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Production of AA2024-Matrix B_4C-SiC- and B_4C-Y_2O_3-Particle-Reinforced Composites by Powder Metallurgy and Investigation of Their Mechanical Properties

Halit Doğan[1*], Yılmaz Mutlu[2]

[1] Manisa Celal Bayar University, Faculty of Engineering, Department of Mechanical Engineering, 45140 Manisa, Türkiye
[2] Manisa Celal Bayar University, Institute of Natural and Applied Sciences, Department of Mechanical Engineering, 45140 Manisa, Türkiye
*halit.dogan@cbu.edu.tr
*Orcid: 0000-0001-9263-8068

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Abstract

In this study, it was aimed to produce Al-matrix composite materials with B_4C-SiC and B_4C-Y_2O_3 particle reinforcement using the Powder Metallurgy (PM) method. In the composites in which the reinforcement materials were used at different particle sizes and ratios, AA2024 powders were selected as the matrix material. The powders were homogeneously mixed and compacted at room temperature under a pressure of 525 MPa. The raw specimens were sintered by keeping them at different temperatures for 45 minutes. The composite materials were subjected to wear tests, and their hardness and density values were investigated. In the study, the effects of reinforcement materials added to the matrix at different particle sizes and ratios on wear resistance, hardness, and density at different sintering temperatures were examined. As a result of the mechanical tests that were performed, wear values decreased along with B_4C reinforcement ratios that increased in parallel with density values. The highest hardness value was observed as 71.73 HB in the composite specimen with a B_4C reinforcement ratio of 20% at the sintering temperature of 595°C.

Keywords: Composite Material, Particle Size and Ratio, Powder Metallurgy, Sintering, Wear.

1.Introduction

Advanced materials have become prevalent worldwide as a consequence of advancements in science and technology, to meet the need for specialized products. The reason for this is that a single material usually cannot meet the requirements of all engineering fields. Therefore, researchers have shown great effort to use composite materials with unique properties. As a result of this, there has been an increase in the production and application fields of metal matrix composites in recent years [1]. In previous years, metal-matrix composites (MMCs) received worldwide attention with their excellent properties combining the best properties of metal matrices and reinforcements [2]. The physical and mechanical properties of MMCs can be improved by adding reinforcement material particles into the matrix. As the matrix material, light metals such as Ti, Al, and Mg that provide support for the reinforcement material are used in general. Among MMCs, the production of aluminum-matrix composites (AMCs) is becoming more prominent each day and finding various usage areas in the industry [3]. Aluminum is an excellent matrix material for developing wear-resistant AMCs [2]. Aluminum alloys are the most convenient alloys following iron alloys [4]. It is well-known that the performance of AMCs is highly dependent on the reinforcements that are added [2]. AMCs use an aluminum alloy as the matrix material and mostly include ceramics like SiC [5-8], B_4C [6,7,9], Si_3N_4 [7], Al_2O_3 [5,6,8], BN [7], Zr [8], and TiC [7] as the reinforcement material. The properties of AMCs can be changed based on their elemental and volumetric ratios [3]. AMCs reinforced with hard ceramic particles are the most promising materials for various automotive and aviation applications with their low density and high wear resistance [5,7], and they are used in many fields in the industry, especially in critical applications such as brake calipers, gears, engine blocks, pump components, and valve components [10,11]. Several Al alloys (e.g., 2xxx, 5xxx, 6xxx, 7xxx) are industrially utilized [12]. As a reinforcement material for AMCs, B_4C has attracted special attention [13]. Boron carbide (B_4C) and silicon carbide (SiC) particles, which are the most preferred reinforcement materials for AMCs, strengthen the matrix structure and provide good wear resistance and high thermal stability [12]. B_4C, which is called "black diamond", has a low density (2.52 g/cm^3), high hardness (29.1 GPa), high modulus of elasticity (470 GPa), and high melting point (2540°C) [14]. Because SiC has high hardness values, high resistance to rupture, a high modulus of elasticity, low density, and a low thermal expansion coefficient, its use as a reinforcement material is common [12]. Y_2O_3 ceramics have critical properties such as high thermal and crystallographic stability, and they are used in various applications including protective coatings, microwave radars, solid-state lasers, superconductors, and catalytic converters [27]. In the literature, there are different methods of production including squeeze casting, stir casting, liquid metal infiltration, mechanical alloying, and powder metallurgy for MMCs [15]. The powder metallurgy [PM] method is a production method where mixed metal powders are shaped by compaction into a mold that has been prepared based on the shape and dimensions of the part to be produced and then sintered [6]. PM allows manufacturing processes that result in parts close to those with precisely shaped parts produced out of Al-based materials and MMCs with certain mechanical, thermal, and functional properties [16]. In this study, by ceramic particle reinforcement, Al-B_4C, Al-B_4C-SiC, and Al-B_4C-Y_2O_3 composites with an aluminum alloy matrix were produced, and the effects of the reinforcement materials on the mechanical and microstructure properties of the composites were examined.

2. Materials and Methods

In this study, where reinforcement materials were used at different ratios and particle sizes, AA2024 aluminum alloy powder was used as the matrix component, and B_4C, SiC, and Y_2O_3 powders were used as the reinforcement components at different ratios and particle sizes. Aluminum alloy at a particle size of 100 µm was used as the matrix, while the reinforcement materials included boron carbide (B 4 C) at ratios of 7, 10, 15, and 20% and particle sizes of 10 and 22-59 µm, 20% B_4C + silicon carbide (SiC) at ratios of 3-10% and a particle size of 10 µm, and 20% B_4C + yttrium oxide (Y_2O_3) at ratios of 3-10% and a particle size of 10 µm. The chemical composition of the AA2024 alloy that was used as the matrix material is shown in Table 1.

