Using Fly Ash as a Reinforcement to Increase Wear Resistance of Pure Magnesium

E. Karakulak, R. Yamanoğlu, M. Zeren

***Abstract*—**In the current study, fly ash obtained from a thermal power plant was used as reinforcement in pure magnesium. The composite materials with different fly ash contents were produced with powder metallurgical methods. Powder mixtures were sintered at 540°C under 30 MPa pressure for 15 minutes in a vacuum assisted hot press. Results showed that increasing ash content continuously increases hardness of the composite. On the other hand, minimum wear damage was obtained at 2 wt. % ash content. Addition of higher level of fly ash results with formation of cracks in the matrix and increases wear damage of the material.

***Keywords*—**Mg composite, fly ash, wear, powder metallurgy.

I. Introduction

METAL matrix composite (MMC) systems are currently under various stages of development [1]. Different metallic materials especially light metals (aluminum, magnesium and titanium) and their alloys are commonly used metallic matrices for the production of MMCs [2]. The reinforcements being used are fibers, whiskers and particulates [3], [4]. Recently magnesium alloys are widely applied to structural components both to reduce the energy consumption and to improve the mobility of personal digital assistants because they are lightest of the industrial metals in the practical use [5]. The density of magnesium is approximately two thirds of that of aluminum, one quarter of zinc, one fifth of steel and even lower than the glass fiber reinforced polymers [6]. As a result, magnesium alloys offer a very high specific strength among conventional engineering alloys [7].

Magnesium matrix composites can be produced with different techniques such as stir casting, squeeze casting, powder metallurgy (PM) and some other techniques [8]-[11]. Among these different producing techniques PM provides homogeneous distribution of reinforcing phase and allows production of sintered composite parts with small dimensions. Some other advantages of this processing method include the capability of incorporating a relatively high volume fraction of reinforcement and fabrication of composites with matrix alloy and reinforcement systems that are otherwise immiscible by liquid casting [7].

This study aims to investigate the usage of fly ash particles as reinforcement in magnesium composites. For this purpose, powder metallurgical composites with different ash contents were produced. According to the microstructural investigations and results of hardness and wear tests optimum fly ash content is obtained.

II. Experimental procedures

Pure magnesium powders (-150 μm) and fly ash particles (-45 μm) were used to produce composite materials. The fly ash used in the study was obtained from a thermal power plant. Magnesium powders were mixed mechanically with varying weight fractions of fly ash and sintered by a DIEX VS 50 hot press under vacuum atmosphere. The powder mixtures were consolidated at 540°C for 15 minutes under 30 MPa pressure. After sintering the densities of the sintered compacts were measured with Archimedes' technique. To understand the effect of fly ash content on the hardness Brinell hardness tests were conducted with a hardness tester. All reported hardness values are average of five measurements. Wear tests were carried out with Nanovea MT/60/NI type pin-on-disc tribometer under the normal load of 20 N using a AISI 52100 steel ball 5 mm in diameter at room temperature according to ASTM: G99-05. Sliding speed and sliding distance were kept constant for all tests as 0.13 ms^{-1} and 300 m respectively. The weight loss of the alloys during wear tests was measured using an AND GR200 type microbalance with the resolution of 0,1 mg. The obtained weight loss data is used to calculate wear rate of the specimens. Fallowing equation is used to calculate wear rate of specimens: W= M/ρD, where W is the wear rate (mm^3/m), M denotes mass loss (g), and ρ (g/mm^3) and D (m) are the density and sliding distance respectively [12]. Microstructures and worn surfaces of the specimens were investigated with a Jeol 6060 scanning electron microscope.

III. Results and Discussion

The SEM micrographs of the powders used in the current study are given in Fig. 1. Magnesium powders have an irregular shape (Fig. 1 (a)) while fly ash particles taken from a thermal power plant are mainly spherical in shape (Fig. 1 (b)). To examine chemical composition of the fly ash particles EDX (Energy Dispersive X-Ray Spectrum) point analysis was taken from the ash particles. The result of the EDX analysis is given in Table I. As can be seen from table, the fly ash particles mainly consist of Si, Al, Mg and Fe oxides.

