Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi
Niğde Ömer Halisdemir University Journal of Engineering Sciences

Araştırma makalesi / Research article

www.dergipark.org.tr/tr/pub/ngumuh / www.dergipark.org.tr/en/pub/ngumuh

Effects of multi walled carbon nanotube and silicon carbide reinforcement on wear performance in zinc-aluminium alloys

Çinko-alüminyum alaşımlarda karbon nanotüp ve silisyum karbür takviyesinin aşınma performansına olan etkisinin incelenmesi

Emre Deniz Yalçın[1,*], Aykut Çanakçı[2]

[1] Karadeniz Technical University, Abdullah Kanca Vocational School of Higher Education, 61530, Trabzon, Türkiye
[2] Karadeniz Technical University, Department of Metallurgical and Material Science Engineering, 61080, Trabzon, Türkiye

Abstract

In this study, hybrid composite materials were produced by adding SiC (Silicon carbide) and MWCNT (Multi-walled carbon nanotube) to Zinc-Aluminium (ZA40) alloy, sintering under 700 MPa pressure and 500 °C using mechanical alloying and hot press technique. Hybrid samples were produced with 2% MWCNT constant and SiC ratio 1-2-3 and 4% by weight in the mixtures. The mechanical properties such as hardness and porosity of the produced hybrid composite materials were determined and their wear properties were investigated by traveling 300 m using 10 and 20N loads under 300 rpm constant speed in a ball-on-disc wear test setup. The obtained microstructure and wear surface images showed that the SiC and MWCNT reinforcement contributed significantly to the wear resistance of the hybrid composites, and in the SEM analyzes of the worn surfaces, there was a transition from abrasive wear to adhesive wear in the wear mechanism.

Keywords: Powder metallurgy, Hybrid composite, Wear, ZA40, SiC, MWCNT

Öz

Bu çalışma kapsamında Çinko-Alüminyum (ZA40) alaşımına SiC (Silisyum karbür) ve MWCNT (Çok duvarlı karbon nanotüp) takviyesi yapılarak, mekanik alaşımlama ve hot pres tekniği kullanılarak 700 MPa basınç altında ve 500 °C sıcaklıkta sinterlenerek hibrit kompozit malzemeler üretilmiştir. Karışımlarda %2 ile MWCNT oranı sabit tutulup SiC oranı ağırlıkça %1-2-3 ve 4% olarak hibrit numuneler üretilmiştir. Üretilen hibrit kompozit malzemelerin sertlik ve porozite gibi mekanik özellikleri belirlenip ball-on-disk aşınma test düzeneğinde 300 rpm sabit hız altında 10 ve 20N yükler kullanılarak 300 m yol alarak aşınma özellikleri incelenmiştir. Elde edilen içyapı ve aşınma yüzey görüntüleri SiC ve MWCNT takviyesinin hibrit kompozitlerin aşınma direncine önemli ölçüde katkılar sağladığı ve aşınmış yüzeylerin SEM analizlerinde aşınma mekanizmasında abrazif aşınmadan adhezif aşınmaya doğru bir geçiş olduğu görülmüştür.

Anahtar kelimeler: Toz metalurjisi, Hibrit kompozit, Aşınma, ZA40, SiC, MWCNT

1 Introduction

Considering the low melting temperature, good machinability, superior tribological behavior, and reasonable cost of Zn-Al series alloys (Zinc-Aluminium) in modern production technologies, brass, cast iron, and aluminium are distinguished from the series alloys and immediately attract the attention of designer engineers [1, 2]. In particular during the cold war years, ZA8-ZA12-ZA27-ZA33 and ZA40 series alloys were produced. Especially, these alloys are used in very few applications due to the deterioration of their mechanical properties at temperatures above 100 °C. Since ZA series are one of significant alloying elements, it is possible to produce new types of hybrid composite materials with advanced engineering properties by performing them with ceramic and carbon-based reinforcement materials at different rates. In recent years, hybrid composites have been produced by adding more than one reinforcement material to ZA series alloys and they have been used successfully in various engineering applications such as automotive, construction, aviation and defence industries [3, 4, 5]. Silicon carbide is used as a reinforcement material in important parts for example transmission boxes, and tribune blades, particularly in the defence-aviation industry [6]. In a study examining the wear behavior of composite materials formed by adding SiC reinforcement to AA7075 alloy in pin-on disc wear device, it was observed that 15% SiC reinforcement significantly reduced the wear rate and friction coefficient of composites [7]. In a study examining the wear behavior of hybrid composite specimens formed by Taguchi method by adding SiC and graphite to ZA27 alloy in pin-on-disc experimental setup in a dry friction environment, it was observed that SiC and graphite additive significantly improved the wear resistance of hybrid specimens [8]. In a study examining the mechanical and wear properties of the composite samples obtained by adding 0-0.5-1-1.5 and 2 wt% SiC into the ZA40 matrix, the wear and tear under 10 and 20N loads by traveling 100 meters at 200 rpm in a ball-on disc wear test setup. Strengths, weight losses and friction coefficients were calculated and examined. After the wear tests, detailed SEM pictures of the samples were examined and the effects of wear were determined by looking at the damages. It was seen that

