Sigma J Eng & Nat Sci 33 (3), 2015, 465-471

Sigma Journal Engineering and Natural Sciences
Sigma Mühendislik ve Fen Bilimleri Dergisi

Research Article / Araştırma Makalesi

WEAR BEHAVIOR OF AZ91D MAGNESIUM COMPOSITE

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Received/Geliş: 08.06.2015 Revised/Düzeltme: 23.06.2015 Accepted/Kabul: 03.07.2015

ABSTRACT

AZ91D alloy was produced using the conventional casting methods in a local foundry. Then, SiC ceramic additive materials (particulates) with 2%, 4% and 8% by weight (average grain size of 7 µm and 32 µm) were mixed with AZ91 alloy by stir-casting method. The properties of the AZ91 alloy and AZ91/SiC composite materials produced were determined by means of hardness and wear tests, and microstructural characterization was conducted by optical microscopy, scanning electron microscopy and x-ray diffraction. It was observed that the improvement in hardness for the composite with a diameter of 7 µm diameter is higher than the composite with a diameter of 32 µm. Wear testing was conducted through the ball-on-disc method at a rate of 10 $cm.s^{-1}$ under a load of 5 N. The friction coefficient was found to be between the 0.115-0.172 intervals, and no wear was observed on the alumina (Al_2O_3) ball material.
Keywords: AZ91 alloy, metal matrix composite, wear.

AZ91D MAGNEZYUM KOMPOZİTİN AŞINMA DAVRANIŞI

ÖZ

AZ91D alaşımı İstanbul'da bir dökümhanede geleneksel döküm yöntemleri kullanılarak üretilmiştir. Daha sonra 7 µm and 32 µm boyutlarında ve % 2, 4 ve 8 ağırlık oranlarında SiC seramik takviye malzemesi AZ91 alaşımı ile karıştırmalı döküm yöntemi ile karıştırılmıştır. Üretilen AZ91 alaşımı ve AZ91/SiC kompozit malzemelerin özellikleri sertlik ve aşınma testleri ile belirlenerek, optik mikroskop ve taramalı elektron mikroskobu ile X-ışını kırınımı yöntemi kullanılarak mikroyapı karakterizasyonu yapılmıştır. Yapılan çalışmada, 7 µm çapındaki kompozitin sertlik gelişiminin 32 µm çapındaki kompozitten daha yüksek olduğu görülmüştür. Aşınma araştırması 10 $cm.s^{-1}$ hızda, 5 N yük altında ball-on-disc yöntemi ile gerçekleştirilmiştir. Sürtünme katsayısı 0,115-0,172 aralığında bulunmuş olup, alumina (Al_2O_3) batıcı uç (ball) malzemesinde herhangi bir aşınma gözlenmemiştir.
Anahtar Sözcükler: AZ91 alaşımı, metal matrisli kompozit, aşınma.

1. INTRODUCTION

Magnesium alloys have important properties such as low density, high specific mechanical properties and high potential for the reduction of weight. Particularly in the automotive industry,

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the goals that are determined regarding the lightening of vehicles in order to reduce CO_2 emissions have made Mg alloys attractive in recent years [1-6]. Although its superior properties, including the fact that it has the lowest density among structural metallic materials along with high specific strength, good castability and suitable for high-pressure casting, it is necessary to improve the alloy properties through ceramic-based reinforcement due to disadvantages such as a relatively low elastic modulus and low resistance to high temperatures, which cannot be overcome with conventional alloying techniques [7,8].

The main advantages that metal-matrix composites have by comparison to monolithic alloys are given below:

- High resistance
- High rigidity (stiffness)
- Low density (weight)
- Improved high-temperature properties
- Controlled thermal expansion coefficient
- Thermal/ heat management
- Improved electrical performance
- High wear-resistance
- Batch control (in applications with piston displacement)
- High damping ability

Particle-reinforced metal matrix composites consist of strengthening particles that are uniformly distributed throughout the matrix. The most important property of these materials is that their physical and mechanical properties can be tailored by adjusting the volume ratio and type of reinforcement material. Generally, these materials have good wear and corrosion resistance as well as high stiffness, hardness and strength properties. The other important characteristics are that the coefficient of thermal expansion (CTE) and dimensional stability can be adjusted by controlling the type, size, morphology and amount of reinforcement.

Despite the fact that particle-reinforced composite materials can be produced through stir-casting, powder metallurgy and spray deposition, the stir-casting method is preferred on the basis of advantages such as high applicability, near-net shape production, low production cost and high production rate. In the stirring method, reinforcement particles are introduced into the molten metal through the side of the vortex formed by a mechanical stirrer blade

The addition of surface activating elements such as Mg or solid particles covered by metal facilitates the progression of the method. The main reason for utilizing this method is that it is possible to use the conventional metal production and processing methods, thereby achieving a relatively low cost.

