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Effects of carbonaceous reinforcements on microstructure and corrosion properties of magnesium matrix composites

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HIGHLIGHTS

- Carbonaceous reinforced magnesium matrix composites were succesfully produced by semi powder metallurgy method.
- Hardness of AZ91 magnesium alloy was improved considerably with the addition of reinforcements.
- Fullerene reinforced composite has the highest hardness among the samples.
- Corrosion performance of magnesium alloy was affected negatively due to galvanic reaction.

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ABSTRACT

In this study carbonaceous (C-based) reinforced AZ91 matrix composites were fabricated with the same weight fraction of 0.50 wt.% via semi powder metallurgy. The hot pressing test machine was used under high purity argon atmosphere. Multi-wall carbon nanotube (MWCNT), Graphene Nanoplatelets (GNPs) and Fullerene (C60) were used as reinforcements. Microstructure, hardness and corrosion performances of fabricated composites were investigated. Results show that hardness of AZ91 alloy was improved with the addition of carbonaceous reinforcements. AZ91/C60 composite exhibited highest hardness performance. However, corrosion performance of AZ91 was affected negatively by the addition of reinforcements. MWCNT exhibited highest corrosion rate among the fabricated samples.

1. Introduction

In recent years, the interest in lightweight materials is increasing because of economic and environmental reasons [1]. Magnesium is lightest structural metal due to its density of 1.74 gr/cm^3 (about 35% lighter than aluminum), so magnesium alloys are attractive materials for automotive, aerospace, and electronic industries [2]. Magnesium has high specific strength, good machinability and damping ability [3]. However, it has low ductility because of its hexagonal closed packed structure [4,5]. Furthermore, compared to other metals, magnesium performs poor corrosion resistance due to its low standard potential (E° = -2.37V) [6,7]. In recent years, metal matrix composites (MMCs), where matrix and reinforcements are used together to fabricate new material, have big importance to develop the properties of base metals [8]. MMCs are high-tech composites because of their high specific strengths and young modulus [9]. When MMCs are fabricated by powder metallurgy technique, more homogenous distribution of particles in matrix material can be achieved compared to casting method. Also, powder metallurgy may provide uniform microstructure with no dendritic phases, which could be detrimental to mechanical properties [10].

Researchers have generally attempted to improve mechanical and corrosion performances of magnesium by incorporating reinforcements such as SiC [11], TiC [12,13], B_4C [14] [15], Al_2O_3 [16] into magnesium and its alloys. In addition to these materials, nano-sized carbonaceous reinforcements such as carbon nanotubes (CNT) [17,18] and graphene nanoplatelets (GNPs) [19,20] have become popular due to their unique mechanical and physical properties.

Carbon nanotubes are formed when the sheet of carbon atoms are rolled [21]. CNTs have high stiffness up to 1 TPa and high tensile strength up to 200 GPa as well as lubricant nature [22]. There are several studies about using CNT as a reinforcement in metal matrix composite (MMCs) especially aluminum, titanium and magnesium alloys [2,23]. Akinwekomi et al. [24] observed that hardness of AZ61/

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CNT alloy was improved with increasing content of CNTs. The highest hardness value was achieved with the addition of 3.0% volume fraction of CNT, while highest ultimate compressive yield strength and 0.2% offset yield strength was achieved with the addition of 1.0% volume fraction of CNT. Shimizu et al. [25] fabricated AZ91/CNT composite with a tensile strength of 388 MPa and a ductility of 5% with 1.0 wt.% CNT. Han et al. [26] determined that the elongation to failure of Mg/CNTs composite has increased greatly by 32% with the addition of 0.08 wt. % CNTs. In addition to studies about mechanical behavior of CNT/Mg composites, there are limited reports on corrosion behavior of CNT reinforced Mg alloys. Fukuda et al. [27] investigated the influence of carbon nanotubes on the corrosion behavior of AZ31B magnesium alloy. Results show that addition of carbon nanotubes decreased the corrosion resistance of the AZ31B Mg alloy due to the formation galvanic cell between Mg and CNTs.

A single layer of graphite is known as graphene and that is two-dimensional material [27]- [28]. Graphene consists of sp^2 hybridized carbon atoms. It has 1 TPa modulus of elasticity and fracture strength of 125 GPa is another carbonaceous reinforcement to improve mechanical properties of magnesium matrix composites [29–32]. Rashad et al. reported that [28] the uniform dispersion of 0.30 wt% GNPs in magnesium matrix led to increase in microhardness, tensile strength, Young's modulus, yield strength and failure strain of composite. In another study, mechanical properties of magnesium composites were increased with the increase of Al-GNPs content [31]. Optimum properties were achieved with 0.18 wt.% GNPs and 1 wt.% Al in magnesium matrix. Mg-1Al-1Sn-0.18 GNPs composite was fabricated via semi powder metallurgy. It was determined that high specific surface area and adhesion of GNPs cause to increase in strength of composite [33]. Generally, graphene was preferred in studies to evaluate its effects on mechanical performances like carbon nanotubes. Our previous results show that graphene addition leads to increase in corrosion rate of pure magnesium [34].