* Sorumlu yazar / Corresponding author, e-posta / e-mail: emredenizyalcin@ktu.edu.tr (E. D. Yalçın)
Geliş / Recieved: 24.12.2022 Kabul / Accepted: 27.03.2023 Yayımlanma / Published: 15.04.2023
doi: 10.28948/ngumuh.1223929

increasing SiC reinforcement changed the mechanical properties, and physical of the composites and made significant contributions to the abrasion resistance [4]. In a recent study, composite samples were produced using the powder metallurgy technique and hot press method by adding 0-1-2-3 and 4% hexagonal boron nitride (h-BN) to zinc-aluminium alloy (ZA40) by weight. Wear tests were carried out under 5N and 10N loads in a dry friction environment using the ball-on-disk method. According to the results, it was clearly seen that there are physical, mechanical, and tribological differences between the h-BN reinforced ZA40 and the unreinforced ZA40. It was observed that the wear values decreased significantly, especially with increasing h-BN reinforcement [9]. In the wear tests of hybrid composites formed by adding B_4C and nanographene to AA6061 aluminium alloy, it was observed that B_4C and graphene reinforcement caused improvements in the wear resistance of the samples [10]. In a study examining the mechanical properties of the composite samples formed by adding SiC to the AA2024 alloy, increases in the hardness and relative densities of the composites with a SiC content of 10-20-30-40% by weight were observed [11]. In the pin-on-disc wear tests of the composites produced by the addition of SiC into atomized aluminium, powder metallurgy, and hot press method. It was observed that SiC reinforcement significantly improved the wear resistance of the composites [12]. With the semi-solid molding method, SiC was added to the Al A356 matrix in 4 different weight ratios (5, 10, 15, and 20) and the wear behavior of the produced composites was investigated in the pin-on-disc abrasion test setup with 30 and 60N loads and 500-1000-1500-2000. According to the results, the highest abrasion resistance was observed in the composite sample containing 20% SiC [13]. In a recent study, it was determined that MWCNT-reinforced Al-Cu-Mg composites travelled 500 m under 2N and 5N loads in ball-on-disc wear tests, and MWCNT-doped composites showed lower wear loss under 2N load [14]. According to the test results of AA2024 aluminium alloys reinforced with MWCNT in the ball on disc wear mechanism, MWCNT supplementation increased the lubricating properties of the composites and resulted in significant decreases in wear losses [15].

Our study aims to strengthen the structure and wear resistance of the matrix by adding hard particles to the matrix. Especially with SiC reinforcement, and to minimize the wear caused by adding lubricating properties to hybrid composite materials obtained with MWCNT reinforcement, which is known for its lubricating properties. Thus, it is aimed to increase the wear resistance and load carrying capacity of the hybrid composite samples under heavy loads and long wear path progression.

2 Material and methods

ZA40 alloy was obtained from İki-El Metal Tozları A.Ş. Reinforcement materials SiC and MWCNT were obtained from Alfa Aesar. In addition, the reinforcement ratios and coding of the samples are given in Table 1. The reinforcement material and ZA40 matrix powders (Retsch PM 200) were mixed in a planet type ball mill with a brand name of 400 rpm in an argon atmosphere for 3 hours. Balls made of tungsten carbide with a diameter of 10 mm were used in the grinding process, and the ball: powder weight ratio was found to be 5:1. Powder mixtures were placed in a 30 mm wide mould made of 4140 steel material and subjected to hot pressing (hot press) at 700 MPa and 500 °C for 3 hours. Before hot pressing, the samples were subjected to cold pre-pressing under 400 MPa pressure for 1 minute. The theoretical densities of the produced samples were determined by applying the Archimedes method at the experimental densities of the mixture rule. The dimensions of the samples are ± 0.01 mg after measuring with a caliper to an accuracy of ± 0.01 mm. The measurements were made by measuring with precision scales. The hardness measurements of the samples were made by using a 2.5 mm diameter penetrating tip under a load of 2.5 kgf with the Vickers hardness measurement method and determined by taking the arithmetic average. The surfaces of the samples prepared for the abrasion tests were sanded and a flat surface was obtained. The ball-on-disc wear test setup shown in Figure 1 was used in the wear resistance tests. Abrasive balls are 10 mm in diameter and manufactured from H11 hot work tool steel. Abrasion tests were performed by traveling 300 meters under 10N and 20N loads at a constant speed of 300rpm. The aim here is to determine the load carrying capacity of the samples on different loads and roads. Morphologies and microstructure analyses of the ground composite powders were examined using a ZEISS LS 10-SEM. The distribution of the reinforcements in the matrix, the porosity, and the interface analyses of the samples were made in detail by SEM analysis. After the wear tests, the type of wear, the surface condition and the damages on the wear surface were examined.

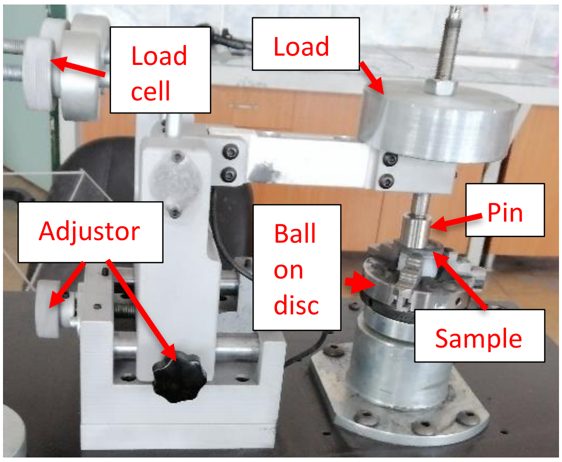


Figure 1. Applied ball on disc wear test

Table 1. Coding of samples and reinforcement ratios

Sample code	ZA40(%)	SiC(%)	MWCNT(%)
H-0	100	0	0
H-1	97	2	1
H-2	96	2	2
H-3	95	2	3
H-4	94	2	4

3 Results and discussion

3.1 *Microstructure*

A mechanical alloying time of 3 hours was determined in order to ensure as a homogeneous a mixture as possible in the produced Zn-Al based hybrid composite samples and also to disperse the SiC and MWCNT powders into the matrix thoroughly. If good performance is desired, especially in ZA derivatives alloys, it is essential that the reinforcement particles are sufficiently homogeneously dispersed into the matrix and that a good interfacial bond is formed [16]. SEM-EDS mapping images are shown in Figures 2a-d.

