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Microstructure, Physical and Mechanical Properties of Al/SiC and Al/B_4C Metal Matrix Composites Produced by Powder Metallurgy

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ABSTRACT: In this study, aluminum (Al) matrix composites reinforced with silicon carbide (SiC) and boron carbide (B_4C) in different weight ratios (8 wt.%, 16 wt.%, 24 wt.%) were produced by powder metallurgy method. After mixing, the resulting powder mixtures were compressed with a uniaxial hydraulic press. Compressed cylindrical block-shaped raw samples were subjected to sintering at different temperatures (540°C, 580°C, 620°C) and times (2 and 4 hours). After sintering samples, metallographic sample preparation processes were applied, the density and hardness measurements were made, then the microstructure examinations were performed by optical microscope, scanning electron microscope (SEM) and energy distribution spectrometer (EDX) and the results were evaluated. Thus, the effect of changing reinforcement rate, sintering temperature and sintering time on the microstructure and mechanical properties of the composites produced was determined and a comparison was made. As a result of the study, it was determined that the optimum values were obtained in samples sintered at 620°C for 4 hours. The highest hardness values obtained were determined as ~92 HV for 24wt.% SiC reinforced samples sintered at 620°C for 4 hours and, ~60 HV for 8wt.% B_4C reinforced samples sintered at 620°C for 4 hours. Thus, compared to ~54 HV value, which is the highest hardness value obtained in unreinforced Al samples sintered at 620°C for 4 hours, 70% higher hardness was obtained in SiC samples and 11% higher in B_4C samples. Although the B_4C hardness value is higher than SiC, it was interpreted that the difference in the matrix/reinforcement particle size ratio was effective in obtaining these hardness results.

Keywords: B4C, Metal matrix composites, Powder metallurgy, SiC.

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Toz Metalurjisi ile Üretilmiş Al/SiC ve Al/B_4C Metal Matrisli Kompozitlerin Mikroyapı, Fiziksel ve Mekanik Özellikleri

ÖZET: Bu çalışmada, farklı takviye oranlarında (%8, %16, %24) silisyum karbür (SiC) ve bor karbür (B_4C) ile takviyelendirilmiş alüminyum (Al) matrisli kompozitler toz metalurjisi yöntemi ile üretilmiştir. Tozlar karıştırıldıktan sonra, elde edilen toz karışımları tek eksenli bir hidrolik pres ile preslenmiştir. Silindirik blok şeklinde preslenen ham numuneler, farklı sıcaklıklarda (540°C, 580°C, 620°C) ve sürelerde (2 ve 4 saat) sinterleme işlemine tabi tutulmuştur. Sinterleme sonrası numunelere metalografik numune hazırlama işlemleri uygulanarak, yoğunluk ve sertlik ölçümleri yapılmış, ardından mikroyapı incelemeleri optik mikroskop, taramalı elektron mikroskobu (SEM) ve enerji dağılım spektrometresi (EDX) ile gerçekleştirilmiş ve sonuçlar değerlendirilmiştir. Böylece değişen takviye oranı, sinterleme sıcaklığı ve sinterleme süresinin üretilen kompozitlerin mikroyapı, fiziksel ve mekanik özelliklerine etkisi belirlenmiş ve karşılaştırma yapılmıştır.

Anahtar Kelimeler: B_4C, Metal matrisli kompozitler, Toz metalurjisi, SiC.

1. INTRODUCTION

Metal matrix composites, together with their superior properties such as high strength, low density, good wear and corrosion resistance, constitute a better alternative material group compared to traditional materials. Thus, it has widespread use in many fields, especially in the automotive, aerospace and defense industry (Venkatesh and Harish, 2015).

In metal matrix composite materials, metals such as aluminum (Al), magnesium (Mg), titanium (Ti), nickel (Ni), copper (Cu), zinc (Zn) and their alloys are generally used as matrix materials (Kalemtaş, 2014). Among these, aluminum and its alloys are the most preferred ones due to their lightness, good thermal and electrical conductivity, high corrosion resistance, easy availability and therefore economic (Baradeswaran and Elaya Perumal, 2013; Karakoç et al., 2019).

Aluminum and its alloys are reinforced with ceramic particles in order to improve their properties such as strength and wear resistance (Çolak and Turhan, 2016). In this study, particle reinforced metal matrix composites were investigated. Since, metal matrix composites with particulates as reinforcement are comparatively less expensive and have isotropic properties compared to fiber-reinforced metal matrix composites (Bhushan, 2021). The most preferred of these ceramic reinforcing materials are generally alumina (Al_2O_3), SiC and B_4C. However, B_4C has been less studied than other reinforcing materials due to its high cost (Gökmeşe et al., 2013).

Powder metallurgy method and liquid phase production methods such as various casting methods are generally used in the production of composites with particle reinforced aluminum metal matrix (Lindroos and Talvitie, 1995). When these two methods are compared, the powder metallurgy method stands out with some advantages. These are advantages such as the wetting problem frequently encountered in liquid phase production methods is much less in the powder metallurgy method and there is no reaction between the matrix-reinforcement due to the production being carried out at low temperatures. In addition to these, net shaped production possibilities with homogeneous distribution and good dimensional tolerances are among the advantages of this method. Powder metallurgy, as a near net shape technology, also provides significant advantages in minimizing material and energy waste for mass production of structural parts (Jeevan et al., 2012; Mohapatra et al., 2016; Hu et al., 2017; Basavarajappa and Parashivamurthy, 2017; Karakoç et al., 2019).