2.1 Specimen Preparation

The powders were weighed using a RADWAG PS 1000/C/2 brand precision scale with a sensitivity of 0.001 g and homogeneously mixed at different weight ratios. Composite materials were produced by applying a pressure of 525 MPa onto a mold prepared with the dimensions of 10x10x55 mm using a 100-ton uniaxial hydraulic press branded Hidrokar. Polyethylene glycol (1% wt.) was added to the powder mixtures as a binder. The specimens were sintered at 550, 575, and 595°C for 45 minutes using a Protherm brand furnace.

2.2 Hardness Test

The hardness measurements were made with specimens that were brought to the dimensions of 10x10x10 mm using an EMCO-TEST DuraVision Brinell hardness tester device (Load: 15.625 kg, Ball Diameter: 2.5 mm, Time: 10 s). The effects of B_4C at a particle size of 10 µm that was added to the AA2024 matrix on hardness are shown in Figure 1. It was seen that at all sintering temperatures, as the ratio of the B_4C reinforcement increased, hardness values also increased. This was an expected result because of the higher harness value of the B_4C that was added to the matrix compared to the matrix material. The highest hardness value was found as 71.73 HB in the composite specimen produced using 20% B_4C and sintered at 595°C. Similarly, in the study conducted by Karakoc H. et al. using Al6061 as the matrix material and B_4C and SiC powders as the reinforcement materials, it was found that the composite materials including reinforcements were harder than the unreinforced Al6061 alloy, where the unreinforced alloy had a mean hardness of 50 HB, and the 12% B_4C composite had a mean hardness of 76 HB [12]. Likewise, in their hardness tests on SiC- and B_4C-reinforced Al7071-matrix composite materials they produced with the PM method, Pul M. and Baydaroğlu V. observed that as the reinforcement particle ratio in the structure increased, hardness values also increased [6]. Hasırcı H. and Gül F. also produced AMCs with B_4C reinforcement and examined their mechanical properties. They found higher hardness values in the composite material produced with B_4C reinforcement addition to the Al [17]. Additionally, Ergul E, Kurt H. İ., Cıvı C. and Eyıcı G. mixed 50% MgO and 50% carbon nanotubes (CNT) by weight with the die casting method, added these reinforcement materials to the Al2024 matrix material at ratios of 0.2, 0.5, 1, and 2% by weight,

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produced MgO/CNT-reinforced Al2024 composite materials, and investigated hardness results. They observed that the hardness values of the specimens increased by reinforcement addition [18]. Şenel M. C., Gürbüz M. and Koç E. produced composite materials with the PM method by adding Si_3N_4 reinforcement to the aluminum matrix at ratios varying in the range of 0-12% and examined the effects of the reinforcement ratio on the mechanical properties of the composites. According to the results of their experiments, while the hardness value of the pure aluminum was approximately 28 HV, hardness could be increased to 58 HV by adding 9% Si_3N_4 by weight [19].

Table 1. Chemical composition of the AA2024 matrix material (%). [20]

Matrix Material Chemical Properties								
AA2024	Fe	Si	Cu	Mn	Mg	Zn	Ti	Cr
	0.50	0.50	3.80-4.90	0.30-0.90	1.20-1.80	0.25	0.15	0.10

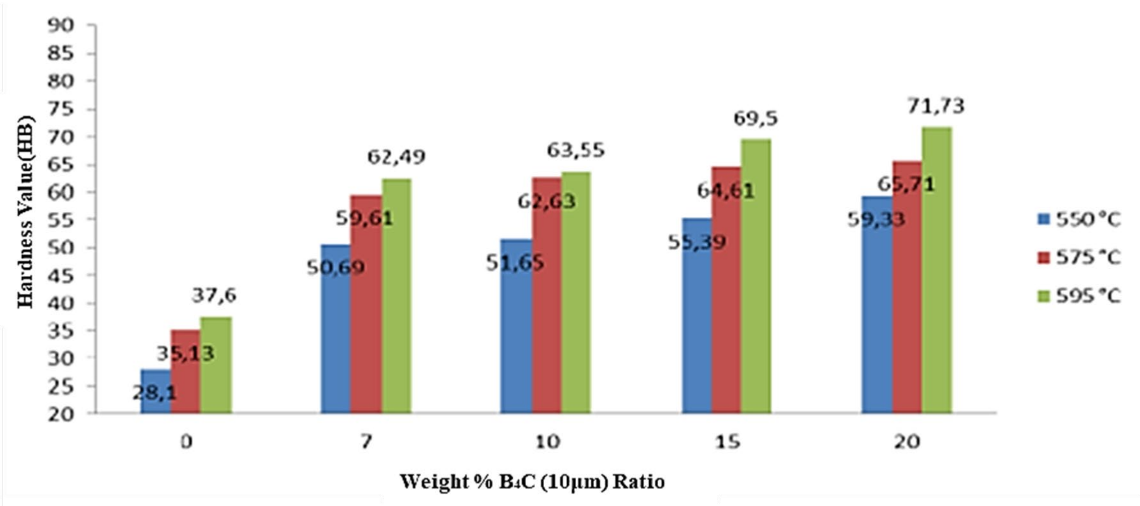

Figure 1. Changes in the hardness values of AA2024 + 10 µm B_4C depending on temperatures and reinforcement ratios.