The other allotrope of carbon atoms is known as fullerene which consists of sp^2 and sp^3 bonds [35]. A C60 form of fullerene which combines 12 pentagons and 20 hexagons structure is generally used in practical applications [36]. There are limited studies about fullerene reinforced metal matrix composites. Researchers have tried using fullerene as reinforcement for magnesium matrix composites to investigate mechanical and damping properties. In our previous study, effect of fullerene on mechanical and corrosion performance for pure magnesium matrix was investigated [37]. To the best of our knowledge, there is no detailed study about the influence of fullerene on corrosion performance of magnesium alloy.

As mentioned above, there are some studies about graphene, carbon nanotube and fullerene additions to magnesium alloys for mechanical investigations while there are limited studies about corrosion performance of carbonaceous reinforced magnesium matrix composites. Therefore, MWCNT, GNP, and C60 reinforced AZ91 matrix composites were fabricated with the same weight fraction to investigate microstructure, hardness and corrosion effects of reinforcements on AZ91 magnesium alloy in this study. Also, these reinforcements were compared each other utilizing hardness and corrosion performances.

2. Experimental

2.1. Raw materials and production

AZ91 magnesium alloy powder (%99.7 purity and 100 μm size ranges) and reinforcement materials were purchased from Nanografi Co. Ltd. in Turkey. Graphene has between 5 and 8 nm diameter and its surface area is about 750 m^2/g. Multiwall Carbon Nanotube has 8 nm diameter and its surface area is lower than graphene powder (250 m^2/g). Fullerene has 96% purity and 1–2 nm average thickness. Scanning Electron Microscope (SEM) images of raw materials are presented in Fig. 1.

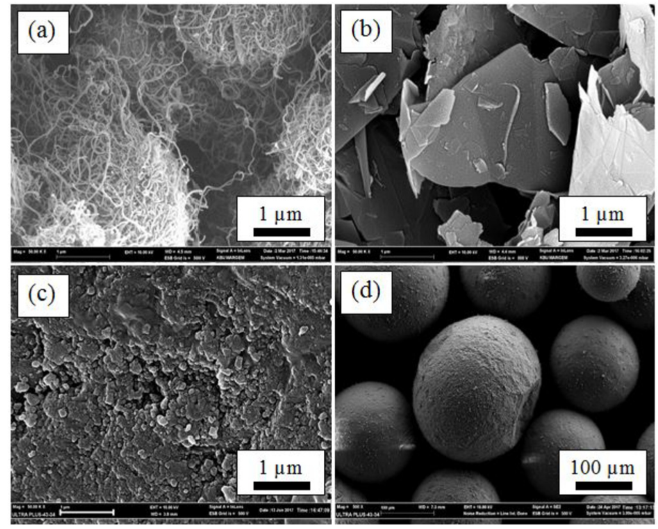

Fig. 1. SEM images of MWCNT (a), GNPs (b), C60 (c) and AZ91 (d).

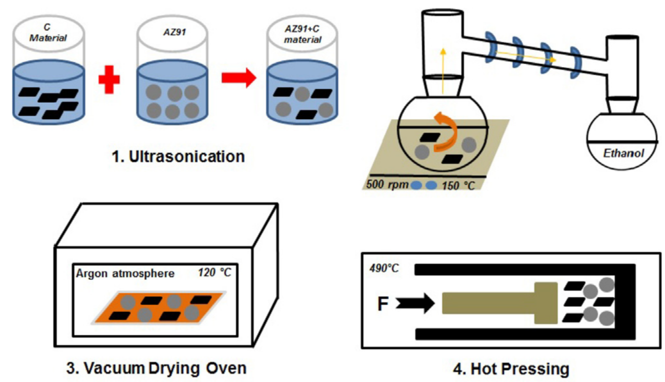

Fig. 2. The schema of production steps.

Composites were fabricated by semi powder metallurgy technique according to the production steps which are presented in Fig. 2. At first, carbonaceous materials were ultrasonicated in ethanol separately to break Van der Waals bonding between carbon atoms for 2 h using Alex Ultrasonication Test Device (660 Watt). Then, AZ91 magnesium alloy powders were poured into the solution. The aim of this process was to prevent agglomeration of carbon based materials. After ultrasonication process, powders were mixed by a magnetic stirrer in vacuum distillation system and ethanol was removed from the system at the end of 3 h. Finally, powders were dried at 120 °C in an atmosphere controlled furnace under argon gas.

AZ91/GNP, AZ91/MWCNT, and AZ91/C60 powders were compacted in graphite mold at 490 °C with a 50 MPa pressure in the hot-press system. Also, specimens were sintered at the same device and at same degrees for 1 h. The diameters of specimens with Ø 20 × 25 mm cylindrical were fabricated. At the same time, AZ91 powders were compacted in same conditions to make a comparison between unreinforced AZ91 alloy and carbonaceous reinforced composites.

2.2. Microstructure and hardness tests

Metallographic processes which include grinding with SiC grit papers from 240 to 2000, polishing with diamond suspension and etching with picric acid solution were performed for all samples. The phases present in composites were characterized by Cu-based X-ray diffraction machine (Rigaku Ultima IV) in the range of 15-75°. SEM was used to examine microstructures of composites. Furthermore, line and mapping EDX analysis were taken to see the distribution of reinforcement for