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Research Article

INVESTIGATION OF WEAR BEHAVIOR OF Ti6Al4V / B_4C COMPOSITES PRODUCED BY POWDER METALLURGY

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In this study, Ti6Al4V / B_4C Metal Matrix Composite (MMC) was produced using powder metallurgy (PM) method. Ball-milled powders, containing 0, 5, 10, and 15 wt% B_4C were hot compacted at 950 °C for 20 minute under 450 MPa pressure in ambient air. The wear tests performed at 300 rpm sliding speed, 300 m sliding distance and three different loads of 5N, 10N, 15N, the effects of Ti6Al4V compound on B_4C reinforced wear properties at different rates were investigated. It was determined that composite materials reinforced with B_4C powder give better results than unreinforced Ti6Al4V and generally, as the amount of B_4C powder increases, the friction coefficient values decrease and the wear resistance increases. In the wear test, it was observed that the friction coefficient of all materials decreased as the load increased. As a result of the changes in B_4C reinforcement ratios, differences were observed in wear types and wear track depth. The results of the study showed that the wear resistance increased in parallel with the B_4C addition and the best wear resistance was obtained with the wt. 15% B_4C added sample.

Key words*: metal matrix composite, Ti6Al4V, B_4C, wear*

1. Introduction

In today's world, where science and technology are advancing rapidly, the need for new materials increases day by day. Especially composite materials, which provide the properties of materials with several different properties in a single material, have provided great advantages in this field [1]. Among composite materials, MMK (Metal Matrix Composites) have scientific, technological and commercial importance. Particle reinforcement, which is one of the methods used to improve the mechanical properties of composites in the production of metal matrix composites, can increase the properties of the formed composite up to several times the matrix. Generally, in the production of particle reinforced MMC materials, although there are liquid state methods such as casting, a solid state method such as powder metallurgy may be preferred [2,3]. The use of powder metallurgy manufacturing technique is increasing day by day in the production of engineering materials. Advances in powder technology allow the production of complex shaped machine parts with high production speed, high quality, low dimensional tolerance and economically with different pressing techniques [4]. New materials with different structures and desired properties can be obtained by adding alloying elements or various

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particles into the metal matrix in order to contribute to the performance of parts produced by powder metallurgy method. Thus, it is possible to obtain new products that appeal to different application areas [5].

Titanium alloys have a wide variety of applications in the aerospace, automotive and biomedical industries. Ti-6Al-4V alloy containing 6% Aluminum and 4% Vanadium by weight has been used in aircraft, turbines and surgical implants due to its heat treatment capability, sufficient mechanical strength, good wear resistance and biocompatibility [6, 7]. Titanium alloys are widely used in many industrial areas as they have excellent mechanical properties, higher specific strength than stainless steel and better wear resistance than stainless steel [8]. Due to the compatibility of titanium alloy with matrices, titanium carbide (TiC) and carbide-forming reinforcements should be used [9].

B_4C is the third hardest (in 9.5+ Mohs scale) material known after diamond and cubic boron nitride. It has a covalent bonded ceramic structure with different advantages for applications requiring neutron absorption, creep resistance and impact resistance. It is also the lightest of ceramics. On that account, it can be used to improve the mechanical properties of the composite without increasing the total weight [10]. There are many studies in the literature regarding the production of B_4C reinforced MMC in Al matrix. However, there are not many B_4C particle reinforced studies with Ti-6Al-4V matrix. Boron carbide has a low pore content as an advanced ceramic. The most important reason for using it as reinforcement in B_4C composites is to benefit from its high hardness and wear properties[11].

In this study, it was aimed to produce 5% B_4C, 10% B_4C, 15% B_4C, reinforced composites in Ti6Al4V matrix and analyze their properties. The wear behaviors of the newly produced B_4C reinforced composites, together with the friction coefficients and corroding surface morphology, were examined with the an optical microscope.

2. Material and Method

2.1. Production of Composite Materials

In this study, Ti-6Al-4V powders produced by atomizing method with a nominal size of 45-180 μm were used as the main matrix. Particle reinforcement element B_4C was used as reinforcement material and in average size 4-6 μm. Both powders were obtained from Nurol company. In terms of producing powder metal test specimens in pressing studies, the percentage by weight and sample codes of the prepared matrix and reinforcement particles are given in Table 1. A total of 12 materials were produced, 4 of each of the composite materials.