Figure 2 shows the effects of the B_4C+SiC added into the AA2024 matrix on hardness. Accordingly, in all specimens sintered at different temperatures, as the ratio of SiC increased, hardness values also increased. The reason for this result was the fact that the hardness values of the B_4C and SiC reinforcement materials were higher than that of the matrix material. The highest hardness value was found as 91.82 HB in the specimen that was produced by adding 20% B_4C + 10% SiC and sintered at 595°C. Likewise, Gündoğan K. and Özsarı A. R. B. investigated the mechanical properties of composite materials produced with an AA2024 or AA6061 matrix and reinforced with B_4C and SiC particles using the pressure infiltration technique. As the pressure values of the composite materials increased, the authors observed an increase in their hardness and strength values. After they compared the reinforcement components, they concluded that the composites with the B_4C reinforcement had better mechanical properties than those with the SiC reinforcement [21].

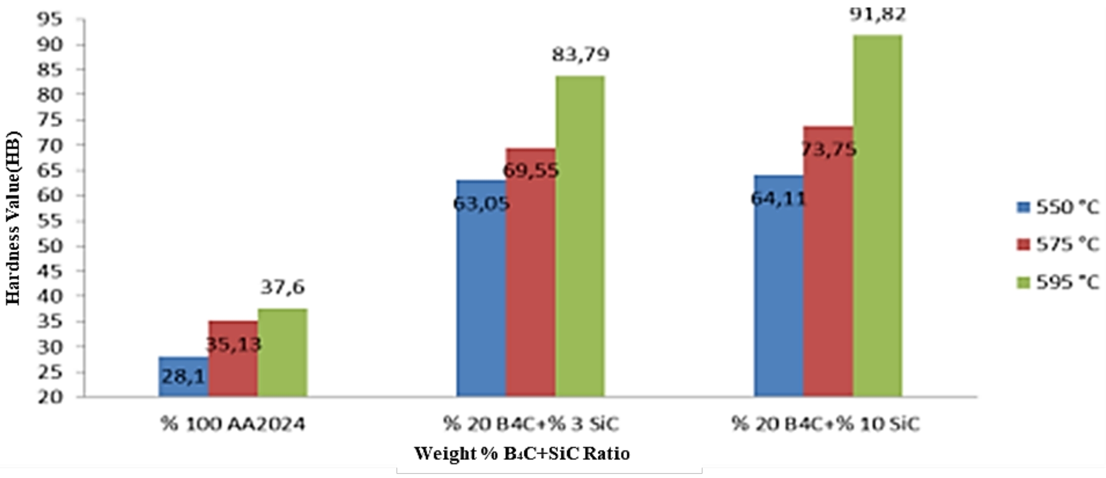

Figure 2. Changes in the hardness values of AA2024+B_4C+SiC depending on temperatures and reinforcement ratios.

Figure 3 shows the effects of $B_4C+Y_2O_3$ added into the AA2024 matrix on hardness. It is seen that as the ratio of Y_2O_3 increased, hardness values also increased. The reason for this result was the fact that the hardness values of the B_4C and Y_2O_3 reinforcement materials were higher than that of the matrix material. The highest hardness value among the AA2024-matrix $B_4C+Y_2O_3$-reinforced composite materials was found as 85.33 HB in the specimen that was produced by adding 20% B_4C + 10% Y_2O_3 and sintered at 595 °C.

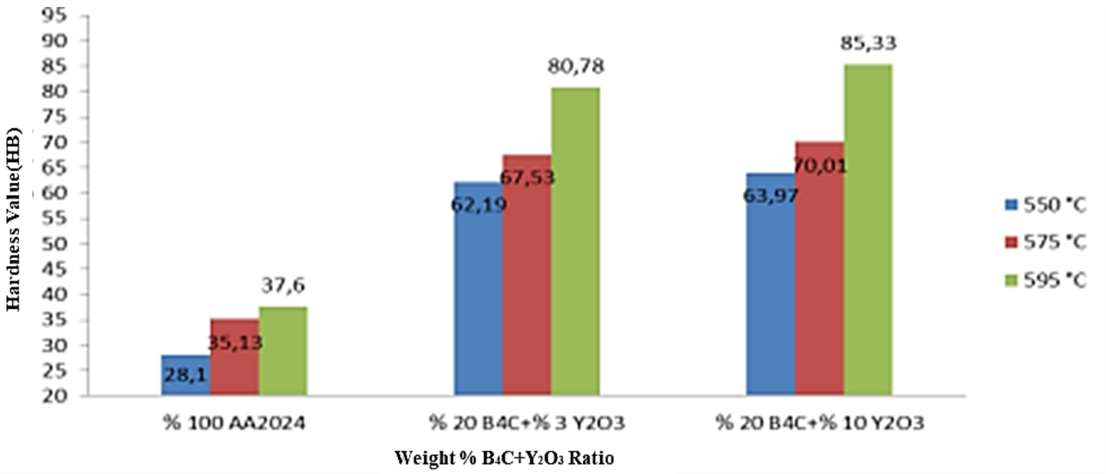

Figure 3. Changes in the hardness values of AA2024+B_4C+ Y_2O_3 depending on temperatures and reinforcement ratios.

In the composites that were produced, in general, hardness values were observed to increase along with increased reinforcement ratios and sintering temperatures.

2.3 Density

The density measurements of the composite materials were made using a RADWAG AS 220/C/2 brand density measurement device based on the Archimedes principle. Figure 4 presents the effects of B_4C at a particle size of 10 µm that was added into the AA2024 matrix on density and porosity. Accordingly, in all specimens sintered at different temperatures, as the ratio of B_4C reinforcement increased, density decreased, and porosity increased. The density values of the examined specimens were compatible with those reported in the literature, and as the B_4C reinforcement ratio increased, density decreased. The main reason for this was the increased porosity that was observed and the fact that B_4C is a material that has a low density.

