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Araştırma Makalesi - Research Article

AZ91, AS91 ve AM90 Magnezyum Alaşımlarının Aşınma ve Isıl Davranışları Üzerine Karşılaştırmalı Bir Çalışma

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ÖZ

Bu makale, AZ91, AS91 ve AM90 (Mg-9Al-X) döküm magnezyum alaşımlarının aşınma direnci ve termal davranışları üzerine karşılaştırmalı bir çalışmadır. Bu alaşımlardaki üçüncü alaşım bileşenlerindeki değişimin (X; sırasıyla, 1 Zn, 1 Si, 0.5 Mn ve sabit 9 Al, % ağırlıkça) alaşımların aşınma direnci, ısıl özellikleri ve yoğunlukları üzerindeki etkileri karşılaştırmalı olarak analiz edilmiştir. Alaşımların mikroyapısında bulunan intermetalik fazların (AZ91'de $Mg_{17}Al_{12}$, AS91'de Mg_2Si ve AM90'da Al_8Mn_5) sertlik, yoğunluk, aşınma direnci ve ısıl özellikler üzerinde etkili olduğu görülmüştür. Alaşımların termal özellikleri artan sıcaklıkla artmıştır (sıcaklık değişimi 25 °C'den 400 °C'e kadar). En yüksek termal yayılma AZ91 alaşımında, en düşük termal yayılma ise AM90 alaşımında ölçülmüştür. Öte yandan, en yüksek aşınma direnci AM90'da gözlenmiştir.

Anahtar Kelimeler- AZ91, AS91, AM90 Magnezyum Alaşımları, Aşınma, Termal Yayılma, Termal İletkenlik, Yoğunluk

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A Comparative Study on Wear and Thermal Behaviors of AZ91, AS91 and AM90 Magnesium Alloys

ABSTRACT

This paper is a comparative study on wear resistance and thermal behaviors of AZ91, AS91 and AM90 (Mg-9Al-X) cast magnesium alloys. The effects of the changing in third alloy components (X;1 Zn, 1 Si, 0.5 Mn, respectively, and constant 9 Al, wt.%) in these alloys on wear resistance, thermal properties and densities were comparatively analyzed. It was seen that intermetallic phases ($Mg_{17}Al_{12}$ in AZ91, Mg_2Si in AS91 and Al_8Mn_5 in AM90) found in the microstructure of the alloys have an effect on hardness, densities, wear resistance and thermal properties. The thermal properties of the alloys were increase with increasing temperature (the temperature range from 25°C to 400°C). The highest thermal diffusivity were measured on AZ91 alloy and the lowest thermal diffusivity were measured on AM90 alloy. On the other hand, the highest wear resistance was observed in AM90.

Keywords- AZ91, AS91, AM90 Magnesium Alloys, Wear, Thermal Diffusivity, Thermal Conductivity, Density

I. INTRODUCTION

Nowadays, there are numerous areas that use magnesium and its alloys because of their characteristics and these areas are growing day by day. This is especially due to being among the lightest structure metals for their density-strength properties. Magnesium alloys gain more importance in many fields, mostly in automotive, aerospace and logistics industries [1-3]. Their vast usage in various fields continues depending on improving its certain characteristics. Some of such characteristics to be improved are their mechanical properties, hardness, wear resistance, machinability and thermal properties. A large number of studies carried out on magnesium alloys were about obtaining different alloys and investigating the mechanical characteristics of such alloys [4-6]. Studies conducted on alloy properties affecting the improvement of wear characteristics of magnesium alloys and their correlation with thermal properties are few in number and insufficient. It is quite important to investigate the use of magnesium alloys in engine, piston and cylinders especially in automotive and aerospace industry and also its characteristics such as hardness, wear resistance, density and thermal properties (thermal diffusivity and thermal conductivity). It is known that wear resistance is related to alloy composition, microstructure and hardness of the material [4,6,9-11,14]. Wear can be defined as the resistance of metal against friction in its most basic sense. The most commonly used magnesium-aluminum (Mg-Al) alloys are AZ91, AM20, AM60, AS21, AS41 and AJ62 [1-26] etc. and their most significant properties are their well castability and improvable mechanical properties.

The influence of Al content on the machinability of AZ and AS series cast magnesium alloys were previously investigated [10, 23-27]. However, studies conducted on the thermal properties of magnesium alloys are few and insufficient. In literature, to the best of author’s knowledge, there isn't any study found investigating the effect of the alloy component in the AZ91, AS91 and AM90 cast magnesium alloys comparing on the density, hardness, wear resistance and thermal behaviors/properties. Investigating the microstructure properties formed depending on alloy compositions, the effects of intermetallic phases on thermal properties, density, hardness and wear resistance were studied comparatively. This study is important within this scope.

