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EFFECT OF FIBER VOLUME FRACTIONS ON CORROSION RESISTANCE OF MG AM60 ALLOY-BASED COMPOSITES IN NACL SOLUTIONS

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Abstract

Magnesium-based MMCs with their high stiffness-to-weight ratio bring a great interest to automotive and aerospace industries. Besides the enhanced mechanical properties of the MMCs, corrosion resistance is often a concern for applications being used in harsh environment. In this study, Magnesium alloy AM60 matrix composite reinforced with 7 vol%, 11 vol% and 22 vol% Al_2O_3 fibers were squeeze casted. The corrosion behavior in aqueous solutions containing 3.5% NaCl was investigated in comparison with magnesium alloy AM60. The scanning electron microscopy (SEM) was employed for the microstructure analysis of the composites and matrix alloy AM60 before and after corrosion test. The results show that the addition of Al_2O_3 fiber deteriorated the corrosion resistance of the matrix and the corrosion rate increases as the fiber volume fraction increased. The formation of the interfaces between the reinforcement and the matrix should be the primary mechanism for the corrosion to easily take place.

Introduction

To further improve the performance of lightweight materials in automotive and aerospace industries, metal matrix composites (MMCs) are introduced and developed. Magnesium metal matrix composites (Mg MMCs) become popular for applications in automotive industries due to their high strength and high stiffness with lower density. Alumina (Al_2O_3) fiber is one of the popular reinforcing materials for Mg MMCs. It has been reported that Mg/Al_2O_3 composites can be potentially applied for applications in power transmission housing, rotating shafts and also aircraft engines [1, 3].

Preform-squeeze casting technique is considered to be a desirable and cost effective process among the available techniques for fabricating Mg MMCs. The volume fraction and the distribution of Al_2O_3 fibers can be easily controlled during fabricating preforms. The volume fractions and the uniformity of the fiber have significant influence on the physical and mechanical properties of the composites [4-6].

Even though the addition of the reinforcement can improve the physical and mechanical properties of the composites, it also can deteriorate the corrosion resistance of the composites 7]. In this study, the influence of Al_2O_3 fiber volume fractions on the corrosion behavior of Mg AM60/Al_2O_3 composites by preform-squeeze casting was carried out in aqueous solutions containing 3.5% of NaCl by electrochemical experimentation and microstructure analysis.

Experimental Procedure

The base magnesium alloy selected for this study was the conventional magnesium alloy AM60. The chemical composition of this alloy is shown in Table 1[2]. Al_2O_3 short fibers with their cost effective and possess adequate properties were employed as the raw materials for preparation of preforms. The thermophysical properties of the matrix alloy AM60 and the Al_2O_3 fiber are listed in Table 2[8]. Both of the unreinforced AM60 and the composites with fiber volume fractions of 7%, 11% and 22% were cast under the same conditions. The details of fabricating preforms and composites can be found in reference [9].

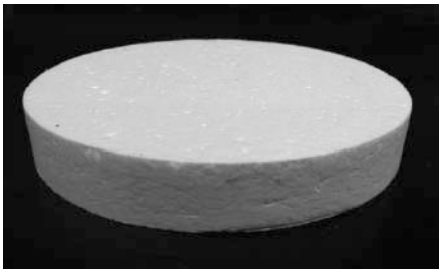


Figure 1: A preform with fiber volume fraction of 9%.

Table 1: Chemical composition of the investigated alloy (mass fraction, %) [2]

Alloy	Al	Mn	Si	Fe	Mg
AM60	5.93	0.18	<0.02	0.013	Bal.

Table 2: Thermophysical properties of Al2O3 short fibers and matrix alloy AM60 [8]

Materials	**Al2O3 fiber**	**AM60**
Elasticity modulus (GPa)	200	35-44
Density (kg/m^3)	3400	1740
Diameter (μm)	4.0	
Heat expansion coefficient (10^{-6}/K)	6	45
Specific heat (J/kg K)	1000	1250
Thermal conductivity (W/ m K)	5	85

During casting process, protective gas mixture of sulfur hexafluoride, SF_6 and carbon dioxide, CO_2 in which CO_2 act as the carrier gas, was applied to protect the melt from any excessive oxidation or possible burning. All tools were preheated to 150 °C on the top of a box furnace for at least 20 minutes. The upper and lower molds were preheated to 300 °C. Before placing the preform into mold, the preform was preheated to 750 °C. Then, the molten matrix alloy AM60 with temperature of 760 °C was infiltrated into the preheated preform under an applied pressure of 90 MPa. The pressure was hold for 25 seconds. The heater for the mold was quickly turned off after the pressure withdrawal in order to cool the mold as soon as possible. After solidification, a cylindrical composite coupon was ejected. All of the 7, 11, 22 and 35 vol% composites were fabricated in the same procedure. Figure 2 illustrates the fabrication process of the fiber-reinforced composite by using the squeeze casting technique.

