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Investigation of Microstructure and Tribological behavior of WE43/nano B_4C Composites Produced by Spark Plasma Sintering

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Abstract

In this study, composite samples of WE43 (Mg-4Y-3RE-Zr) reinforced with nano-B_4C particles in different ratios (0.5 and 2 wt.%) were prepared by spark plasma sintering (SPS). The powders were mixed in a 3-dimensional ball mill at 300 rpm. The mixed powders were then hot pressed under 35 MPa pressure at 525 °C for 6 min. XRD and FESEM-EDS instruments were used to characterize the composite samples. Microhardness and wear tests were performed to designate the mechanical properties. It was found that the highest hardness occurred in the composite sample with 2% nano-B_4C composites. It was also found that tribological properties improved with the increase of nano-B_4C content.

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1. INTRODUCTION

Metal matrix composites (MMC) exhibit excellent mechanical properties compared to their conventional, non-reinforced counterparts. In particular, magnesium (Mg)-based MMCs occupy an important position due to their lightweight advantage (Nimityongskul et al., 2010). By reinforcing the Mg matrix with a hard ceramic phase, properties for example high hardness, high strength, and low wear resistance can be improved. Therefore, Mg, which has the lowest density among metals, is increasingly used in aerospace, automotive, and medical applications (Ghasali et al., 2017a). Among Mg alloys, WE43 alloy, which have stand out the attention of researchers in recent years, are preferred because of their superior mechanical and microstructural properties compared to other Mg alloys, as they contain rare earth elements. Despite neodymium, yttrium and other rare earth elements exhibit properties such as good mechanical performance at high temperatures, flame retardancy and high temperature creep resistance, studies are continuing to improve the problems in wear properties (Banijamali et al., 2022).

Studies have long been conducted to reinforce Mg-based alloys with ceramic particles to increase their strength. It is well known that various ceramics such as SiC, Al_2O_3, ZrB_2, TiB_2, and B_4C are dispersed in the matrix phase as reinforcing materials during the fabrication of MMC. B_4C is a very hard ceramic with low density, high chemical resistance and abrasion resistance. It is well known that B_4C reinforcement of the Mg matrix increases the interfacial bonding strength, hardness and wear resistance of the composite (Taşcı et al., 2013). Ceramic reinforced metal matrix composites (MMCs) can show very good mechanical and wear properties when compared to non-reinforced metals (Yadav et al., 2022). It is extremely important that the composites have a defect-free microstructure and maintain their mechanical properties. For this purpose, it is necessary to distribute the reinforced ceramics homogeneously in the matrix phase. It is very difficult to

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achieve such homogeneous distribution, especially in the casting process. Therefore, it is possible to produce a fine and non-porous microstructure using the powder metallurgy (P/M) technique (Ghasali et al., 2017b). Spark plasma sintering (SPS), which has occupied an important place in the P/M technique in the last decade, makes it possible to produce metal alloys and MMCs under vacuum, at very low pressing pressure and in a very short time (Saheb et al., 2012).

In this study, nano-B_4C (nB_4C) was added to the WE43 alloy in amounts of 0.5% and 2% using the SPS technique to provide homogeneous mixing of the powders. Microstructure characterization and mechanical properties of these produced composites focused on improving their wear performance.

2. MATERIAL AND METHOD

2.1. Production Method of Composite Specimens

The matrix WE43 powder with an average diameter of 45 µm was supplied by Magnesium Elektron™ ltd. The nB_4C (55 nm) was provided by Nanografi Nanotechnology™ and used for 0.5 and 2% nB_4C to prepare the composite powders. In order to mix the starting powders homogeneously, the mixing process was carried out for 4 hours at 300 rpm in a 3D ball mill with an atmospherically controlled chamber. Table 1 shows the chemical composition of WE43.

Table 1. *WE43 Chemical Composition*

Element	Mg	Y	Nd	Gd	Z
WE43	Bal	3.72	2.13	1.11	0.41

Powders with different ratios of nB_4C in the WE43 alloy were prepared by SPS. A custom-made graphite mold was used to press the powders. The powders placed in the mold were first recompressed at a pressure of 5 MPa at room temperature. The mixed composite powders were then pressed under a load of 35 MPa at 525 °C for 6 minutes.

