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THE EFFECT OF REINFORCEMENT RATIO ON THE COMPOSITE STRUCTURE AND MECHANICAL PROPERTIES IN Al-MgO COMPOSITES PRODUCED BY THE MELT STIRRING METHOD

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ABSTRACT

In this study, Al- MgO metal matrix composites (MMC) were produced with 5 %, 10 % and 15 % reinforcement- volume (R-V) ratios by the melt stirring method. In the production of composites 99.5 % pure Al was used as the matrix and MgO powders with the particle size of -105 μm were used as the reinforcement. For every R-V ratio; stirring was made at 500 rev/min at 750°C liquid matrix temperature for 4 minutes and the samples were cooled under normal atmosphere. Then hardness and fracture strengths of the samples were determined and their microstructures were evaluated by using Scanning Electron Microscope (SEM). In general, it was observed that the reinforcement exhibited a homogeneous distribution in horizontal direction. But there is a slight inhomogeneity in vertical direction. It was determined that the increase in the R-V ratio increased the porosity and also the hardness. As for the fracture strength, the highest strength was obtained with the 5 % MgO reinforced sample.

Keywords : Melt stirring, composite, MgO

1. INTRODUCTION

In the recent years, depending on the increasing demands of industry, the investigations on the composites of different characteristics have accelerated. Composite materials find more usage in industry day by day due to their excellent strength properties, producibility at different compositions and shapes, high strength to fatigue, toughness, high temperature, oxidation and wear [1]. There are many different composite materials and production types and every day new ones are being added. One of these composite materials is the metal matrix composite (MMC). For the MMC materials almost all of the engineering materials can be used as matrix [2]. Aluminium, magnesium and their alloys are most commonly used as matrix materials in the production of MMC due to their lightness and ductility. Materials like SiC, SiO_2 , Al_2O_3 and MgO are generally preferred as reinforcement elements [3]. In the production of MMC, different methods such as casting, melt stirring, powder metallurgy, in-situ, and infiltration are used [4-6]. As being one of the production methods of particle-reinforced MMC materials, the melt stirring method has a good potential in the general-purpose applications for low cost MMC production [7].

For the successful addition process of reinforcement elements used in the production of MMC materials, it was seen in literature that the important and effective criteria was the selection of a suitable method and material. Furthermore, in the MMC production with the melt stirring method it has been specified that with the increase of the percentage of reinforcement amount and decrease of particle size, the production process was more difficult and the amount of porosity and particle agglomeration was increased [7, 8].

By using the melt stirring and other casting methods, MMC materials with very different characteristics can be produced. In several studies various matrix materials and reinforcement elements were used and it was observed that many investigations were made for the distribution of reinforcement elements inside the composites and for their effect on the microstructure, porosity, hardness, abrasion behaviour and rupture strength and for the effect of

stirring time and speed [9-20]. In this study, the effect of R-V ratio on the composite microstructure and some mechanical characteristics were investigated for the composites which were produced by the melt stirring method.

2.EXPERIMENTAL STUDY

In composite production, ETIAL 5 aluminum alloy and MgO with the particle size of –105 μm were used as the matrix and reinforcement material respectively. The chemical compositions of these materials are given in Table 1 and Table 2.

Table 1. Chemical composition of matrix material Al

Eti norm	Al%	Fe%*	Si%*	Cu%*	Zn%*	Ti%*	Others
EtiAl 5	99.50	0.40	0.25	0.05	0.05	0.04	0.03

* Unless the limits are given the values are max.

Table 2. Chemical composition of reinforcement element MgO

MgO %	Fe %	SiO_2 %	CaO %
98	0,6	1.0	0.4

Matrix material was put into a stainless steel crucible ladle (Fig 1.) and melting process started and the liquid matrix temperature was increased to 750°C. The melt was kept for 5 minutes in order for the melt temperature to be homogenous. Stirring apparatus was immersed into the liquid metal and the stirring speed was gradually increased up to 500 rev/min. Then the previously determined amount of MgO powder was added into the liquid metal with the aid of a funnel. Upon completion of the addition of the reinforcement element into the liquid matrix (Al), stirring process continued at 500 rev/min for 4 minutes. Then the liquid-solid mixture was casted into steel moulds of 30 mm diameter and 80 mm length and cooled to room temperature in normal atmosphere. The same processes were applied for every R-V ratio separately.