2. EXPERIMENTAL STUDIES

2.1. Materials and Methods

The composition of the magnesium-aluminum alloy, as specified in the project proposal and described as AZ91 by international classification, was prepared by means of ingot casting. The composition analysis of the alloy is given in Table 2.1. Analysis was carried out using a Thermo Scientific XL3t-51217 device.

Table 2.1 AZ91D alloy composition (wt %)

Al	Mn	Zn	Fe	Mg
8,936	0,467	1,073	0,046	89,419

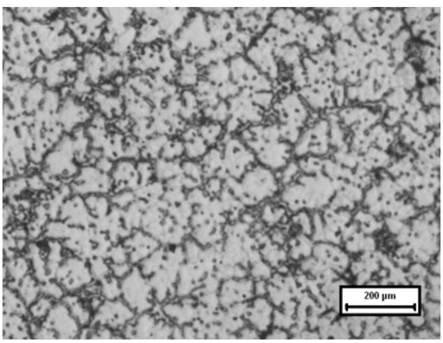
A new mold design was made for use in the melting and casting processes of the composite material planned for production. A permanent mold was produced through machining.

AZ91 magnesium alloy ingots were melted in a laboratory-scale, controlled-atmosphere (argon) induction furnace. SiC ceramic reinforcement material with two different grain sizes (7 μm and 32 μm) at 2%, 4% and 8% weight percent was prepared for composite material production and preheated to 450°C. Since the blockage of dislocation movement increases with the decreasing reinforcement particle size, a wide range of particulate size was used to exhibit the effect of particle size more clearly. The SiC reinforcement material was then introduced to the molten alloy through the stir-casting method at 698°C without removal from the furnace. The casting of molten material in the permanent mold was performed at a temperature in the range of 700-720°C.

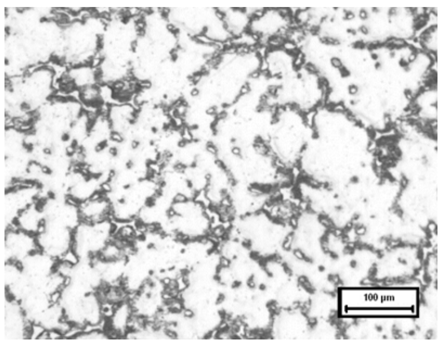
The AZ91 alloy and ceramic particle-reinforced AZ91/SiC composite materials produced were prepared for microscopic examination and characterization. For this purpose, samples with 30 mm diameter and 10 mm thickness were cut, and grinding operation (meshes of 180, 320, 600, 800 and 1000, respectively) was applied. The samples, which were polished at two levels (3 μm and 1 μm) using diamond paste on a polishing machine (Struers), were etched by a reagent consisting of 20 ml alcohol, 2 ml pure water and 1 g picric acid. Microstructures of the samples were examined on an illuminated microscope (Leica ICM 1000) and SEM (Scanning Electron Microscope) (JEOL JSM 5410LV). Hardness measurement employed a 62.5 kp load and a ball indenter with 2.5 mm diameter on a Brinell test machine. All measurements were repeated three times and average hardness values were calculated.

2.2. Microstructural Examination

The matrix α-Mg phase, intermetallic β-Mg17Al12 phase and eutectic α+β phase were observed within the AZ91 magnesium alloy cast structure. In terms of microstructure, α-Mg phase was observed, being surrounded by the dendritic eutectic phase. The microstructures of the AZ91 alloy are shown in the figures 2.1 and 2.2. In these figures, the black-colored structure is the intermetallic phase and the white-colored structure is the α-Mg phase.



(a)



(b)

Figure 2.1 AZ91 magnesium alloy (a) and (b) optical microscopy microstructure images

The chemical content of the phases of the AZ91 alloy was investigated using EDS (Energy Dispersive Spectrometry) analysis via the SEM. BSE (back-scattered electron) images of the α phase, β phase, and eutectic α and β phases were obtained. The results of the analyses are shown in Figure 2.3.