3. RESULTS AND DISCUSSION

3.1. Examination of Powders

The images of the initial WE43, nB_4C, and mixed WE43/nB_4C composite powders used in the study are shown in Figure 1. Mixing of the composite powders was performed in a 3D high energy mixer. Figure 1a shows that the WE43 powder used as matrix alloy has a spherical shape. In Figure 1b, the nB_4C particles were found to have a complex shape with sharp corners. By examining the images, a series of grooves and micro ploughing, plastic deformations parallel to the sliding direction, debris and significant crater areas were visible on the worn surface of the unreinforced WE43 matrix alloy. It can also be seen that the morphology of the matrix powder does not change and remains spherical during the mixing process.

3.2. Microstructure Characterization

The XRD patterns of the WE43/%2 nB_4C composites produced by SPS are shown in Figure 2. Examination of the XRD peaks shows that the produced composites contain $Mg_{41}Nd_5$ intermetallic phase and α Mg matrix phase. It was found that the rare earth elements yttrium and neodymium form compounds with the matrix phase Mg to different extents. Since the crystal structures of these phases are compatible with the matrix, they are believed to increase the obstacle of the composite by preventing dislocation movement. The matrix alloy in the XRD patterns was found to increase slightly with the addition of nB_4C particles, along with additional peaks corresponding to nB_4C (Tang et al., 2022).