Percentage weight calculations were used for the production of composite materials. For this reason, powder mixtures were produced by adding different proportions of B_4C reinforcement (5-15%) to Ti6Al4V powder metal. The mixed powder was mixed at 60 rpm for 30 minutes. Composite samples were produced by pressing the mixed matrix and reinforcing powders under 450 MPa pressure at 950 ^{0}C for 20 minutes. Ti6Al4V / B_4C weight percentages and material codes are given in Table 1 for the production of composite materials.

2.2. Metallographic Examination

Metallographic and corroded surface examinations of the produced composites were carried out in Leica brand optical metal microscope. After the polishing process, which is one of the metallographic processes of all materials, microstructure images were taken at 50 times of magnification.

Table 1. Mixing ratios of powders used in composite materials

Sample code	Ti6Al4V (%)	B_4C (%)	Sintering temperature (^{0}C)
A1	100	-	950
A2	95	5	950
A3	90	10	950
A4	85	15	950

2.3. Wear Test

All samples produced were subjected to a pin on disc wear test under 300 rpm sliding speed, 300 m sliding distance and three different loads of 5N, 10N, 15N. Four different samples produced with different additive rates for each load used in the wear test were used. Thus, as a result of subjecting each material to wear tests at 3 different loads, a total of 12 pin on disc wear tests were performed. A ball (WC) with a diameter of 6 mm was used during wear and Fig. 1. shows the picture of the device used for the wear test performed at different loads. Tribometer T10 / 20 device is used as an wear device.

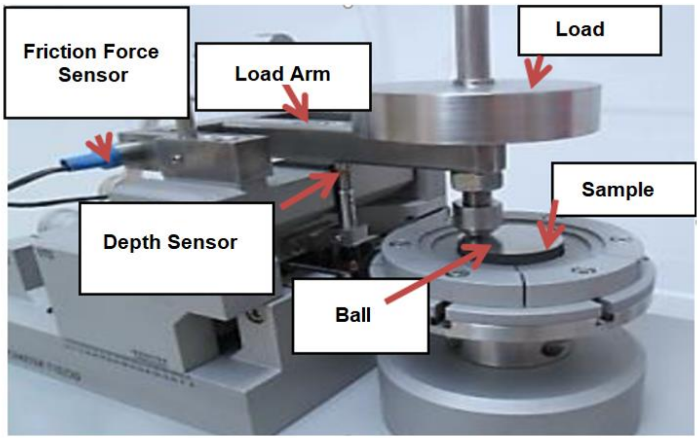

Figure 1. Wear test device used in experiments [1].

Fig. 2. shows a schematic view showing which letter refers to what in the formula used to calculate the track depth after the wear test applied to Ti6Al4V and B_4C reinforced composite materials at different loads. Regarding this matter, after the friction trace widths were determined under the optical microscope, the trace depths were calculated with the equation stated here in below:

$$h = \frac{(D - \sqrt{D^2 - d^2}\,)}{2}$$

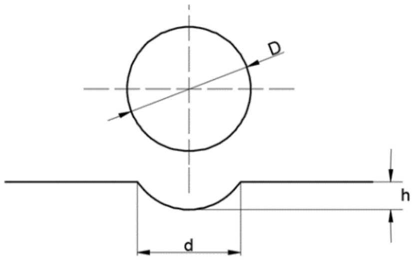

Figure 2. Wear depth calculation method used in wear tests.

3. Result and Discussion

Although titanium (Ti) has about 56% lower density than steel, it is a material with high specific strength (tensile strength / density). Titanium is defined as a non-magnetic material with high wear resistance and biocompatibility [12]. Due to these properties, it is an advanced engineering material preferred in chemistry, space, biomaterials and cutting tool surface coating technologies . The properties of Ti alloys are characterized by the transformation of the phases. In industrial applications, Ti alloys are preferred in regard to the transformations of the phases, and phases close to α/β and are often recommended in biomaterial manufacturing (12, 13). Ti-6Al-4V and Ti-5Al-2.5Fe alloys are α/β alloys and are often seen in the literature as the preferred material for aircraft landing gear, gas turbine wheels and hip implant manufacturing (13). However, with the use of machining processes after the production of these alloys by casting method, the production of parts causes high costs with machining difficulties and material consumption (14-16). For this reason, manufacturing parts from these expensive alloys has made it necessary to use parts production techniques close to the final shape.

