Research Article GU J Sci 35(4): 1572-1583 (2022) DOI: 10.35378/gujs. 959850

Gazi University

Journal of Science

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Wear and Mechanical Behavior of ZA27 Alloy Reinforced with B_4C Produced by Powder Metallurgy Method

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Highlights

- This article focuses on the wear behavior of ZA27/B_4C nanocomposites.
- Different loads were applied to determine the wear performance in the study.
- Mechanical alloying and hot pressing technique showed effective results.

Article Info

Received: 30 Jun 2021
Accepted: 09 Dec 2021

Keywords

ZA27
B_4C
Nanocomposite
Powder Metallurgy
Wear

Abstract

In this study, ZA27 matrix alloy was reinforced with nano-sized B_4C and its wear behavior and mechanical properties were investigated. The samples were produced using the powder metallurgy technique. The reinforcement ratio (0, 0.125, 0.5, 1, 2, and 3% by weight) the internal structure, morphology, and wear surfaces were investigated and by SEM analysis and X-ray diffractometer (XRD). Wear tests were carried out in a dry friction environment using 1, 2, 5, and 10 N loads. The results showed that the increased B_4C reinforcement increased the abrasion resistance of the composite samples, especially under 10 N load, the weight loss was 250 mg in the matrix material, while it was measured as 0.023 mg in the 3% B4C reinforced sample. As a result of this, while the B_4C reinforcement increased, the weight losses decreased under all loads. Although, all the wear types changed from adhesive to abrasive wear when the adhesive wear mechanism was more dominant for ZA27 alloy and had a lot higher weight loss composites. Essentially, reinforcement with nano B_4C particles changed the mechanism to abrasive wear. The increase in nano B_4C content resulted in the changing of wear from two-body to three-body abrasion.

1. INTRODUCTION

Today, zinc-aluminum derivatives are successfully used in many engineering applications. Especially, ZA27 alloy attracts increasing attention day by day by design engineers due to its properties such as good rigidity, good machinability, and good heat transfer. In addition, researchers are focused on strengthening the ZA27 matrix alloy with ceramic-based hard particle reinforcements and increasing its wear performance [1-6]. Yalcin et al. investigated dry sliding (not lubricated), abrasive wear, and corrosion behavior of ZA27/Graphene/B_4C nanocomposites. The composites made by the powder metallurgy method were made with various loads (1, 2, 5, and 10 N) using a ball type on the disc. According to their results, increasing B_4C reinforcement improved the wear and corrosion behavior of hybrid composites. In addition, the weight loss decreased by 0.009 mg with 3% graphene and 2% B_4C supplementation of the matrix material, which lost 250 mg of weight under 10 N load [2]. Dama et al. examined the mechanical properties of ZA27 by adding micro-sized B_4C particulates and producing with the stir casting method. The results showed that the B_4C reinforcement was observed to improve hardness, tensile strength, and yield strength [7]. In a study conducted by Mishra and Biswas, the density, hardness, and stress values of composite materials produced by adding 3, 6, and 9% SiC by volume to the Zn-Al alloy were investigated. With respect to the results of this study, density and hardness values increased with increasing SiC reinforcement [8]. Wu et al. added 7.5% by weight of B_4C to the Al7075 matrix in a study conducted in 2014. As a result, they obtained 181.6 Hv hardness, 1100.3 MPa bending strength, 878 MPa compression strength, and 469.3 MPa fracture toughness under optimum sintering conditions [9]. In a study performed by Baradeswaran et al. in 2014,