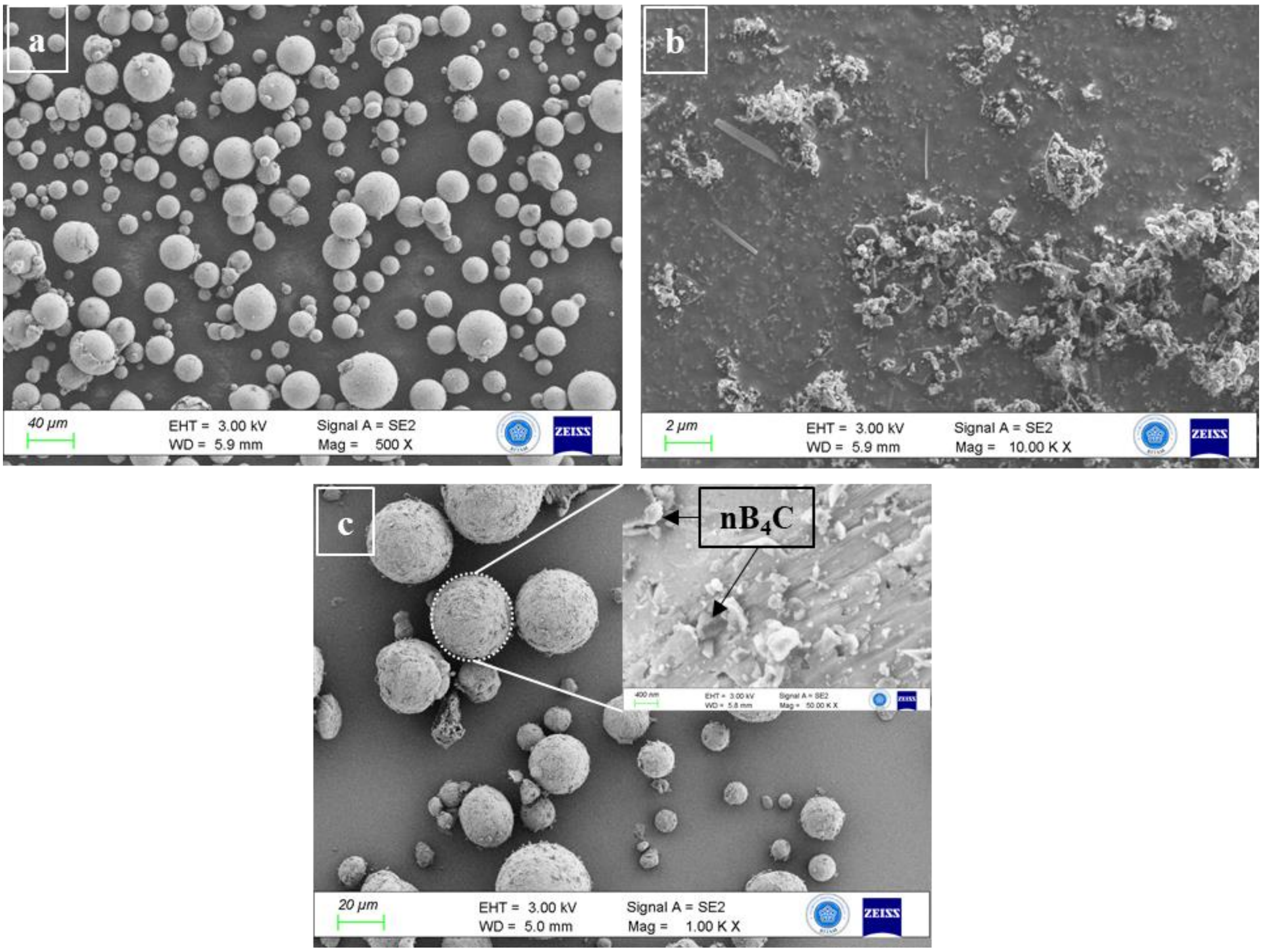

Figure 1. ***a)*** *WE43 powder morphology,* ***b)*** *nB_4C ceramic reinforcement powder,* ***c)*** *WE43/nB_4C composite powder*

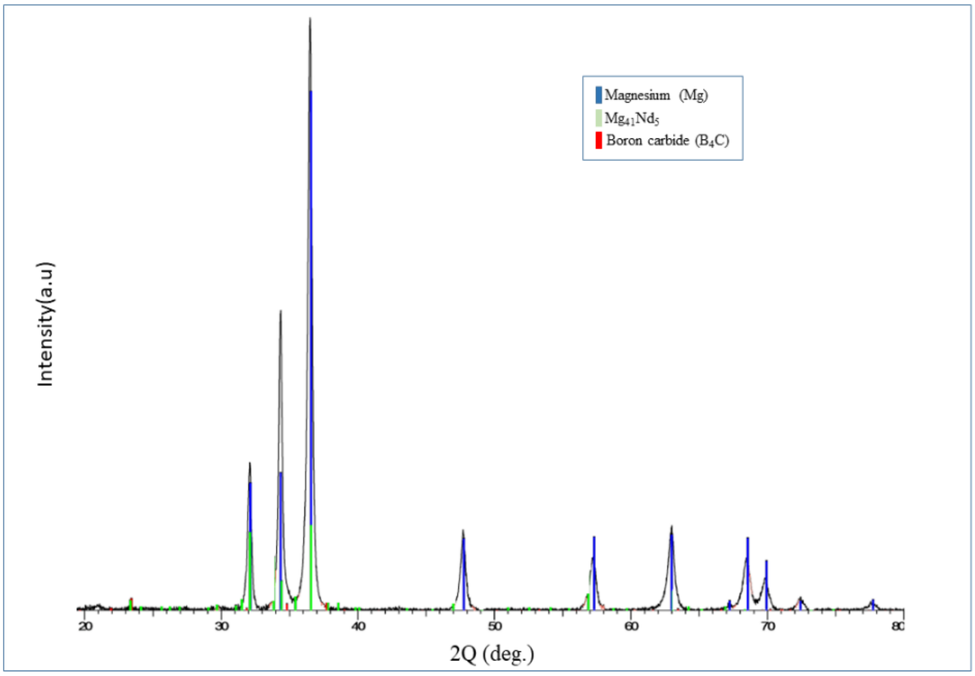

Figure 2. *XRD analysis of WE43 alloy and WE43/nB_4C composites*

After the spherical powders were subjected to 35 MPa pressing in the SPS device and sintered at 525 °C, the surface images of all samples were examined using FESEM to characterise the microstructure. Figure 3a shows the unreinforced WE43 alloy, Figure 3b indicates the 0.5% nB_4C composite, and Figure 3c reveals the microstructure images of these samples fabricated with 2% nB_4C ceramic reinforcement. When the images were examined, no significant difference was found in the grain sizes of these unreinforced and composite specimens. This is because the driving force required for grain size growth and the absence of deformation in the powder morphologies during the mixing process play a certain role (Shuai et al., 2021). It is desirable that the grain sizes are close to each other during the sintering process. It was found that nB_4C reinforcement ceramics are generally formed at grain boundaries. It was found that the phases that appear as white dots in the grains are phases such as $Mg_{41}Nd_5$, Y_2O_3. It is therefore suspected that the WE43 alloy contains a rare earth element that affects the growth kinetics of the intermetallics.