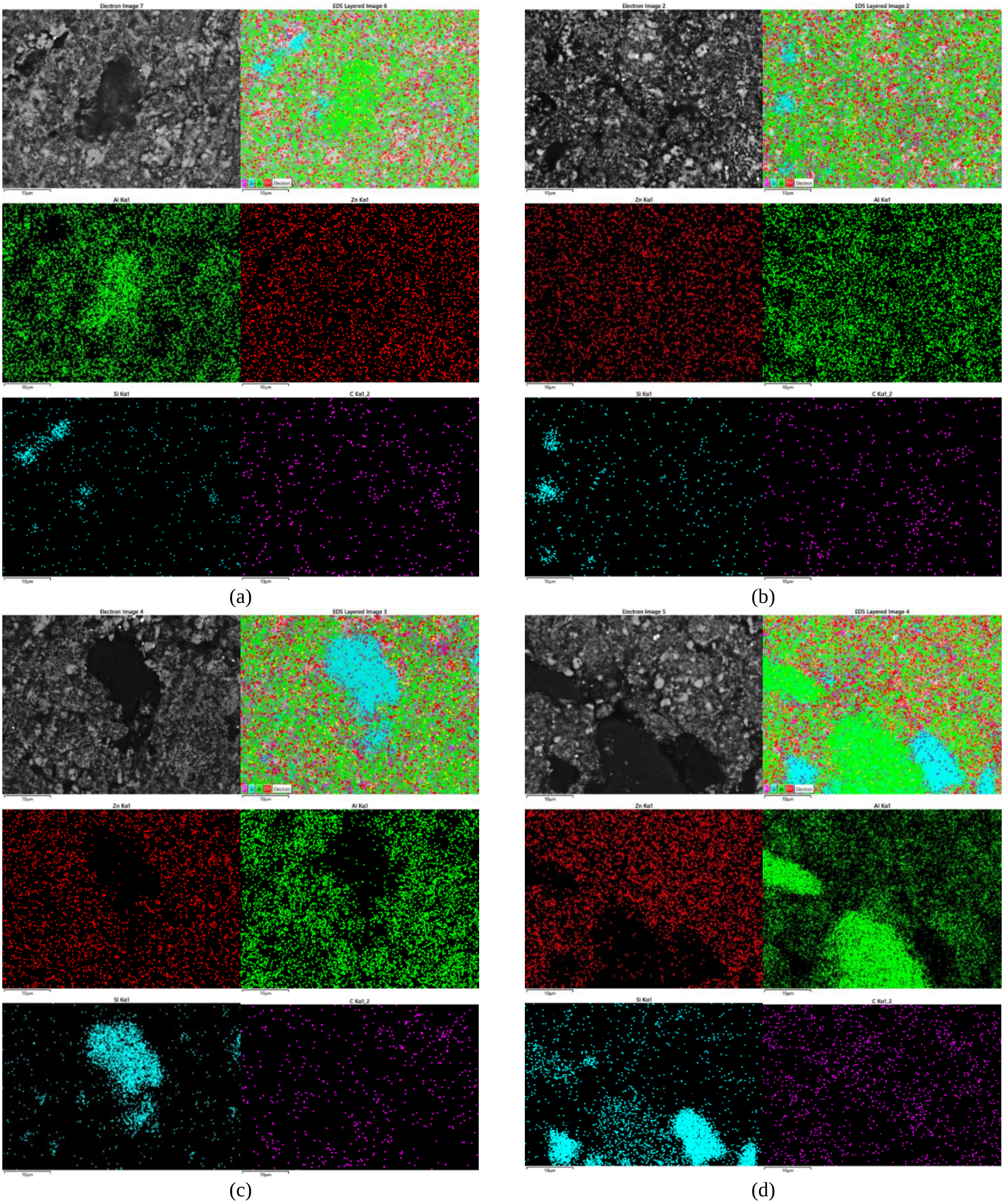


Figure 2. EDS analysis of hybrid composites; (a) H-1, (b) H-2, (c) H-3 and (d) H-4

The red, green, blue, and purple colored regions in these microstructures show the distribution of Zn, Al, Si, and C elements. When Figure 2a-d is examined, it is seen that the mapping patterns of Si, and C elements in SiC and MWCNT structure are less compared to Zn and Al elements, but the mapping patterns of both elements increase significantly with increasing reinforcement ratio. The mechanism that occurs here is that the ZA40 powders surround the SiC and MWCNT powders during mechanical alloying and the reinforcement powders are trapped in the Al matrix. As can be seen from the EDS images, it was determined that SiC powder became agglomerated with increasing reinforcement rates. It is clearly seen that agglomeration areas increase in hybrid composite powders reinforced with 2% MWCNT and 4% SiC, which is the highest ratio. Even though agglomeration regions are seen in Figure 2, it is seen that the distribution of the reinforcement powders in the matrix is successful, and a complete agglomeration does not occur despite the ceramic reinforcement-metal matrix interface, which is known to have poor wetting properties.

3.2 Porosity and hardness

In Figure 3 and Figure 4, hardness values and porosity amounts of ZA40 and reinforced hybrid samples are given. It was clearly seen that increasing SiC reinforcement increased the amount of porosity and caused a decrease in the amount of hardness. The amount of porosity measured at 7.33% in the matrix material increased to 9.06% with the addition of 1% SiC and 2% MWCNT, and reached the highest value of 14.73% in the H-4 sample. Here, the H-1 sample is the sample with the lowest amount of porosity among the hybrid composites. From this, it can be said that the H-1 sample has less agglomeration than other hybrid composites. Specially, the increase in the amount of reinforcement increased the agglomeration of the powders and led to the expansion of the grain boundaries [4, 5]. It is thought that the effect of the packaging factor is here. When we examined the hardness values in Figure 4, it was observed that the hardness of ZA40 measured as 142 HV decreased with the addition of MWCNT and SiC in the matrix.