Similarly, in the Al2024-matrix B_4C- and TiB_2-reinforced composite materials produced by Pul M., as the ratio of reinforcement increased, the ratio of pores between TiB_2 and B_4C particles and the aluminum powder increased, and thus, density values decreased [22]. Topcu İ., Dikici M. and İpek C. also investigated the density and wear resistance of aluminum-matrix B_4C-reinforced composite materials. The lowest density value was observed in the Al/B_4C composite with the highest B_4C ratio by weight (15%). It was seen that the density values of the specimens decreased along with increased B_4C ratios, but the values of the specimens with the same B_4C reinforcement ratios increased along with increased sintering temperatures [23].

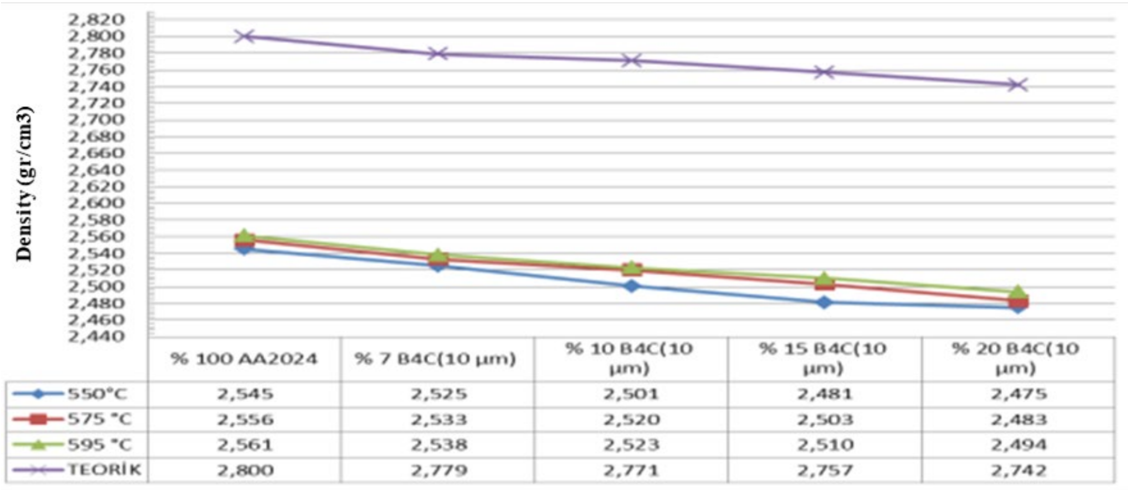

Figure 4. Changes in the density values of AA2024 + 10 µm B_4C depending on temperatures and reinforcement ratios.

The effects of B_4C+SiC added into the AA2024 matrix on density are shown in Table 2. Accordingly, as the ratio of SiC that was added increased, the ratio of porosity also increased. The effects of B_4C and Y_2O_3 added into the AA2024 matrix on density are shown in Table 3. Accordingly, in all specimens sintered at different temperatures, as the ratio of Y_2O_3 that was added increased, both density and porosity increased.

Table 2. Changes in the density values of AA2024 + B_4C+SiC depending on temperatures and reinforcement ratios.

AA2024+(B4C+SiC)										
Sequence No	**% AA2024**	**% B_4C**	**% SiC**	**AA2024 particle size (µm)**	**B_4C particle size (µm)**	**SiC particle size (µm)**	**Sintering temperature (^oC)**	**Theoretical density value (g/cm^3)**	**Experimental density value (g/cm^3)**	**Pore ratio (%)**
1	77	20	3	100-150	22-59	10	550 575 595	2,754	2,470 2,479 2,495	10,31 9,98 9,40
2	70	20	10	100-150	22-59	10	550 575 595	2,783	2,475 2,483 2,499	11,06 10,77 10,20

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Table 3. Changes in the density values of AA2024 + B_4C+Y_2O_3 depending on temperatures and reinforcement ratios.

AA2024+(B4C+Y_2O_3)										
Sequence No	**% AA2024**	**% B_4C**	**% Y_2O_3**	**AA2024 particle size (µm)**	**B_4C particle size (µm)**	**Y_2O_3 particle size (µm)**	**Sintering temperature (^oC)**	**Theoretical density value (g/cm^3)**	**Experimental density value (g/cm^3)**	**Pore Ratio (%)**
1	77	20	3	100-150	22-59	10	550	2,808	2,501	10,93
							575		2,519	10,29
							595		2,523	10,14
2	70	20	10	100-150	22-59	10	550	2,963	2,609	11,94
							575		2,619	11,60
							595		2,635	11,06

2.4 Wear Test

The wear tests were carried out with the Tribometer pin-on-disk wear testing device shown in Figure 5 under a 2N load for 15 minutes (3.516 mm track diameter, 20000 mm sliding distance, and 2000 cm/s linear velocity). Like the density test results, as the ratio of B_4C reinforcement increased, wear values decreased. As seen in Figure 6, in all specimens sintered at different temperatures, wear values decreased along with increasing reinforcement ratios. These results were similar to the results of other studies conducted with composite materials. Hasırcı H. and Gül F. produced Al-matrix B_4C-reinforced composite materials and investigated their wear behaviors. They reported that the hardness of the composite increased due to the B_4C reinforcement particles added into the matrix, the pure Al material had the lowest hardness values, and in general, wear amounts decreased in the composites in comparison to the pure Al material as the ratio of reinforcement increased [17]. Likewise, Karakoç H. observed lower wear amounts based on weight loss as a result of B_4C and Si_3N_4 reinforcement addition [24]. In another study by Karakoç H., Al7075/B_4C and Al7075/B_4C/Si_3N_4 composite materials were produced using the powder metallurgy method, and their wear behaviors were analyzed. The researcher determined a decrease depending on increased ratios of B_4C and Si_3N_4 by weight and found the lowest weight loss value in the Al7075/15%B_4C/2%Si_3N_4 material [24]. Furthermore, Arık H. studied the effects of SiC as a reinforcement component on the wear properties of aluminum-matrix composite materials. The author used PM as the production method for Al-SiC composite materials and the pin-on-disk method in the wear test. It was observed that the weight loss value decreased by 48.4% to 79.6% when SiC was added at 10% by weight to the matrix [25]. Aksöz S. and Bostan B. produced 10/20% B_4C-reinforced AA2014-matrix composite materials using the casting method and sintering at 600°C for 2 hours after casting and examined the effects of reinforcement ratios on wear behaviors. They found lower wear-related weight loss as a result of adding increased ratios of B_4C reinforcement and sintering. The lowest weight loss was observed in the composite material containing 20% B_4C that was sintered at 600°C for 2 hours [26].