II. EXPERIMENTAL PROCEDURE

The compositions of AZ91, AS91 and AM90 series cast magnesium alloys utilised in the study are listed in Table 1. These alloys contain 1 Zn, 1 Si and 0.5 Mn, respectively, and in constant 9 Al, wt.%. The samples casting and mechanical test details are well described by Ünal [15] and Akyüz [23-25].

Table 1. AZ91, AS91 and AM90 alloy composition (wt. %)

Alloys	Al	Zn	Si	Mn	Fe	Mg
AZ91	9.1	1.1	-	-	0.02	Rest
AS91	9.1	0.2	1.2	-	0.02	Rest
AM90	9.1	0.2	-	0.5	0.02	Rest

(“A”, “Z”, “S” and "M", refers to the Al, Zn, Si and Mn content of the alloy, respectively.)

Microstructural surveys were conducted on the metallographic samples by optical light microscopy-OM (LV150 Nikon Eclipse). Furthermore, polishing and etching process details were explained in previous studies of the author [23-26]. XRD (X-ray diffraction) analyses were carried out under Cu Kα radiation (Panalytical-Empyrean) with an incidence beam angle of 2°. The sample hardness values were obtained by Vickers hardness test (Shimadzu HMV-2) (on each sample at ten measurements in all tests). Wear resistance tests were performed (on each sample at four measurements in all tests by Tribotester TM, Clichy). Wear resistance test details are described in previous studies of the author [23-26]. Density of AZ91, AS91 and AM90 magnesium alloys was measured. The density was measured by the Archimedes method (He gas atmosphere, under 22 psi/1.5 pressure and in 10 cm^3 specimen container). At least five measurements were obtained on each sample (15 mm in diameter and 18 mm in length). Then, density values of alloys were determined by averaging the values. Density tests were performed on tester (AccuPycII 1340 Pycnometer, Micromeritics Instrument Corp. U.S.A.).

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The thermal diffusivity of AZ91, AS91 and AM90 series cast magnesium alloys were measured. The thermal diffusivity measurement was carried out the temperature range from 25°C to 400°C (with a NETZSCH model LFA 457 Laser Flash Device, and Atmosphere N_2, gas flow 100.00 ml/min, more than 10 min. under isothermal conditions). Chunming at.al (2013) explained a comprehensive description the test sample standards and test procedures or process of the magnesium alloys [29]. The thermal conductivity was calculated using the following the equation:

$$\lambda = \alpha \, \rho \, c_p \tag{1}$$

Where λ is the thermal conductivity (λ: $W \cdot m^{-1} K^{-1}$), α is the thermal diffusivity (α: $mm^2 s^{-1}$), ρ is the density (ρ: $g\ cm^{-3}$) and c_p is the specific heat capacity (c_p: $J\ g^{-1}\ K^{-1}$ accepted as fixed).

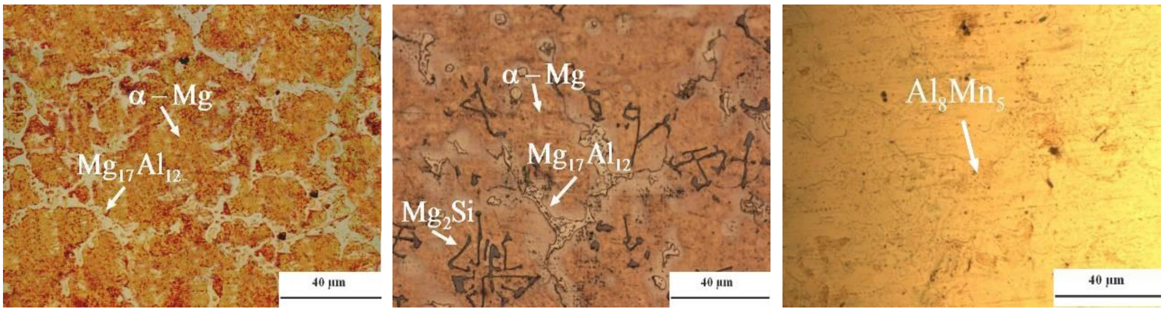
Lee at al 2013 [28] reported that the specific heat capacities of AZ31 and AZ61 are not significantly different due to the relatively small difference in aluminum quantities. The specific heat capacities of magnesium and aluminum at room temperature, 1.0241 $Jg^{-1}K^{-1}$ and 0.9025 $Jg^{-1}K^{-1}$, respectively, show very little difference [28]. Therefore, changes in the specific heat capacities of magnesium alloys for differing proportions of aluminum are insignificant. In this study, the specific heat capacity (c_p) is accepted as fixed.