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they produced hybrid composites by adding B_4C and graphite to Al6061 and Al7075 alloys, and they improved mechanical properties with B_4C reinforcement and maintained their lubrication properties with graphite reinforcement. Besides, lubricating materials such as graphite increase abrasion resistance while reducing physical and mechanical properties [10]. Miloradovic et al. investigated the wear properties on samples prepared from ZA27 matrix metal matrix hybrid composites containing 10% SiC and 1% graphite by volume. As a result of the experiments conducted in different experimental conditions using block-on-disc in a dry friction environment, they observed that ZA27 matrix hybrid composites showed lower amounts of wear than pure ZA27 material at all applied loads and speeds. They determined that the amount of wear increased with increasing speed and load and that the wear mechanism of pure ZA27 material was the same as that of hybrid composites. It was observed that the tendency to form micro-cracks increased with increasing loads and speeds, and thus demonstrated that mechanically mixed layers on the contact surfaces played an important role during the wear process [11]. Varol et al. studied the effect of reinforcement amount of Al2024-B_4C composites on mechanical and physical properties. They found that the reinforcement amount of 10% by weight was an optimum amount for superior physical and mechanical properties [12]. Prasad examined, the wear behavior of Zn/SiC composites in a dry and oily environment was examined. It was stated that the wear rate increased with increasing load in dry and oily friction. The graphite supplement added to the oil reduced the abrasion rate by up to 6%. It was observed that SiC reinforcement hardened the soft matrix against abrasion and the graphite particles transferred into the oil in an oily environment reduce the wear on the surface by mixing with the oil [13]. This finding indicates that composite materials have a better tribological performance than matrix materials. B_4C ceramic particles were used to increase mechanical strength within the scope of this research work. The significant reason for using B_4C instead of SiC (3.21gr/cm^3) and Al_2O_3 (3.98 gr/cm^3) ceramic particles is that B_4C (2.52 gr/cm^3) particles have a very low density compared to SiC and Al_2O_3 particles and will therefore be made using B_4C. This is because composites and nanocomposites have higher specific strength values. Another feature that provides superiority to B_4C particles over SiC and Al_2O_3 particles is its high chemical stability due to its high melting temperature. There is a difference of approximately 700°C between the melting point of B_4C particles (2763°C) and the melting point of Al_2O_3 particles (2072°C). Another advantage of B_4C particles (3200 kg/mm^2) compared to SiC (2800 kg/mm^2) and Al_2O_3 (2000 kg/mm^2) particles are that they have high hardness. Thus, the desired mechanical strength can be obtained easily by using a lower reinforcement ratio [14]. An increase in reinforcement content or a decrease in particle size increases the amount of reinforcement, as a larger interfacial zone is required for dislocation drilling to occur. Moreover, dislocation growth results in a coherent ground of precipitates in the metal matrix. Eventually, both the reinforcement and the precipitates obstruct the mobility of these dislocations causing improved yield and ultimate tensile strength [15]. Additionally, B_4C content is a direct relationship in the mechanical properties of the composite. There are limited research studies in the materials science literature on the effect of B_4C content of ZA27/B_4C composites produced by hot-pressing techniques on the wear and mechanical properties.

B_4C reinforced ZA27 nanocomposite materials used in the study; it is produced by combining mechanical alloying and powder metallurgy techniques, which have a significant place among material production methods. Powder metallurgy is a suitable method in producing and metal–matrix composites. A significant benefit of this technique is its low processing temperature compared with casting methods. It is feasible to achieve a good distribution of reinforcing particles. Another benefit of the powder metallurgy method is its ability to manufacture near net shape products with low cost [16]. Because of this, our study focused on the production, mechanical properties, wear characteristics of nano B_4C reinforced ZA27 alloy, containing different rates of B_4C, produced using the conventional powder metallurgy method.

2. MATERIAL METHOD

Nano-sized B_4C powders were obtained from Alfa Easer with 99.9% purity and 50 nm size. ZA27 matrix powders were produced by the casting method. The chemical composition of the ZA27 is shown in Table 1. The experimental flow chart is shown in Figure 1. ZA27/B_4C nanocomposites with different content of nano B_4C (0, 0.125, 0.5, 1, 2, and 3 vol %) were produced by mechanical milling (Table 2). ZA27 and B_4C powders were ground in a planetary ball mill (Retsch PM 100) at 400 rpm for 1 h. Ball powder ratio was chosen as 5:1 and 10 mm diameter tungsten balls were used. To prevent clumping, 1% zinc stearate was added to the mixtures. The prepared mixtures were pre-pressed at 200 MPa for 1 minute and then hot pressed at 435 degrees under 500 MPa pressure. Brinell hardness values were determined by applying a load of 31.25 kgf with 6 replicate measurements and the hardness results were calculated by taking the arithmetic average of the results obtained. Wear tests of ZA27/B_4C nanocomposites were performed using the ball-on disc (DUCOM-TR20-LE) technique. The wear tests were performed in unoiled conditions, with a sliding speed range (100 rpm) and load (1, 2, 5, and 10 N). The sliding distances were chosen as 300 m, separately. Before and after the abrasion tests, the weights of the nanocomposites were measured with precision scales and weight loss was determined. The produced ZA27/B_4C nanocomposite materials were cut with a diamond disc for metallographic examination and covered in a Bakelite removal device. The samples prepared after these processes were gritted with 600, 800, 1000, 1200, and 1500 numbered grinding papers, respectively, in an automatic polishing device. The surface of grinded samples was polished using alumina liquid and their surfaces were cleaned with ethyl alcohol. The morphology and microstructure analysis of the starting powders, the ground powders were examined using a ZEISS LS 10 brand SEM-EDX (Figure 2). The distribution of reinforcements in the ZA27, porosity, interfacial research of nanocomposite samples were carried out in detail by SEM and X-ray diffractometer (XRD) analysis. A laser particle size analyzer (Malvern-Mastersizer Hydro2000) was used for determination of particle size of ZA27/B_4C nanocomposite powders (Figure 2).