Zaki and Hussain examined the properties of Al/B_4C composites by producing them with powder metallurgy method at reinforcement ratios of 2-4-6%. According to their results, they found that there was an increase in the hardness values up to 4% B_4C reinforcement and a sudden decrease in the 6% B_4C reinforcement rate. From SEM studies, they determined that B_4C particles in the aluminum matrix have a homogeneous distribution (Zaki and Hussain, 2020). Surya and Prasanthi produced Al7075/SiC composites with varying reinforcement ratios (0, 5, 10, 15, 20, 25 and 30%) using powder metallurgy method and examined their microstructure and mechanical properties. From SEM studies, it was determined that SiC particles up to 15% SiC reinforcement ratio had a homogeneous distribution in the Al matrix and showed less porosity than higher reinforcement ratios than 15%. This showed that a homogeneous distribution can only be achieved up to a certain weight% of the reinforcement. Accordingly, it was determined that the optimum reinforcement ratio was 15% and that the microstructure and mechanical properties of composites were better than other samples at this ratio (Surya and Prasanthi, 2021). Dangarikar and Dhokey produced Al7075/B_4C composites by using powder metallurgy method with B_4C reinforcement varying from 2% to 20% in their studies and examined their wear and mechanical properties. It was determined that the density decreased and the hardness increased with increasing reinforcement ratio, and the lowest wear rate was obtained from 10% B_4C reinforced samples. It has been stated that in B_4C reinforced composites between 12-20%, the wear rate was higher due to reinforcement segregation and dislodgment (Dangarikar and Dhokey, 2020). Surya produced 0, 5, 10 and 15% SiC reinforced Al6061/SiC composites at varying sintering times (1, 2, and 3 hours) using powder metallurgy technique and examined their microstructure and mechanical properties. It has been determined that the sintering time is highly effective on the density of composites since diffusion is largely dependent on sintering temperature and time. When the SiC reinforcement, ratio was increased from 5% to 15%, the hardness value for composites sintered at 530°C for 3 hours increased from 73 HRB to 81 HRB. When the sintering time increased from 1 hour to 3 hours, the hardness value of the 15% SiC reinforced composite increased from 70 HRB to 81 HRB (Surya, 2021). Salman produced Al6061 matrix composites reinforced with SiC and B_4C in different ratios (3, 6, 9, and 12%) by powder metallurgy and examined their physical and mechanical properties. It has been determined that mechanical properties such as hardness and compressive strength of composites produced with increasing SiC and B_4C reinforcement ratios have improved. It has been determined that the hardness of SiC reinforced composites is higher than the B_4C reinforced ones. It has been suggested that this is due to the stronger bonding of SiC with the matrix compared to B_4C. It was stated that the optimum rate of reinforcement for SiC and B_4C was 9% (Salman, 2017). Celik and Kilickap produced B_4C and SiC reinforced composites in different weight ratios with powder metallurgy technique and examined their hardness and wear properties. It has been observed that the homogeneous distribution of reinforcement elements in the matrix affects the hardness value of the composite produced. It has been determined that the increasing rate of reinforcement increases the hardness. The highest hardness value was determined as 58.7 HV from 16% B_4C reinforced composite. In addition, it has been determined that the increase in the reinforcement ratio contributes to the increase in wear resistance (Celik and Kilickap, 2019). Kumdalı investigated the properties of B_4C reinforced composite materials with Al matrix produced by powder metallurgy. It was stated that the increasing size difference between the reinforcement and the matrix grain size resulted in the accumulation of reinforcement powders between the matrix grains and thereby causing agglomeration and thus negatively affecting the sintering and thus material properties. For the reinforcement ratio, it was determined that the hardness increased up to a certain rate, but decreased in 25% reinforced samples. In addition, it was stated that the samples reinforced at this rate (25%) had a highly porous structure, there were voids where B_4C grains should be in their structures and these samples were dispersed during the study (Kumdalı, 2008). Ay studied the wear behavior of composite materials produced by reinforcing different proportions of Ti and B_4C to Al7075 alloy by powder metallurgy method. It was determined that the hardness increased and the density decreased with increasing B_4C reinforcement ratio. It was determined that the highest hardness was obtained from the composite samples with reinforcement ratios of 6% Ti and 9% B_4C. As a result of the wear tests, it was stated that the weight loss, i.e. the wear, increased with the increasing sliding distance, and with SEM examinations, the parts that ruptured from the surface during the test were again welded to the surface and this situation increased with increasing reinforcement rates (Ay, 2014). Kalaycıoğlu investigated the effect of reinforcement ratio and reinforcement grain size on microstructure and mechanical properties of Al2017/SiC composite materials produced by powder metallurgy method. It was determined that hardness and porosity increased and density decreased with increasing reinforcement ratio (Kalaycıoğlu, 2010). Kevenlik investigated the effect of different reinforcement ratios and sintering temperatures on Al2014/SiC composite materials produced by powder metallurgy. It has been determined that the hardness, density, and porosity increased with the increasing reinforcement ratio. It was determined that hardness and density increased and porosity decreased with increasing sintering temperature (Kevenlik, 2013).

In this study, besides to a frequently preferred ceramic reinforcement material such as SiC, a relatively less studied B_4C was selected and comparison was made. In addition, different reinforcement rates, different sintering temperatures and times were selected for each reinforcement, and their effect on the microstructure and mechanical properties of the composite material produced was examined.

2. MATERIALS AND METHODS

The general properties of the materials (Al, SiC, B4C) that will form the metal matrix composite material composition to be examined in the study are given in Table 1 and the flow diagram of the experimental procedure applied is given in Figure 1. These materials were obtained from Ege Nanotek company, with Al powder average ~40 µm size and >98% purity, SiC powder average ~36 µm size and ~98% purity, B4C powder average ~6 µm size and >96% purity.

At the beginning of the experimental studies, the powder mixture weight calculations required for the production of the test samples in desired dimensions were made. These were calculated based on the density of the powder mixture and the volume of samples to be produced. The volume of samples to be produced was calculated using Equation 1. Based on this value, the sample weights to be produced were calculated by using Equation 2. The theoretical densities of the powder mixtures produced were calculated using Equation 3.

$$V = \pi r^2 h \quad (1)$$

$$W = \rho \, . V \quad (2)$$

$$\rho_{mix} = [(\%W)1 * \rho 1] + [(\%W)2 * \rho 2] + \cdots + [(\%W)n * \rho n] \quad (3)$$

Here V, W, ρ, ρmix, $(\%W)_n$ and ρ_n are volume(cm^3), weight(g), density(g/cm^3), the theoretical density of the powder mixture (g/cm^3), the weight percentage of n component in the mixture and the density of the n component (g/cm^3); respectively.

Powder mixtures were prepared by weighing on with Shimadzu precision scales. Mixing processes for the purpose of obtaining homogeneous dispersed powder mixtures were carried out in a V-shaped mixer at 20 rpm for 3 hours. As a result of the examinations made at the end of this period, it was decided that the given mixing time was sufficient to obtain a homogeneous powder mixture.

Before the pressing process, preparation works of the mold to be used in pressing the powder mixtures and thus in the production of raw samples were carried out. The produced mold and the used punch are given in Figure 2. The prepared powder mixtures were pressed with a uniaxial hydraulic press under a load of 450 MPa, and thus the production of raw samples was carried out. Literature studies and preliminary experiments were decisive in the selection of pressing pressure. Prior to pressing process, the inner surface of the mold and the surface of the punch were lubricated with zinc stearate in order to reduce friction and mold wear and to allow the samples to come out of the mold more easily after pressing. The produced samples are cylindrical samples with a diameter of 12 mm and a height of 22 mm. A total of 126 samples were produced, 3 pieces for each different parameter. One of the samples produced is given in Figure 3.

Raw density measurements of raw samples obtained after pressing were made before sintering and then samples were subjected to sintering. Sintering was carried out in three different sintering temperatures, 540°C, 580°C and 620°C, in Nabertherm heat treatment furnace under normal atmosphere. Samples were taken to the sintering temperature in 1 hour and kept at two different sintering times, 2 and 4 hours at this temperature, then left to cool in the furnace environment. In order to reveal the change in density values by sintering, density measurements were performed twice, one before and the other after sintering. These measurements were made according to the Archimedes principle with Shimadzu precision scales. In order to measure densities by Archimedes Principle, Shimadzu Density Measurement Set was also used. Then, the porosity rates and density percentages of the samples were calculated using the experimental densities measured after sintering and the calculated theoretical densities.

The density of unreinforced pure aluminum and produced composite samples were measured using the Archimedes principle described in ASTM B962-13 (Shaikh et al., 2019). For this, first the weights of the samples in air (W_a) and water (W_w) were measured, then density (ρ) was calculated according to Equation 4.

$$\rho = \left[\frac{W_a}{W_a - W_w}\right] * \rho_w \tag{4}$$

The theoretical density of the composite samples produced was calculated according to the mixing rule. The pores formed in the samples were calculated as the percentage of the difference between the theoretical and experimental density relative to the theoretical density as in Equation 5.

$$\%\,Porosity = \frac{\rho_{th} - \rho_{sin}}{\rho_{th}} * 100 \tag{5}$$

Here ρ_{th} and ρ_{sin} are theoretical and sintered (experimental) densities, respectively.

Metallographic sample preparation procedure was applied to the samples after density measurements. For this, the samples were first cut with the Metkon Micracut 201 precision cutter and brought to appropriate dimensions for the bakelite moulding process. The cut samples were then embedded in bakelite with Metkon Ecopress 100 mounting press. Then the samples were grinded with 600, 800, 1000, 1200 and 2000 grit abrasive papers in Metkon Forcimat grinding-polishing machine, respectively. Lastly, the samples were polished with 1-micron alumina suspension in Metkon Digiprep Accura grinding-polishing machine, and thus metallographic sample preparation processes were completed.