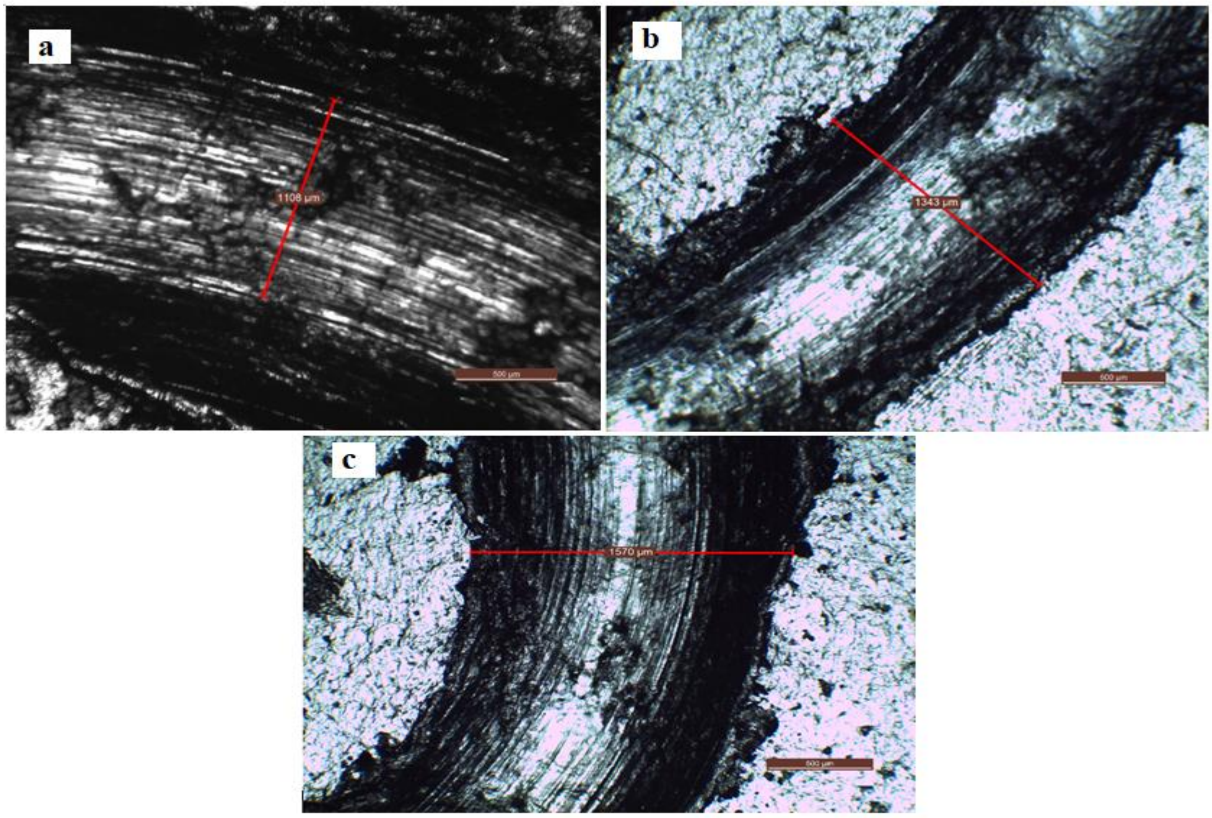

Figure 3. Microstructure images of sample A1 at different loads (a. 5N, b. 10N and c. 15N).

For this reason, in the study, by using powder metallurgy technique, different proportions of B_4C reinforcement (5-15%) were added to Ti6Al4V powder metal and wear test was performed at different loads to see the wear effect of B_4C on the matrix material. After the wear test, the friction coefficient values and wear tracks of the samples were measured and the reaction of the materials against wear was tried to be determined.

Fig. 3a-c After the wear test of the sample numbered A1 under 5N-15N loads, the wear track images taken under the optical microscope were observed. Wear tracks on the surface were measured after the wear test of the sample numbered A1. Trace widths measured for 5N, 10N and 15N loads were measured as 1108 µm, 1343 µm and 1570 µm, respectively. From the track width and the images taken, it was observed that the track width increases as the load increases.

