If we examine this result at 700°C, when the particle ratio of required composite is 8, 16, and 24%, differences of particle ratios of product-composite and rest-composite are, respectively, approximately 1.9%, 3.8%, and 5.7%.

The effect of particles ratio on hardness of composite

Figure 6 shows that change of hardness of Al-2011 matrix and particle ratio of different Al_2O_3 composites. Hence, the hardness of composite is increased when volume ratio of particle is raised. Compared to the hardness of material of matrix, the hardness of MMC is far greater.

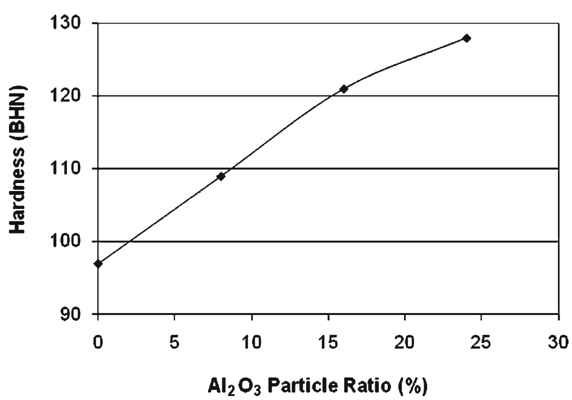

Figure 6 The change of hardness with changing particle ratio of Al_2O_3 in Al-2011 matrix is shown.

Conclusions

In this experiment, it was seen that the product-composite particle rate was below the targeted composite particle rate. In addition, it was observed that the rest-composite's particle rate was higher than that of targeted composite under the same conditions. As the casting temperature is increased, the difference between rest-composite particle rate and product-composite particle rate also increases. Considering these results, it can be concluded that in order to produce the composite that has the closest possible composite particle rate to targeted composite particle rate, the most appropriate casting temperature should be determined. In order to reduce the difference between ratios of these two composites and produce the composite that has targeted particle ratio, suitable casting temperature must be determined. Moreover, observed in this study, hardness of the composite is much greater than hardness of the matrix. In addition, as long as particle ratio of composite is raised, hardness is also increased.

References

1. Jiang, J.Q., Ma, A.B., Liu, H.N., and Tan, R.S., ''The Wear Properties of an Alumina-Aluminosilicate Fibre Hybrid Reinforced Al-Si Alloy in a Lubricated Condition,'' *Wear* **8**:171–163 (1994).
2. Chen, E.Y., Lawson, L., and Meshii, M., ''The Distribution of Fatigue Microcracks in an Aluminum-Matrix Silicon Carbide Whisker Composite,'' *Scripta Metallurgica et Materialia* **30**:737–742 (1994).
3. Taya, M., and Arsenault, R.J., *Metal Matrix Composites, Thermomechanical Behavior,* Pergamon Press, Oxford, UK, (1989).
4. Aykul, H., and Ozdin, K., ''Residual Stres Analysis of Aluminum Metal Matrix Composite Laminated Plates with a Square Hole,'' *Journal of Reinforced Plastics and Composites* **28**(11):1281–1295 (2009).
5. Ibrahim, I.A., Mohammed, F.A., and Lavernia, E.J., ''Particulate Reinforced Metal Matrix Composites a Review,'' *Journal of Materials Science* **26**:1137–1156 (1991).
6. Ünlü, B.S., ''Investigation of Tribological and Mechanical Properties Al_2O_3-SiC Reinforced Al Composites Manufactured by Casting or P/M Method,'' *Materials and Design* **29**:2002–2008 (2008).

7. Sahin, Y., and Ozdin, K., ''A Model for the Abrasive Wear Behaviour of Aluminium Based Composites,'' *Materials and Design* **29**:728–733 (2008).
8. Hanumanth, G.S., and Irons, G.A., ''Particle Incorporation by Melt Stirring for the Production of Metal-Matrix Composites,'' *Journal of Materials Science* **28**:2459–2465 (1993).
9. Gül, F., and İnem, B., ''Development of SiC-Reinforced Composites via Casting,'' *Technological Advances Symposium on Defence Industry*, Military Academy, Ankara, Turkey (1997).
10. Akbulut, H., Durman, M., and Yılmaz, F., ''SiC Seramik Partikül Takviyeli Alüminyum-Silisyum Metal Esaslı Kompozitlerin Üretimi ve Özelliklerinin İncelenmesi Investigation of Ceramic SiC Particle Reinforced Aluminum-Silicon Metal Based Composites Production and their Characterization,'' *7th International Metallurgy and Material Congress,* Ankara, **7:**1183–1194 (1993).
11. Ghost, P.K., and Ray, S., ''Influence of Process Parameters on the Porosity Content in Al(Mg)-Alumina Cast Particulate Composite Produced by Vortex Method,'' *AFS Transactions* 775–782, 88–214 (1998).
12. Lloyd, D.J., ''Particle Reinforced Aluminum and Magnesium Matrix Composites,'' *International Materials Reviews* **39**(1):1–23 (1994).