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Research Paper / Makale

Wear Characteristics of Carbon Nanotube Reinforced Al2024 Composites

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Abstract: Composite materials have high specific strength and modulus of elasticity compared to traditional materials, thus, over the past 10-20 years, the demand for these kinds of materials has increased significantly due to their specific properties. This means, the weight of the machine component produced from these materials can be reduced. In this study, the mold casting method was used in the production of Al 2024 matrix composite materials. In sample production, 50% MgO and 50% MWCNT are mixed by weight and added to the matrix material in the ratio of 0.2% - 0.5% - 1% - 2%. The hardness and wear behaviors of Al 2024 composites with MgO / MWCNT additive were investigated using Rockwell tester and a ball-on-disc wear tester. The effects of composite materials on the wear properties have been investigated by determining the wear weight loss. 5N load and 250 m distance were chosen as the wear test parameters and percent wear amounts of the samples were examined. It was observed that hardness values of samples increased, and the wear percentage of specimens decreased with the addition of reinforcement. The best ratio for the composite design is the mixing of 50 wt.% + MgO 50 wt.% CNT with 1 wt.%.

Keywords: Metal matrix composite, wear, Al 2024, carbon nanotube (CNT)

Magnezyum Oksit ve Karbon Nanotüp Takviyeli Al2024 Kompozitlerin Aşınma Özellikleri

Öz: Kompozit malzemeler, geleneksel malzemelere kıyasla yüksek özgül mukavemet ve esneklik modülüne sahiptir, bu nedenle, son 10-20 yıl boyunca, bu tür malzemelere olan talep, spesifik özellikleri nedeniyle önemli ölçüde artmıştır. Bu malzemelerden üretilen makine bileşeninin ağırlığının azaltılabileceği anlamına gelir. Bu çalışmada, Al 2024 matris kompozit malzemelerin üretiminde kokil kalıba döküm yöntemi kullanılmıştır. Numune üretiminde, ağırlıkça% 50 MgO ve% 50 MWCNT karıştırılmıştır ve matris malzemesine %0.2- %0.5 - %1 - %2 oranında ilave edilmiştir. MgO/MWCNT katkılı Al2024 kompozitlerinin sertlik ve aşınma davranışları, Rockwell test cihazı ve bir disk üzerinde bilya aşınma test cihazı kullanılarak araştırıldı. Kompozit malzemelerin aşınma özellikleri üzerindeki etkileri, aşınma kütle kaybı belirlenerek araştırılmıştır. Aşınma testi parametreleri olarak 5N yük ve 250 m mesafe seçilmiştir ve örneklerin aşınma yüzdesi miktarları incelenmiştir. Güçlendirici ilavesiyle numunelerin sertlik değerlerinin arttığı ve numunelerin aşınma yüzdesinin azaldığı gözlenmiştir. Kompozit oluşturma için en iyi oran, ağırlıkça % 1 (50% MgO +50% CNT) karışımıdır.

Anahtar kelimeler: Kompozit, aşınma, Al 2024, karbon nanotüp (CNT)