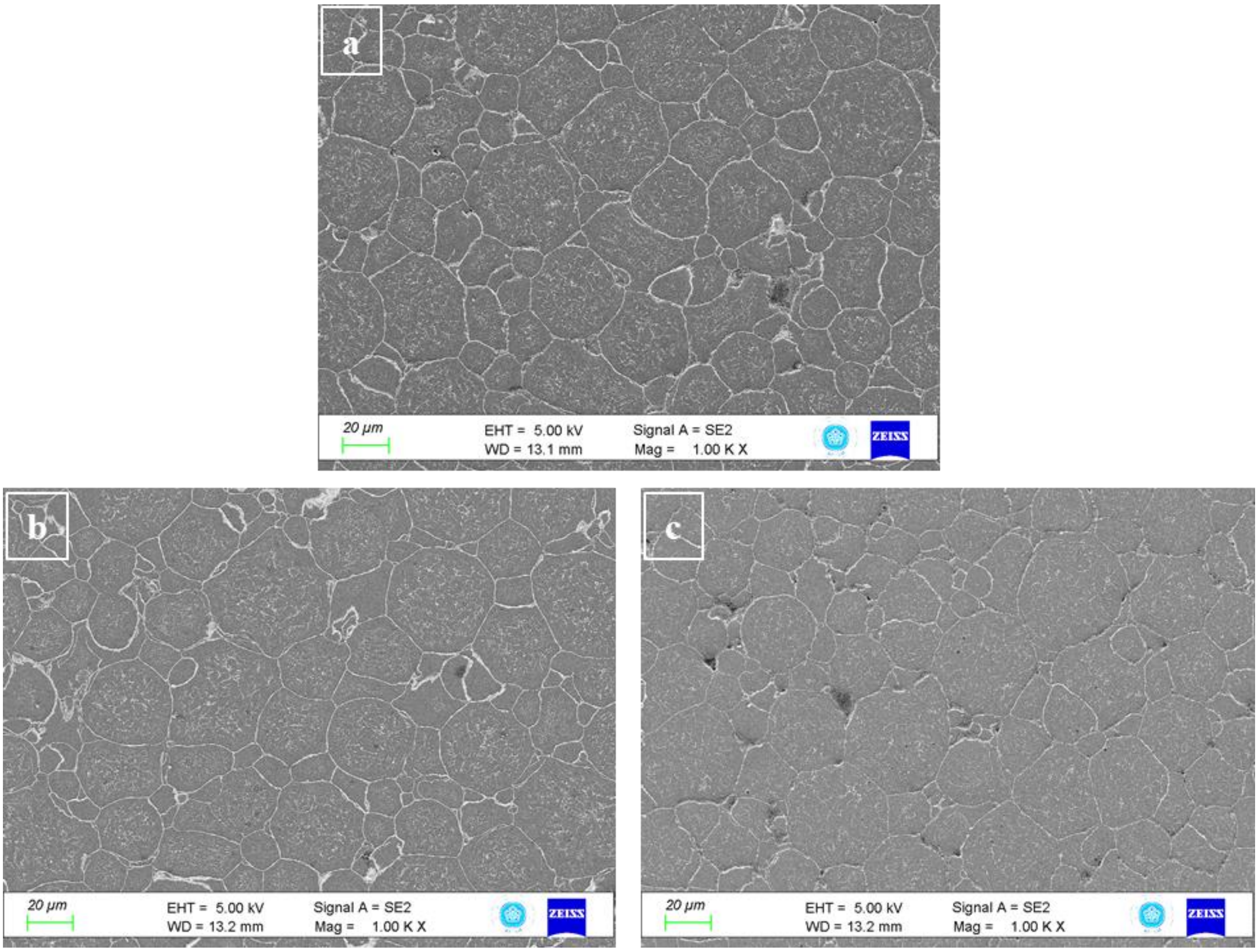

***Figure 3. a)** WE43 alloy, **b)** WE43/0.5% nB_4C composite, **c)** WE43/2% nB_4C*

By studying the microstructure of WE43 by FESEM/EDS (Figure 4), it was found that the precipitates at the grain boundaries are rich in neodymium and yttrium, which are determined and homogeneously distributed in the matrix structure of the nB_4C ceramic particles.