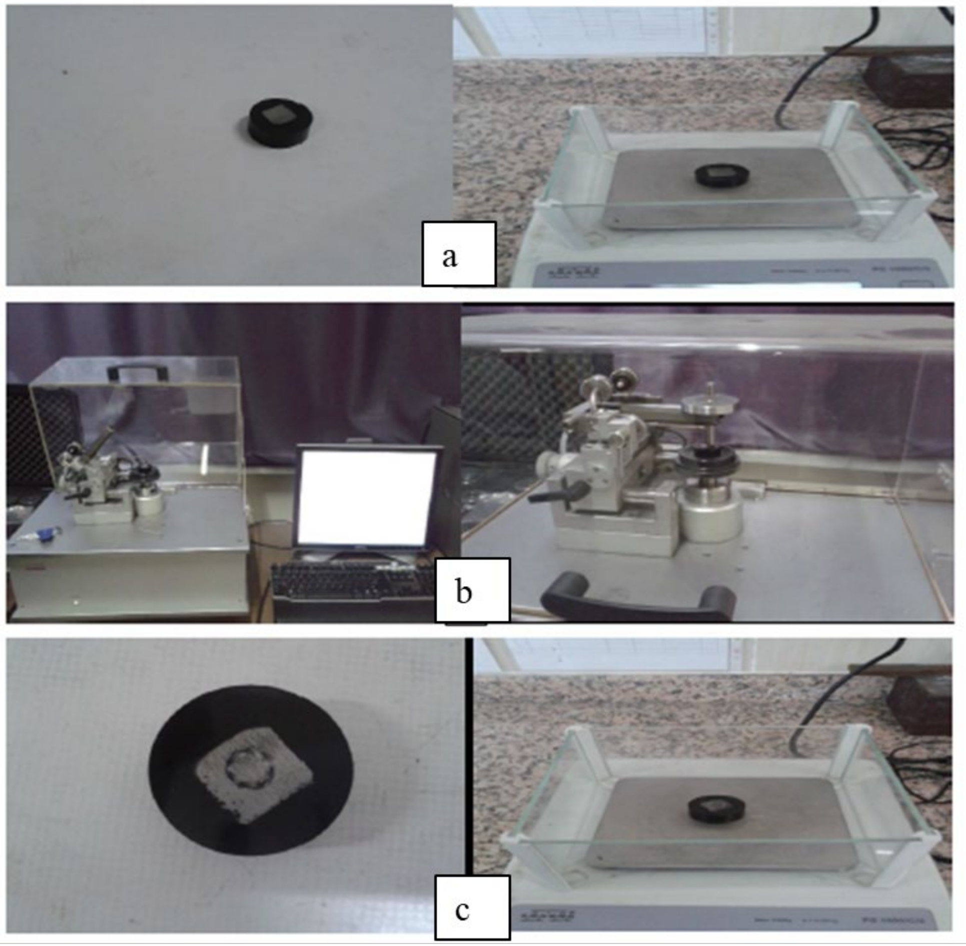
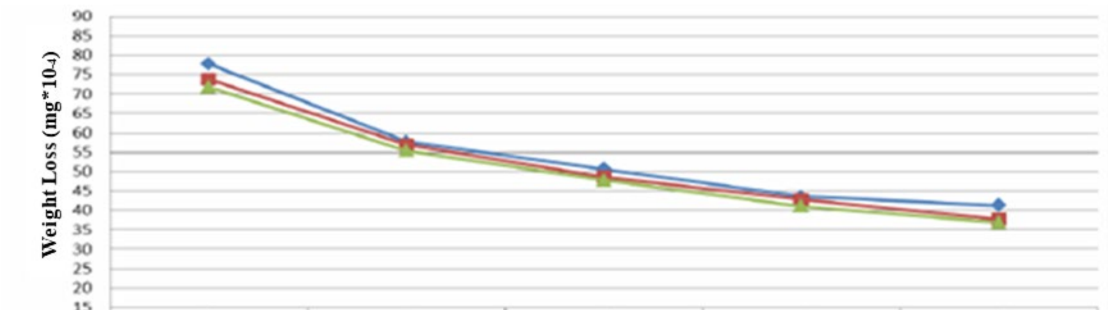
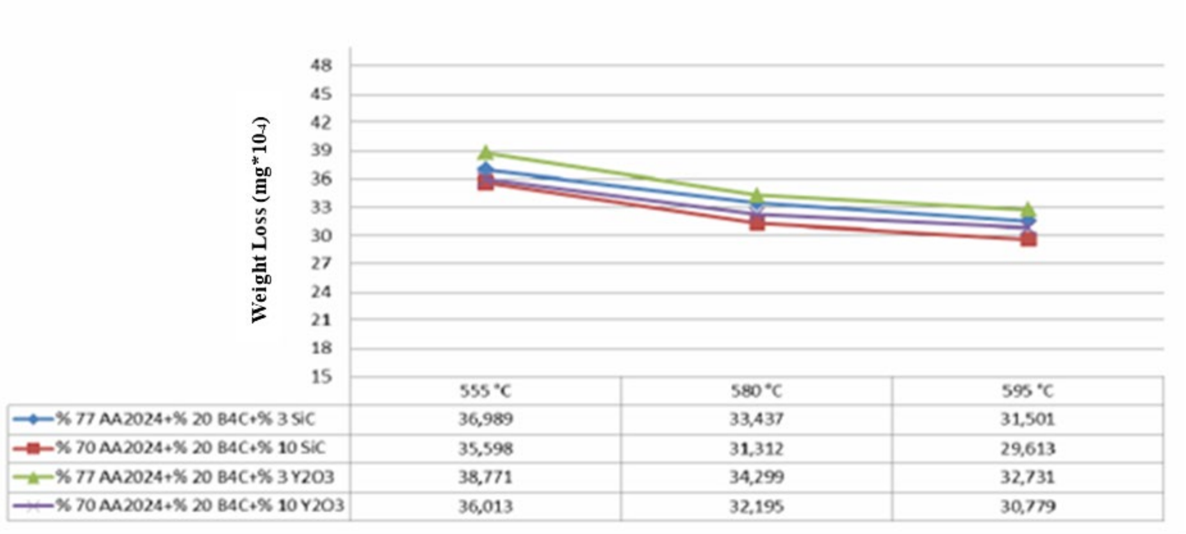