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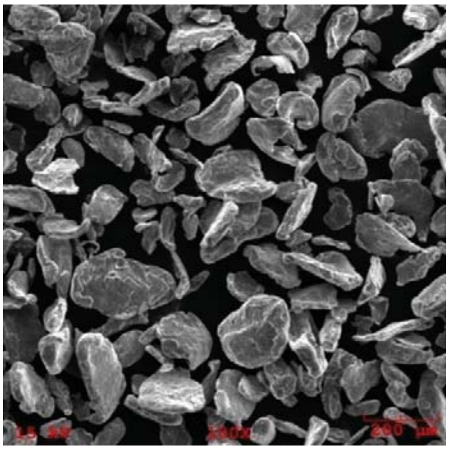
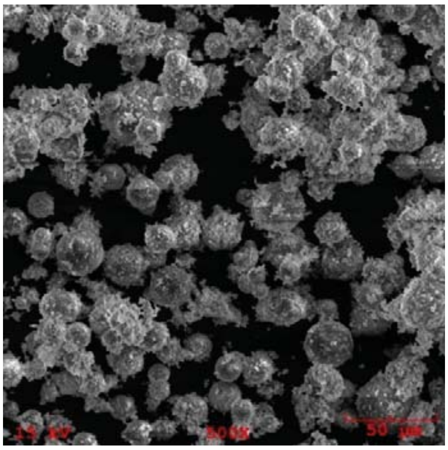


(a)



(b)

Fig. 1 SEM images of (a) Mg and (b) ash particles

TABLE I
CHEMICAL COMPOSITION OF THE FLY ASH

Element	wt.%
O	53,620
Na	0,324
Mg	1,150
Al	16,745
Si	22,687
K	1,759
Ca	1,500
Ti	0,363
Fe	1,853
Total	100,000

Fig. 2 shows the density change of the sintered composites with different fly ash additions. The results showed that increasing fly ash content in the composite decreases the density. Microstructural investigation of produced composites was carried out on metallographically prepared samples. Micrographs of pure magnesium and ash reinforced composites are shown in Fig. 3. No evidence of macro porosity was reported on the specimens and the reinforcement particles were distributed homogeneously in the microstructure.

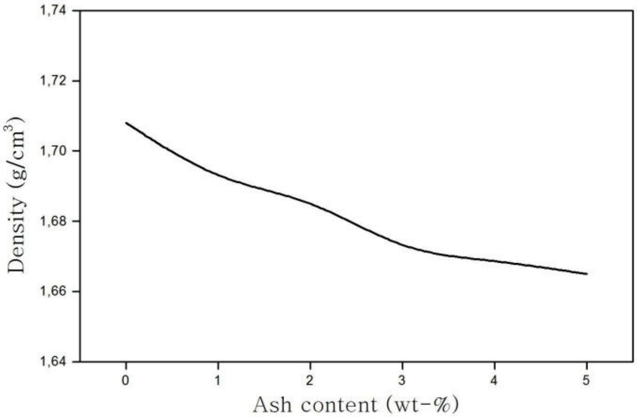
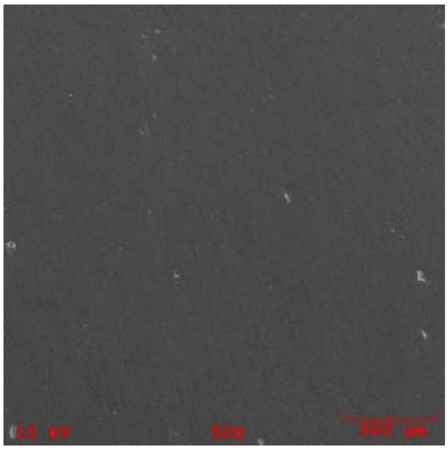
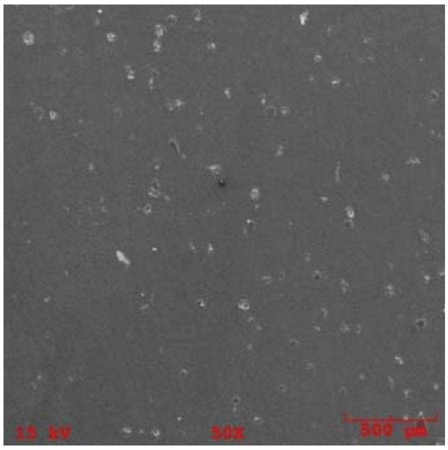