III. RESULTS AND DISCUSSION

A. Microstructure and XRD Pattern

Microstructure photographs and XRD patterns of the alloys used in the study are seen in Fig. 1 and Fig.2. The intermetallic phases could easily be distinguished from the matrix under the OM (seen on Fig.1). Microstructure of these Mg alloys analysed in the study was generally occurred to be made up of α Mg matrix and intermetallic phases. It was seen that the network formation of intermetallic phase in the alloys tended to surround α-Mg grains throughout the matrix [7,10]. In the alloys, beside from $Mg_{17}Al_{12}$ as an addition intermetallic phase, Mg_2Si intermetallic phase in AS91 and Al_8Mn_5 intermetallic phase in AM90 were observed/occurred. $Mg_{17}Al_{12}$ intermetallic phase was established in AZ91 alloy [10]. In AS91 alloy, Mg_2Si intermetallic phase was present along with $Mg_{17}Al_{12}$ intermetallic phase [8,24]. In AM90 alloy, Al_8Mn_5 intermetallic phase was observed in the alloy [6].

Previous studies showed the presence of $Mg_{17}Al_{12}$ intermetallic phase in AZ91 alloy [9,10,24,26]. The formation of $Mg_{17}Al_{12}$ phase was repeatedly reported due to changes of the solidification behavior of the melt caused by Zn addition [9,10,24,26]. In AS91 Mg alloys, the constitution of the matrix is α-Mg and the intermetallic phases ($Mg_{17}Al_{12}$ and Mg_2Si) were shown in Fig.1 and Fig.2. The formation of Mg_2Si phases in AS91 alloy appeared as in a form of Chinese script in accordance with the published literature [5-12 24,26]. Microstructure images and XRD pattern obtained in this study were in accordance with the literature [5-12,18-26].



a)AZ91 **b)AS91** **c)AM90**

Figure 1. Optical Micrographs of AZ91, AS91 and AM90 magnesium alloys (50x).

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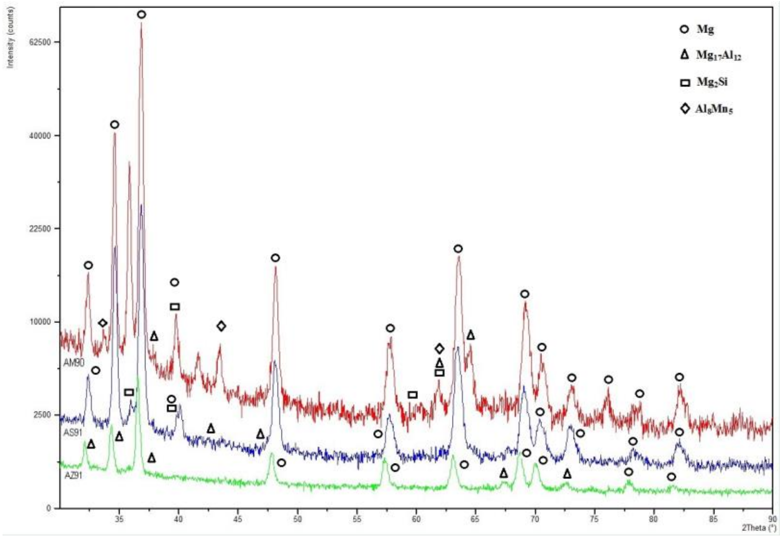

Figure 2. XRD patterns of AZ91, AS91 and AM90 magnesium alloys.

B. Hardness and Wear Resistance

Hardness and wear test results obtained from the alloys were given in Fig.3 and Fig 4. When checked, the mean hardness values of alloys were estimated as 60.8 HV_{10} in AZ91 alloy, 68.7 HV_{10} in AS91 alloy and 90.5 HV_{10} in AM90 alloy. The highest hardness was obtained in AM90 alloy.

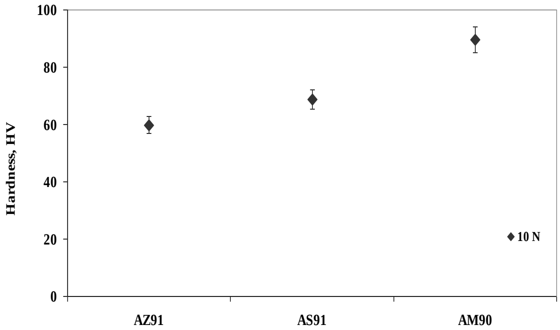

Figure 3. Hardness (HV) of AZ91, AS91 and AM90 magnesium alloys.