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1. Introduction

Aluminum-based metal matrix composites are important for their high specific strength and play a notable role in the improvement of technological materials. It is due to their ability to improve their properties such as mechanical processing, forging and heat treatment in different ways. Besides, it is an advantage to have the ability to form aluminum-based composites using a wide variation of strengthens materials of different structures. The purpose of using reinforcing materials to produce Al-composites is to maximize the mechanical properties of aluminum by improving particular properties such as hardness, wear-resistance and strength[1-3].Overall, many works have noticed that abrasives and composites show better wear resistance than unreinforced alloys for sliding towards metals and abrasives. Also, under various wear situations, particle-reinforced composites fulfill better than the fiber-reinforced composites[4].Elements reinforced to Metal Matrix Composites [5]can improve their mechanical properties. This can expand the use of composites. To develop the properties of composites, the size and reinforcement ratios should be controlled well. The need for light and high-strength materials has increased, particularly with the discovery of the aircraft[6]. Al alloys are a high demand material due to their weak density and high certain strength in the aviation industry [7]. This leads to many advantages such as increasing the load carried on aircraft and automobiles or improving fuel efficiency[6]. As reinforcement materials, SiC, SiO_2, Al_2O_3, MgO are generally preferred because of their high strength and lightweight [4, 5]. Also, Carbon nanotube (CNT)[10-13] is used because of its thermal conductivity, mechanical and electrical properties[6]. Carbon nanotubes (CNTs) do not have only great higher mechanical properties than ceramics. It also has other useful properties such as large thermal and electrical conductibility. CNT / Al composites are a widely used material produced using traditional material preparation technologies such as friction stir welding, powder metallurgy and molding[7,14,15].Lately, researchers have focused onto score the influence of nanoparticles on abrasive resistance of aluminum and its compounds. One of the hopeful nano-reinforcements was carbon nanotubes (CNTs) with excellent mechanical properties[16]. Several studies have reported that the abrasive resistance of aluminum increases because of the addition of CNTs. Lim et al. fabricated Alumina-CNT composites with different amounts of CNTs by several processing techniques to analyze the influence of the CNT dispersion in the ceramic matrix on abrasive behavior. They manufactured aluminum oxide composites with CNT contents up to 12 wt.% by strip casting. They investigated the abrasive behavior of CNT supported composites using a ball-on-disk wear tester run at room temperature without lubrication. They reduced the wear rate of tape-cast composites stably with the addition of CNT, which has increased by up to 12 wt.%. In their works, the results showed that the strip casting process notably improved the dispersion of CNT in aluminum oxide and the abrasive resistance of composites increased[17].Zhou et al. manufactured aluminum composites doped with CNTs by non-pressurized infiltration treatment. They investigated the abrasive properties of composites. They infiltrated Al into the CNT-Mg-Al performed by non-pressurized infiltration treatment at 800 °C in a N_2 atmosphere. They investigated the abrasive behaviors of the composites by using a pin-on-disk abrasion tester under ungreased conditions. They point out that the friction coefficient of the composite reduced with growing the number of CNTs owing to the self-lubrication and structure of CNTs. They found that the wear rate of the composite reduced continuously with the increase of CNTs content in the composite, within the range of CNTs density from 0% to 20%[18]. Choi et al. researched the abrasive properties of ultrafine-grained aluminum and aluminum-matrix composites. They found that as grain size is decreased to ∼150 nm and MWCNT vol. rising to 4.5 vol.%, wear resistance increases. They also reduced the coefficient of friction to ∼0.1 by adding 4.5 vol.% of MWCNTs [19-21]. As a result of literature studies, wear and mechanical properties are improved with CNT reinforcement for aluminum matrix composites.

In this work, aluminum 2024 [22] alloy was used as a matrix material. The 50% MgO and 50% MWCNT by weight were mixed and added to the matrix material at the rates of 0.2% - 0.5% - 1% - 2%. The mixtures of multi-walled carbon nanotubes (MWCNTs) and magnesium oxide (MgO) nanoparticles were used as reinforcement. The effects of composite materials on the wear properties were studied by determining the wear weight loss. The load of 5N and distance of 250 m were chosen as the wear test parameters and percent wear amounts of the samples were investigated. The abrasive wear behavior of the alloy 2024 (Al-2024), and MgO and MWCNT particles reinforced aluminum matrix composites have been researched under dry sliding wear conditions [23-25].

2. Experimental Methods

2.1. Materials

In this study, aluminum 2024 alloy was used as a matrix material. As reinforcement, multi-walled carbon nanotubes with 9.5 nm in diameter, 1.5 microns in length and magnesium oxide (MgO) nanoparticles with 40 nm in diameter were used. The matrix material was melted into 800 °C. 50% MgO and 50% MWCNT by weight were mixed and added to the matrix material at the rates of 0.2% - 0.5% - 1% - 2%. The composite materials were produced by mixing the semi-solid method (640 ± 5°C) at 500 rpm for 10 minutes. The casting temperature was 800 °C and the atmosphere was controlled by Argon gas (%99.99). The melt was casted into a steel mold that was heated to 200 ^{o}C.

Hardness and abrasion tests were performed on specimens, respectively, using Rockwell hardness tester and a ball-on-disc machine in CSM Instruments brand device without a lubricant at room temperature (Fig. 1).