Table 1. *Chemical composition of ZA27 (wt%)*

Al	**Cu**	**Mg**	**Zn**
25.8	2.4	0.012	Bal.

Table 2. *The nanocomposites produced by mechanical milling*

Sample Number	**Milling Time (h)**	**ZA27 (wt%)**	**B_4C (wt%)**
ZA27	1	100	0
ZAB-0.125	1	99.875	0.125
ZAB-0.5	1	99.5	0.5
ZAB-1	1	99	1
ZAB-2	1	98	2
ZAB-3	1	97	3

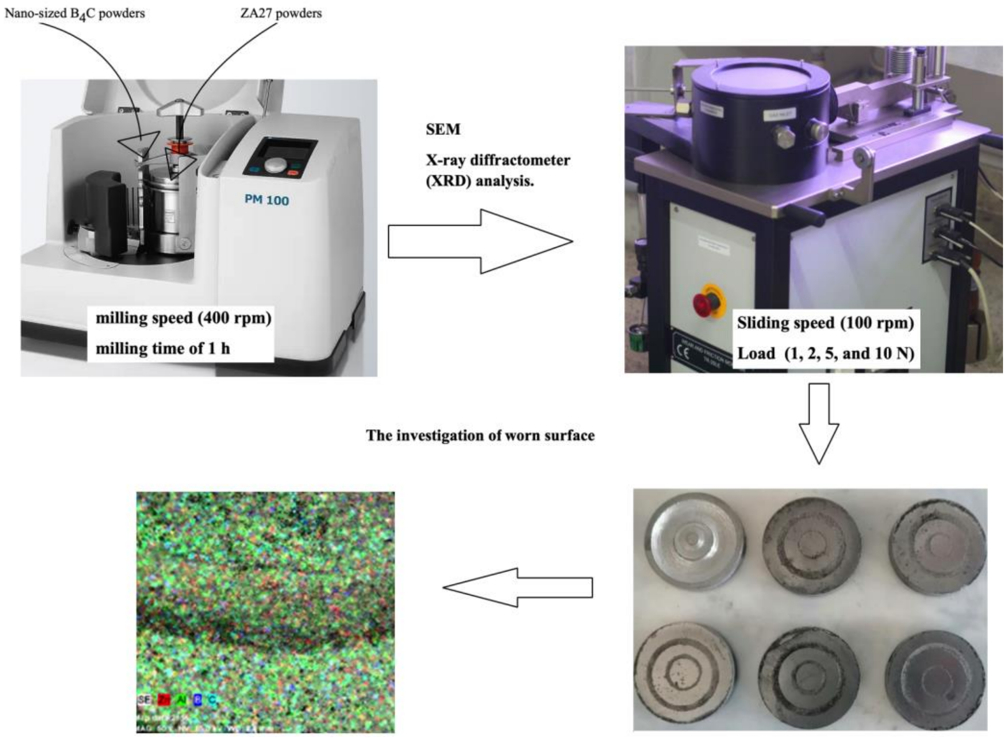
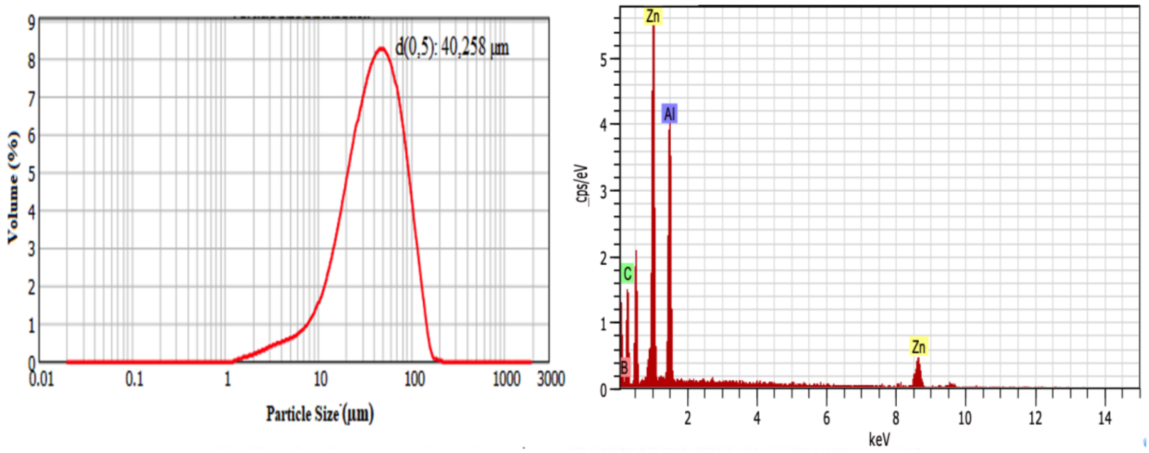


Figure 1. *The experimental flow chart*



a) b)