The relative wear resistance (RWR) values of these alloys were performed at AZ91, AS91 AM90. The RWR increase from AZ91 up to AM90 (Fig.4). It was observed that wear resistance was higher at rate of ~25% AS91 and ~29% AM90 when compared to AZ91 alloy (Fig.4a). The reason for the AM90 alloy demonstrating the highest hardness and also a wear resistance was due to the effects of the intermetallic phases ($Mg_{17}Al_{12}$ and Al_8Mn_5) found in the microstructure. There was no significant difference in the friction coefficients of the alloys (Fig. 4b). When the correlation between third alloy components (Zn, Si and Mn) and hardness and wear resistance in the experimental study analysed, it was observed that the hardness and wear resistance changed/increased depending on the third alloy components (Fig.3 and Fig.4).

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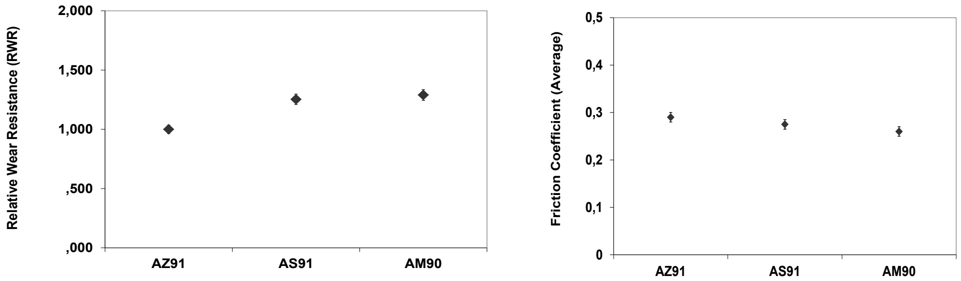

Figure 4. AZ91, AS91 and AM90 magnesium alloys (a) Wear resistance and (b) Friction coefficient (Average)

An evaluation of the results indicated that the intermetallic phases ($Mg_{17}Al_{12}$, Mg_2Si and Al_8Mn_5) could be very effective at hardening and also on wear resistance in these magnesium alloys. Results obtained from this section are in concordance with literature [7-16, 18-26].

C. Density and Thermal Properties

The thermal properties (thermal diffusivity and thermal conductivity) and the density values of AZ91, AS91 and AM90 series cast magnesium alloys are given in Fig.5 and Fig.6a-b. The density values of AZ91, AS91 and AM90 alloys are 1.762 g/cm^3, 1.798 g/cm^3 and 1.843 g/cm^3, respectively, (seen on Fig.5). The density of the alloys increases from AZ91 up to AM90 (Fig.5). The highest density was acquired from the AM90 alloy.

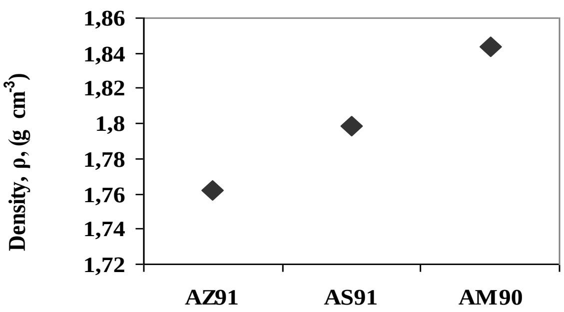

Figure 5. Density of AZ91, AS91 and AM90 magnesium alloys

Figure 6 shows the effect of microstructure variations on the thermal behaviors of the alloy samples as a function of the alloy content. Depending on the temperature increase (from 25°C to 400°C) in these alloys, increasing thermal diffusivity and thermal conductivity are observed (Fig.6a-b). While the highest thermal diffusivity and thermal conductivity (in all temperatures) were performed in AZ91 alloy, the lowest thermal properties (at all temperatures) were in AM90 alloy (seen on Fig.6a-b).