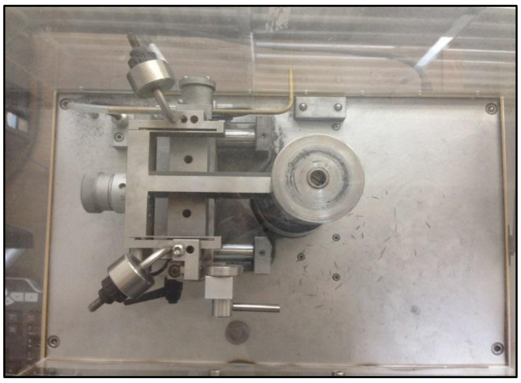

Figure 1. Ball-on-Disk wear device

In experiments, a slip speed of 1.0 m/s was used with a load of 5 N. The slip distance was determined as 250 m. The purpose of the abrasion tests was to examine the percent abrasion amounts by considering the weight loss of the material according to the content of the metal matrix composite materials produced by the mixing casting method. Wear surfaces of parts were analyzed by scanning electron microscopy (SEM).

3. Results and Discussion

3.1. Synthesis and Characterization

The hardness test was measured with a Rockwell (15-T) hardness tester to achieve an average value. 1/16” steel ball was used for hardness measurements. The results were the average of 10 reading. In Fig. 2, (15-T) hardness measurement values of composites doped with MgO and MWCNTs were given .With the increased reinforcement content, an increase in the hardness of composite materials was obtained.

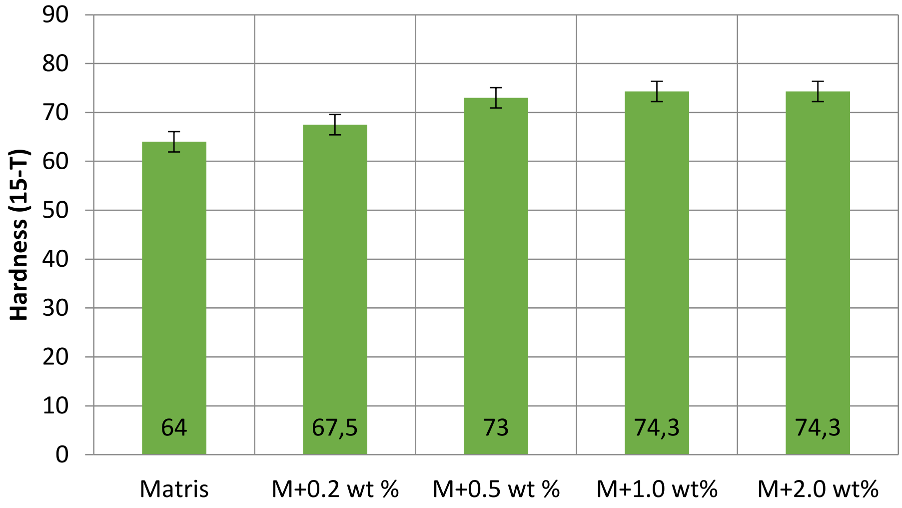

Figure 2. (15-T) hardness values of composites containing MWCNT.

In Fig. 3, the hardness increases rates % (percentage) of composites doped with MgO and MWCNTs were given. The maximum hardness value 74.3 (15-T) was obtained by adding 1% reinforcement and then the increase in hardness remained constant. The increase in hardness can be attributed to the addition of reinforcements with high hardness and strengthening mechanisms such as Orowan and grain size [26]. Also, reinforcement addition can be caused porosity in composites and this respect can deteriorate the mechanical properties of samples like hardness and wear resistance.

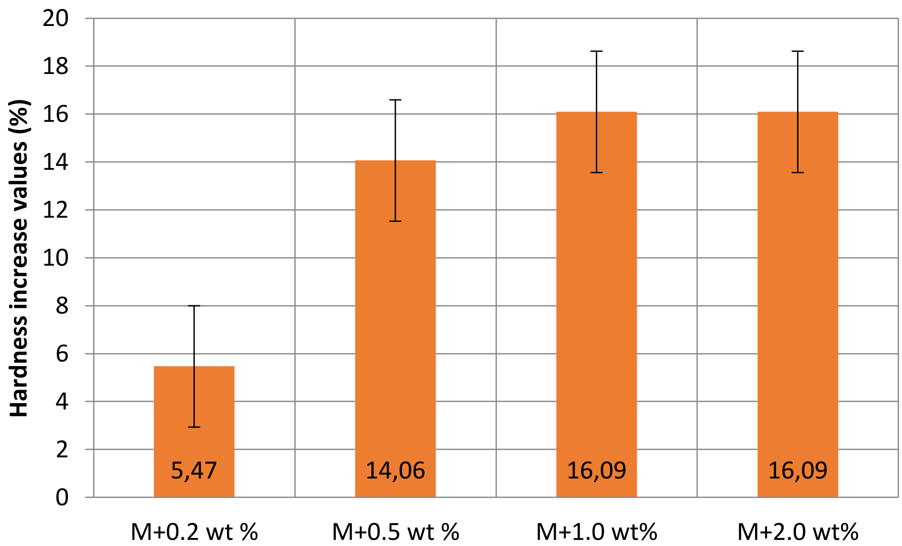

Figure 3. % increase rates of hardness.