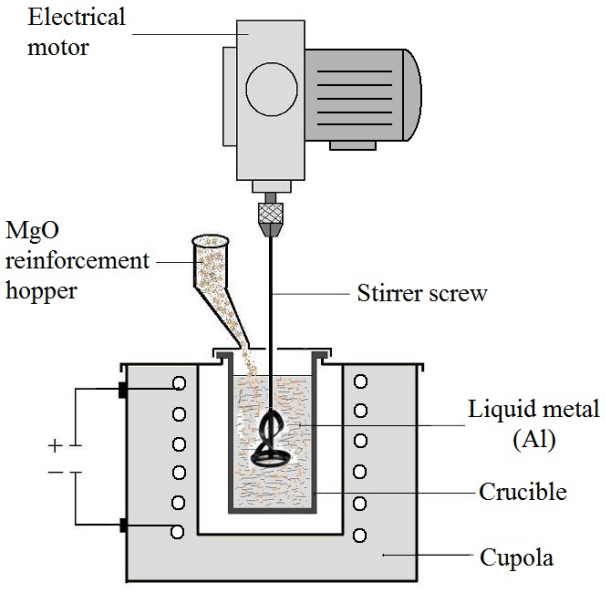


Fig 1: Melt stirring test apparatus

Firstly, for the aim of determining the mechanical properties, composites were produced at 5 %, 10 % and 15 % MgO reinforcement-volume rates for the hardness measurement and the surface of the samples was polished with 1200 mesh emery paper by preparing three piece of samples for each reinforcement-volume ratio. Hardness measurements were made by Brinell Hardness method under 31.25 kgf load using a steel ball of 2.5 mm diameter. On the samples for every R-V ratio, separate hardness measurements were made at ten different points and averages of the values were taken.

Secondly, three pieces of transverse rupture test samples were prepared for each R-V ratio. For the purpose of determining the mechanical strength of the composite materials, test samples of 6.35mm x 12.7mm x 31.75mm were prepared according to ASTM-B 528-05 [21] and on the hydraulic test press, transverse rupture tests were carried on under 0.05 kN/s load. Tests were repeated three times on the samples which were made from composite materials for every R-V ratio and the averages of the measured values were taken. After the mechanical tests, the amounts of porosity of the composites were determined by Buoyancy method which is based on Archimedes principle. Finally, by employing SEM and optical microscope, the images of the fractured surfaces were taken to examine the microstructure and fracture behaviour of composite materials.

3. RESULTS AND DISCUSSION

3.1. The effect of R-V ratio on the mechanical characteristics

The hardness values of composite materials according to R-V ratio is given in Fig 2.

As seen from Fig 2, 5 % MgO, 10 % MgO and 15 % MgO reinforced composite materials exhibited the average hardness values of 50.2 HB, 52.1 HB and 56.4 HB respectively. Depending on the increase of MgO reinforcement particles in the MMC samples, hardness values were observed to increase as well. With the increase of R-V ratio from 5 % to 10 %, hardness increased approximately 4 % whereas increase in hardness was 8 % when the R-V ratio increased from 10 % to 15 %. The hardness values of MMC samples exhibited a higher increase than the increase of MgO ratio. It was observed that there

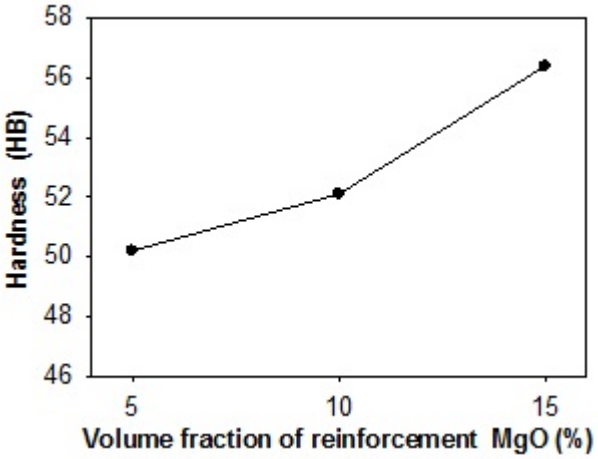


Fig 2: R-V ratio and HB hardness relationship of composite samples

were no big differences among the ten hardness values that were measured on each sample. This was attributed to the fairly homogeneous distribution of reinforcement inside the matrix. Besides, increase of hardness with the increase of R-V ratio was an expected result. Transverse rupture forces of MMC samples with respect to R-V ratio are given in Fig 3.