Figure 2. *a) Particle size distribution and b) EDX spectrum of ZAB-3 composite powders at milling time of 1h*

3. THE RESEARCH FINDINGS AND DISCUSSION

3.1. Microstructure

During the high-energy ball milling process, the impacts between the surfaces of the powder-ball-powder, and ball-powder-ball, which is subjected to a high-energy grinding process, caused changes in particle size. Therefore, nanocomposite powders were subjected to 0, 1, and 4 h of milling processes to determine the optimum milling time. Figure 3 shows the morphology and SEM-EDS element distributions of 2% B_4C containing nanocomposite powders at a milling time of 1h. It was observed that a small amount of nano B_4C was embedded in the matrix during the initial milling time. More B_4C particles were embedded into the matrix after a milling time of 1 h. A milling time was determined in which the B_4C particles were homogeneously dispersed into the ZA27 powders and at the same time embedded. Figure 4 shows the B_4C

particles into the matrix that are used for reinforcement. The black region shows the reinforcement particles for ZAB-3 sample. As compared with ZAB-2, the distribution of B_4C particles was non homogeneous. It is clear that the agglomerated particles settle around the grain boundary.

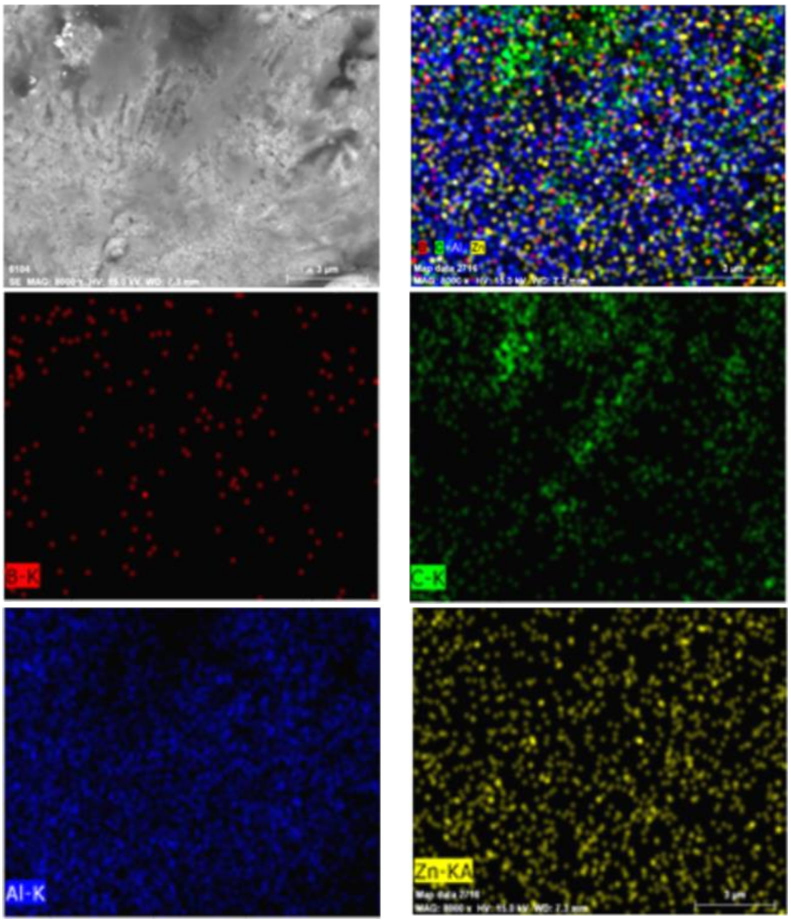


Figure 3. *SEM mapping images of ZAB-2 sample at milling time of 1h*

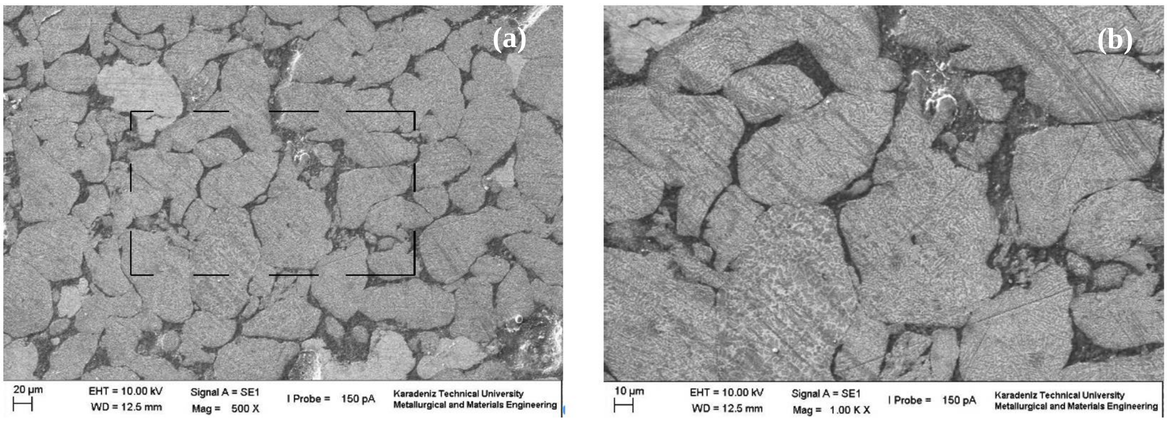


Figure 4. *SEM images of ZAB-3 sample at milling time of 1h; a) 500 X and b) 1.00 K.X*