3.2. Investigation of Wear Properties

Al alloys are used in the aviation industry because of their low density and high specific strength. In the study carried out, by adding MgO and MWCNT compounds in different proportions to the Al

2024 metal matrix material, a wear test was carried out at a distance of 250 m with a load of 5 N to see the wear effect on the material. Table 1, Figures 4 and 5 show the wear test results.

Table 1. Weight loss (g) or percentage (%) as a result of the wear test

Material	Load	Weight loss (g)	Percentage weight loss (%)
Al 2024 (Base)	5 N	**0,0018**	**-0,0307**
%50 CNT %50 MgO %0,2		**0,0023**	**-0,0583**
%50 CNT %50 MgO 0,5		**0,0046**	**-0,0521**
%50 CNT %50 MgO %1		**0,0022**	**-0,0235**
%50 CNT %50 MgO %2		**0,0028**	**-0,0355**

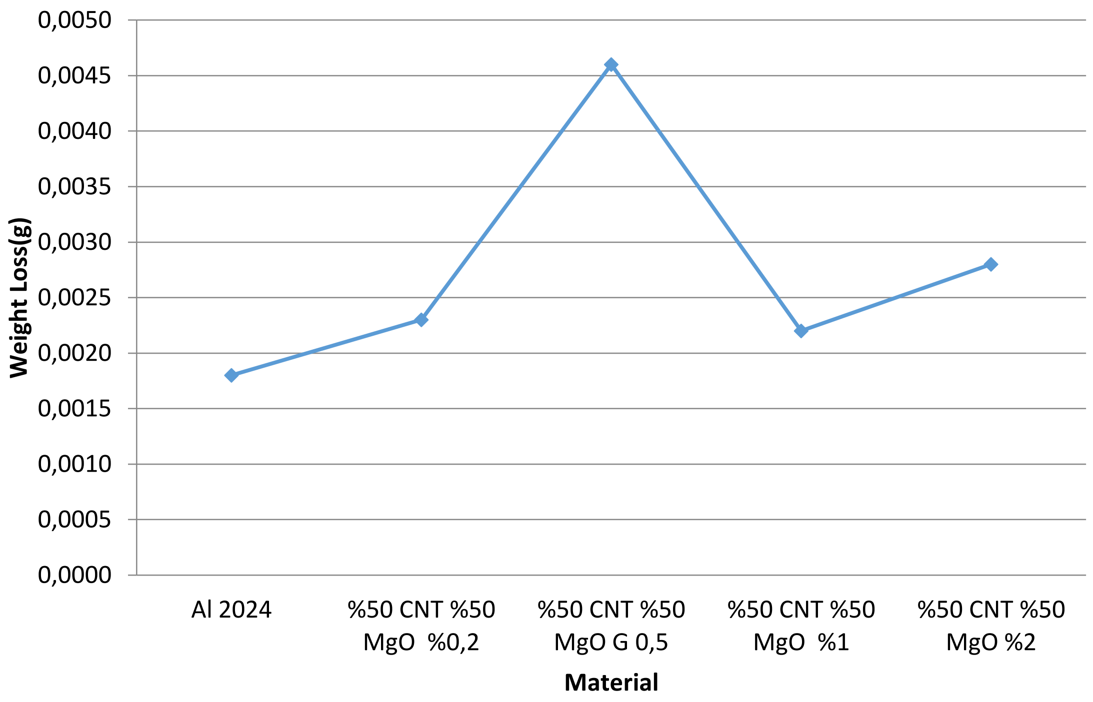

Figure 4. Wear test results /weight loss (g)