Fig. 2 Density vs ash content



(a)



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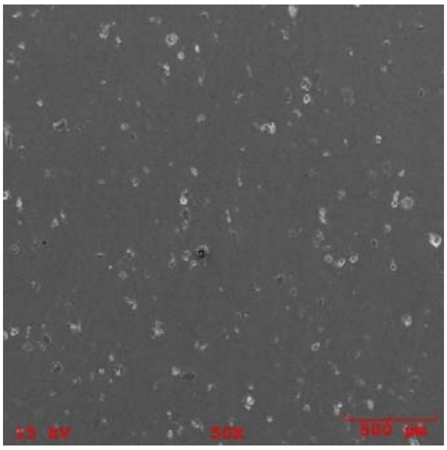


(c)

Fig. 3 SEM images of produced composites showing homogeneous distribution of ash particles, (a) pure Mg, (b) % 2 Ash and (c) % 5 Ash

Brinell hardness tests were conducted to understand the effect of different fly ash additions on the magnesium composites. Hardness tests results can be seen in Fig. 4 which shows a continuous increase in hardness with increasing fly ash content. The hardness value of pure magnesium was 25 HB whereas composite with 5 wt.% ash has a 42 HB hardness. Increasement of hardness with increasing fly ash content was also reported by Rohatgi et al. before [13].

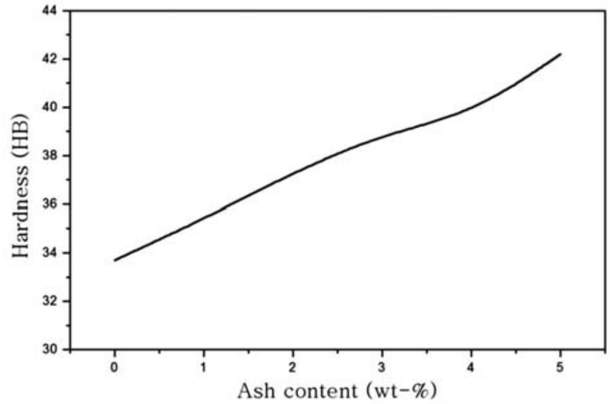


Fig. 4 Hardness change with ash content

Wear of materials is one of the main problems encountered in industrial applications. Particle reinforcements can increase wear resistance of metal matrices. For this reason, wear tests were carried out on the pure magnesium matrix and Mg-Ash composites. Fig. 5 illustrates the wear rate change of the magnesium matrix and sintered composites as a function of ash content. The wear rate is decreased with increasing ash content at low ash contents. This is contributed to the high hardness of the materials by ash addition. However, after 2 wt.% ash content the wear rate of the material increased. Materials become more brittle and tend to fracture easily after that ash content. High content of ash particles causes particle clustering and weakens the mechanical properties of the material due to weak bonding between magnesium matrix and ash particles. For this reason, optimum ash content for pure magnesium is determined as 2wt.%.