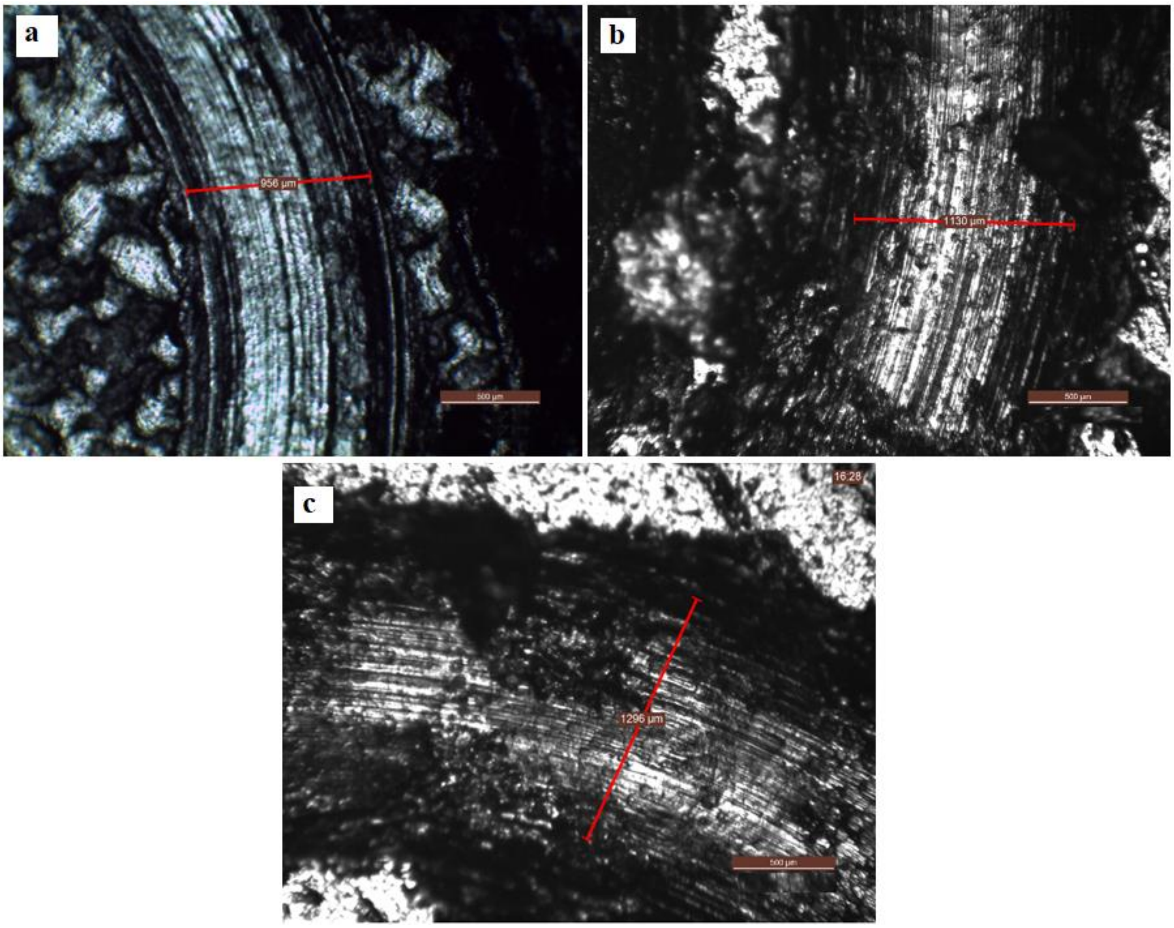

Figure 4. Microstructure images of sample A2 at different loads (a. 5N, b. 10N and c. 15N).