3.2. Porosity and Hardness

The Brinell hardness and porosity measurement results of the samples (with data distributions) are shown in Figures 5 and 6, respectively. It was seen that there was an important decrease in the hardness values. Gülsoy et al. studied Injection molding of 316L reinforced with Al_2O_3. They briefed that the tensile strength decreased due to the increase in the Al_2O_3 particle content of the microstructure, more increased porosity, and lower theoretical density [17]. Erdemir et al. produced functionally graded Al2024/SiC composites by hot press method. They stated that the porosity value of composites increased from 0,56% to 2,02% with changing the SiC content of the composites from 30% to 60%. Similar results with this study were observed in hard particle reinforced composite [18]. High amounts of reinforcing increases resulted in increases in pore amount and more plastic deformation of the ZA27 alloy matrix material powders while reductions in the hardness of the samples. When we examined the hardness values of ZA27/B_4C nanocomposite samples, after 1h of the milling time, the hardness values of nanocomposite did not change at low reinforcement amounts but decreased at increased reinforcement rates. High amounts of reinforcing increases resulted in increases in pore amount more plastic deformation of the ZA27 alloy matrix material powders during milling, while reductions in the hardness of the samples. The lowest hardness value was 67.9 HB for the ZAB-3 nanocomposite. The increase in pore amount to 11.07% caused the hardness values to decrease. According to the results, while the distribution of reinforcing materials in the matrix was one of the factors affecting the hardness values of nanocomposite materials, the amount of porosity played an important role. The relative density decreased with increasing supplementation amount while the amount of porosity increased.