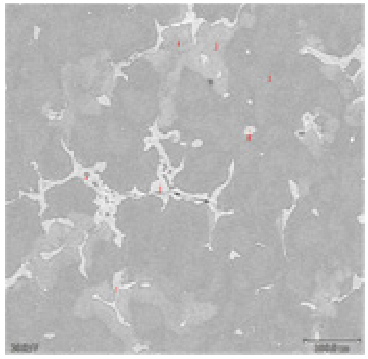


Figure 2.2 SEM image of AZ91 magnesium alloy

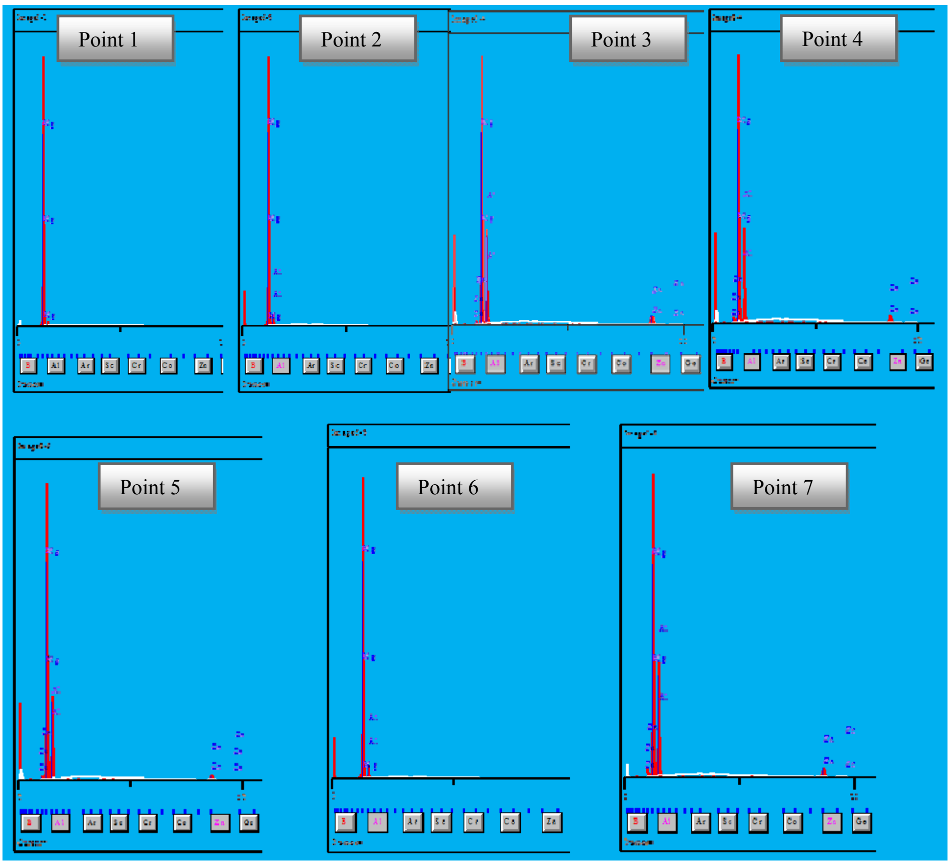


Figure 2.3 EDS analysis of AZ91 alloy

XRD analysis of AZ91 alloy and composite material produced with SiC particle addition (Fig. 2.4) was conducted. According to the results of such analysis, Mg and $Mg_{17}Al_{12}$ phases were present in the alloy. In the case of composite material, the peaks of Mg, $Mg_{17}Al_{12}$ and α-SiC phases could be observed.

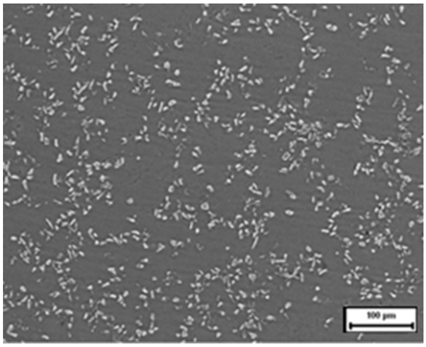


Figure 2.4 Microstructure of AZ91/SiC composite material

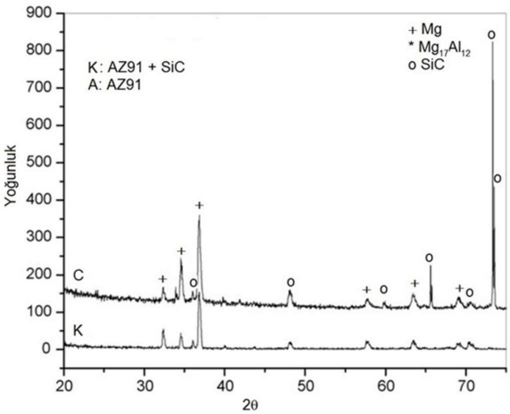


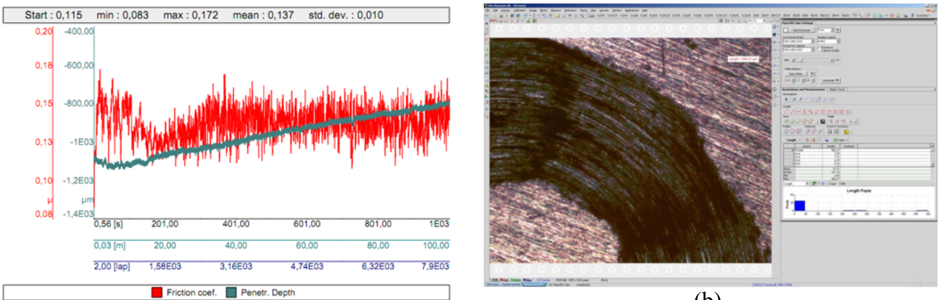
Figure 2.5 XRD patterns of AZ91 alloy (A) and AZ91/SiC composite (K) material