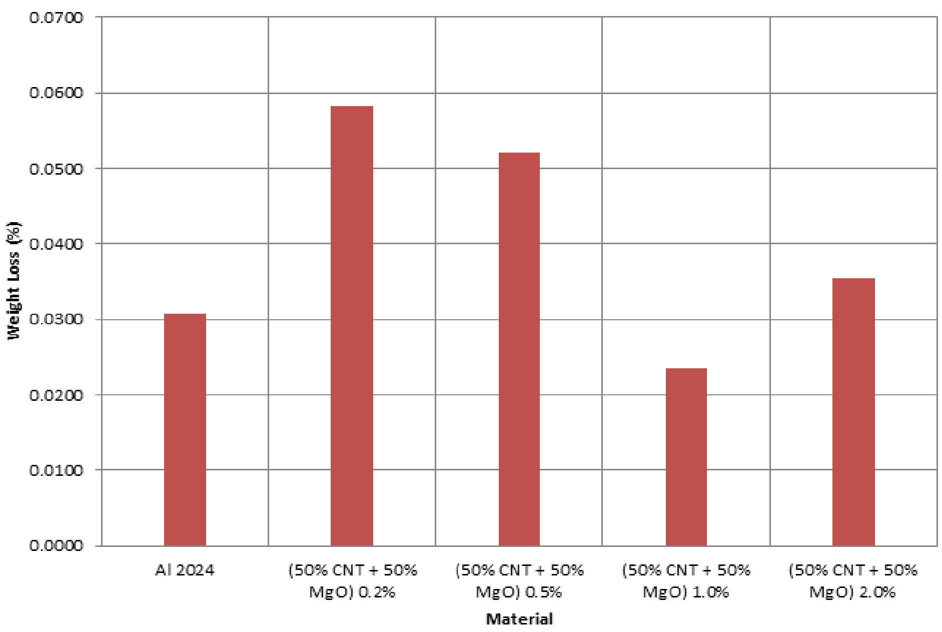

Figure 5. Wear test results/weight loss (%)

To analyze the wear properties, abrasive wear behaviors of composite samples were investigated similar to previous studies [6, 7]. As a result of the wear test, it was seen that, while the wear loss was in an increasing trend, it turned to a decreasing trend starting from the 0.5% reinforcement. While the maximum weight loss was observed with the addition of 0.2% reinforcement, the minimum weight loss occurred with the addition of 1% reinforcement. The increase in the hardness rates of the materials is likely directly proportional to the increase in the wear characteristics of the composite, but the increase in the hardness of the excessive hardness may cause the tendency to become brittle and lead to increased wear loss of the broken pieces.