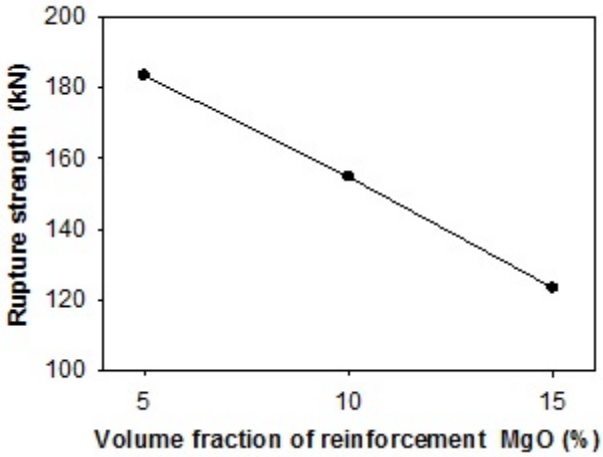


Fig 3: R-V ratio and transverse rupture strength relationship of composite samples

As seen from Fig 3, 5 % MgO, 10 % MgO and 15 % MgO reinforced composite materials showed the average transverse ruptured values of 183.5 kN, 154.8 kN and 123.4 kN respectively. Fracture strength decreased with the increase of the reinforcement ratio. This can be explained by the notch effect made by the reinforcement element particles during fracture and affecting the fracture strength adversely. Besides, as in Fig 5, the porous structure in the composite materials can possibly affect the fracture strength adversely. Similar results were claimed in the studies of Calın [22] and Chong [23].

When the microstructures in Fig 5 and Fig 6 were examined, the most porous structures were on the 15 % MgO reinforced sample . Porosities were generally forming around the reinforcement particle and the highest porosity ratio was on the 15 % MgO sample. This might speed up the fracturing and decrease the fracture strength. In Fig 4 SEM images taken from the fractured surfaces are given.

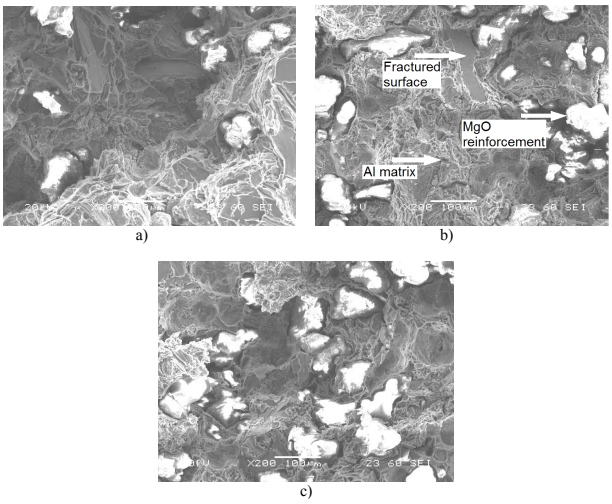


Fig 4: Fracture microstructures of composites which were produced on the R-V ratio of
a) 5% MgO b) 10% MgO c) 15% MgO

When the fracture microstructures in Fig 4 were examined, it was observed that due to the characteristics of the matrix material (Al) the ductile fracture mechanism was effective and there was fracture on the reinforcement particles rarely and it can be said that the fracture occurred generally on the matrix-reinforcement interface.

3.2. The effect of R-V ratio on the porosity and microstructure

The porosity amounts and microstructure images of composite samples are given in Fig 5 and Fig 6.