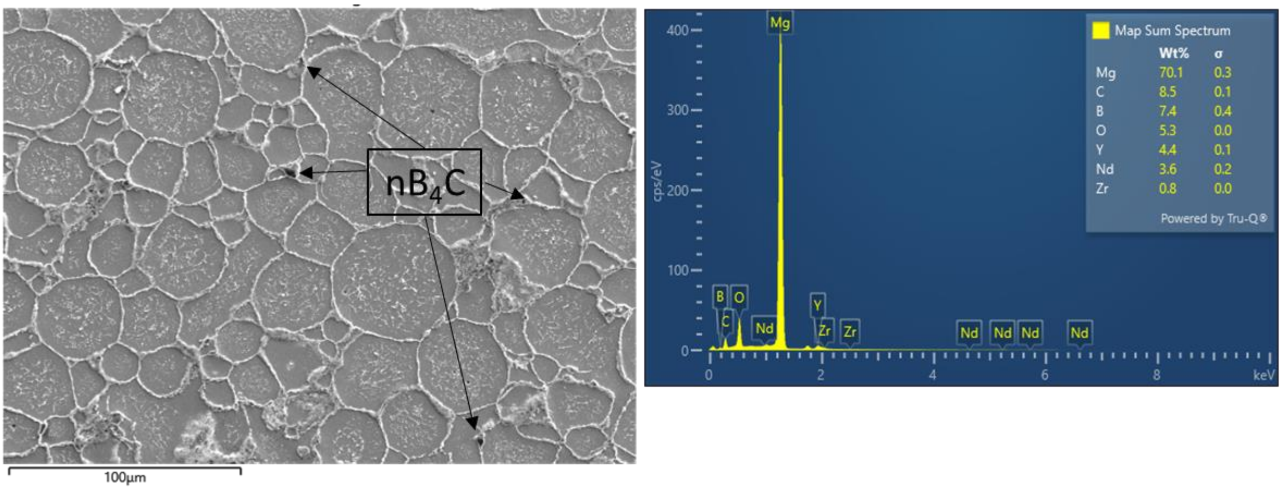

Figure 4. *FESEM/EDS analysis result of WE43/2% nB_4C composite material*

3.3 Mechanical Properties

By examining the density graph (Figure 5a) of WE43 alloy and WE43/ nB_4C composites, it was seen that the highest density occurred in WE43 alloy (99.00%) and the lowest density in WE43/2 nB_4C composite (97.8%). It is known that composites reinforced with ceramic particles have lower density compared to unreinforced matrix specimens. Also, by looking at the hardness graphs in Figure 5b, it can be seen that the sample with the highest hardness is WE43/2 nB_4C and the sample with the lowest hardness is the unreinforced WE43 alloy. The B_4Cs in the matrix phase, which is soft along with the ceramic particle reinforcement, accumulate at the grain boundaries and prevent dislocation movement. Therefore, an increase in the strength values of the composites is observed. Comparing the hardness value with that of the unreinforced WE43 alloy, it is found that it increases by about 5% at 0.5% nB_4C. Similarly, when comparing the hardness values of the unreinforced WE43 alloy and the composite reinforced with 2% nB_4C, it was found that there was an increase of about 12%. The reinforcement by nB_4C ceramic particles was homogeneously distributed in the structure and increased the strength.