Microstructure images of the finished samples at magnification rates of x10, x20, x50 and x100 were obtained with Leica optical microscope. Microstructure images at x100, x250, x500 and x1000 magnification rates and energy-dispersive X-ray spectroscopy (EDX) analysis were obtained by Jeol JSM 5600 scanning electron microscope (SEM). Hardness tests were carried out with Metkon Duroline-M microhardness tester in the Vickers scale. In order to obtain optimum results, measurements were taken from three different points on the surface for each sample, and the arithmetic average of these values was determined as the hardness value.

Table 1. General properties of the materials used in the experiments

Material	Density *(g/cm^3)*	Melting Temperature *(°C)*	Hardness *(kg/mm^2)*
Al	2.7	660	16.7
SiC	3.21	2730	2600
B_4C	2.52	2350	3200

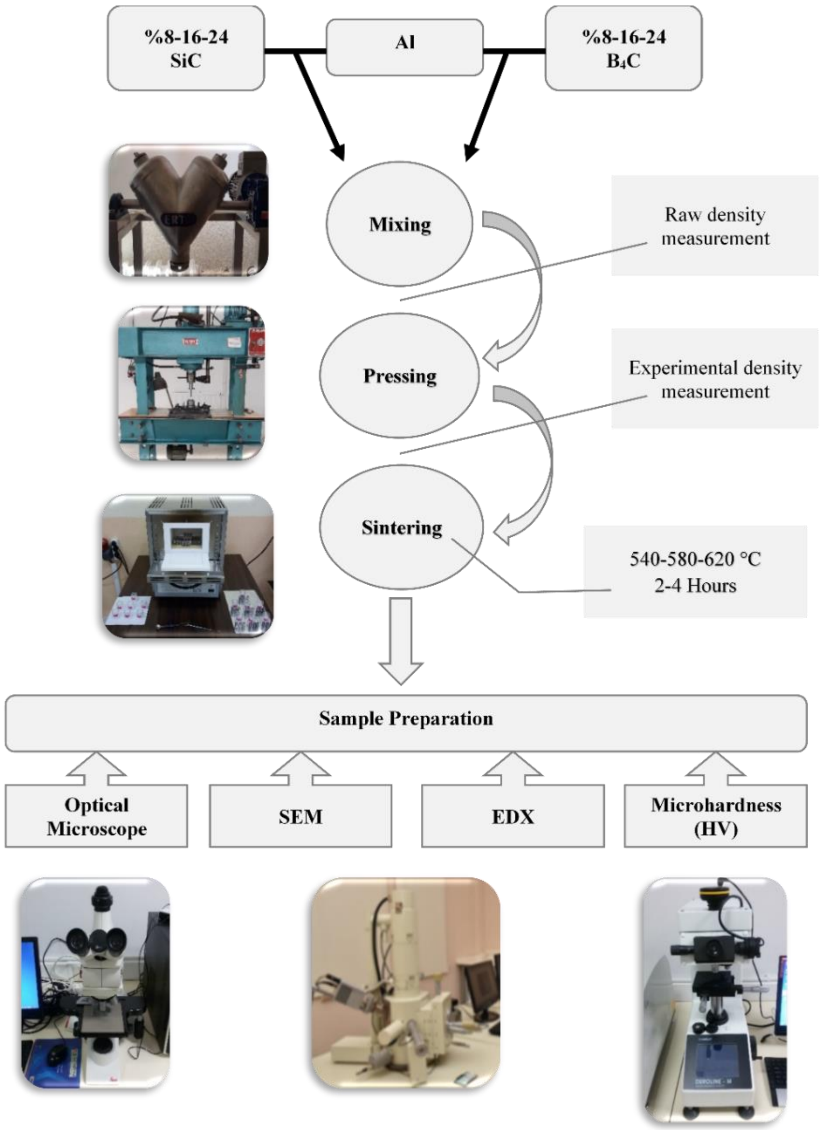

Figure 1. Flow chart showing the experimental procedure of this study

Figure 2. Mold and punch used in pressing

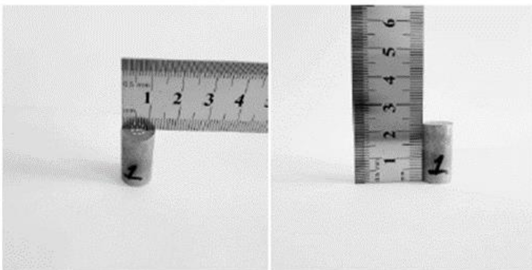

Figure 3. Produced sample

3. RESULTS AND DISCUSSION

As a result of the experimental studies, it was determined that there was an increase in the density values of the samples depending on the increasing sintering temperatures and times. This increase is thought to occur due to the shrinkage of the pores due to the increase in bond breakage of atoms at the temperatures close to the melting temperature and thus the increase of diffusion between Al grains. In Figures 4 and 5, density variations depending on sintering temperatures of pure Al samples and SiC and B_4C reinforced Al samples are given.

From the graphs showing the change in density depending on the sintering temperature, it can be seen that the 8wt.% SiC graph in Figure 4 and the 24wt.% B_4C graphs in Figure 5 are different from the others. Since a single sample to be produced for the parameters examined in the study may not always give the correct result and to evaluate the results based on the majority considering the tolerances in the samples and measurements; 3 samples were produced for each parameter and the graphs were obtained by taking the average values of these samples. As mentioned above, since the samples, which do not always give the desired and correct results, are also taken into account, they may cause a difference in the average values taken. This situation can be put forward as an explanation for the situation seen in the graphs mentioned above. Therefore, a similar situation is also reflected in the porosity graphs taken from the same samples.

It has been determined that there was a numerically increase in density values due to the increased reinforcement rates for SiC because the SiC density is higher than Al density. But in real, it was found that with increasing reinforcement rates, porosity increased and density values grow away from the theoretical density value. Similarly, it was determined that there was a numerical decrease in density values due to the B_4C density being less than Al density, and again with the increasing reinforcement rates, it was found that porosity increased and density values grow away from the theoretical density value.

When porosity values were analyzed, it was seen that porosity decreases with increasing sintering temperatures and times. In Figures 6 and 7, porosity variations depending on sintering temperatures of pure Al samples and SiC and B_4C reinforced Al samples are given. It was determined that the least porosity was observed in pure Al samples and the highest porosity was observed in 24 wt.% SiC and 24 wt.% B_4C reinforced Al samples. The reason for this is thought to be due to the increasing SiC and B_4C ratios, and the diffusion difficulty of Al around this increasing reinforcing grains in the structure and thus Al's having difficulty in binding these grains. In other words, it has been commented that porosity generally increases in increasing reinforcement rates and the reason for this situation is that pores generally occur around the reinforcement grains. In addition, due to the refractory properties and low thermal conductivity of the reinforcing materials, it is thought that the increased reinforcement rates in the structure reduce the diffusion by preventing the heat conduction and thus the sintering mechanism during sintering, thereby preventing the shrinkage and reduction of the pores. It is thought that another reason for the increase of porosity with increasing reinforcement rates may be the reduction of the compressibility of the composite by increasing the amount of reinforcement grains, which has high hardness and low compressibility, in the structure. As a result, it was determined that porosity decreases with increasing sintering temperature and time, and increases with increasing reinforcement rates. It has been determined during literature studies that similar results have arisen in studies conducted by Kumdalı, Kalaycıoğlu and Kevenlik (Kumdalı, 2008; Kalaycıoğlu, 2010; Kevenlik, 2013).