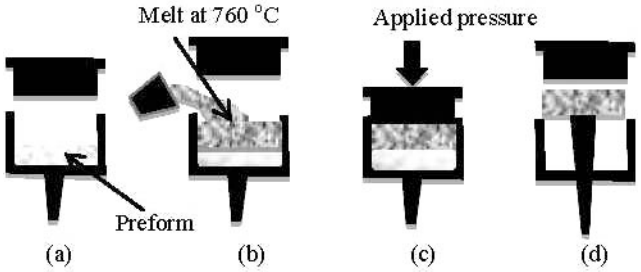


Figure 2: Schematic diagram of the squeeze casting procedure a) placing preform into the mold, b) pouring melt into the mold, c) applying pressure and d) composite is produced.

The rectangular samples (20x20x5mm) were cut form the middle part of the cast. Figure 3 shows a sample squeeze cast composite. All samples were polished prior the corrosion tests. All samples were ground by using silicon carbide papers with grades 240, 600 and 2500 grits. Then the samples were cleaned in acetone, rinsed with deionized water and dried before the potentiodynamic polarization.

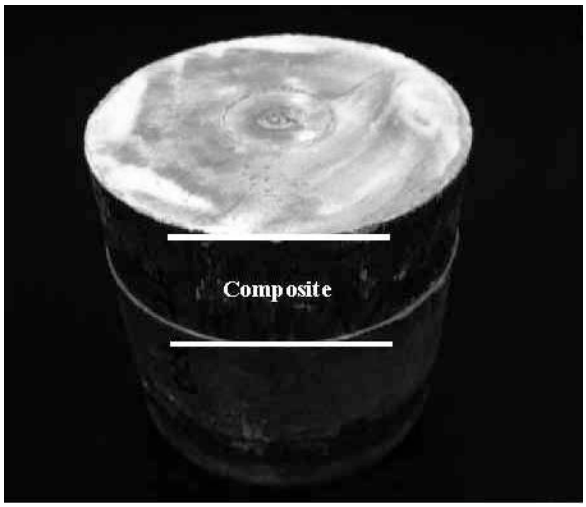


Figure 3: A squeeze cast magnesium matrix composite (AM60/ Al_2O_3).

Electrochemical Experimentation

The equipment used for the corrosion tests were EC-LAB SP-150 electrochemical apparatus with corrosion analysis EC-LAB software. A three-electrode cell was used for all tests. The prepared samples were set to be the working electrode, Ag/AgCl/sat'd KCL electrode as a reference electrode and Pt metal electrode as counter-electrode. For all of the experiment, 3.5% NaCl solution was prepared (salt mixing with deionized water). At the beginning of the test, samples were immerging into the salt solution to allow the open circuit potential to settle to a constant value. Potentiodynamic polarization scans were conducted at a rate of 10mv/s form –0.5v versus open circuit potential in a more noble direction up to 0.5v versus the reference electrode.

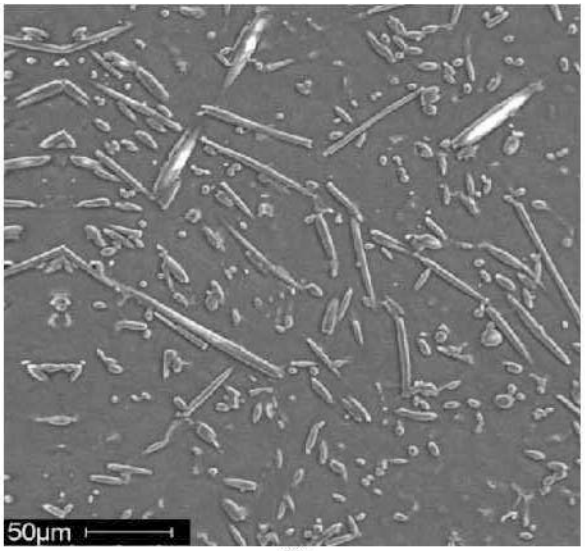
Microstructure Analysis

A Buehler optical image analyzer 2002 system was used for determining the primary characteristics of the composite. The detailed features were characterized at higher magnification by JSM-5800LV SEM, which had a maximum resolution of 100 nm in a backscattered mode and maximum useful magnification of 30,000X. Before placing the samples into the SEM, they were coated with Au and a copper tape was used on the surfaces to enhance the sample conductivity to eliminate the surface charging.