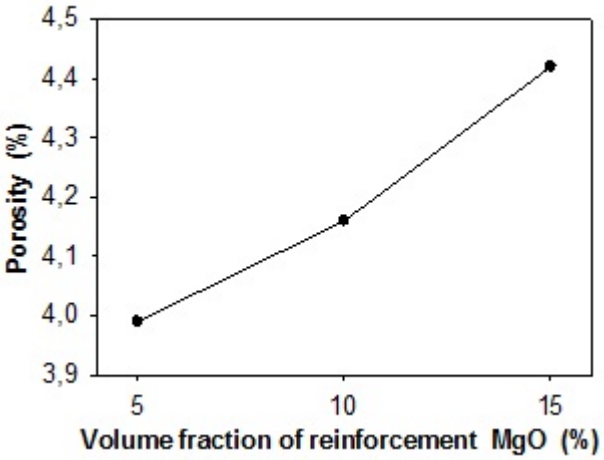
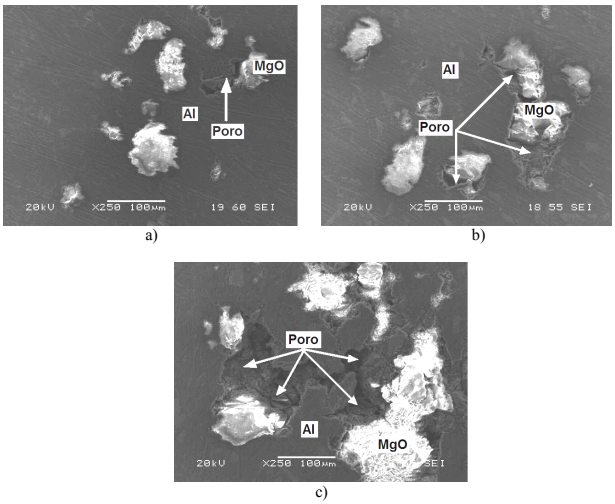


Fig 5: R-V ratio and porosity value relationship of composite samples

When the theoretical and experimental calculation results were transferred to draw a graph, porosity value of the 5 % MgO reinforced composite was 3.99 % whereas it was 4.16 % for the 10 % MgO reinforced composite. The highest porosity value was calculated as 4.42 % for the 15 % MgO reinforced sample. This also supports the increasing amount of porosity depending on the R-V ratio on the SEM images in Fig 6. Similar results were also stated by Calın and Cıtak, Acılar [24, 25].



a) b) c)

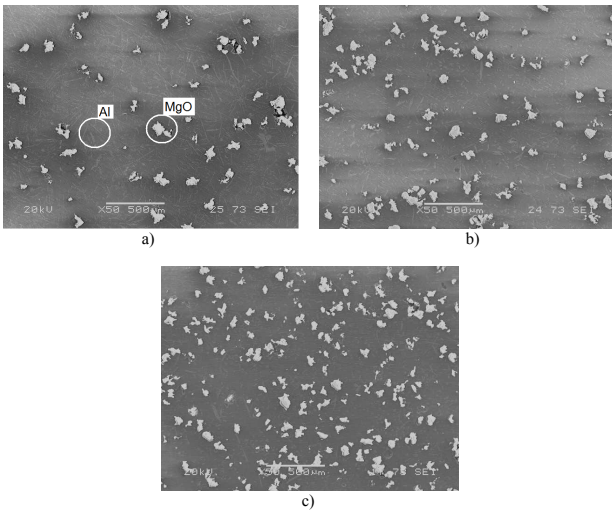
Fig 6: Porosities of composites which were produced depending on the R-V ratio of
a) 5% MgO b) 10% MgO c) 15 % MgO

When the SEM images were examined in Fig 6, it was seen that the amount of porosities of composities increased with the increase of R-V ratios. The porosities were concentrated at the reinforcement-matrix interface. Although the MgO particles in the liquid matrix increase, this situation can be explained as the inadequate wetting of the reinforcement element by the liquid matrix.

3.3. Microstructure characteristics and the effect of R-V ratio on the MgO particle distribution

In order to examine the composite structure in MMC materials, the microstructure images of the 5% MgO, 10% MgO and 15 % MgO reinforced composite samples taken at the SEM are given in Fig 7. The microstructure images were taken from the samples (20 mm diameter x 8 mm lentgh) prepared from the central part of the composite material for every R-V ratio.

When the SEM images were examined, it was observed that the distribution of MgO particles were generally homogeneous. The microstructures at the three R-V ratios showed the level of reinforcement



a) b) c)

Fig 7: The microstructures of composite samples produced depending on the R-V ratio of
a) 5 % MgO b) 10 % MgO c) 15% MgO

agglomeration was negligibly low. As it was seen from these favourable structure properties the liquid Al temperature of 750°C was suitable, stirring speed of 500 rev/min and stirring time of 4 min were sufficient. Besides, it can also be stated that the addition of MgO with the particle size of -105 µm into the Al matrix by the melt stirring method was suitable and the matrix can be produced successfully.