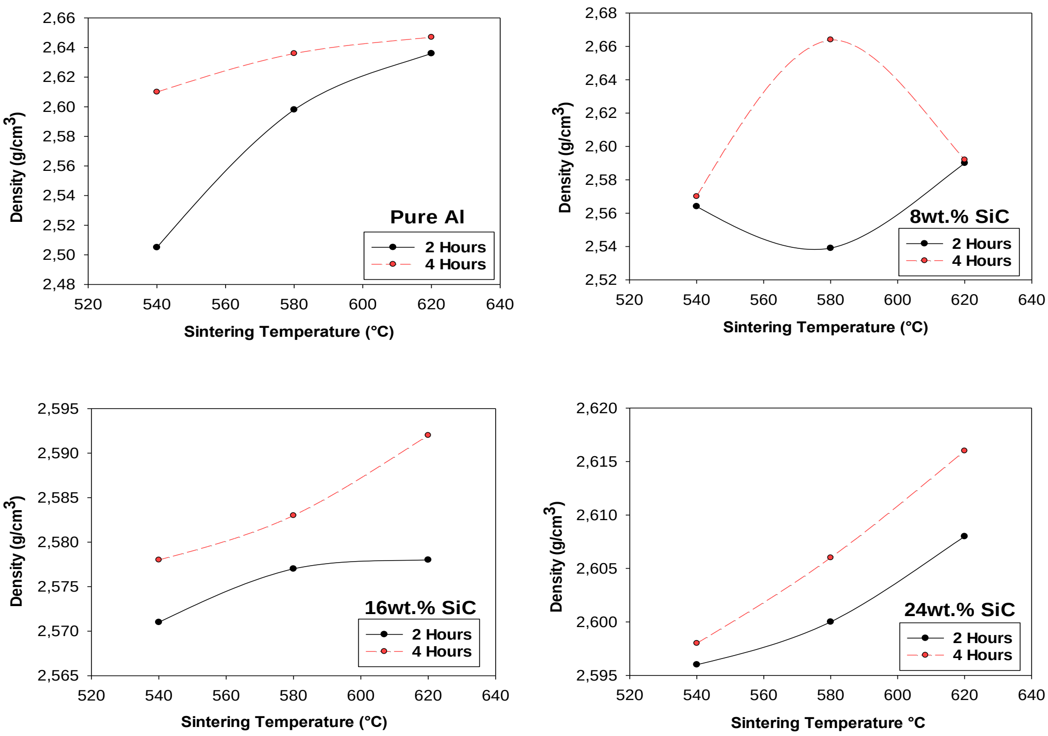

Figure 4. Variation of density depending on sintering temperature in SiC reinforced samples

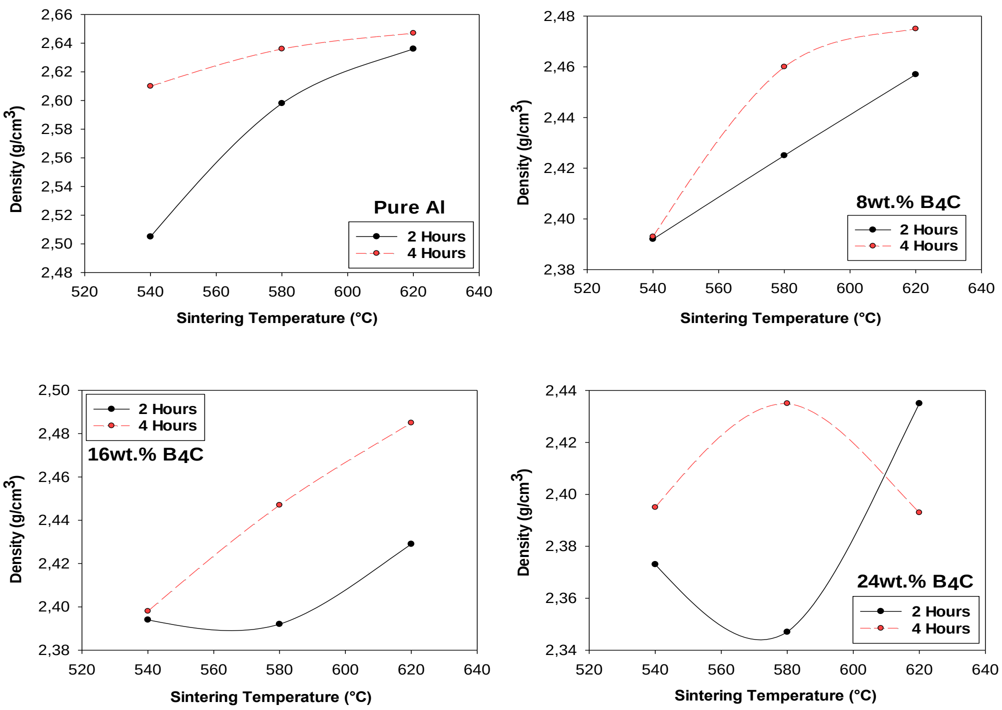

Figure 5. Variation of density depending on sintering temperature in B_4C reinforced samples

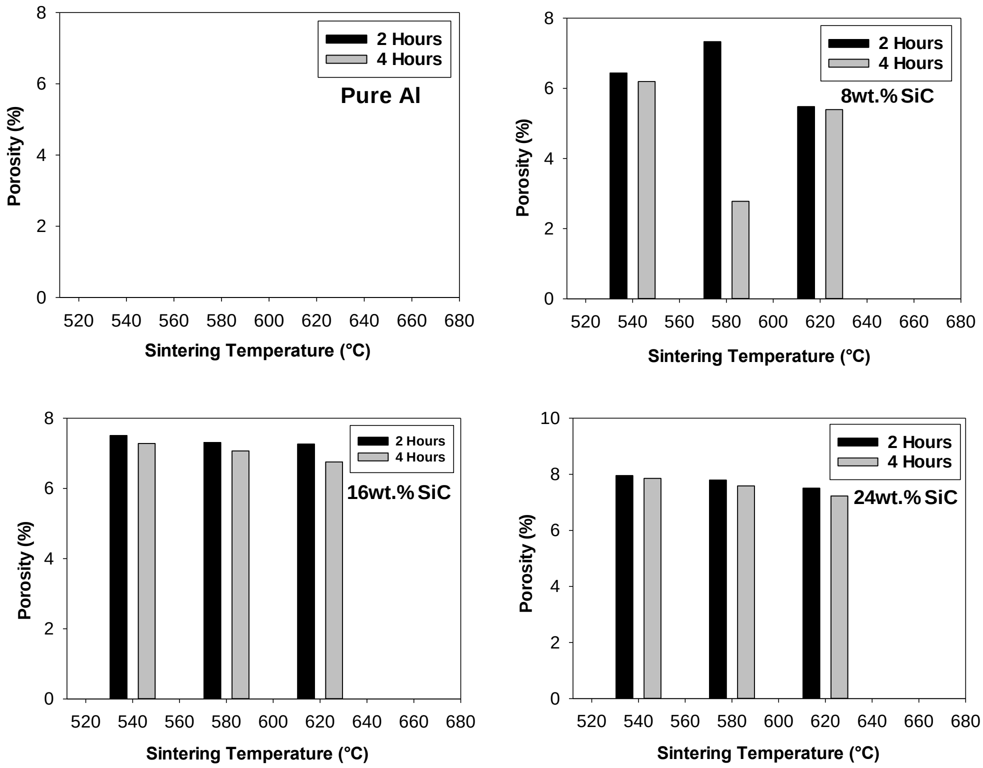

Figure 6. Variation of porosity depending on sintering temperature in SiC reinforced samples