Results and Discussion

Microstructure

The distribution of the reinforcement has significant influence on the properties of the composites. To ensure the fibers were randomly and uniformly distribute in the composites, the samples were etched at difference time periods to bring out the fibers from the matrix alloy and to reveal their distribution at different depths of the composites. Figure 4 shows the composites surfaces of the composite with the reinforcement of 22% Al_2O_3 fibers which were etched for 10s, 50s and 110s.



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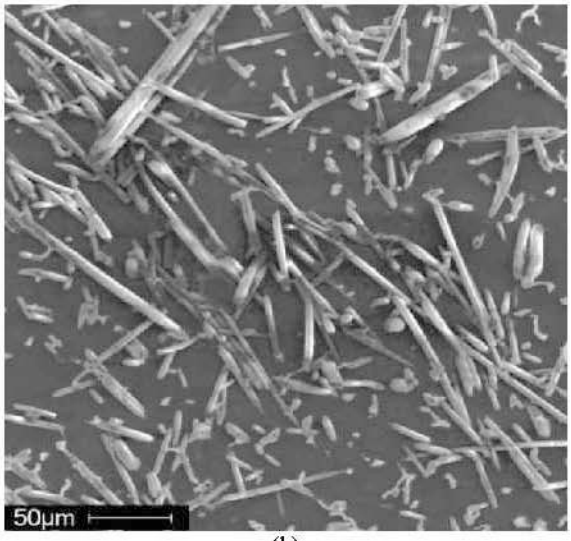

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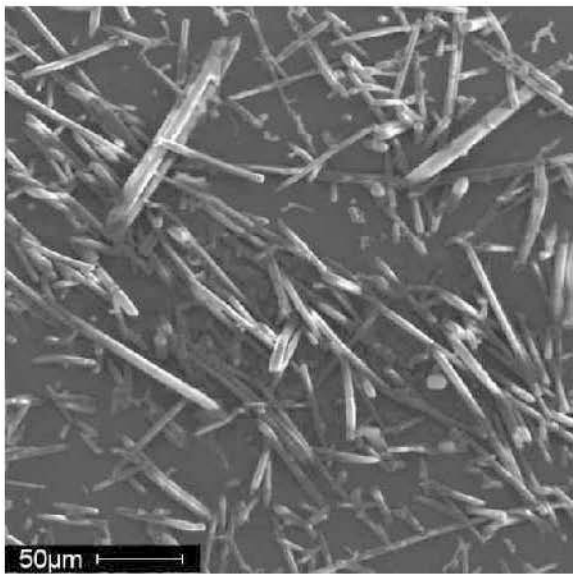
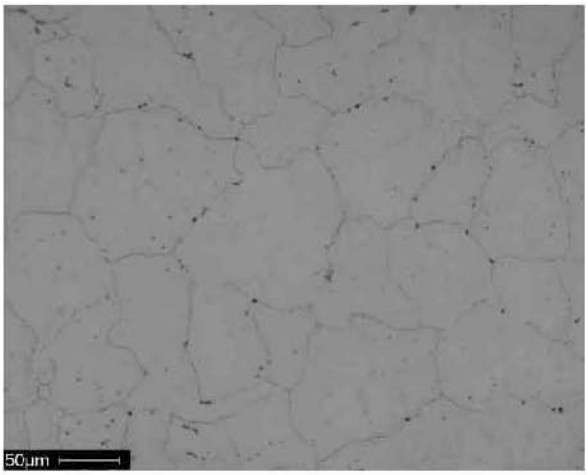


(c)

Figure 4: SEM micrographs showing the 22% fiber reinforced composite samples etched by (a) 10s, (b) 50s and (c) 110s.

As shown in figure 4, the fibers were distributed in a random and isotropic orientation and no agglomeration observed. This uniformity of the fiber distribution evidenced great contribution of the infiltration process during squeeze casting. The previous study found that the porosity has significant influence on the corrsion current values as well as the corrosion resistance [9]. Thus, the good infiltration could effectively improve the corrosion resistance from minimizing the formation of the porosity during squeeze casting.