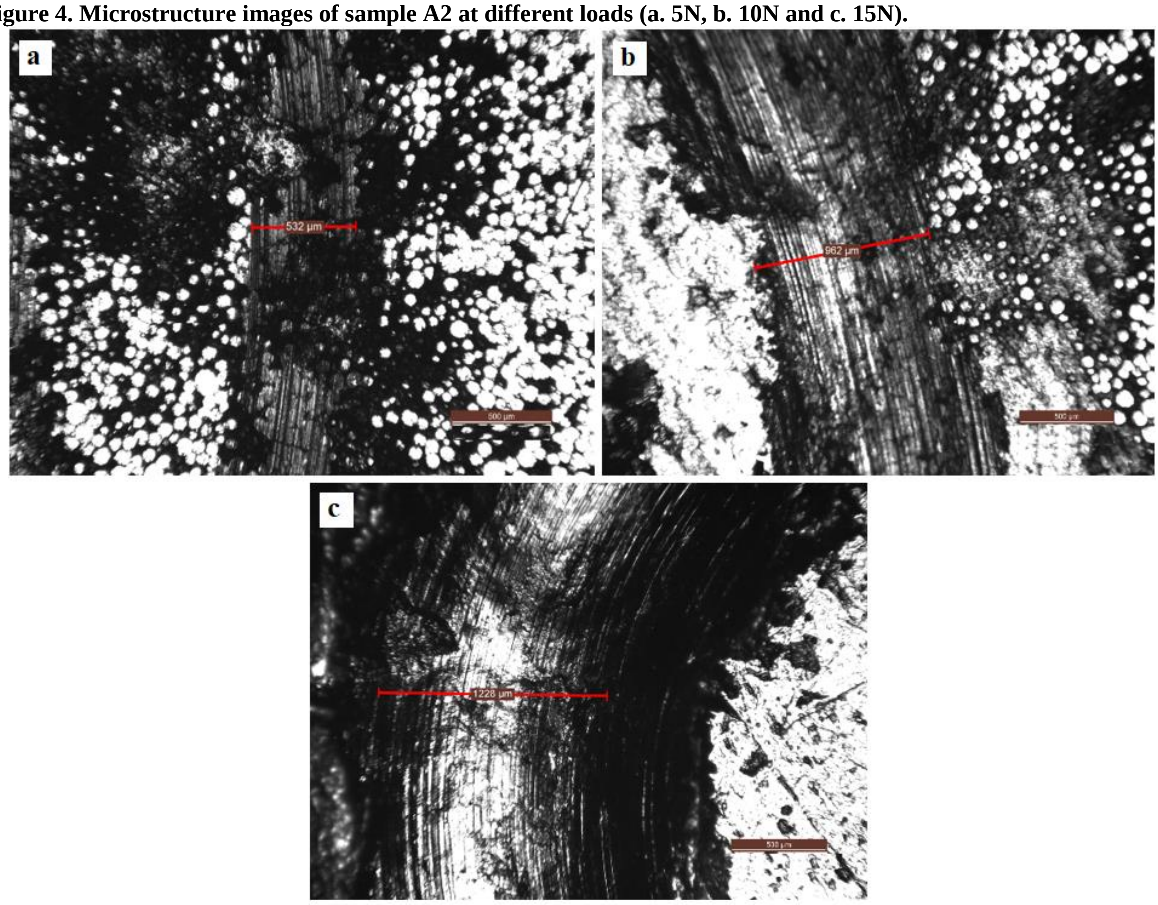

Figure 5. Microstructure images of sample A3 at different loads (a. 5N, b. 10N and c. 15N).

Optical microscope images of the sample A2, reinforced with 5% B_4C of Ti6Al4V matrix, after the wear test are shown in Fig. 4. It was observed that the wear track widths are narrower compared to the non-reinforced composite sample numbered A1. This situation is due to the presence of 5% B_4C reinforcement in the composite. After the wear test of sample A2, the wear track width measurements on the surface were measured as 956 μm, 1130 μm and 1296 μm for 5N, 10N and 15N loads, respectively. In the wear test, an increase in track width was observed due to increased load. In Fig. 4c, in the wear test performed at a load of 15 N, it was observed that the wear tracks are less obvious than the other loads.

Fig. 5 a-c presents optical microscope images after wear test of composite material with 90% Ti6Al4V and 10% B_4C content by weight. In the composite sample numbered A3, it was observed that as the wear load increases, the width of the track increases, while the track lines are less explicit and thin. After wear, wear track widths for 5N, 10N and 15N loads from the sample surface were measured as 532 μm, 962 μm and 1228 μm, respectively.