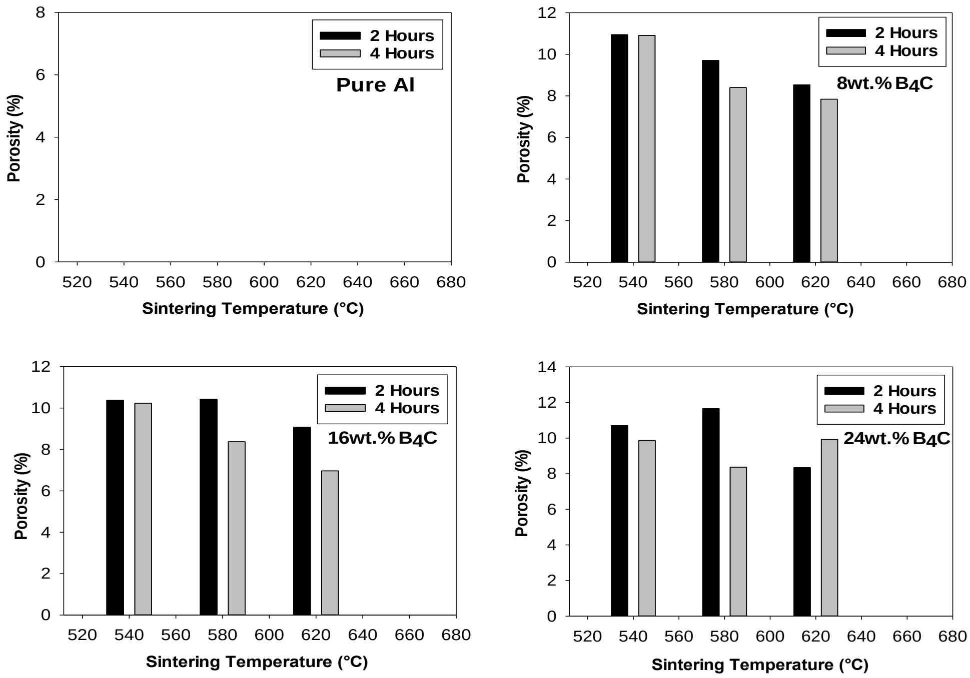

Figure 7. Variation of porosity depending on sintering temperature in B_4C reinforced samples

When the hardness results were evaluated for SiC reinforced samples, it was determined that there was an increase in the hardness of the samples with increasing SiC reinforcement rate, sintering temperature and sintering time (Figures 8 and 9). It can be said that this situation is due to the increase in the amount of SiC, which has a much higher hardness than the matrix material. Increasing hardness with increasing sintering temperature and time is thought to be due to the increase in diffusion and bonding between the grains thereby shrinking the pores and thus obtaining a structure closer to the theoretical density. In Figure 8, the variation of hardness depending on sintering temperature in SiC reinforced samples is given. It has been determined during literature studies that similar results have arisen in studies conducted by Kalaycıoğlu and Kevenlik (Kalaycıoğlu, 2010; Kevenlik, 2013).

When the hardness results of B_4C reinforced samples were evaluated, it was seen that the hardness increased with sintering temperature and time, similar to SiC reinforced samples. However, it was determined that there was a decrease in the hardness of the samples at increasing B_4C ratios, above 8 wt.% reinforcement rate (Figures 9 and 10). So much so that during sample preparation for microstructure studies, 24 wt.% B_4C reinforced samples had ruptures from the surface during grinding. One of these samples is given in Figure 11. Even when these samples were compared with pure Al samples, there was no significant increase in their hardness, only 8 wt.% B_4C reinforced samples sintered at 620°C for 2 and 4 hours had higher hardness values It has been determined during literature studies that similar results have arisen in studies conducted by Kumdalı, Ay, Salman, and Zaki and Hussain (Kumdalı, 2008; Ay, 2014; Salman, 2017; Zaki and Hussain, 2020). This situation is thought to occur due to the decrease in compressibility of the powders as a result of the increase in the amount of B_4C, whose hardness in the structure is higher than the matrix. It is thought that pressing does not take place effectively in these samples since the pressing pressure is insufficient for these samples, and this situation can be eliminated by increasing the pressure. In addition, B_4C with refractory properties and low thermal conductivity is thought to make sintering difficult by reducing Al diffusion with its increase in structure, thereby reducing hardness by poor binding due to reduced wetting of B_4C grains. It is also thought that the average size of the B_4C grains being much smaller than the average size of the SiC grains and the divergence from the average size of the Al matrix is also effective in this situation. Because, it is thought that the divergence of the matrix and reinforcement grain sizes prevents a good mixture, in such cases, B_4C grains aggregate at the Al grain boundaries, thereby preventing binding and causing a weak structure. Hence, it is concluded that matrix and reinforcement grain sizes should be chosen close to each other.

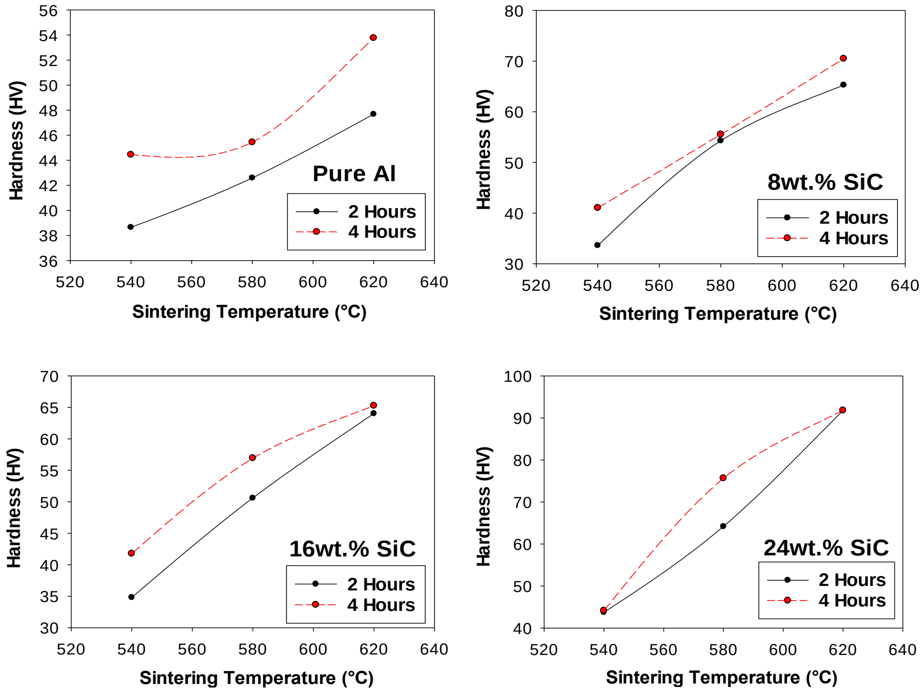

Figure 8. Variation of hardness depending on sintering temperature in SiC reinforced samples