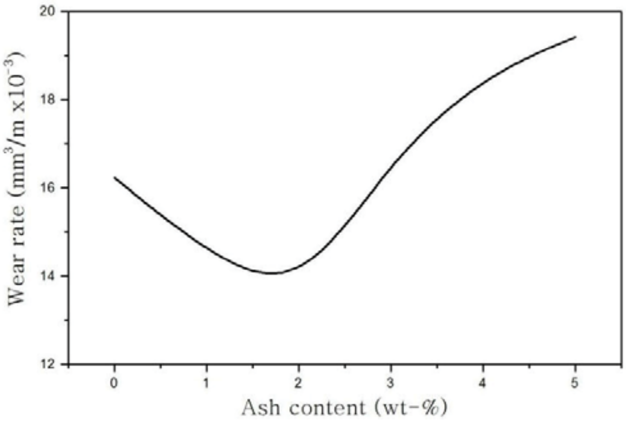
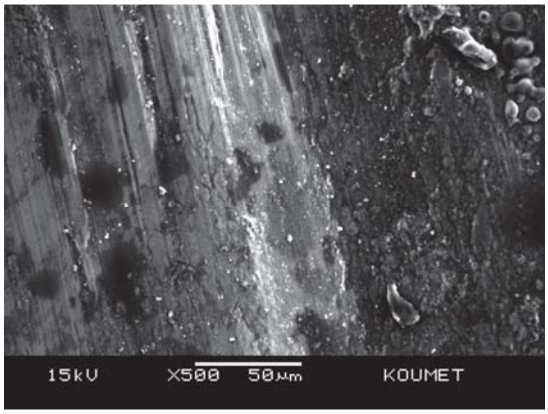
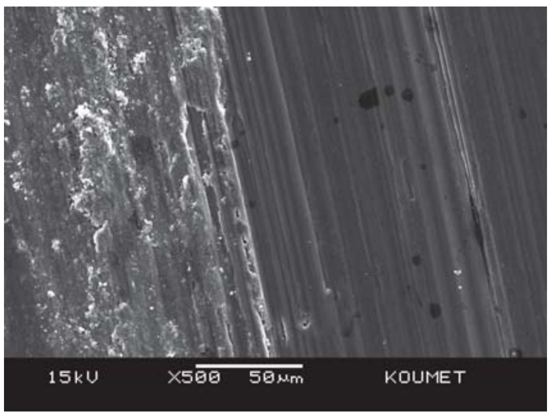


Fig. 5 Wear rate change as a function of ash content

The produced magnesium ash composites showed a lowest wear rate at 2wt.% ash content. To understand the wear mechanisms operated during the wear tests worn surfaces of the specimens were investigated under SEM.



(a)



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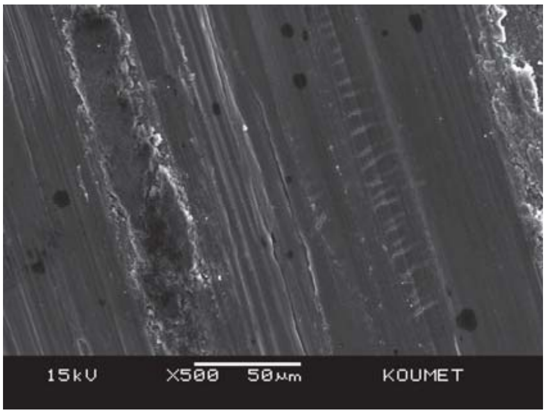

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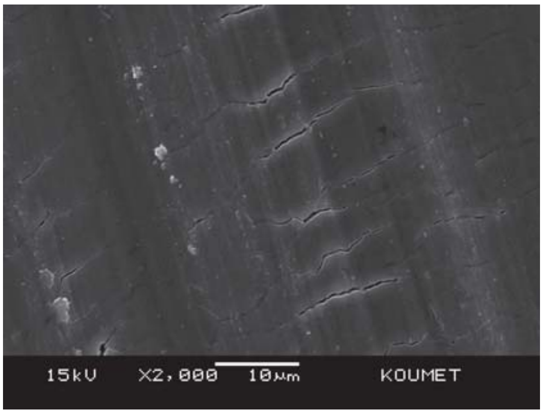

(d)

Fig. 6 SEM images of worn surfaces, (a) magnesium matrix, (b) 2wt.% ash, (c) 5wt.%ash at low magnification and (d) high magnification

For pure magnesium, abrasive wear dominated by a plastic deformation was found to be the major wear mechanism. From Fig. 6 (a), it is evident that oxidative wear is also clear on the worn surface. For higher ash contents, oxidative wear decreased and main wear mechanisms consist of abrasive and adhesive wear. The reinforcement ash particles increased the hardness and decreased the plastic deformation ratio of the material. Figs. 6 (c) and (d) showed that delamination layer formation reduced at highest ash content.