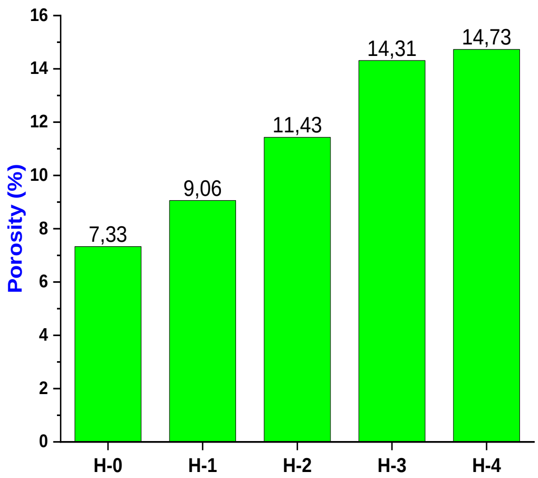


Figure 3. Porosity values of samples

It has been stated in similar publications that the effect of SiC reinforcement on the hardness values of composites is directly proportional to the sintering time [17, 18]. The sample with the lowest hardness value is the H-4 sample with 117 HV. It is possible to clearly say that the increase in the amount of porosity is effective in the decrease of the hardness values.

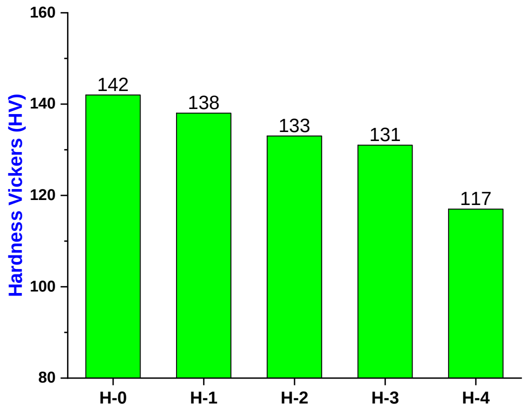


Figure 4. Vickers Hardness values of samples

3.3 Wear

As seen in Table 2 and Figure 5, weight losses of ZA40 and hybrid composites at 10 and 20N loads are given. The weight losses of the hybrid samples under both loads were significantly less than that of the ZA40 alloy. The reason for this is that the SiC hard particles in the ZA40 matrix strengthen the structure of the matrix and absorb the wear, while MWCNT shows wear resistance thanks to its lubricating feature in the system. When the load amount was increased, the weight losses showed a linear increase.

Table 2. Weight loss of samples

Sample Code	10N (mg)	20N(mg)
H-0	0.4261	0.7882
H-1	0.0832	0.1855
H-2	0.0468	0.1503
H-3	0.0167	0.0595
H-4	0.0087	0.0147

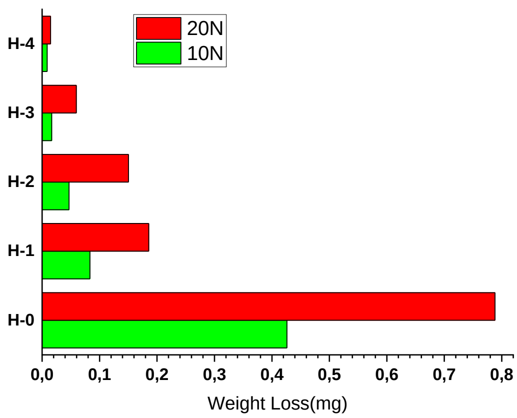


Figure 5. Weight loss of samples

The H-4 sample was the hybrid sample with the least weight loss with 0.0087 mg under 10N load. The least weight loss under all loads occurred in the H-4 sample. When the load ratio was increased by 2 times, the weight loss in the matrix material was almost 2 times, while in hybrid composites this ratio was almost 4 times, especially in the H-2 and H-3 samples. The heterogeneous distribution of SiC and MWCNT particles in the ZA40 matrix, and the interfacial reactions between the matrix material and the reinforcement particles were the properties that affected the wear behavior.

3.4 Worn surface analysis

In Figure 6, detailed SEM images of the worn surfaces of the samples formed after the abrasion tests are given. Stratification and cold ruptures occurred at loads below 10N, and cracks and plastic deformations occurred at 20N loads. In the wear tests performed with a 20N load in the SEM images, more particles were broken off from the samples due to greater weight losses along the 300 m road, only the broken particles adhered to the surface of the hybrid specimen again and cold welding was carried out inside of the wear mechanism. We can say that there is an abrasive wear mechanism in the non-reinforced alloy. Since H11 steel type was used in the wear tests, this tip became the determining parameter in determining the wear mechanism by tearing off large pieces from the surface of the samples that are softer than itself. The basic paradigm used in such studies, especially in the literature, is when a material with a high hardness value is pressed by applying force on another material with very little hardness, localized plastic flow occurs from the abrasive surface of the hard material to the soft material [19, 20]. When the wear trace diameters are measured in Figure 7, the trace diameters decreased when the MWCNT ratio increased at all loads. Under 10 N load, the trace diameter of ZA40 alloy was measured as 3.406 mm while it was measured as 1.311 mm in H-4 sample. Likewise, under 20 N load, the trace diameter of ZA40 alloy was measured as 4.70 mm while it was measured as 2.022 mm in H-4 sample.