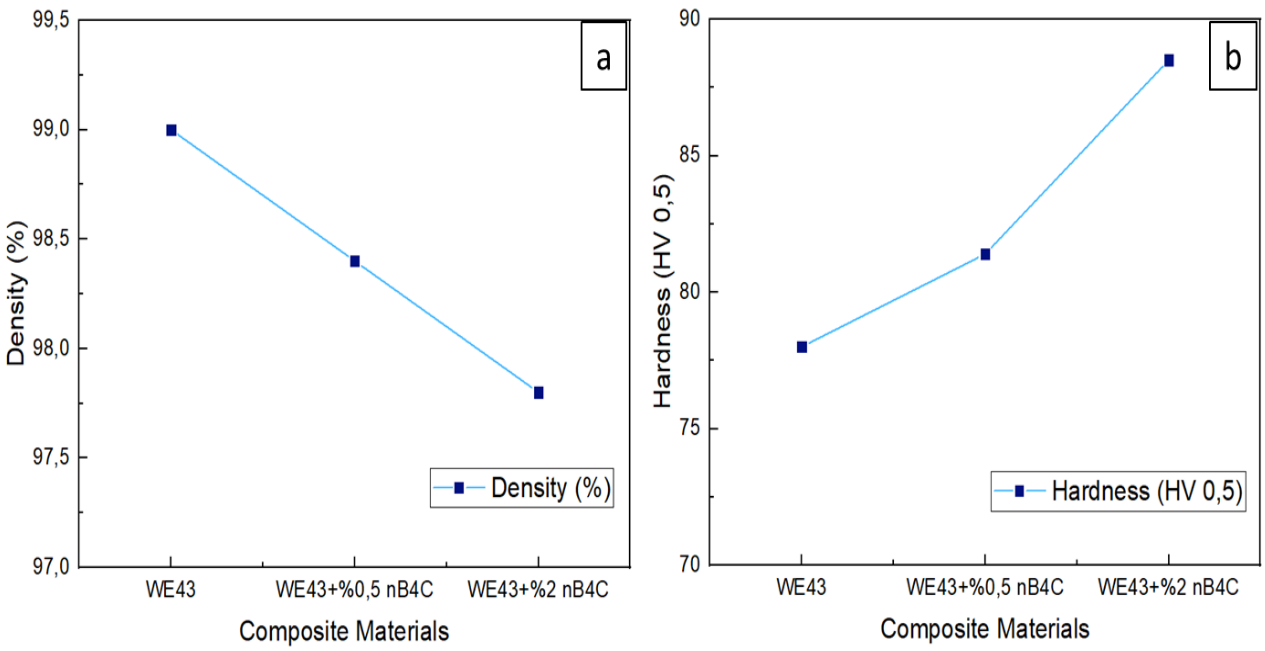

Figure 5. a) *Density,* ***b)*** *Hardness*

3.4. Tribological Behavior

3.4.1. Weight loss

Figure 6 shows the weight loss of the unreinforced WE43 matrix alloy and the WE43/nB_4C composites with different reinforcements under 15 N load. The weight loss decreases with increasing reinforcement ratio compared to the matrix material. It is known that various properties such as grain size, porosity in the structure, strength and hardness affect the wear behavior of materials. It is believed that the reinforcement particles act as a coercive factor at the grain boundaries, leading to the development of wear resistance (Moheimani et al., 2021).