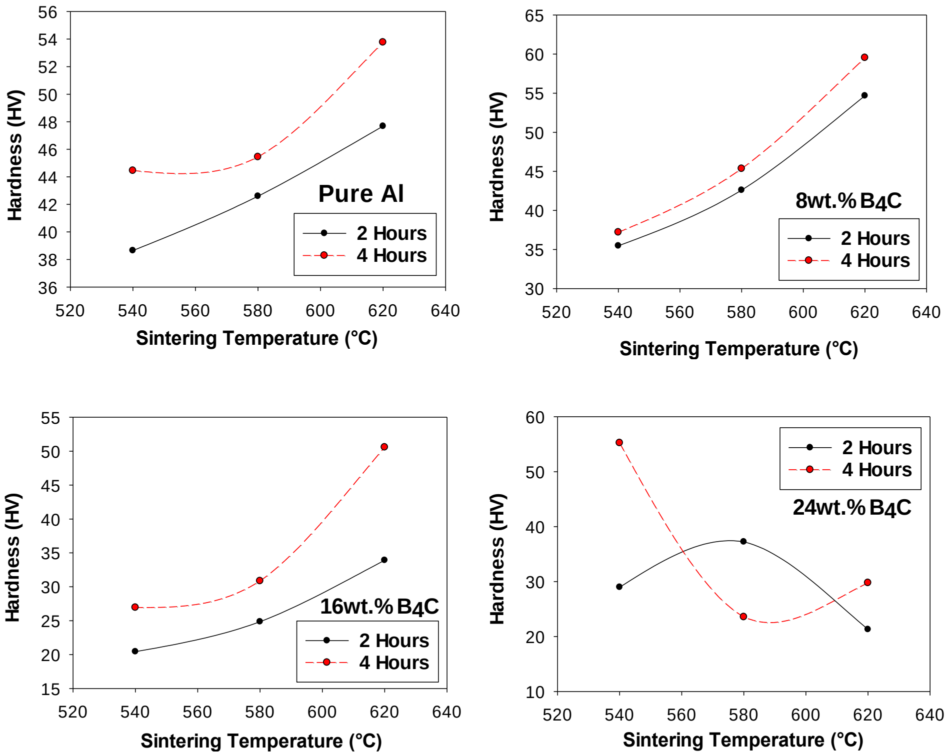

Figure 9. Variation of hardness depending on sintering temperature in B_4C reinforced samples

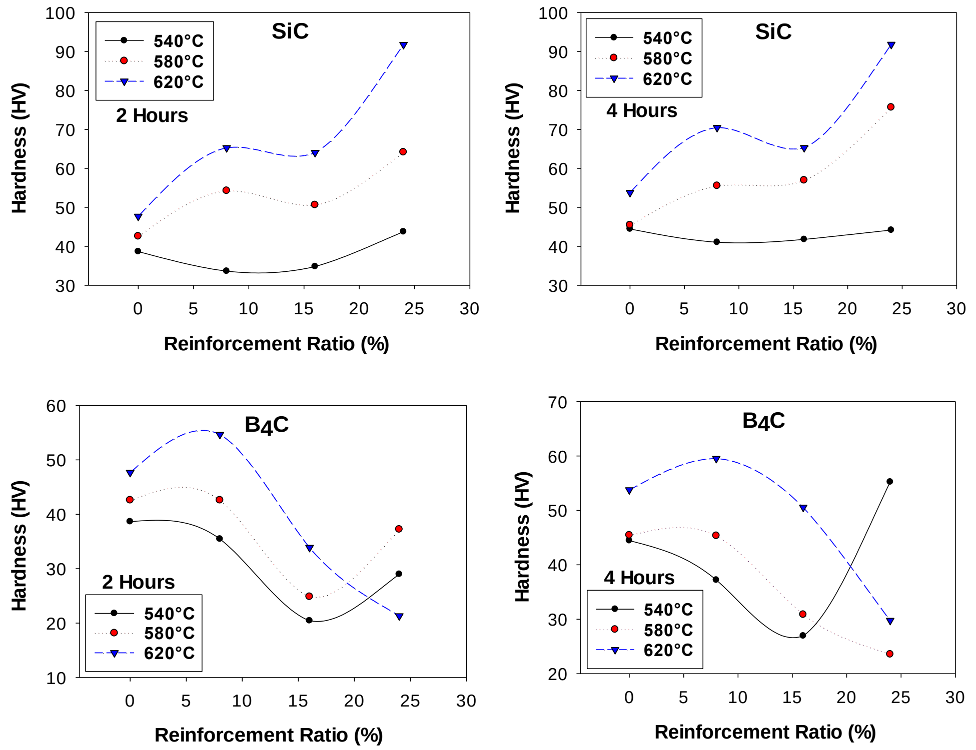

Figure 10. Variation of hardness depending on the reinforcement ratio of SiC and B_4C reinforced samples sintered for 2 and 4 hours

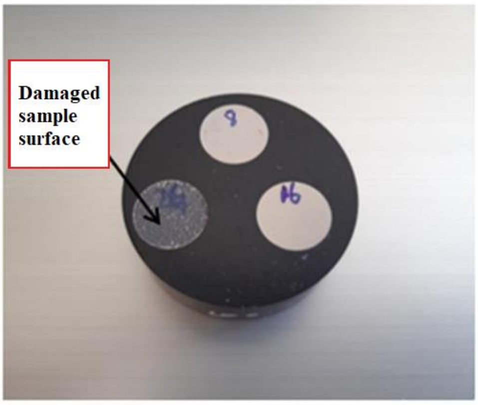

Figure 11. One of the 24 wt.% B_4C reinforced samples where surface damages occur

As the optimum experimental parameters, 620°C and 4 hours were determined. The highest hardness and experimental density values and the lowest porosity were obtained at these parameters. The highest hardness value was determined as ~92 HV from the samples with 24wt.% SiC reinforcement produced with these parameters, and thus, a 70% increase was obtained compared to the ~54 HV, which is the highest value obtained from the unreinforced Al samples.

In order to carry out microstructure studies, microstructure images were taken with optical microscope and SEM from samples and EDX analyzes were carried out to verify their elementary composition (Figure 12-16). For comparison, only SEM images of those with the highest and lowest parameter values from samples produced in different parameters were given.

When the microstructure images were examined, it was seen that the mixing time was sufficient to obtain a homogeneous distribution in the structure. In other words, it has been seen that SiC and B_4C reinforcing materials were homogeneously distributed in the structure. However, in samples reinforced with 24 wt.% B_4C, surface ruptures were detected during the sample preparation stage, as mentioned before in the hardness measurements. In the microstructure studies of these samples, this situation can be clearly seen due to the differences with the images of other samples. In addition, the increase of reinforcement particles and porosity in the structure with increasing reinforcement rates, can be noticed. Because, the pore formation in the structure generally occurred at the matrix grain boundaries and matrix-reinforce interfaces.