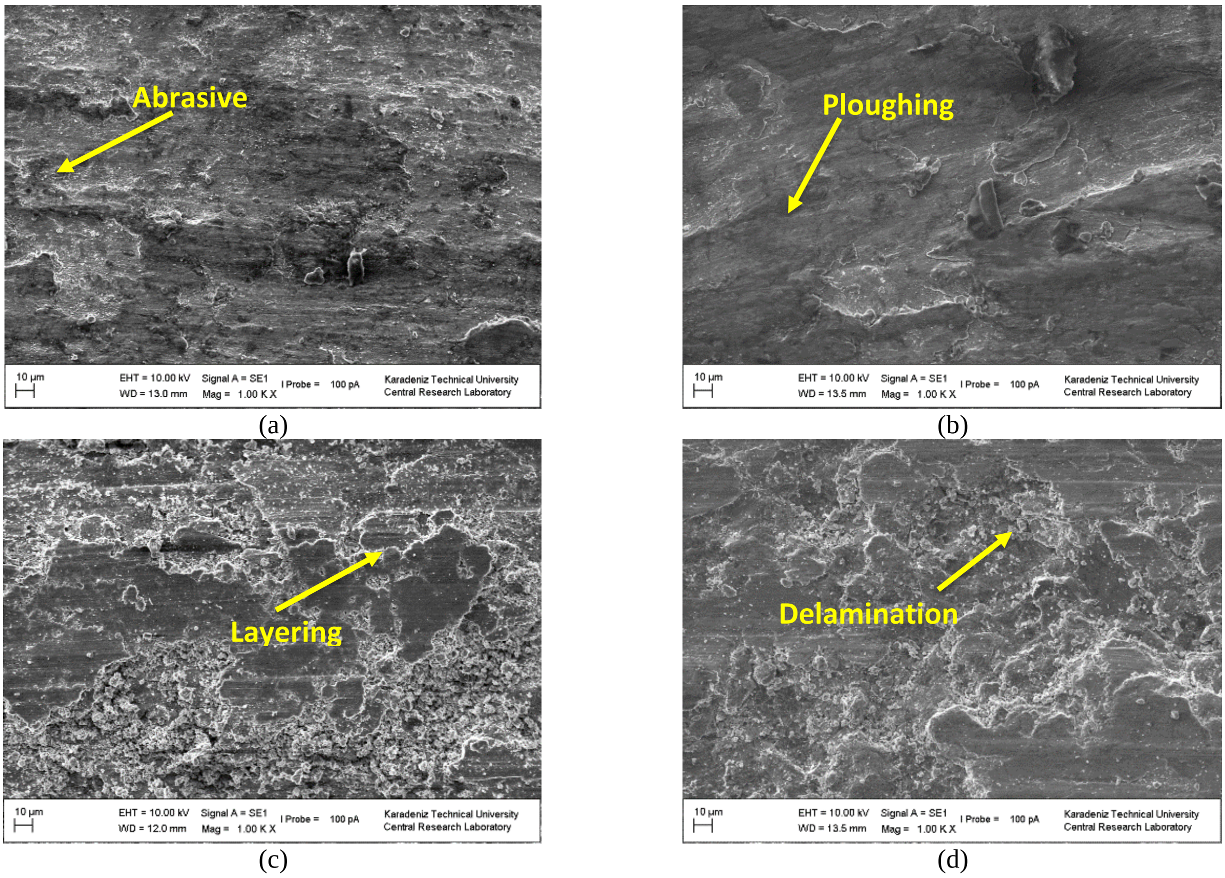
4 Conclusion

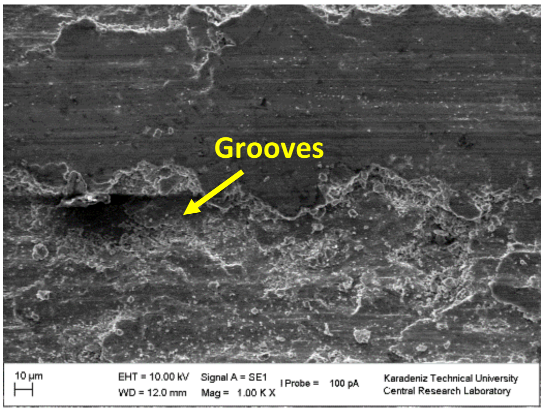
In this study, ZA40 matrix material was reinforced with SiC and MWCNT, and samples were produced by powder metallurgy and hot press technique, and their mechanical properties and wear parameters were investigated. The results of the study are listed below.

1- When the microstructure results of the mixed powders obtained after mechanical alloying are examined; the milling time during which SiC and MWCNT particles were ideally dispersed in the matrix was determined as 3 hours.

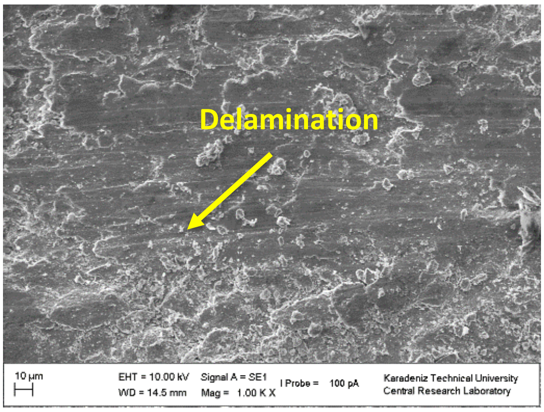
2- The porosity values of 2-hybrid composites increased with the increase of reinforcement ratios. The porosity amount, which was measured as 7.33% in the lowest ZA40 matrix alloy, was measured as 14.73% in the H-4 sample and took the highest value.

3- The hardness data decreased with the increase of reinforcement ratios and the lowest hardness was obtained from the H-4 hybrid sample with 117 HV, and the highest hardness value was obtained from the matrix material with 142 HV.

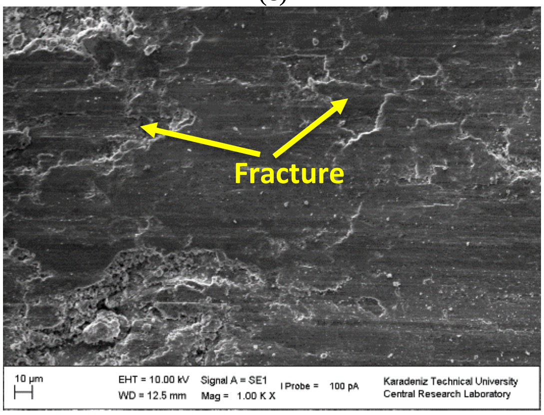




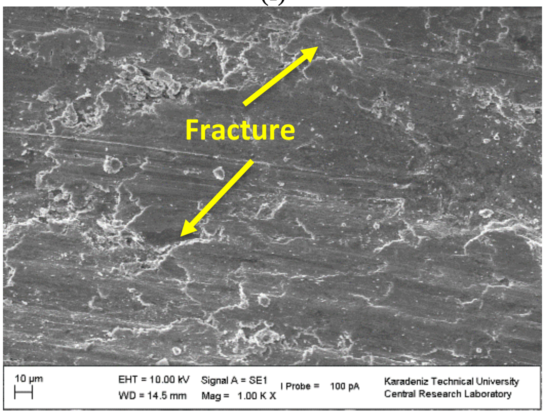
(e)