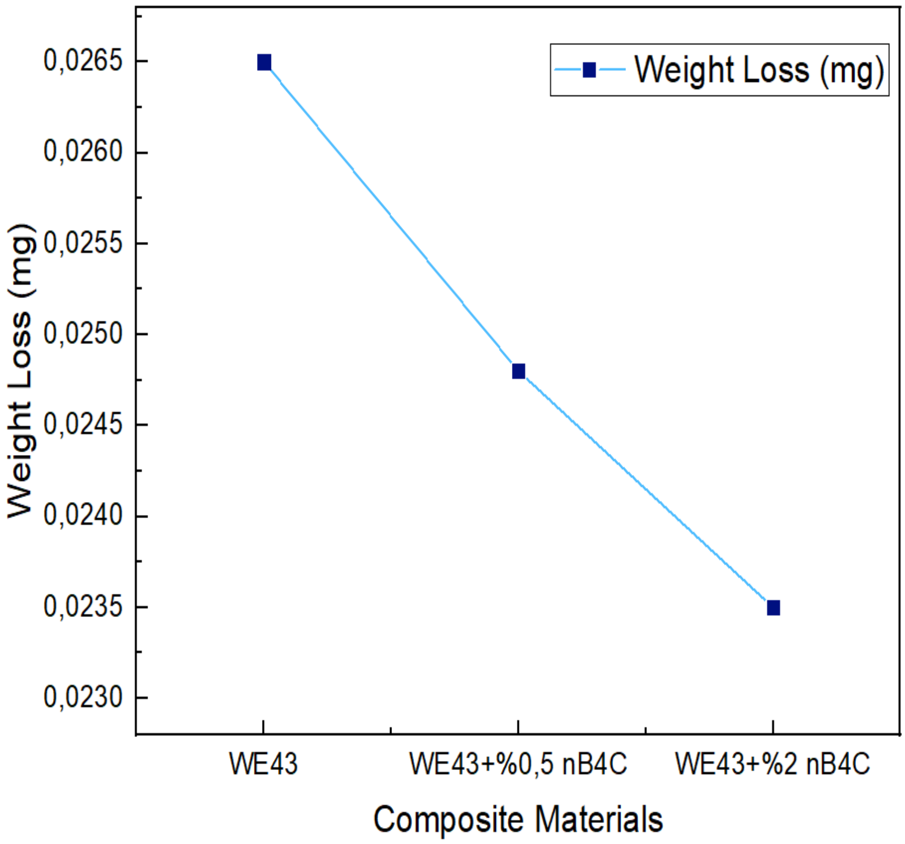

Figure 6. *Weight loss*

3.4.2. Wear mechanisms

FESEM analysis was performed to investigate the wear mechanisms of WE43 alloy and WE43/ nB_4C composites during wear testing and the effects of the presence of nB_4C particles in different proportions on wear behavior. Figure 7. SEM shows images of the worn surfaces of the WE43 alloy and WE43/nB_4C composites subjected to the wear test under 15N load. By examining the images, a series of grooves parallel to the sliding direction, debris, plastic deformations and significant crater areas were visible on the worn surface of the unreinforced WE43 matrix alloy. It is assumed that this situation exhibits typical characteristics of abrasive wear.

4. CONCLUSION

In this study, powder-metal composites were produced by the SPS method after homogeneously mixing WE43 alloy and WE43/nano B_4C powder in a 3D ball mixer. The microstructure, hardness and wear properties of the composites were investigated. The following conclusions can be drawn from the results.

The mixing process in an atmospherically controlled 3D ball mill showed that the nB_4C particles were homogeneously distributed at the grain boundaries. While the highest density value was observed in the unreinforced WE43 alloy, the density values decreased with increasing nB_4C particle addition. The lowest density value was found in the WE43/2% nB_4C composite. While the lowest hardness occurred in the unreinforced WE43 alloy, the highest hardness was observed in the WE43/ 2% nB_4C composite. It was observed that the hardness values increased with increasing nB_4C ratio. The addition of nB_4C particles improved wear resistance and minimized weight loss.