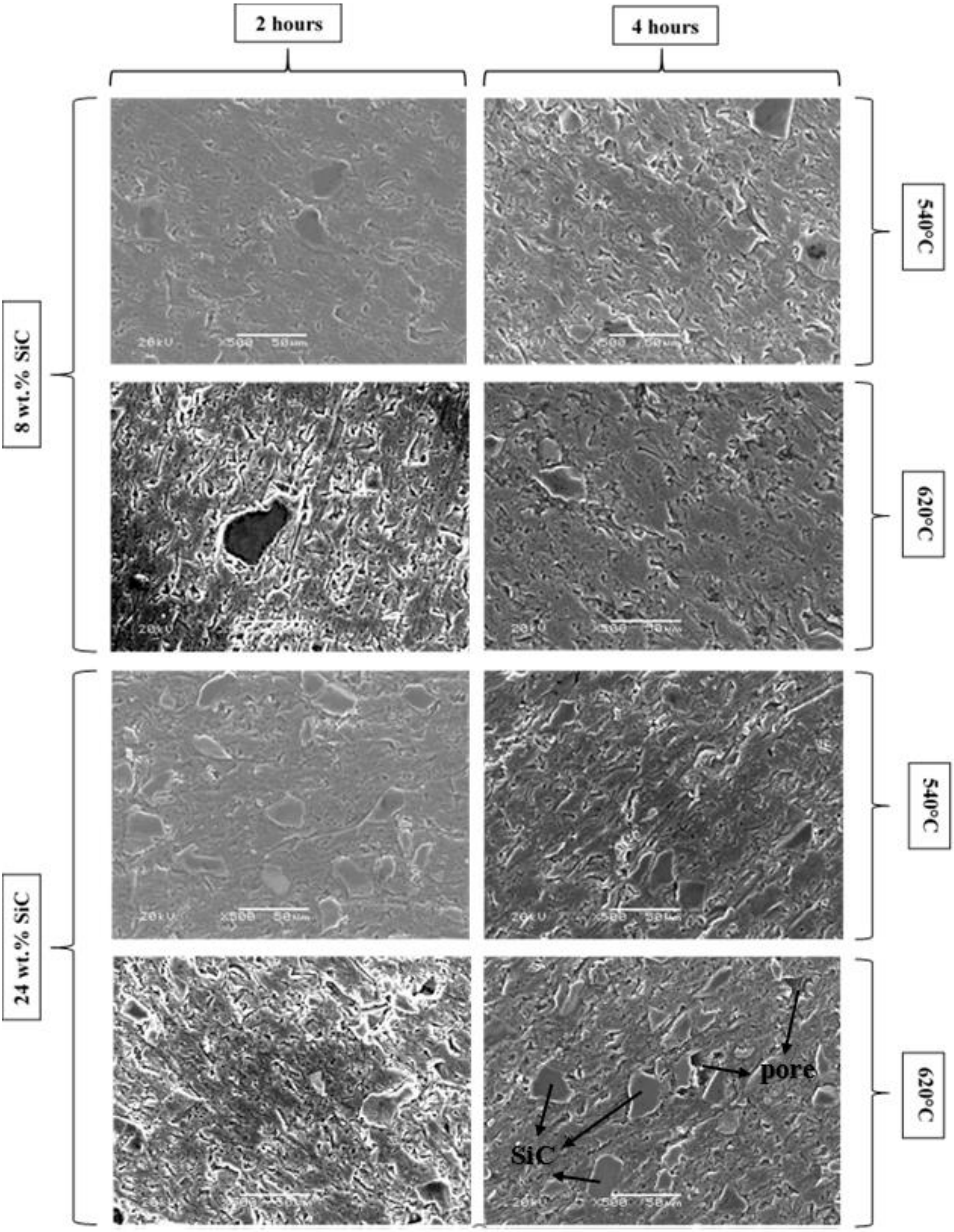

Figure 12. SEM photos of SiC reinforced samples produced with different production parameters at a magnification of x500

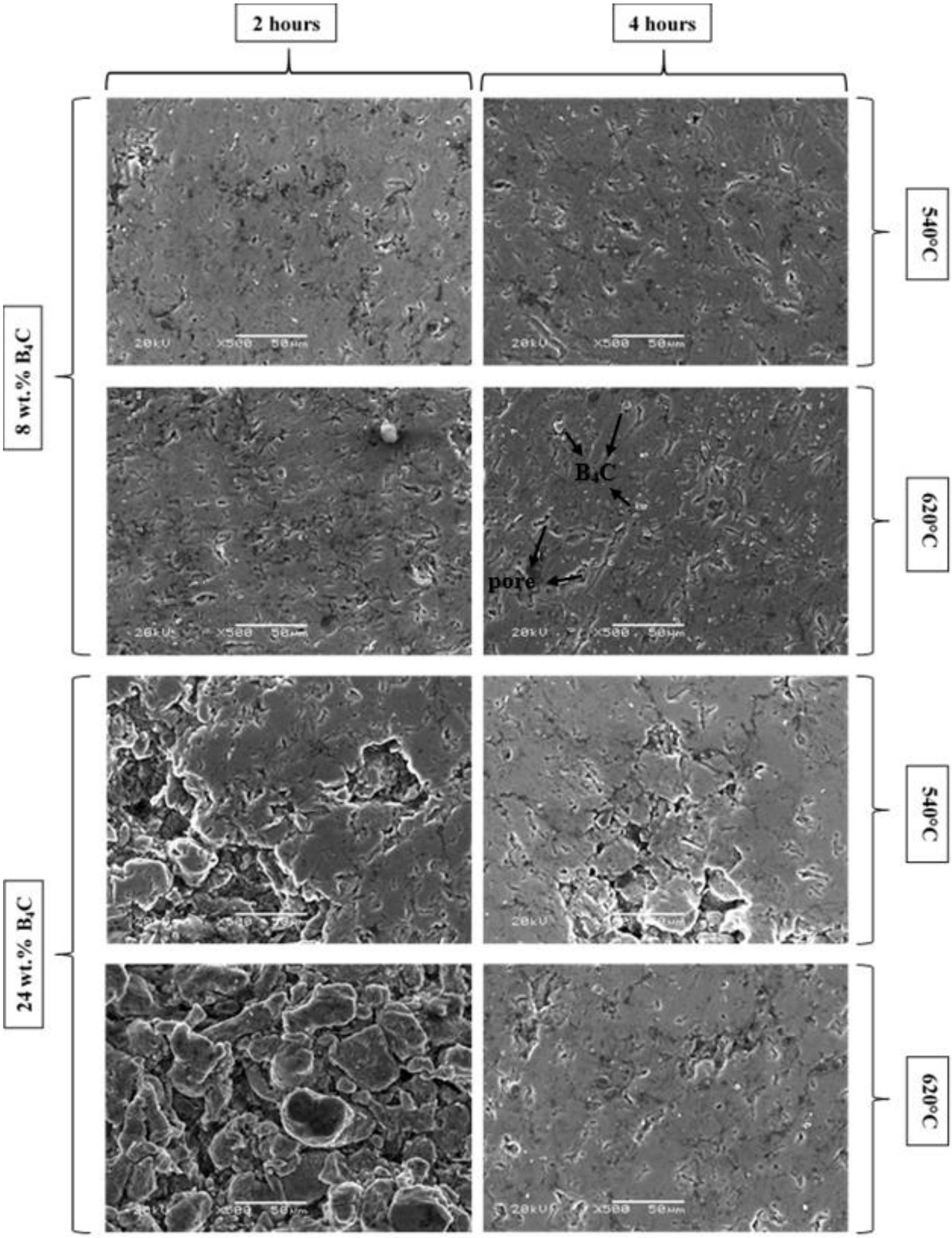

Figure 13. SEM photos of B_4C reinforced samples produced with different production parameters at a magnification of x500

When the EDX analysis was examined, it was seen from the analysis results of the pure Al sample given in Figure 14 that the structure consists of 100% Al and contains no impurity. Figure 15 shows the numbered regions where measurements were taken from a 24 wt.% SiC reinforced sample for EDX analysis. When the EDX analysis obtained from these regions is examined, it can be seen that the results are as expected. In EDX analysis for B_4C, healthy analyses could not be obtained due to both device inability and the problem on the surfaces. Although boron was selected as an element, it could not be seen by the device, because it was inadequate in determining sub-carbon elements. Still, the result of the analysis is presented in Figure 16, and as seen, the net results could not be obtained. So much so that the percentage of Al was read as 0.357%, although the screening was a general scan. Therefore, these results were not taken into account in terms of evaluation.