As the material with high ash content become harder, the steel ball produces cracks across the wear track during sliding wear test resulting brittle fracture. This formation causes a decrease in the wear resistance of the material. At high ash contents (above 2wt.% ash), small cracks which are perpendicular to the sliding direction observed in the samples causing higher wear rate and removal of the material during the tests. High amount of ash particles accelerates the crack formation under loading during wear tests and cause fracture and removal of the materials.

IV. Conclusion

In this study, effect and usability of fly ash particles as reinforcement in magnesium matrix composites were investigated. The listed conclusions were drawn,

- The distribution of fly ash particles in composites is homogeneous for low concentrations. Agglomeration was reported in the specimen with 5 wt.% fly. Ash.
- Density of the composite material decreases with fly ash addition.
- Increasing fly ash content increases the hardness of the material.
- Wear rate of the composites depends on the reinforcement amount. Maximum wear rate was obtained at 2 wt.% fly ash addition. Further addition of fly ash causes a drop in the wear resistance of composite because of agglomeration and crack formation.

Acknowledgment

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References

[1] R.A. Saravanan, M.K. Surappa, “Fabrication and characterisation of pure magnesium-30 vol.% SiCP particle composite”, *Materials Science and Engineering A*276, pp 108–116, 2000.

[2] R. Yamanoğlu, E. Karakulak, A. Zeren, M. Zeren, “Effect of heat treatment on the tribological properties of Al–Cu–Mg/nanoSiC composites”, *Materials and Design* 49, pp 820–825, 2013.

[3] G.B. Veeresh Kumar, C. S. P. Rao, N. Selvaraj. “Studies on mechanical and dry sliding wear of Al6061–SiC composites”, *Compos Part B – Eng,* 43, pp 1185–1191, 2011.

[4] V. Kalaichelvi, D. Sivakumar, P. Karthikeyan, K. Palanikumar, “Prediction of the flow stress of 6061 Al–15% SiC – MMC composites using adaptive network based fuzzy inference system” *Materials and Design,* 30, pp 1362–1370, 2011.

[5] J. Umeda, K. Kondoh, H. Imai. “Friction and wear behavior of sintered magnesium composite reinforced with CNT-Mg_2Si/MgO”, *Materials Science and Engineering A* 504, pp 157–162, 2009.

[6] K. Ponappa, S. Aravindan, P. VenkateswaraRao, “Influence of Y_2O_3 particles on mechanical properties of magnesium and magnesium alloy (AZ91D)”, *Journal of Composite Materials* 47(10), pp 1231-1239, 2013.

[7] H. Z. Ye, X. Y. LIU, “Review of recent studies in magnesium matrix composites”, Journal of Materials Science 39, pp6153 – 6171, 2004.

[8] X. J. Wang, X. S. Hu, K. Wu, K. K. Deng, W. M. Gan, C. Y. Wang, M. Y. Zheng, “Hot deformation behavior of SiCp/AZ91 magnesium matrix composite fabricated by stir casting”, *Materials Science and Engineering A* 492, pp 481–485, 2008.

[9] H. Lianxi, W. Erde, “Fabrication and mechanical properties of ZK51A magnesium matrix composite by two-step squeeze casting”, *Materials Science and Engineering A* 278, pp 267–271, 2000.

[10] M. S. Yong, A. J. Clegg, “Process optimisation for a squeeze cast magnesium alloy metal matrix composite”, *Journal of Materials Processing Technology* 168, pp 262–269, 2005.

[11] K. Kondoha, H. Fukudaa, J. Umedaa, H. Imaia, B. Fugetsub, M. Endoc, “Microstructural and mechanical analysis of carbon nanotube reinforced magnesium alloy powder composites”, *Materials Science and Engineering A* 527, pp 4103–4108, 2010.

[12] R. Yamanoglu, E. Karakulak, M. Zeren, F. G. Koc, “Effect of nickel on microstructure and wear behaviour of pure aluminium against steel and alumina counterfaces”, *International Journal of Cast Metals Research*, pp 289-295, 2013.

[13] P. K. Rohatgi, A. Daoud, B. F. Schultz, T. Puri, “Microstructure and mechanical behavior of die casting AZ91D-Fly ash cenosphere composites”, *Composites: Part A* 40, pp 883-896, 2009.