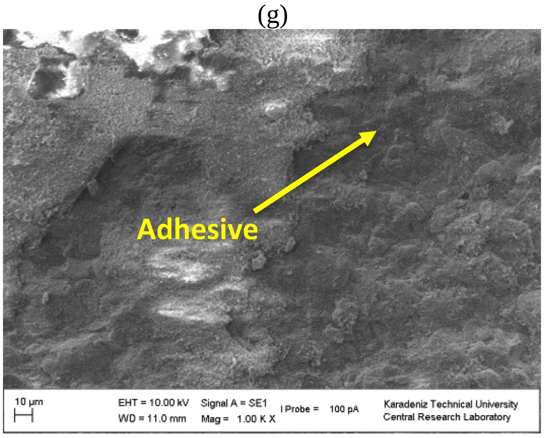
(f)



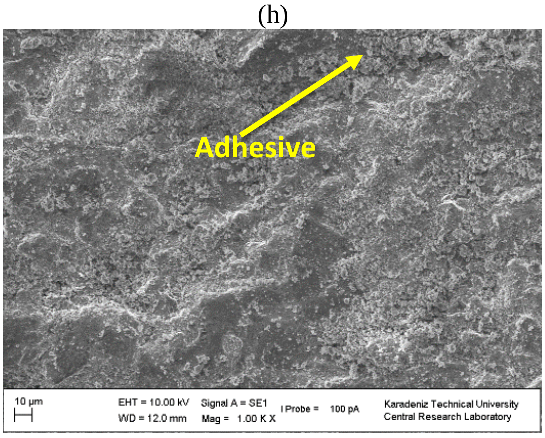
(g)



(h)

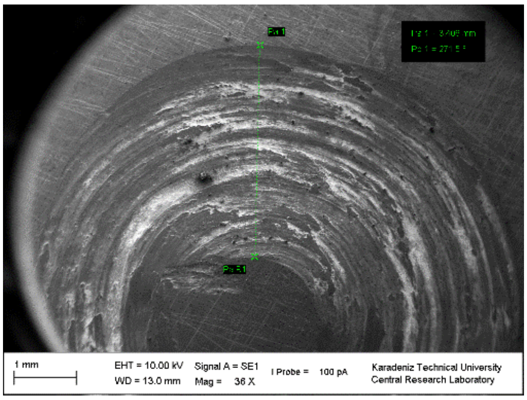


(k)

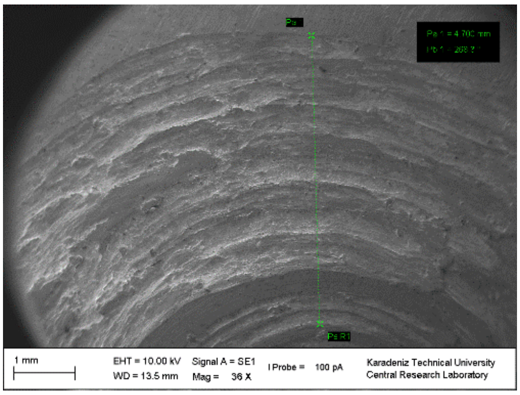


(l)

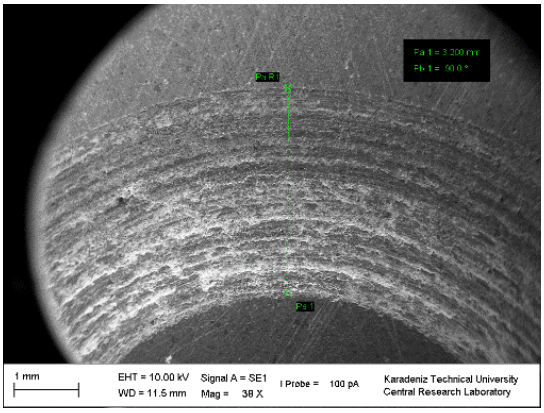
Figure 6. Worn surface examinations (SEM) of samples under 10 and 20N loads; (a) H-0-10N, (b) H-0-20N, (c) H-1-10N, (d) H-1-20N, (e) H-2-10N, (f) H-2-20N, (g) H-3-10N, (h) H-3-20N, (k) H-4-10N and (l) H-4-20N



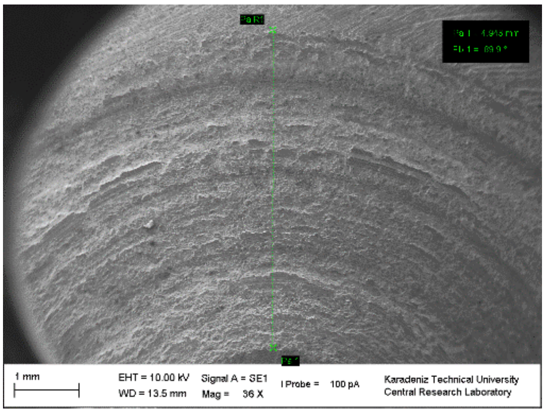
(a)