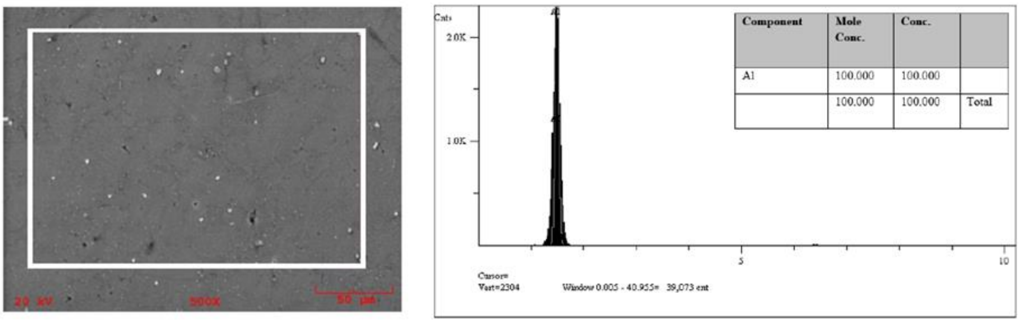

Figure 14. EDX analysis of pure Al sample sintered at 540°C for 2 hours

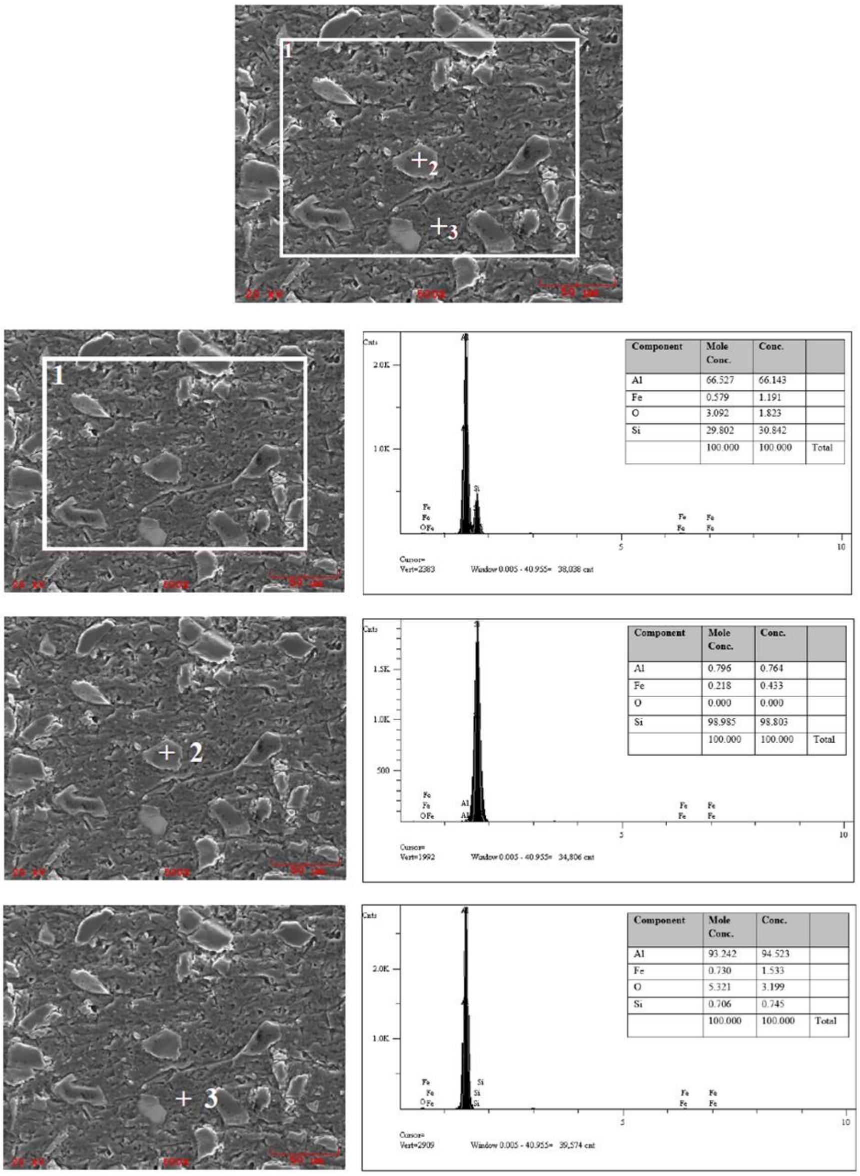

Figure 15. EDX analysis of 24 wt.% SiC reinforced samples sintered at 540°C for 2 hours

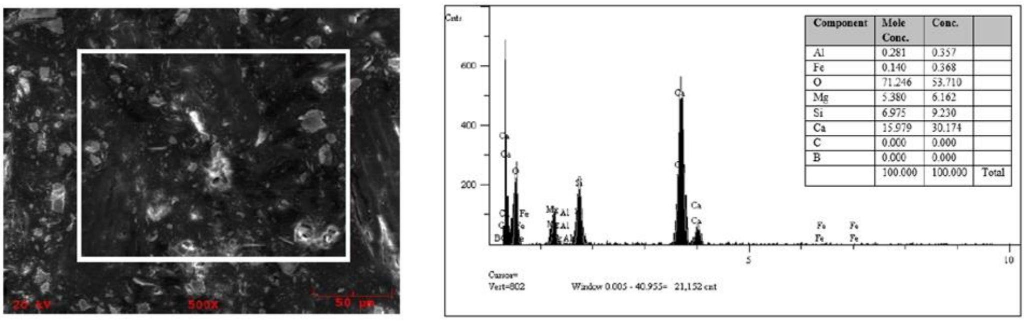

Figure 16. EDX analysis of 24 wt.% B_4C reinforced samples sintered at 540°C for 2 hours

4. CONCLUSION

In this study, microstructure and mechanical properties of composite samples produced in 3 different reinforcement ratios, 3 different sintering temperatures and 2 different sintering times were investigated. The results obtained by evaluating the effects of these different production parameters on these properties were interpreted as follows:

- With increasing sintering temperature and time, hardness and density increased and porosity decreased.
- Porosity in samples increased with increasing reinforcement rates.
- While the hardness values increased with increasing reinforcement rates for SiC reinforced samples, there was no effective hardness increase for the B_4C reinforced samples with more than 8 wt.% reinforcement ratios. In fact, high reinforcement rates in these samples caused ruptures.
- It has been found that the difference between the matrix and reinforcement grain sizes causes the B_4C grains, which are smaller than Al, to aggregate at the Al grain boundaries, thereby preventing wetting and thus resulting in a weak structure.
- It is concluded that a homogeneous distribution is obtained from microstructure examinations, the porosity increases with increasing reinforcement rates, and these pores mostly occur in matrix grain boundaries and matrix-reinforcement interfaces.
- As the optimum experimental parameters, 620°C and 4 hours were determined. The highest hardness values were obtained at these values, and it was detected as ~92 HV for 24wt.% SiC reinforced samples and ~60 HV for 8wt.% B_4C reinforced samples. In other words, 70% higher hardness value was obtained in SiC samples and 11% higher in B_4C samples compared to ~54 HV, which is the highest hardness value obtained in unreinforced Al samples.

To summarize, it was found that the perception that there will be an improvement in the mechanical properties of the materials produced with the increasing B_4C ratio in the structure, which is frequently seen in the literature reviews, was not confirmed by our study. On the contrary, it was found that a negative effect occurred on the mechanical properties after a certain B_4C ratio in the produced part. As a result, it has been observed that increasing reinforcement rates do not always lead to an improvement in the structure.

In light of the findings of the study and literature reviews, it has been interpreted that this situation is highly dependent on particle size, particle morphology, and reinforcement ratio. Accordingly, it has been interpreted that when optimization of properties such as particle size, particle morphology, and reinforcement ratio is achieved, the properties that could be obtained with the addition of high rates of SiC might be obtained with the addition of B_4C at lower rates. Thus, a new discussion has also been opened for further studies.

5. CONFLICT OF INTEREST

Authors approve that to the best of their knowledge, there is not any conflict of interest or common interest with an institution/organization or a person that may affect the review process of the paper.

6. AUTHOR CONTRIBUTION

Polen ŞANLI and Muammer GAVAS have the full responsibility of the paper about determining the concept of the research, data collection, data analysis and interpretation of the results, preparation of the manuscript and critical analysis of the intellectual content with the final approval.

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