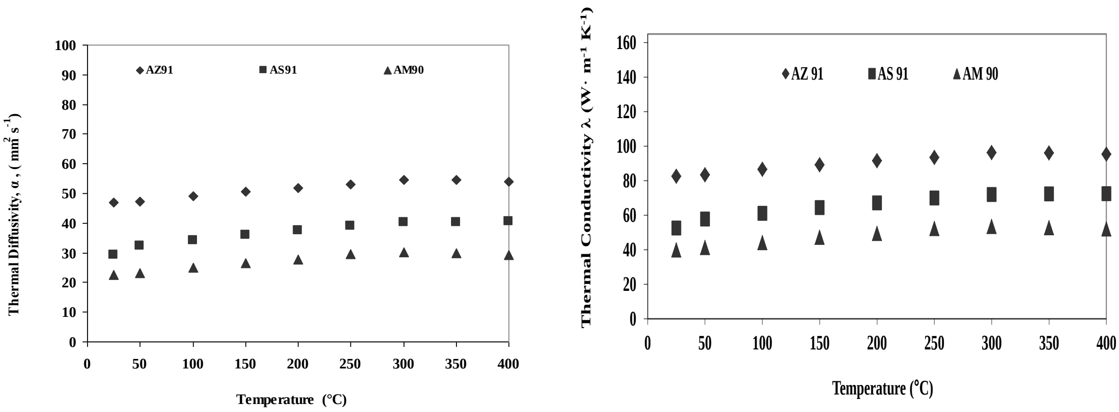

Figure 6. Thermal properties of AZ91, AS91 and AM90 Magnesium Alloys a) Thermal Diffusivity b) Thermal Conductivity

Considering the thermal diffusivity values of the alloys at 25 °C, the thermal diffusivity values of AZ91, AS91 and AM90 alloys are 46.86 mm^2/s, 29.33 mm^2/s and 22.51 mm^2/s, respectively, (seen on Fig.6a). When the temperature is increased to 400 °C, thermal diffusivities are measured as 54.08 mm^2/s, 40.47 mm^2/s and 29.34 mm^2/s, respectively, (seen on Fig.6a). The thermal conductivity values of these alloys are 82.57 $Wm^{-1} K^{-1}$, 52.73 $Wm^{-1} K^{-1}$ and 41.48 $Wm^{-1} K^{-1}$ at 25 °C, respectively, (seen on Fig.6b). When the temperature is increased to 400 °C, thermal conductivity values are measured as 95.29 $Wm^{-1} K^{-1}$, 72.76 $Wm^{-1} K^{-1}$ and 54.07 $Wm^{-1} K^{-1}$, respectively, (seen on Fig.6b). The thermal behaviors/properties of AZ91, AS91 and AM90 alloys were increased ~%15, ~%38 and ~%30, respectively, depending on the temperature (from 25°C to 400°C) (seen on Fig.6a-b).

This experimental study results show that the intermetallic phases ($Mg_{17}Al_{12}$, Mg_2Si and Al_8Mn_5) found in microstructure of the alloys (consist of changing the third alloy component in the alloys; 1 Zn, 1 Si and 0.5 Mn and also constant 9 Al, wt.%) could be very effective on density, thermal behaviors/properties (thermal diffusivity and thermal conductivity), wear resistance and hardness as well. The highest thermal diffusivity were measured on AZ91 alloy (effect of $Mg_{17}Al_{12}$ intermetallic phase). Thus, it can be said that in increasing the thermal properties of the alloys, $Mg_{17}Al_{12}$ intermetallic phase (in AZ91) are the most positive effective than the Mg_2Si (in AS91) and Al_8Mn_5 (in AM90) intermetallic phases. Al_8Mn_5 intermetallic phase found in AM90 has a positive effect on hardness, densities and wear resistance, but negative effect on thermal diffusivity and thermal conductivity. The thermal properties all of the alloys were increase with increasing temperature (the temperature range from 25°C to 400°C). Results obtained from the study are in concordance with literature [7-16, 18-30].

IV. CONCLUSIONS

The results below were obtained from this experimental study;

- In AZ91, AS91 and AM90 series cast magnesium alloys, the alloy components (1 Zn, 1 Si and 0.5 Mn, respectively, and also 9 Al, wt. %) had an effect on the location and form of intermetallic phases.

- It was seen that the intermetallic phases ($Mg_{17}Al_{12}$ in AZ91, Mg_2Si in AS91 and Al_8Mn_5 in AM90) in the alloys had an effect on hardness, density, wear resistance and thermal properties.

- AZ91 alloy has the lowest hardness and wear resistance than compared to AS91 and AM90 alloy. On the other hand, the AZ91 alloy has the highest thermal properties. AM90 alloy has the highest hardness and wear resistance than compared to the others.

- Depending on the increase at temperature (from 25°C to 400°C) in the alloys, increases in the thermal diffusivity and thermal conductivity were observed. While the highest thermal diffusivity and thermal conductivity (in all temperatures) were performed in AZ91 alloy, the lowest thermal behaviors/properties (at all temperatures) were in AM90 alloy (Fig.6a-b).

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