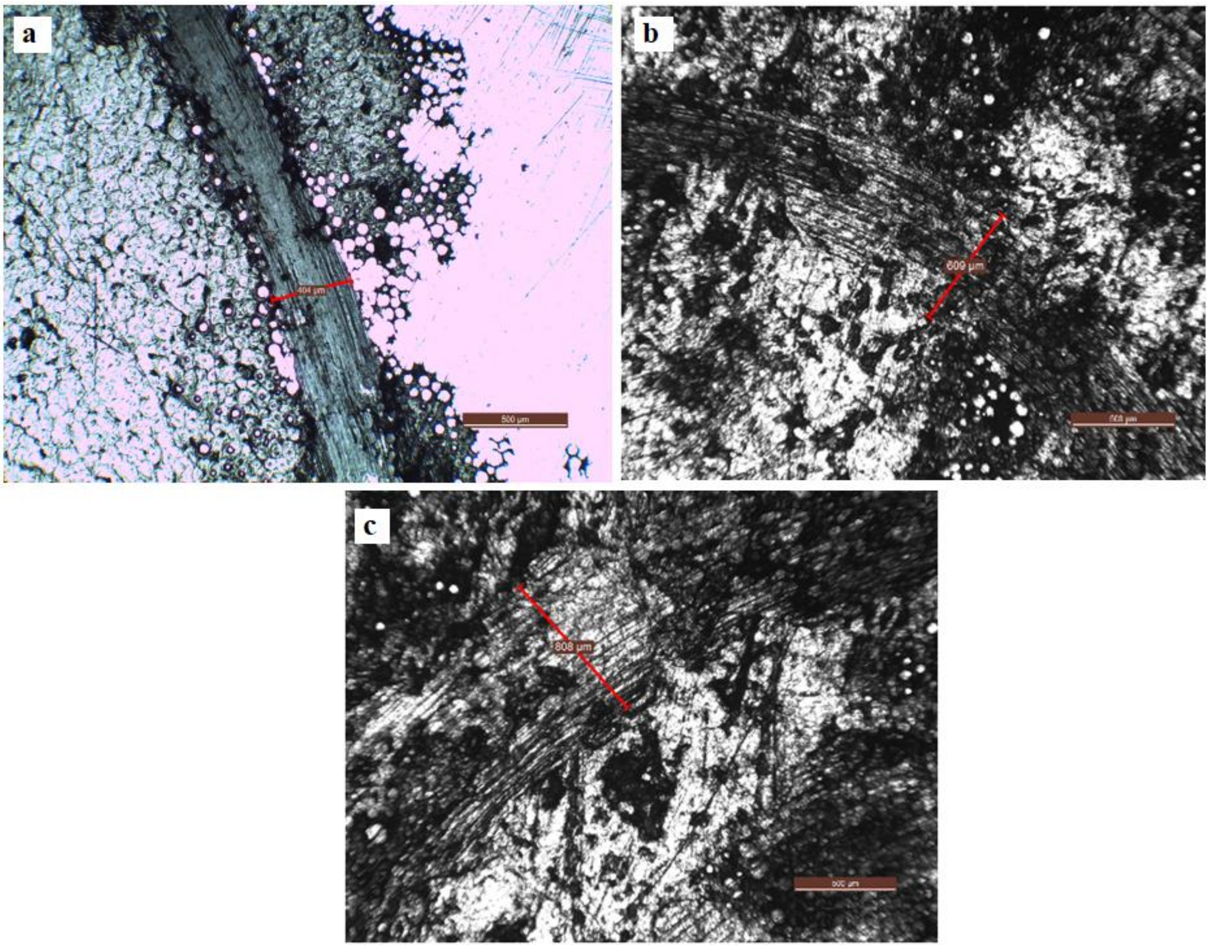

Figure 6. Microstructure images of sample A4 at different loads (a. 5N, b. 10N and c. 15N).

The wear track optical images after the wear test performed under 5N-15N loads of the composite sample A4 obtained by reinforcing 15% B_4C to the Ti6Al4V matrix are given in Fig. 6 a-c. Again, it was observed that there is an increase in wear track widths with the increase of load depending on the load. However, in addition to the increase in the width of the trace, the wear tracks seen at 10 and 15 N loads did not appear distinctively. This indicates that the particles detached from the surface during wear hold on to the abrasive ball surface and exhibit lubricating properties on the surface [17]. Looking at Fig. 6b and c, it is seen that the wear tracks are not obvious and there is a significant slippage on the surface.

When all samples are compared, they are the non-reinforced samples numbered A1 with the widest wear tracks. With the increase in the reinforcement ratio to the Ti6Al4V matrix, a narrowing was observed in the wear track widths and the narrowest wear track width was determined in the sample numbered A4 with 15% B_4C added with 5 N load. This indicates that the A4 sample with 15% B_4C exhibited the best wear resistance.