According to the results of hardness testing, it is apparent that SiC particles increase the hardness of the magnesium-matrix composite material. Particularly, small-sized ceramic particles (7 µm) show better performance in the increase of hardness. It may thus be interpreted that the small grain size brings the material into a denser form (Table 2.2).

Table 2.2 Hardness values of AZ91 alloy and AZ91/SiC composite material

Sample No	wt (%)	SiC Particle diameter (µm)	Hardness (HB)	Penetration depth (µm)
AZ91	-	-	62	450
1	2	7	72	350
2	2	32	64	150
3	4	7	75	246
4	4	32	68	300
5	8	7	78	150
6	8	32	66	400

The effect of particle size was shown clearly in Table 2.2. The increase in particle volume in 7 µm reinforced specimens has resulted in a decrease in penetration and eventually an increase in hardness. But in contrast, the same effect was not detected in specimens reinforced with 32 µm particles due to the lack of dislocation blockage. Friction-wear testing (CSM Instrument) was conducted by means of a universal tribometer testing device. The dual material is an alumina (Al_2O_3) sphere with a diameter of 6 mm. Wear testing was carried out under a load of 5 N load at the rate of 10 $cm.s^{-1}$ speed and distance of 100 m.



(a) (b)

Figure 2.6 a) change in the friction coefficient with sliding distance; b) macro wear marks

It is observed that the principal wear mechanism of the samples is adhesive wear. At a certain load and sliding speed, plastic deformation occurred on the surface of the material. Principally, abrasive wear is observed in AZ91/SiC 32 µm composite. At the beginning of the friction test, the soft-metal matrix surrounding the hard SiC particles was abraded. Subsequently, the matrix was unable to hold SiC particles, which were in turn separated from their locations. The separated reinforcement particles contaminated the matrix alloy and thereby resulted in scratch marks.

Adhesive and abrasive wear were simultaneously observed in AZ91/SiC 7 µm composite. However, the wear scratches (grooves) were smaller in AZ91/SiC 7 µm than in AZ91/SiC 32 µm. This also explains the deeper penetration on the specimens reinforced with 32 µm SiC particles. Because the smaller reinforcement particles are more contributive to friction in unit area, more friction marks were generated. As a result, the effect of friction force on each particle was diminished. Thus the stronger correlation between the matrix and the reinforcement particles results in relatively lower continuity of the damage on the matrix. Consequently, it is more difficult to separate the smaller particles from the matrix.

As shown in the wear graphs, it was observed that quaking occurred at the beginning of friction. However, the situation was mitigated as the test continued. At the beginning of the test, the friction coefficient of AZ91/SiC 32 µm composite was very low (Table 2.3).

Table 2.3 Friction coefficients of AZ91/Si composite material

Sample No	% (Ağ).	SiC Particle diameter (µm)	Friction coefficient (µ)		
			Min	Max	Mean
1	2	7	0.115	0.172	0.137
2	2	32	0.006	0.017	0.014
3	4	7	0.142	0.192	0.147
4	4	32	0.107	0.190	0.146
5	8	7	0.104	0.181	0.141
6	8	32	0.107	0.179	0.145

As the test continued, it showed a high increase and reached a state of equilibrium. The friction coefficient of AZ91/SiC 7 µm composite material was highly stable. The test results show that the addition of SiC helped balance the friction coefficient.

3. RESULTS

A significant increase in the hardness of the composite material that is formed with the addition of SiC particles into AZ91 magnesium material has been observed.

The average hardness of SiC particles with 7 µm diameter is HB 75, and the average hardness of SiC particles with 32 µm diameter is HB 66. Thus the average increase in hardness is 13%. As compared to AZ91 alloy, increases of 13% and 6% are observed in composites with diameters of 7 µm and 32 µm, respectively.

According to the wear testing, the friction coefficient of the 7 µm diameter composite materials is more stable than that of the 32 µm diameter composites.

Acknowledgments / Teşekkür

This research has been supported by Yıldız Technical University Scientific Research Projects Coordination Department. Project Number: 2011-07-02-KAP03.

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