Figure 5. Wear tests of the composite specimens (a: Weighing before the test; b: Wear test; c: Weighing after the test).



	0% (10 µm B4C)	7% (10 µm B4C)	10% (10 µm B4C)	15% (10 µm B4C)	20% (10 µm B4C)
555 °C	77,889	57,803	50,745	43,665	41,325
580 °C	73,855	56,980	48,687	42,889	37,741
595 °C	71,905	55,451	47,876	41,201	36,891

Figure 6. Changes in the weight loss values of AA2024 + 10 µm B_4C depending on temperatures and reinforcement ratios.



	555 °C	580 °C	595 °C
% 77 AA2024+% 20 B4C+% 3 SiC	36,989	33,437	31,501
% 70 AA2024+% 20 B4C+% 10 SiC	35,598	31,312	29,613
% 77 AA2024+% 20 B4C+% 3 Y2O3	38,771	34,299	32,731
% 70 AA2024+% 20 B4C+% 10 Y2O3	36,013	32,195	30,779

Figure 7. Changes in the weight loss values of AA2024+(B_4C+SiC) and AA2024+(B_4C+Y_2O_3) depending on temperatures and reinforcement ratios.

Figure 7 presents the changes in the weight loss values of AA2024+(B_4C+SiC) and AA2024+(B_4C+Y_2O_3) along with increased sintering temperatures. It is seen that with the increase in the sintering temperature, wear values decreased, and the AA2024+(B_4C+SiC) composite had higher wear resistance values in comparison to the AA2024+(B_4C+Y_2O_3) composite.

2.5 SEM

The microstructures of the specimens were examined using a JEOL JSM-6060 brand SEM device.

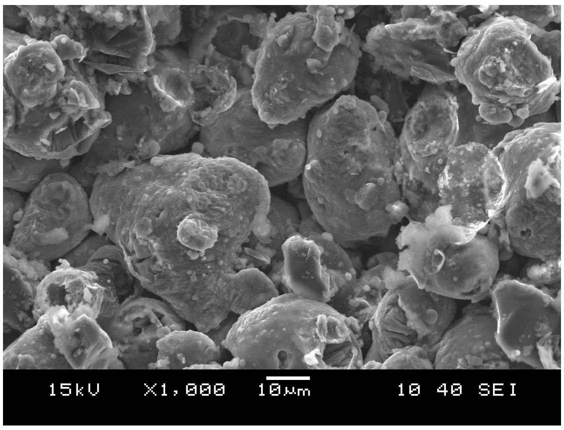


Figure 8. SEM image of 85%AA2024+15%B_4C (10 µm) sintered at 575°C (x1000).

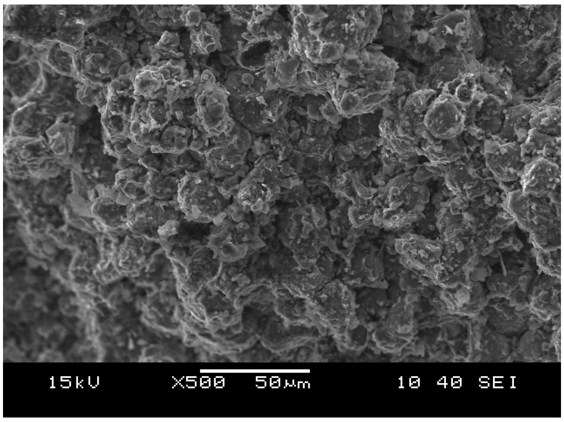


Figure 9. SEM image of 77%AA2024+20%B_4C (22-49 µm) +3%SiC sintered at 575°C (x500).

It was observed in the microstructure of the 77%AA2024+20% B_4C (22-59 µm) +3% SiC composite shown in Figure 9 that the distributions of B_4C and SiC were generally homogeneous but occasionally non-homogeneous, and the structure was non-porous in general.

As seen in Figures 8 and 9, although both materials were sintered at the same temperature, the 77%AA2024+20% B_4C (22-59 µm) +3%SiC composite had a lower porosity value because a more compacted structure was obtained with the addition of SiC (10 µm).