The liquid mixture was put into a mould of 30mm

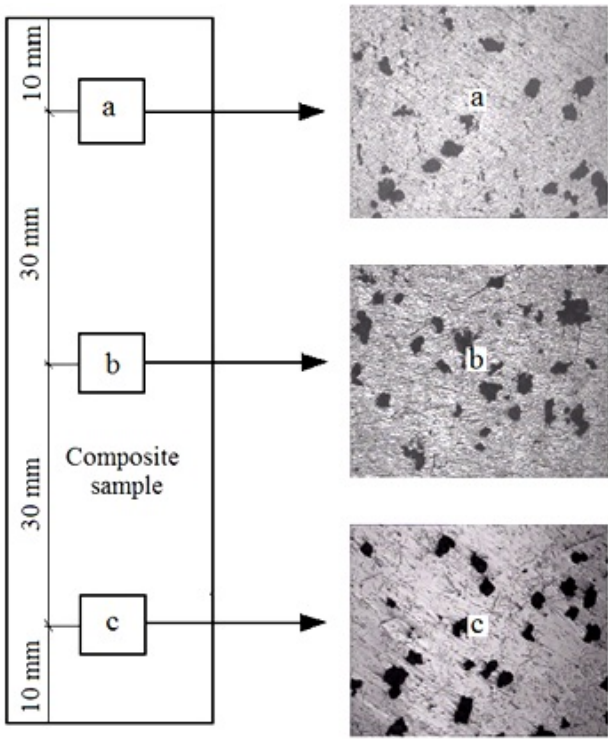


Fig 8: The regional microstructures of 10 % MgO reinforced sample
a)Top b) Central c) Lower

diameter × 80 mm. For the purpose of examining the behaviour of this mixture in every part of the mould and to determine the level of homogeneity of reinforcement distribution, one piece of 10 % MgO reinforced sample was removed from the mould and then polished with 1200 mesh emery paper and optical microscopic images from the top, central and lower parts were taken. In Fig 8 the regional images taken from this sample are given.

When the images were examined it was seen that the reinforcement element MgO was generally distributed homogeneously. On the microstructure in a, b, c regions, besides the homogeneous distribution of reinforcement, a slightly increase in the reinforcement distribution was observed when going down to lower regions. This can be explained by the occurrence of a certain amount of precipitation of reinforcement during the cooling of liquid mixture due to the greater specific gravity of reinforcement than that of the matrix material.

4. CONCLUSIONS

The results obtained from this study are summarized below:

- The hardness value of the composites increase depending on the increase of R-V ratio.
- In the MMC production by the melt stirring method, the MgO with the particle size of – 105 μm was homogeneously distributed inside the liquid Al at all R-V ratios. In this case, the particle size of the composite used in the production of MgO can be said to be appropriate.
- According to the pouring direction; reinforcement element MgO agglomerated more intensively at the central and lower parts of the composite materials.
- Supplemented with MgO to increase the amount of liquid matrix mixing of reinforcements and a little difficult to wetting.
- Selected experiments, 750 ° C liquid Al temperature, 500 rev/min, the mixing speed and mixing time of 4 minutes was sufficient. However, more homogeneous distribution of reinforcement within the matrix provide MgO and further to improve the wetting on some of these values can be said to come up.
- Depending on the increasing MgO reinforcement ratio, the porosities increased in the composites. Porosity to reduce the amount of the liquid Al to the matrix may be benefit to increase the temperature and mixing time. In this case, the liquid Al to, drenched in better reinforcement particles of MgO matrix - reinforcement of interfaces is thought to reduce the porosity.
- To say how much decrease porosity rate within composite structure, experiment parameters like the liquid Al temperature, stirring speed, stirring time are changed, In the R-V rates, wide range of experiments can be made and this may be evaluated as a separate study.
- With the increase of R-V ratio the fracture strengths of composites decreased. This was attributed to the notch effect which was made by the reinforcement in the composite structure. Besides, it can be stated that with the increase of R-V ratio, porosities in the structure increase and speed up the fracture.

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