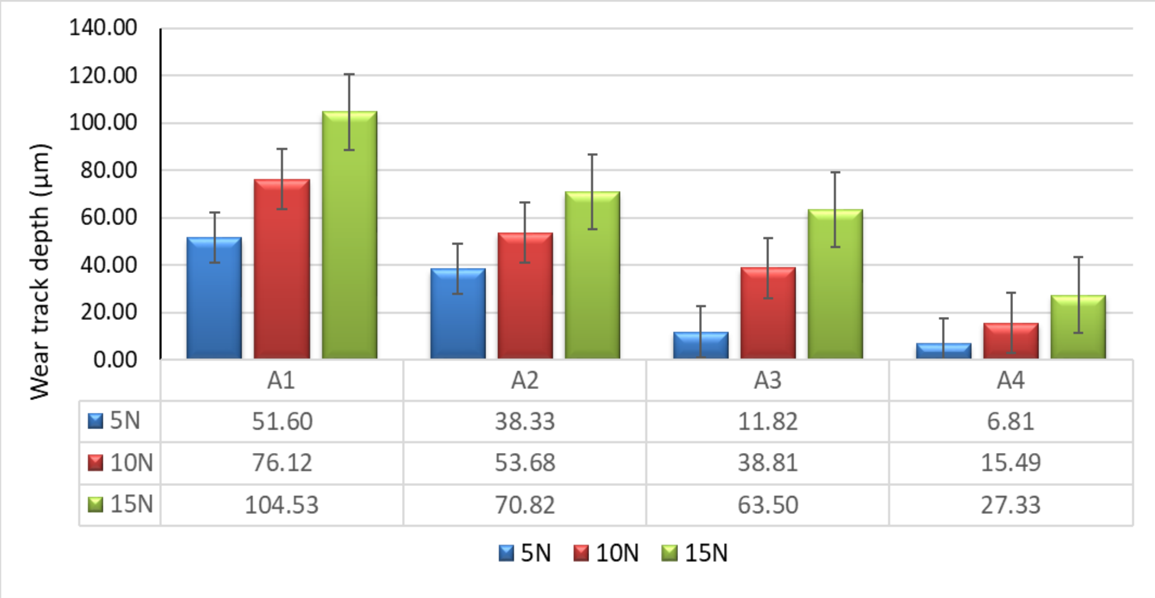

Figure 7. Wear depth graph of materials after the wear

After the wear test was performed under 5, 10 and 15N loads, the wear depth of all composite specimens was calculated and these values are given in Fig. 7. When the wear track depths in the graphic are examined, it is seen that the wear track depth increases as the load increases. As reinforcement ratio increases with B_4C reinforcement, it is seen that there is a serious decrease in the wear track depth. Among all composite samples, the highest wear track depth was observed in the sample (104.53 µm) performed under 15N load in Ti6Al4V samples without reinforcement, while the lowest wear track depth was observed in the wear test (6.81 µm) of 15% B_4C reinforced composite specimens with 5N load. When the wear track depth results were examined, it was determined that the wear resistance increased with the decrease in the wear depth due to the increase in the reinforcement ratio.

Fig. 8. shows the friction coefficients recorded during the wear tests of the samples performed under 5N, 10N and 15N loads. 3 different loads were applied to each sample group and a total of 12 wear coefficients were calculated. In the wear tests of composite materials at all loads, the materials exhibit a first running-in phase in which the friction coefficient is present and a constant level continues after the friction coefficient increases to a maximum value. From the graphic, it was determined that all composite samples with and without reinforcement completed the wear test with 300 m sliding distance at all loads. It was seen that the friction coefficients of the unreinforced Ti6Al4V samples are higher than the reinforced samples. Therefore, this is related to the addition of harder B_4C reinforcement to the Ti6Al4V matrix, resulting in a harder surface. It also positively affected the wear resistance on this hardened surface. With the increase in the B_4C reinforcement ratio, there was a decrease observed in the wear coefficients.