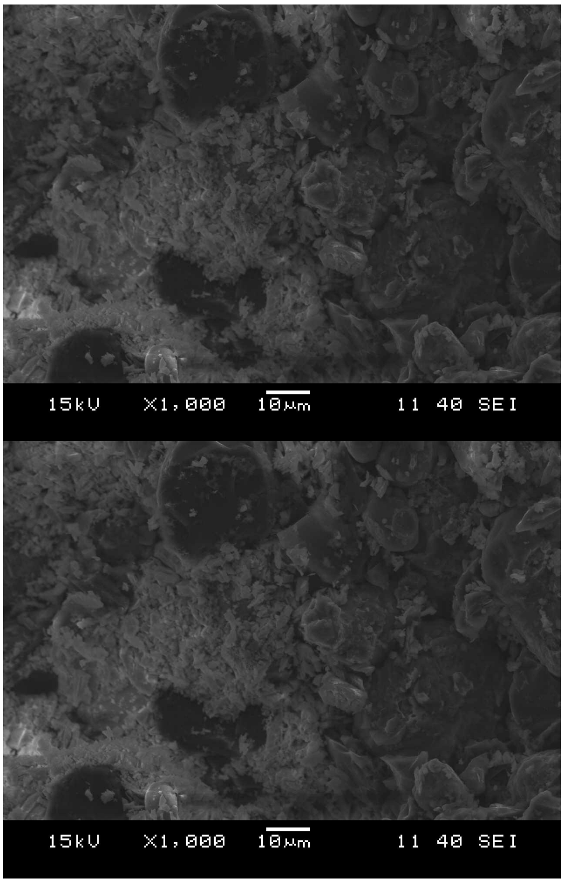


Figure 10. SEM image of 70%AA2024+20%B_4C (22-59 µm) +10%Y_2O_3 sintered at 575°C (x1000).

Figure 10 shows the microstructure of the composite that had lower porosity due to the more compacted structure that was obtained with the addition of 10 µm Y_2O_3.

3. Results

The conclusions made based on the results of the experiments that were conducted in this study are given below.

1- As the reinforcement particle ratio by weight increased, the hardness values of the composites increased, and in comparison to the unreinforced AA2024 matrix material, the hardness values of the composites were approximately 2.5 times higher.
2- The density values of the 10 µm B_4C-reinforced composites decreased along with increasing reinforcement ratios.
3- With the increase in the reinforcement particle ratio by weight, there was a decrease in the wear-related weight loss values of the composites.
4- The SEM examinations (Figures 9 and 10) showed lower porosity values depending on the addition of SiC (10 µm) and Y_2O_3 (10 µm) due to the more compacted structure that was obtained.

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Author Contributions

Halit Doğan: He planned, designed and performed the analysis.
Yılmaz Mutlu: He designed the study, made the statistical analyzes and wrote the article.

Ethics

There are no ethical issues after the publication of this manuscript**.**

References

[1]. Herzallah H., Elsayd A., Shash A., Adly M.,; Effect of carbon nanotubes (CNTs) and silicon carbide (SiC) on mechanical properties of pure Al manufactured by powder metallurgy, j m a t e r r e s t e c h n o l . 2 0 2 0;9(2):1948–1954. https://doi.org/10.1016/j.jmrt.2019.12.027

[2]. Zhang J., Liu Q., Yang S., Chen Z., Liu Q., Jiang Z.,; Microstructural evolution of hybrid aluminum matrix composites reinforced with SiC nanoparticles and graphene/graphite prepared by powder metallurgy, Progress in Natural Science: Materials International 30 (2020) 192–199. https://doi.org/10.1016/j.pnsc.2020.01.024

[3]. Sharma A. K., Bhandari R., Pinca-Bretotean C.,; A systematic overview on fabrication aspects and methods of aluminum metal matrix composites, Materials Today: Proceedings 45 (2021) 4133–4138. https://doi.org/10.1016/j.matpr.2020.11.899

[4]. Fuse K., Badheka V., Patel V., Andersson J.,; Dual sided composite formation in Al 6061/B4C using novel bobbin tool friction stir processing, j o u r n a l of ma t e r i a l s r e s e a r c h and technology 2 0 2 1 ; 1 3 : 1 7 0 9 e1 7 2 1. https://doi.org/10.1016/j.jmrt.2021.05.079

[5]. Devadiga U., Fernandes P.,; Taguchi analysis for sliding wear characteristics of carbon nanotube-flyash reinforced aluminium nanocomposites, Heliyon 7 (2021) e06170. https://doi.org/10.1016/j.heliyon.2021.e06170

[6]. Pul M. ve Baydaroğlu V., B4C/SiC katkılı alüminyum esaslı kompozitlerin mekanik özelliklerin incelenmesi ve balistik performanslarının modellenmesi, Politeknik Dergisi, 23(2): 383-392, (2020).
https://doi.org/10.2339/politeknik.525011

[7]. Şenel M. C.,; Toz Metalürjisi Yöntemiyle Üretilen Saf Al ve Al-B4C, Al-Al2O3 Kompozitlerin Mekanik ve Mikroyapı Özelliklerinin Karşılaştırılması, GÜFBED/GUSTIJ (2020) 10 (3): 783-795.
https://doi.org/10.17714/gumusfenbil.689359

[8] . Yang J., Chung D.D.L.,; Wear of bauxite-particle reinforced aluminum alloys", Composite Materials Research Laboratory, Furnas Hall, State University of New York, Buffalo, NY 14260(U.S.A.), Wear, 135: 53-65 (1989). https://doi.org/10.1016/0043-1648(89)90095-1

[9]. Abenojar J.; Velasco F.; Martinez M.A.; Optimization of Processing Parameters for The Al + 10% B4C System Obtained by Mechanical Alloying, Journal of Materials Processing Technology 184(2007) 441–446. https://doi.org/10.1016/j.jmatprotec.2006.11.122

[10]. Saessı M., Alızadeh A., Abdollahı A.,; Wear behavior and dry sliding tribological properties of ultra-fine grained Al5083 alloy and boron carbide-reinforced Al5083-based composite at room and elevated temperatures, Trans. Nonferrous Met. Soc. China 31(2021) 74−91. https://doi.org/10.1016/S1003-6326(20)65479-6