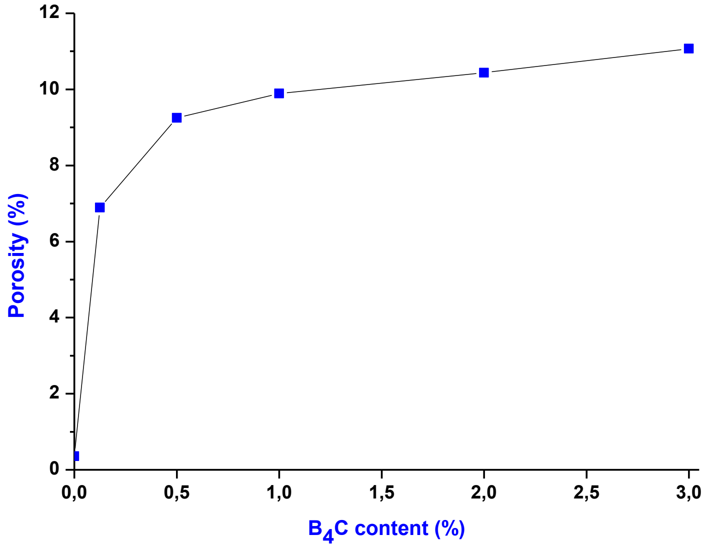


Figure 5. *Porosity values of nanocomposites with different B_4C contents*

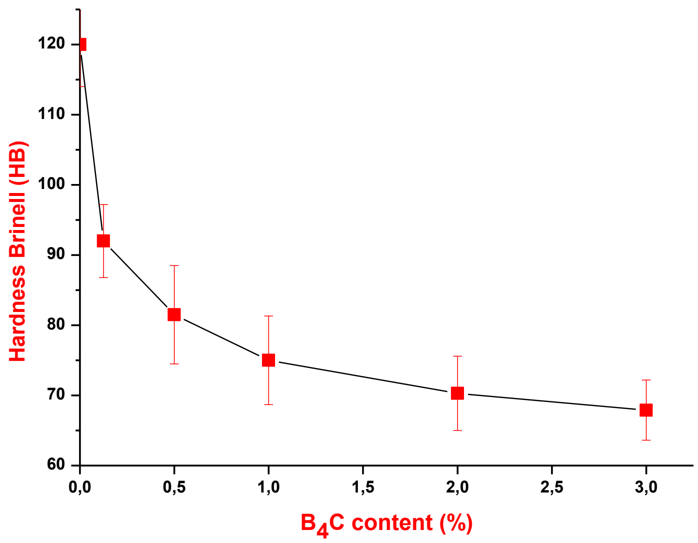


Figure 6. *Hardness values of nanocomposites with different B_4C contents*

3.3. XRD Analyses

XRD patterns of specimens which include B_4C nanoparticle ingredients are shown in Figure 7. The peaks of Zn, Al, and $CuZn_5$ as well as B_4C can be seen in the XRD pattern. When compared with the matrix, newly produced phases such as the B_4C phase were watched for ZA27/B_4C nanocomposites, while the diffraction peaks of the B_4C phase were very weak for the ZAB-0.5 composite. The increase in the diffraction peaks of B_4C was seen in the ZAB-3 composite (Figure 7). XRD patterns showed that a milling speed of 400 rpm was sufficient to get the best results. When the milling speed, ball/powder ratio, and milling time were compared, it was seen that the ground B_4C particles were effective on the particle size [14].

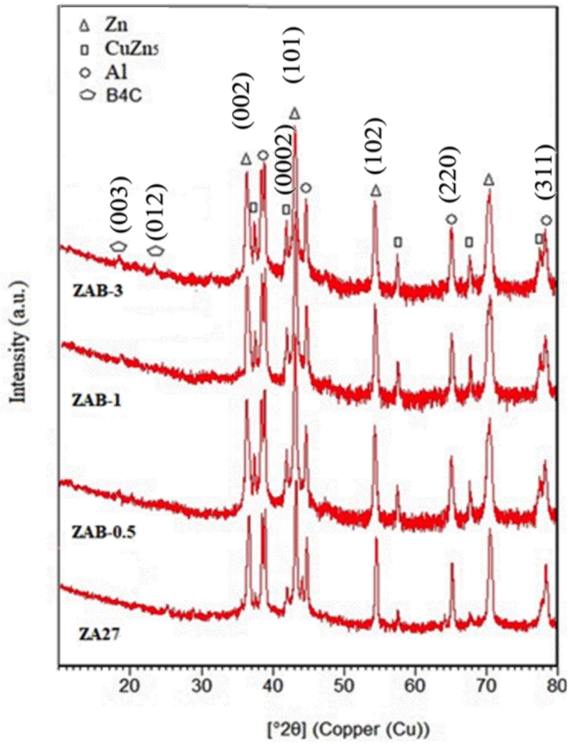


Figure 7. *XRD patterns of nanocomposites for different B_4C content*

3.4. Wear

ZA27/B_4C nanocomposites showed that the wear mechanism is adhesive and delamination wear. The pressure force between the abrasive ball and the contact surfaces of the samples with the increase of the applied load caused scraping and rupture with friction in the samples, and the highest wear amounts were below the burden of 10 N that is the highest load. As a result, ZAB-3 was the highest abrasion resistance. This can be attributed to the weak bounded hard particles coming out of the matrix during the wear test. It appears that while the load increased from 1 to 10 N, an increase was observed in weight loss for ZA27 alloy and its nanocomposites. At the highest load of 10 N, the temperature of the worm surface and pin stroked the rudimentary value. As the load increased on the pin there was the same upsurge in the weight loss of the matrix and reinforcement materials. The weight loss of composite was most noteworthy in all the stacking terms as shown in Figure 8. When Table 3 was examined, the weight loss of the nanocomposites reduced from 0.093 to 0.023; however, nano B_4C content increased from 0.125 to 3% in the ZA27 matrix. The increment in wear opposition of the ZA27 matrix with changing wt% B_4C nanocomposites might be because of the high hardness value of B_4C which drives about as the boundary for the wear damages [19]. Canakci et al. studied the effects of Fe-Al intermetallic compounds on the corrosion and wear behaviors of AA2024/316L composites. Their study indicated that the relative density of composites decreased from 98% to 75% with changing the reinforcement content of the composites from 0% to 25%. AA2024/25% 316L composite has highest wear resistance [20]. Related results with this study were perceived in the composite.

Table 3. *Weight loss of ZA27 and its nanocomposites*

Sample	Weight loss on 1 N load (mg)	Weight loss on 2 N load (mg)	Weight loss on 5 N load (mg)	Weight loss on 10 N load (mg)
ZA27	0.36	1.4	76.6	250
ZAB-0.125	0.04	0.043	0.055	0.093
ZAB-0.5	0.024	0.036	0.045	0.057
ZAB-1	0.018	0.032	0.04	0.048
ZAB-2	0.007	0.013	0.021	0.026
ZAB-3	0.003	0.009	0.02	0.023