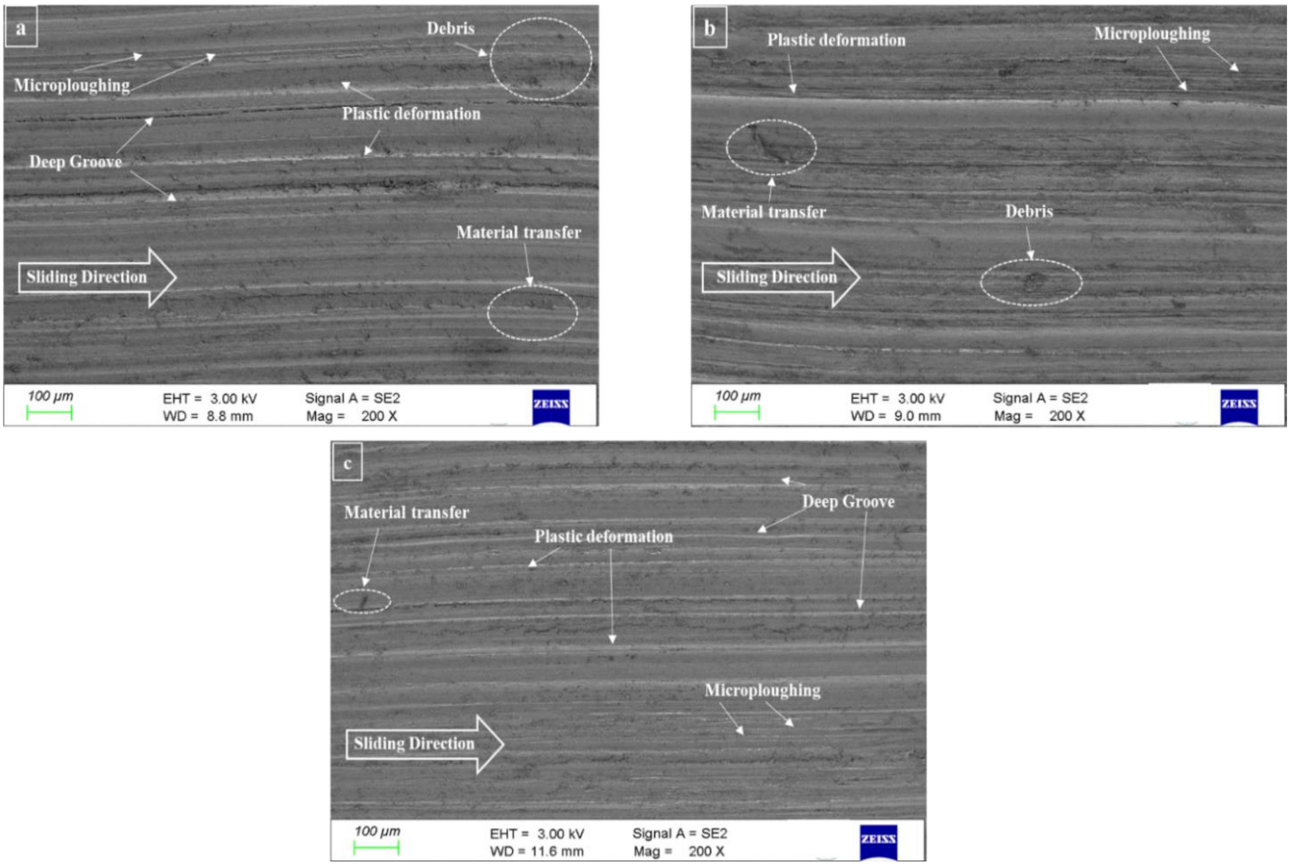

Figure 7. *Worn surface SEM pictures* ***a)*** *WE43 alloy,* ***b)*** *WE43/0.5% nB_4C composite,* ***c)*** *WE43/2% nB_4C*

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Banijamali, S. M., Palizdar, Y., Nekouee, K. A., Najafi, S., & Shariat Razavi, M. (2022). Effect of B_4C reinforcement and hot rolling on microstructure and mechanical properties of WE43 magnesium matrix composite. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, 236(9), 1854-1868. doi:10.1177/14644207221085939

Ghasali, E., Alizadeh, M., Niazmand, M., & Ebadzadeh, T. (2017a). Fabrication of magnesium-boron carbide metal matrix composite by powder metallurgy route: comparison between microwave and spark plasma sintering. *Journal of Alloys and Compounds*, *697*, 200-207. doi:10.1016/j.jallcom.2016.12.146

Ghasali, E., Yazdani-rad, R., Asadian, K., & Ebadzadeh, T. (2017b). Production of Al-SiC-TiC hybrid composites using pure and 1056 aluminum powders prepared through microwave and conventional heating methods. *Journal of Alloys and Compounds*, *690*, 512-518. doi:10.1016/j.jallcom.2016.08.145

Moheimani, S. K., Keshtgar, A., Khademzadeh, S., Tayebi, M., Rajaee, A., & Saboori, A. (2021). Tribological behaviour of AZ31 magnesium alloy reinforced by bimodal size B_4C after precipitation hardening. *Journal of Magnesium and Alloys*, *10*(11), 3267-3280. doi:10.1016/j.jma.2021.05.016

Nimityongskul, S., Jones, M., Choi, H., Lakes, R., Kou, S., & Li, X. (2010). Grain refining mechanisms in Mg–Al alloys with Al_4C_3 microparticles. *Materials Science and Engineering: A*, *527*(7-8), 2104-2111. doi:10.1016/j.msea.2009.12.030

Saheb, N., Iqbal, Z., Khalil, A., Hakeem, A. S., Al Aqeeli, N., Laoui, T., Al-Qutub, A., & Kirchner, R. (2012). Spark plasma sintering of metals and metal matrix nanocomposites: a review. *Journal of Nanomaterials*, *2012*, 983470. doi:10.1155/2012/983470

Shuai, C., He, C., Peng, S., Qi, F., Wang, G., Min, A., Yang, W., & Wang, W. (2021). Mechanical alloying of immiscible metallic systems: process, microstructure, and mechanism. *Advanced Engineering Materials*, *23*(4), 2001098. doi:10.1002/adem.202001098

Tang, B., Li, J., Wang, Y., Luo, H., Ye, J., Chen, X., Chen, X., Zheng, K., & Pan, F. (2022). Mechanical properties and microstructural characteristics of Ti/WE43 composites. *Vacuum*, *206*, 111534. doi:10.1016/j.vacuum.2022.111534

Taşcı, U., Gökmeşe, H., & Bostan, B (2013). AA 2014 Al Matrisli B4C Parçacık Takviyeli Kompozitlerin Mikro Yapı ve Aşınma Davranışının İncelenmesi. *Gazi Üniversitesi Fen Bilimleri Dergisi Part C: Tasarım ve Teknoloji*, *1*(4), 161-168.

Yadav, M., Kumaraswamidhas, L. A., & Singh, S. K. (2022). Investigation of solid particle erosion behavior of Al-Al_2O_3 and Al-ZrO_2 metal matrix composites fabricated through powder metallurgy technique. *Tribology International*, *172*, 107636. doi:10.1016/j.triboint.2022.107636