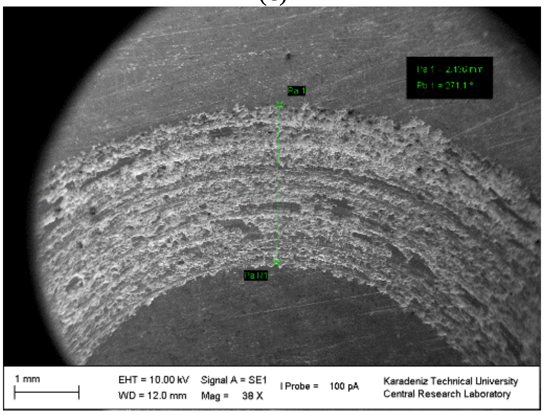
(b)



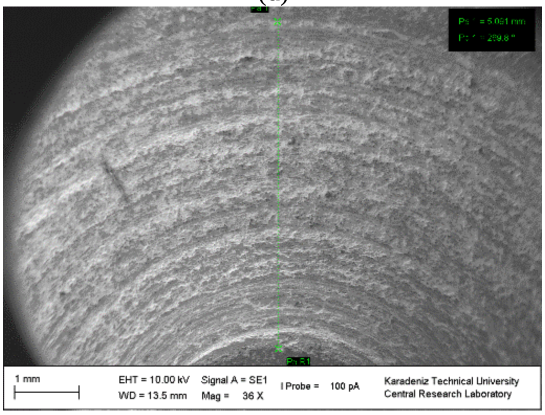
(c)



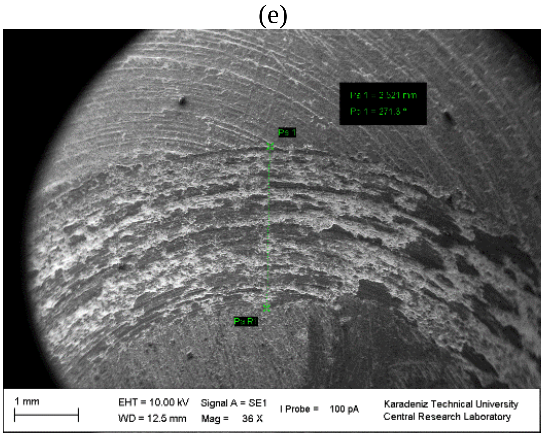
(d)



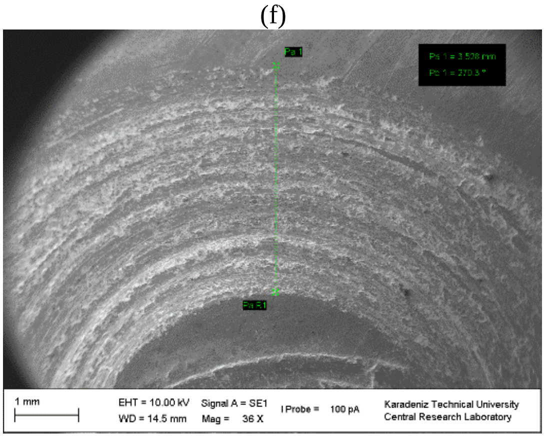
(e)



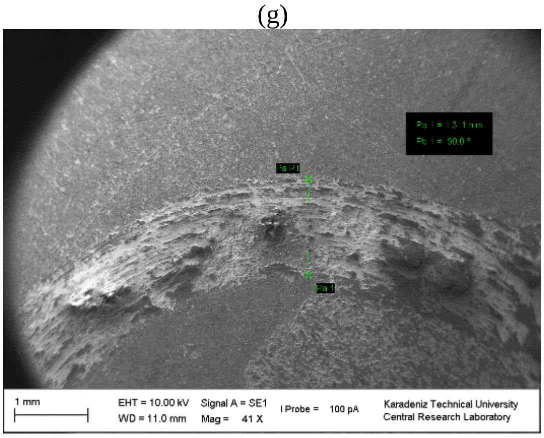
(f)



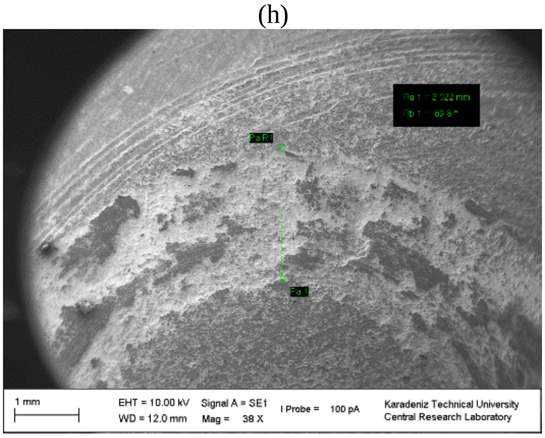
(g)



(h)



(k)



(l)

Figure 7. Wear trace measurements of samples; (a) H-0-10N, (b) H-0-20N, (c) H-1-10N, (d) H-1-20N, (e) H-2-10N, (f) H-2-20N, (g) H-3-10N, (h) H-3-20N, (k) H-4-10N and (l) H-4-20N

4- In all samples, after the wear tests, the weight losses increase with increasing load. The highest weight loss was measured as 0.7882 mg in the matrix material under 20N load. The lowest weight loss was measured as 0.0087 mg in the H-4 hybrid sample under 10N load.

5- There were changes in the wear mechanism in the SEM images that were examined after wear. In particular, it was observed that increasing SiC reinforcement changed the wear type from abrasive wear to adhesive wear.

6- In the study, it was concluded that the MWCNT reinforcement, which is the best among the reinforcement ratios used for the hybrid samples, was 2% and the best SiC reinforcement was 4%.

Conflict of interest

The authors declare that there is no conflict of interest.