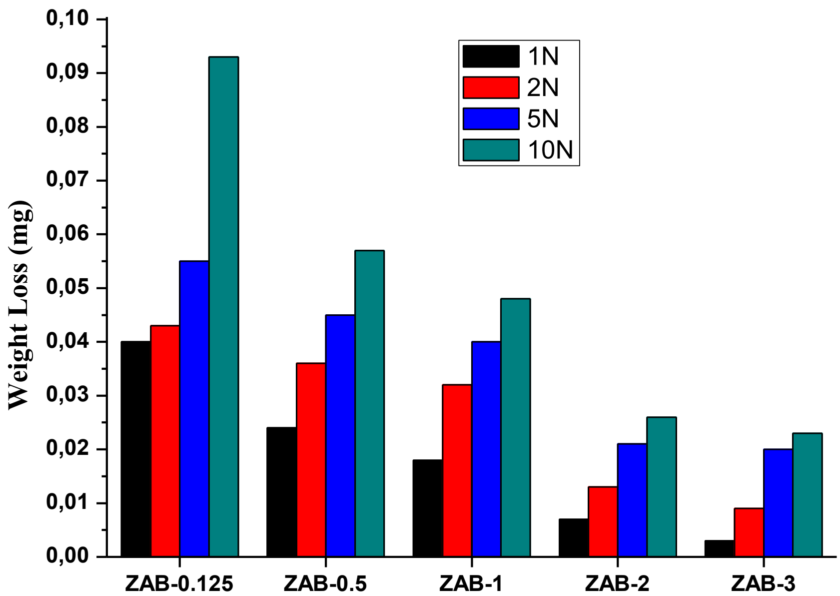


Figure 8. *Weight loss of nanocomposites*

Figure 9 shows the SEM image and EDS analysis obtained from the worn surface of the ZAB-3 nanocomposite. As the EDS analysis of the ZAB-3 sample with the highest abrasion resistance will be seen in the EDS analysis under 10 N load, the Zn element is indicated as red, the Al element is indicated as green and the distribution of the B_4C reinforcement within the ZA27 alloy has determined the wear mechanism. Figure 9 also shows the wear track with the elemental mapping for ZAB-3 nanocomposites after a speed of 100 rpm by holding a heap of 10 N wear tests. From Figure 9, it is reasoned that the volume of nano B_4C showed with blue colors into wear track is lower than that of nano B_4C out of wear track. It can be concluded that hard B_4C particles are coming out of the matrix. It is seen that the wear mechanism here changed from a two-body mechanism to a three-body mechanism. In addition, wear particles undertake the task of wearing between two surfaces. These wear particles also make a free-rolling motion as well as sliding. Wear caused by sand or gravel in a bed, hard debris trapped between moving surfaces are examples of three-body wear [21].

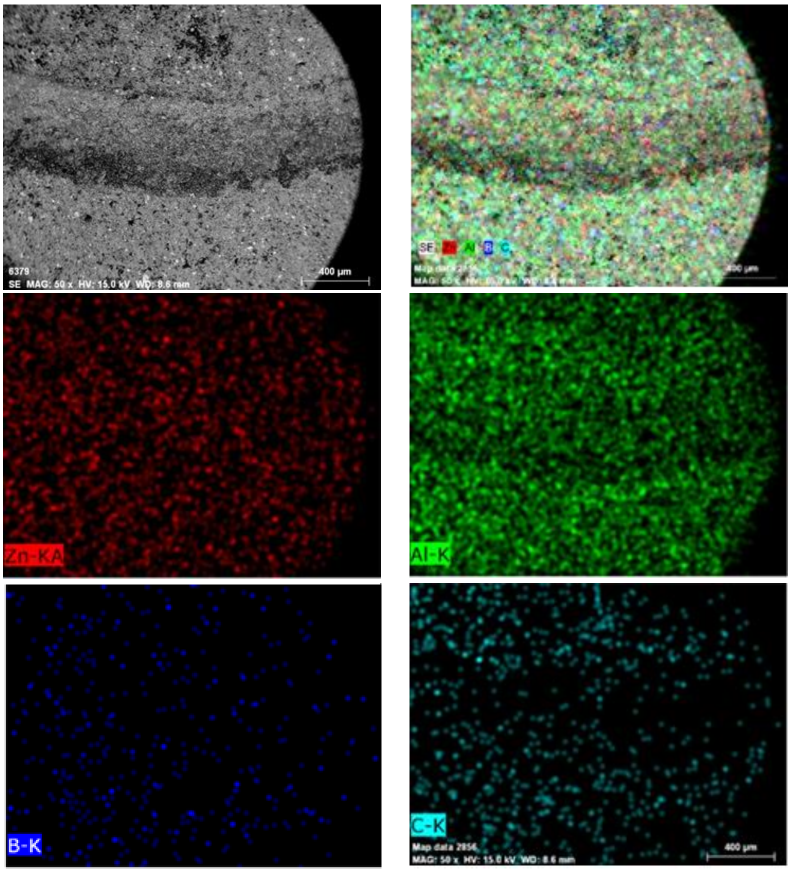


Figure 9. *SEM and EDS analysis of ZAB-3 nanocomposite*

From Figure 10, it is seen that nano B_4C content increases from 0 to 3 wt%, there is a decrement in wear for all the samples tested. Although, all the wear types changed from adhesive to abrasive wear when the adhesive wear mechanism was more dominant for ZA27 alloy and had a lot higher weight loss sample. Fundamentally, reinforcement with hard nano B_4C particles changed the mechanism to abrasive wear. Besides, as the sliding track continued expanding there was an increment in wear damage. The increased temperature rise due to high sliding rates causes plastic deformation of the composites. There was prolonged delamination accumulation to enhanced wear damages.