An evident difference in grain size was found, between the unreinforced alloy AM60 and the composites with 7% and 11% fiber volume fractions. The change in grain size implied that the addition of fibers led to a finer grain structure of the composites. Figure 5 reveal the grain structures of the unreinforced alloy AM60 and the composites reinforced with 7% and 11% fiber. The grain size measurement for 22% fiber reinforced composite was not included in this work, since the grain boundaries were mostly covered by the reinforcing fibers and it was difficult to investigate the grain structure and measure the grain size quantitatively, as shown in Figure 5 (d).



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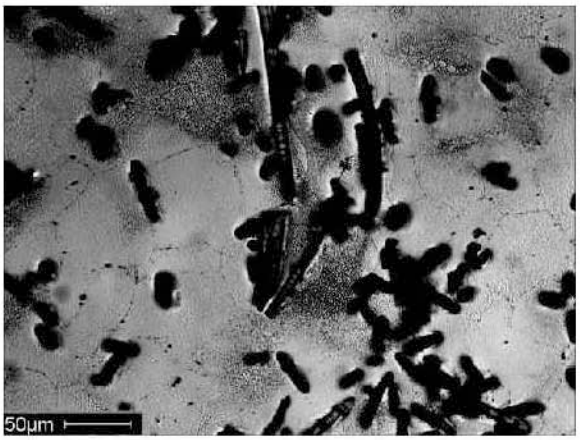

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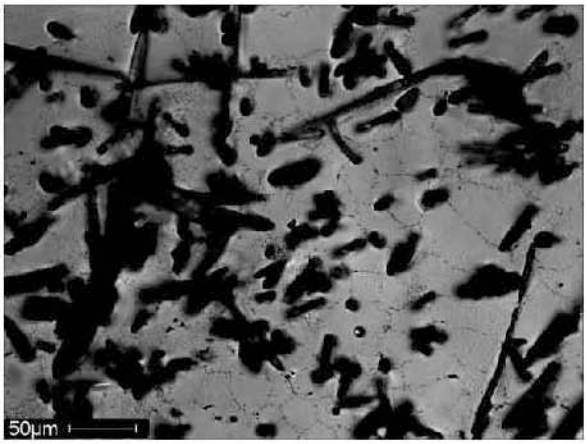

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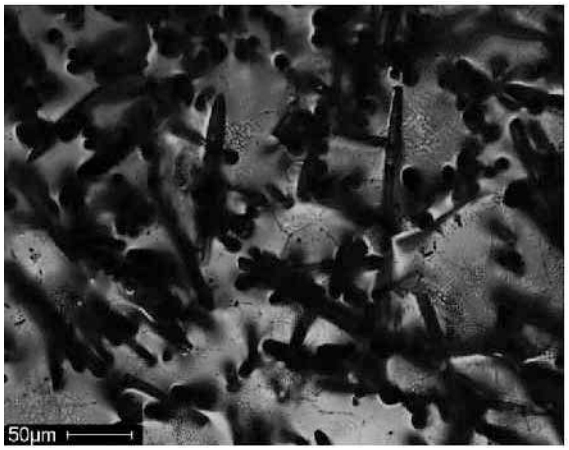

(d)

Figure 5: Optical micrographs showing grain structures of (a) unreinforced AM60, (b) 7%, (c) 11% and d) 22% fiber reinforced composites, repectively (all samples are under T4 condition).

To measure the grain size, a line was drawn across the mirograph and its length was noted. Then, the stage micrometer was used to determine the real length of the line. The number of the grain boundary interceptes was counted and the grain size could be determined by applying the following equation.

$$d = \frac{l}{n} \qquad \text{(Eq. 1)}$$

Where, d is the grain size, l is the length of the line and n is the number of grain boundary intercepts.

As can be seen from Figure 6, the grain size of the composites decreased after the addition of the fibers. The grain size decreased from 67 μm for matrix alloy AM60 to 36 μm for 11% fiber reinforced composite.