[11]. Lakshmikanthan A., Prabhu T.R., Babu U. S., Koppad P. G., Gupta M., Krishna M., Bontha S.,; The effect of heat treatment on the mechanical and tribological properties of dual size SiC reinforced A357 matrix composites, j m a t e r r e s t e c h n o l . 2 0 2 0;9(3):6434–6452. https://doi.org/10.1016/j.jmrt.2020.04.027

[12]. Karakoc H., Ovalı İ, Dündar S., Çıtak R.,; Wear and mechanical properties of Al6061/SiC/B4C hybrid composites produced with powder metallurgy, j m a t e r r e s t e c h n o l . 2 0 1 9;8(6):5348–5361. https://doi.org/10.1016/j.jmrt.2019.09.002

[13]. Aherwar A., Patnaik A., Pruncu C. I.,; Effect of B4C and waste porcelain ceramic particulate reinforcements on mechanical and tribological characteristics of high strength AA7075 based hybrid composite, j m a t e r r e s t e c h n o l . 2 0 2 0;9(5):9882–9894. https://doi.org/10.1016/j.jmrt.2020.07.003

[14]. Boussebha H., Bakan S., Kurt A. O.,; Dynamic / thermochemical method: A novel approach in the synthesis of B4C powder, Open Ceramics 6 (2021) 100133. https://doi.org/10.1016/j.oceram.2021.100133

[15]. Abd-Elwahed M.S., Sadoun A.M., Elmahdy M.,; Electroless-plating of Ag nanoparticles on Al2O3 for enhanced mechanical and wear properties of Cu–Al2O3 nanocomposites, j m a t e r r e s t e c h n o l . 2 0 2 0;9(6):13749–13758. https://doi.org/10.1016/j.jmrt.2020.09.077

[16]. Balog M., Orovcik L., Nagy S., Krizik P., Nosko M., Oslanec P., Zifcak P.,; To what extent does friction-stir welding deteriorate the properties of powder metallurgy Al?, j m a t e r r e s t e c h n o l . 2 0 2 0;9(3):6733–6744. https://doi.org/10.1016/j.jmrt.2020.04.087

[17]. Hasan H., Ferhat G.,; B4C / Al Kompozitlerin Takviye Hacim Oranına Bağlı Olarak Abrasif Aşınma Davranışlarının İncelenmesi, SDU International Technologic Science, 2(1): 15-21, (2010). https://dergipark.org.tr/tr/pub/utbd/issue/25991/273754

[18]. Ergul E., Kurt H.I., Civi C., Eyici G., Wear Characteristics of Carbon Nanotube Reinforced Al2024 Composites, El-Cezerî Fen ve Mühendislik Dergisi 2020, 7(3); 1008-1016. https://doi.org/10.31202/ecjse.716287

[19]. Şenel M. C., Gürbüz M., Koç E.,; Toz Metalürjisi Metoduyla Üretilen Al-Si3N4 Metal Matrisli Kompozitlerin Mekanik Özelliklerinin İncelenmesi, Mühendis ve Makina Dergisi, cilt 59, sayı 693, s. 33-46, 2018. https://dergipark.org.tr/tr/pub/muhendismakina/issue/48384/612874

[20]. Şık A., Ertürk İ. ve Önder M., AA2024 Alüminyum Alaşımının Sürtünme Karıştırma Kaynağında Farklı Parametrelerin Mekanik Özelliklere Etkisinin İncelenmesi, Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi Cilt 16, Sayı 2, 2010, Sayfa 139-147. https://dergipark.org.tr/en/pub/pajes/issue/20508/218316?publisher=pamukkale

[21]. Gündoğan K., Özsarı A.R.B.,; Basınçlı İnfiltrasyon Yöntemiyle Üretilen AA2024 ve AA6061 Matrisli, B4C ve SiC Takviyeli Kompozit Malzemelerin Mikroyapı, Mekanik ve Isıl İletkenlik Özelliklerine Basıncın Etkisi, UMAGD, (2019) 11(2), 657-669. https://doi.org/10.29137/umagd.540610

[22]. Pul M.,; Toz Metalurjisi Yöntemiyle Üretilen B4C+TiB2 Takviyeli Al 2024 Esaslı Kompozitlerde Takviye Miktarının Mekanik Özelliklere Etkisi, UMAGD, (2019) 11(1), 87-99. https://doi.org/10.29137/umagd.407488

[23]. Topcu İ., Dikici M., İpek C.; Seramik Takviyeli Alüminyum Esaslı Metal Matrik Kompozitlerin Aşınma Özelliklerinin İncelenmesi, Published in 6th International Symposium on Innovative Technologies in Engineering and Science 09-11 November 2018 (ISITES2018 Alanya – Antalya - Turkey). https://doi.org/10.33793/acperpro.01.01.91

[24]. Karakoç H., Toz metal Al7075/B4C/Si3N4 kompozit malzemelerin üretimi ve aşınma özelliklerinin incelenmesi, Politeknik Dergisi, 23(4): 1141-1151, (2020). https://doi.org/10.2339/politeknik.585813

[25]. Arık H.,; Investigation of Wear Properties of Al-SiC Composite Materials Produced by Powder Metallurgy Method, GU J Sci, Part C, 7(3): 741-754 (2019). https://doi.org/10.29109/gujsc.587637

[26]. Aksöz S., Bostan B.; AA2014/B4C MMK yapının döküm ve döküm sonrası sinterleme işlemleri ile üretiminin aşınma davranışlarına etkileri, BORON 3 (2), 132 - 137, 2018. https://doi.org/10.30728/boron.373140