Similarity rate (iThenticate): 13%

References

[1] T. Savaşkan, Z. Azakli, and A. P. Hekimoglu, Effect of heat treatment on mechanical and wear properties of Zn-40Al-2Cu-2Si alloy. Transactions of Nonferrous Metals Society of China, 31(9), 2651–2663, 2021. https://dx.doi.org/10.1016/S1003-6326(21)65682-0

[2] O. Güler, M. Çelebı, R. Dalmış, A. Çanakçı and H. Çuvalcı, Novel ZA27/B4C/Graphite hybrid nanocomposite-bearing materials with enhanced wear and corrosion resistance, Metallurgical and Materials Transactions A, 51(9), 4632–4646, 2020. https://doi.org/10.1007/s11661-020-05863-5

[3] S. Yan, J. Xie, Z. Liu, W. Wang, A. Wang and J. Li, Influence of different Al contents on microstructure, tensile and wear properties of Zn-based alloy. Journal of Materials Science & Technology, 26(7), 648-652, 2010. https://doi.org/10.1016/S1005-0302(10)60100-4

[4] E. D. Yalçın ve A. Çanakçı, Silisyum karbür (SiC) ile güçlendirilmiş çinko-alüminyum (ZA40) alaşımının aşınma parametrelerinin incelenmesi. Afyon Kocatepe Üniversitesi Fen Ve Mühendislik Bilimleri Dergisi, 22 (1), 207-213, 2022. https://doi.org/354.14/akufemubid.10352296

[5] E. D. Yalçın, A. Çanakçı and F. Erdemir, Wear and mechanical behavior of ZA27 alloy reinforced with B_4C produced by powder metallurgy method. Gazi University Journal of Science, 35 (4), 1572-1583, 2022. https://doi.org/10.35378/gujs.959850

[6] R. L. Trumper, Metal matrix composites- applications and prospects, Metals and Materials, 3, 662- 667, 1987.

[7] M. S. Surya and G. Prasanthi, Effect of SiC weight percentage on tribological characteristics of Al7075/SiC composites. Silicon, 14, 1083–1092, 2022. https://doi.org/10.1007/s12633-020-00885-5

[8] N. Miloradovic, R. Vujanac, B.Stojanovic and A. Pavlovic, Dry sliding wear behaviour of ZA27/SiC/Gr hybrid composites with taguchi optimization. Composite Structures, 262, 113658, 2021. https://doi.org/10.1016/j.compstruct.2021.113658

[9] E. D. Yalçın, ve A. Çanakçı, Hegzagonal bor nitrür takviyeli ZA40 alaşımının mekanik ve aşınma özelliklerinin araştırılması. Karadeniz Fen Bilimleri Dergisi, 11(2), 716-730, 2021. .https://doi.org/10.31466/kfbd.988720

[10] M. Pul, Al 6061/B4C/GNP hibrit kompozitlerde B_4C ve GNP takviye miktarlarının abrasif aşınma davranışına etkisi. Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi, 11(4), 1179-1187, 2022. https://doi.org/10.28948/ngumuh.1142512

[11] S. B. Akçay, T. Varol, H. C. Aksa ve O. Güler, Al2024/SiC kompozitlerin yüksek SiC takviyesi ile üretimi ve karakterizasyonu. Afyon Kocatepe Üniversitesi Fen Ve Mühendislik Bilimleri Dergisi, 22 (2), 353-365, 2022. https://doi.org/10.35414/akufemubid.1021086

[12] H. Arık, Toz metalurjisi metoduyla Al-SiC kompozit malzeme üretimi ve aşınma özelliklerinin araştırılması . Gazi University Journal of Science Part C: Design and Technology, 7(3), 741-754, 2019. https://doi.org/10.29109/gujsc.587637

[13] İ. Şimşek, D. Şimşek ve D. Özyürek, Yarı katı kalıplama yöntemi ile üretilen farklı miktarlarda SiC takviyeli A356 matrisli kompozit malzemelerin aşınma performansının incelenmesi. Politeknik Dergisi, 23(4), 1237-1243, 2020. https://doi.org/10.2339/politeknik.642506

[14] E. Ergül, H. İ. Kurt, M. Oduncuoğlu and C. Çivi, Wear properties of Al-Cu-Mg composites reinforced with MGO and MWCNT under different loads. The International Journal of Materials and Engineering Technology, 70-75, 2019 https://dergipark.org.tr/tr/pub/tijmet/issue/47615/657090

[15] E. Ergül, H. Kurt, C. Çivi and G. Eyici, Wear characteristics of carbon nanotube reinforced Al2024 composites. El-Cezeri, 7(3), 1008-1016, 2020 https://doi.org/10.31202/ecjse.716287

[16] E. D. Yalçın, A. Çanakçı, F. Erdemir, H. Çuvalcı, and A.H. Karabacak, Enhancement of wear and corrosion resistance of ZA27/nanographene composites produced by powder metallurgy. Arabian Journal for Science and Engineering. 44(2), 1437-1445. 2019 https://doi.org/10.1007/s13369-018-3582-7

[17] E. Şap, Güçlendirilmiş bakır esaslı kompozit malzemelerin mikroyapı ve sertlik özellikleri. Journal of the Institute of Science and Technology, 11 (1), 590-598, 2021. https://doi.org/10.21597/jist.805597

[18] T. Varol, O. Güler, S.B. Akçay and H. Çolak, The evolution of microstructure and properties of Cu-Cr alloys synthesized via flake powder metallurgy assisted by mechanical alloying and hot pressing. Materials Today Communications, 33, 104452, 2022. https://doi.org/10.1016/j.mtcomm.2022.104452

[19] M. Çelebi, A. Çanakçı, O. Güler, S. Ozkaya, A.H. Karabacak and K. Arpaci, Investigation of microstructure, hardness and wear properties of hybrid

nanocomposites with Al2024 matrix and low contents of B_4C and h-BN nanoparticles produced by mechanical milling assisted hot pressing. JOM 74(11), 4449–4461, 2022. https://doi.org/10.1007/s11837-022-05441-7

[20] T. Savaşkan and Z. Azakli, An investigation of lubricated friction and wear properties of Zn 40Al 2Cu 2Si alloy in comparison with SAE 65 bearing bronze. Wear, 264(11), 920-928, 2008. https://dx.doi.org/10.1016/j.wear.2007.06.008