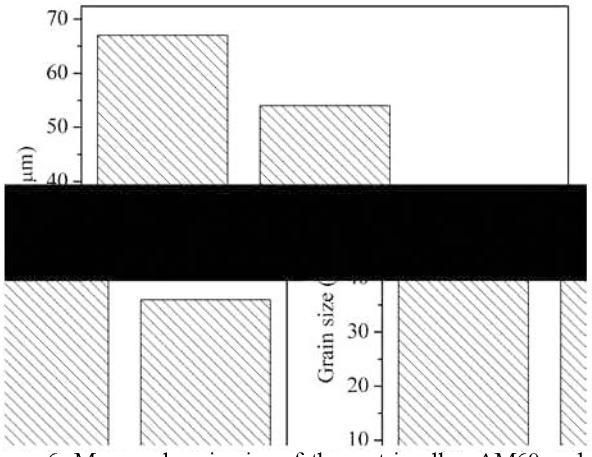

Figure 6: Measured grain size of the matrix alloy AM60 and its composites with fiber volume fractions of 7% and 11%.

Potentiodynamic Polarization

The differences in corrosion behaviors between the composites with the variation in fiber volume fractions and the matrix alloy AM60 are illustrated in Figure 7. The current density (i_{corr}) and polarization resistance (R_p) obtained by Tafel calculations are listed in Table 3. The polarization curves of the composites shifted to higher current densities from comparing the results between the composites and the matrix alloy. As fiber volume fraction increased, the current density rose. On the other hand, the R_p decreased by the addition of Al_2O_3 fibers and the Rp values of the composites were much lower than that of matrix alloy, as shown in Figure 5. By examining the values of the corrosion resistances listed in Table 3, the R_p of the 7% composite (2.301 kΩ cm^2) decreased by 73%, and the R_p of the 22% composite (1.061 kΩ cm^2) further decreased by almost four times in comparison with the matrix alloy (3.995 kΩ cm^2).

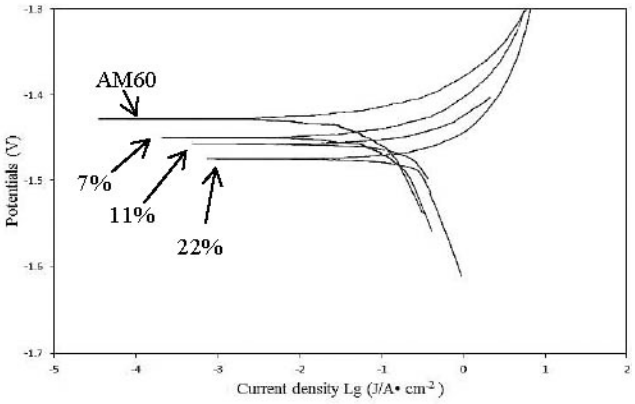

Figure 7: Potentiodynamic polarization curves for the unreinforced alloy AM60 and its composites with fiber volume fractions of 7%, 11% and 22%.

The previous corrosion studies on pure magnesium was carried out in the same 3.5% NaCl solution [10]. It has found that the grain refinement decrease the corrosion resistance of magnesium and the it was attributed to the higher density of grain boundaries and other defects from the grain refinement. However, in the case of fiber reinforced composite, the high density of grain boundaries might not be the main mechanism of decreasing in corrsion resistance. The introduction of the fibers in the composite generated new interfaces between the matrix alloy and Al_2O_3 fibers. As fiber volume fraction increased, a great deal of new interfaces generated in the composite. As a result, the presence of the new interfaces break the continuity of the matrix and form preferential spots for corrosion attack, and consequently the corrosion resistance of the composite decreased.

Table 3: Potentiodynamic polarization parameters of AM60 and its composites with fiber volume fractions of 7%, 11% and 22%

Sample	β_a (mV/dec)	β_c (mV/dec)	I_{corr} (μA/cm^2)	R_p (kΩ cm^2)
AM60	53.1	263.4	4.8	3.995
7%	31.5	189.1	5.7	2.301
11%	41.9	567.1	10.5	1.583
22%	32.3	245.3	11.6	1.061

Conclusions

As 7%, 11% and 22% fibers were added into the matrix alloy, uniform and random fiber distribution was obtain which guarantied the good infiltration during squeeze casting. The addition of Al_2O_3 fibers led to a significant grain refinement, which were 36 μm for 22% composite in comparison with 67 μm for matrix alloy AM60. The electrochemical testing results showed that the presence of Al_2O_3 fibers deteriorated the corrosion resistance of the composites. The decrease in corrosion resistance should attribute to the new interfaces generated as the fiber reinforcement added into the matrix alloy.

Acknowledgements

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