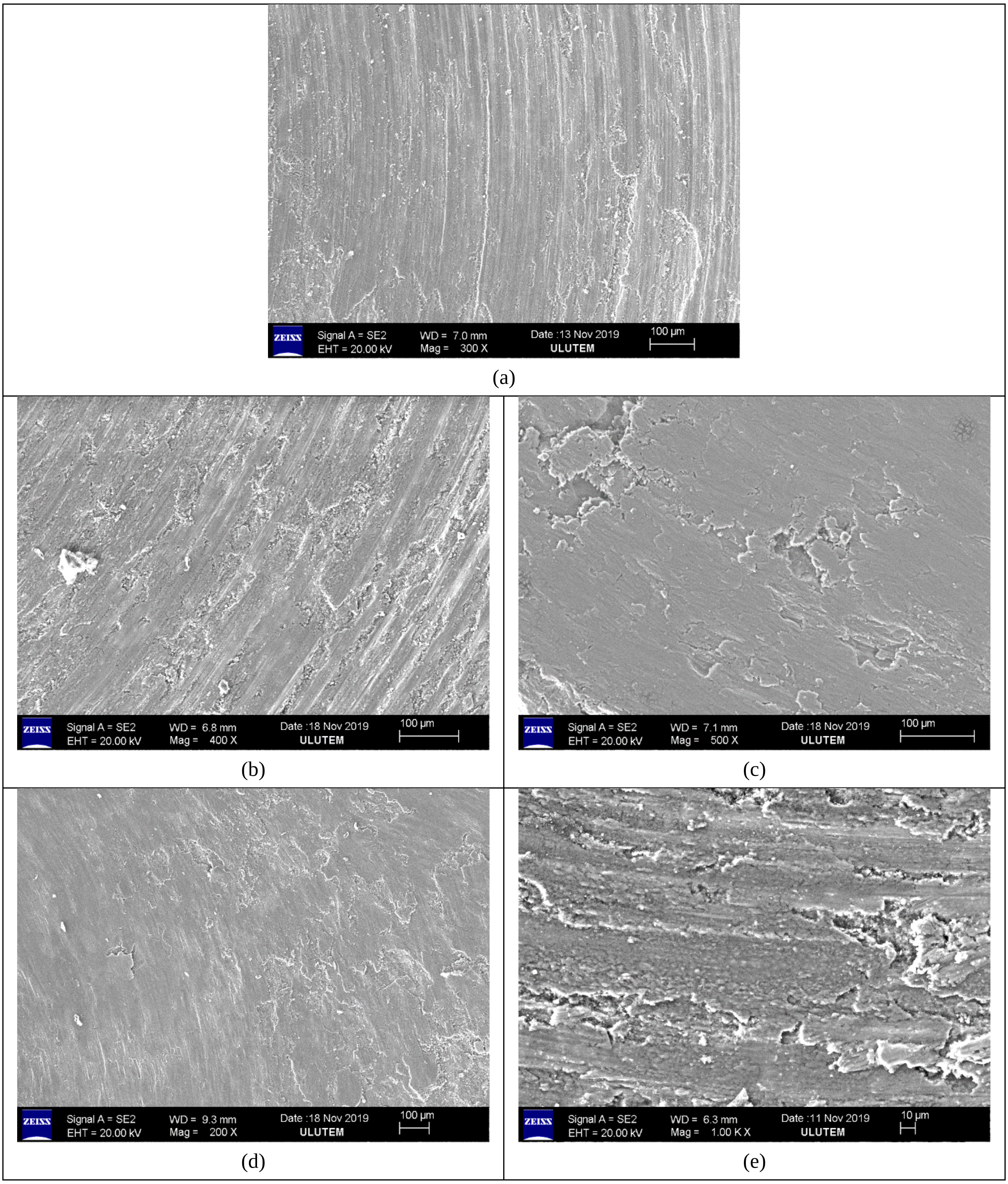

Figure 6. SEM images of the worn surfaces with varying MgO and CNT contents under 5N force a) base, b) 0.2 wt.%, c) 0.5 wt.%, d) 1 wt.%, e) 2 wt.%,

Besides, microstructural changes and the amount of porosity also change the wear properties. MgO-MWCNT reinforcements in Al 2024 metal matrix contributed to the improvement of hardness properties[27,28].

Fig. 6 demonstrates SEM images of worn surfaces as a function of varying CNT substance. In the images from (a) to (e), the adhesive wear was indicated, and the abrasive wear produced by the micro debris that was cut from the surface is shown. For (a) uncontaminated aluminum and the composites doped with (b) 0.2 wt.% of MgO and MWCNTs, SEM micrographs disclose cuttings and material delamination on the worn surfaces, which shows that the wear process of the materials is assumed with micro-plowing and delamination. The trace of plastic deformation by plowing is clear in the areas of abrasive wear as displayed in (a) and (b). Especially, intense surface failures were performed in several places at (d) and (e). In (e), due to the reinforcement content is upper the quantity of agglomerated particles and cavities were bigger than that of (d). The noise is decreased by increasing the volume of MWCNTs up to (d) 1 wt.%. For the composites with (d) 1 wt.% of MWCNTs, the surface of the abrasive tracks is the lower property and quite smooth along the sliding way. The composite including (e) MWCNTs of 2 wt.% shows a rough worn scar because of debris that is easily separated from the surface possibly because of the pores. Depending on these results, the advanced the CNT content advanced the quantity of abrasive because of the separation of conglomerated particles that have poor bonding energy with the surface.

4. Conclusions

In this study, Al2024 / MgO / CNT hybrid composites were produced by stir casting method. The microstructure, hardness and wear properties of composites were examined by considering hardness tester and the weight loss in the samples as a result of the wear test. Hardness values of composites linearly increased by the addition of reinforcements. Whereas the wear behavior appears to be linearly related to increasing the amount of reinforcement, it has been found that the appropriate reinforcement amount ratio should be selected to improve the wear behavior of the composite. The maximum hardness value 74.3 (15-T) was obtained by adding 1% reinforcement. While the maximum weight loss was observed with the addition of 0.2% reinforcement, the minimum weight loss occurred with the addition of 1% reinforcement. The optimum reinforcement content for this study was found to be a mixture of of 50 wt.% + MgO 50 wt.% CNT with 1 wt.%.

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