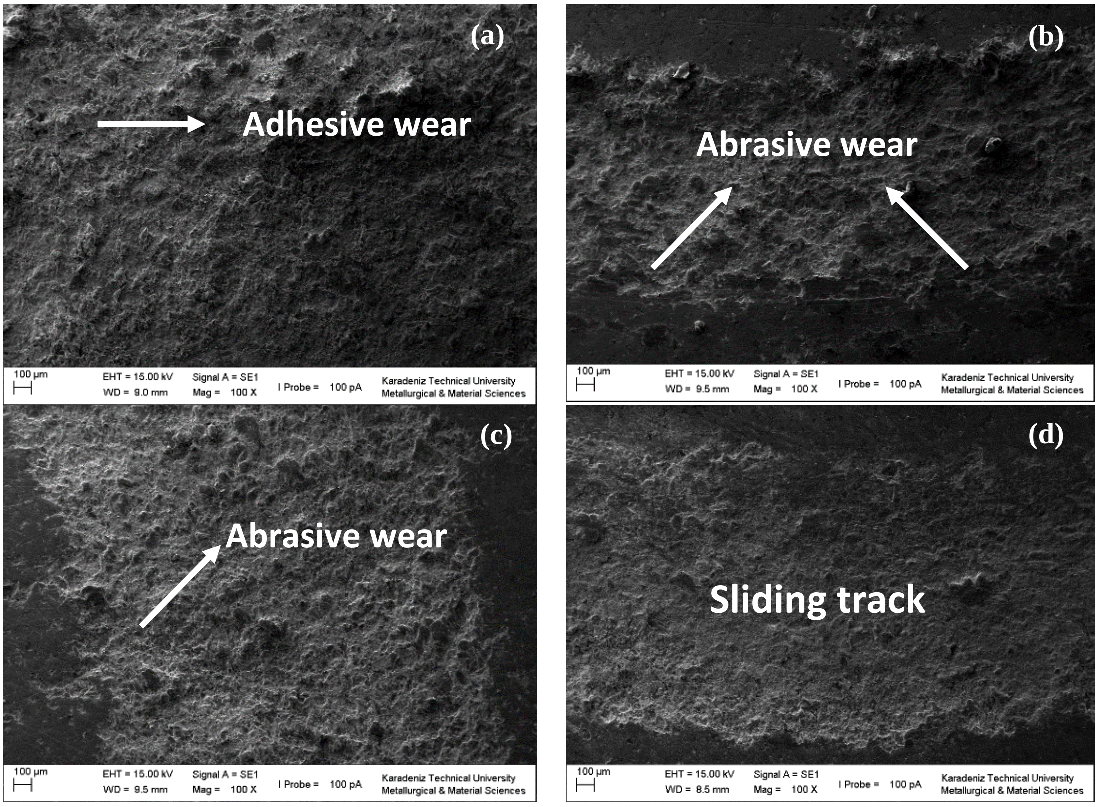


Figure 10. *SEM images of worn surface at speed of 100 rpm and 5 N load; (a) ZA27, (b) ZAB-0.125, (c) ZAB-0.5, and (d) ZAB-3 samples produced by ball milled for 1 h*

4. CONCLUSION

In this paper, the effect of the % B_4C content on the wear and mechanical properties of ZA27/B_4C nanocomposites is examined. The results of our paper can be summarized as follows:

1) ZA27/B_4C nanocomposites were produced by the powder metallurgy technique. Increasing B_4C content increased the agglomeration region into a matrix.
2) The XRD patterns indicated the presence of compounds such as Zn, Al, B_4C, and $CuZn_5$. The B_4C phases become more distinct for composites with the highest B_4C content. Nevertheless, the content of these phases was intensely reduced for ZAB-0.5 composite.
3) The effect of B_4C content on the wear behavior of ZA27/B_4C nanocomposites was analyzed in detail. Increasing B_4C supplementation reduced wear loss. The highest wear resistance was obtained from the ZAB-3 composite. In SEM analyses of the worn surfaces of ZA27/B_4C nanocomposites, increased B_4C reinforcement changed the wear characteristics of the composites from adhesive wear to abrasive wear.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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