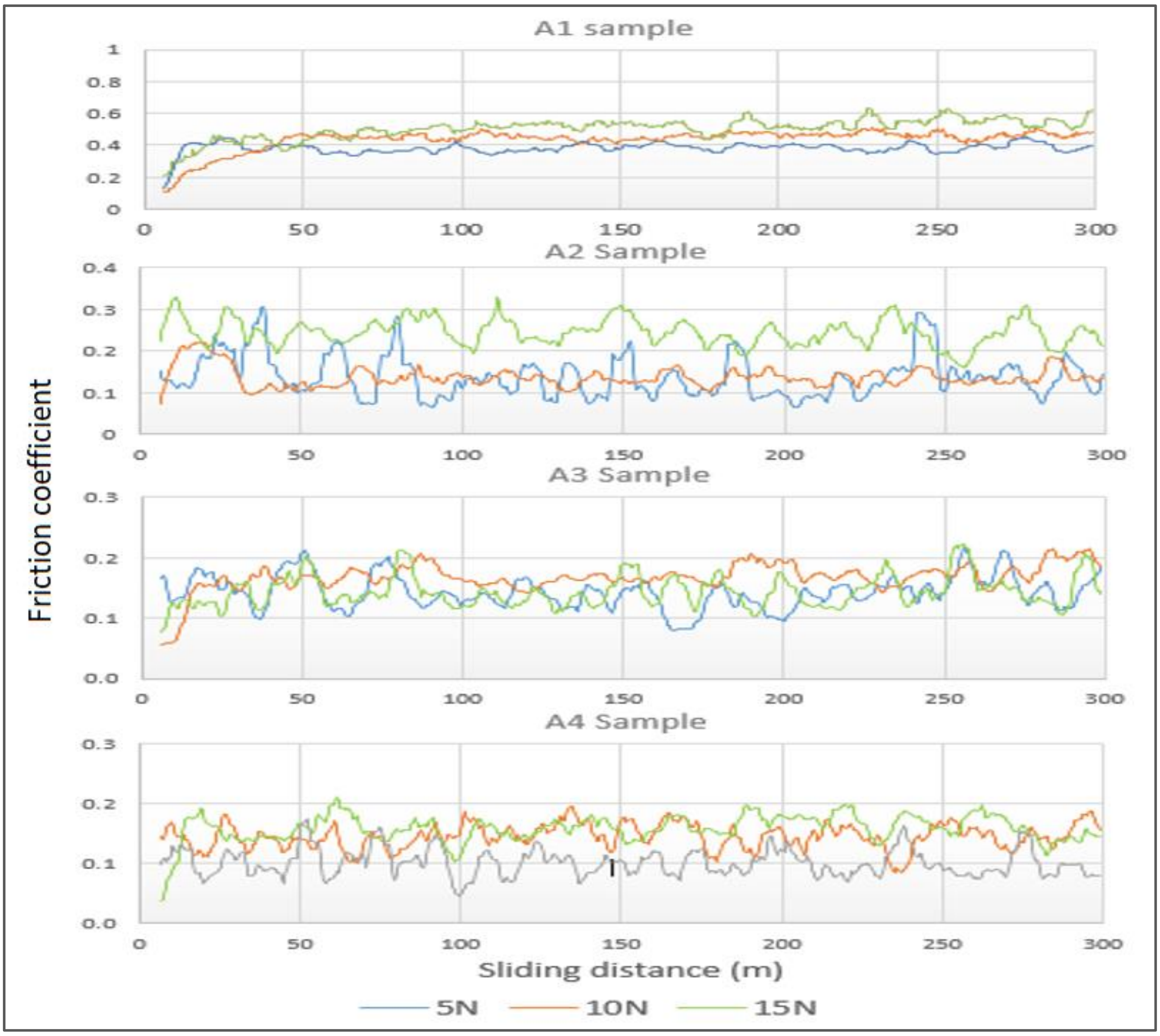

Figure 8. Friction coefficient-Sliding distance values of Ti6Al4V (A1), B_4C 5% (A2), B_4C 10% (A3) and B_4C 15% (A4) materials after wear test at different loads of 5N, 10N and 15N.

Friction coefficients of composite samples numbered A3 and A4 at all loads were relatively lower than A2 samples. It is understood that the B_4C reinforcements on the composite surface form a residue and act as a lubricant on the surface by remaining between the abrasive ball and the abraded surface during wear. The wear tracks of these samples with lubrication surface were smoother and the wear coefficients of these samples showed a relatively lower value.

4. Conclusion

In this study, composite materials were produced by adding 3 different proportions (5%, 10%, 15%) of B_4C reinforcement powder into powder metal containing Ti6Al4V. These produced composite materials were subjected to pin on disc wear test and the following results were obtained:

- As a result of the wear test performed at different loads, it was observed that B_4C reinforced composite materials yield astonishing results compared to non-reinforced Ti6Al4V materials and the wear track width decreases with the increase of B_4C ratio.
- While the widest wear tracks were seen in unreinforced Ti6Al4V materials, the narrowest wear tracks were detected in samples of 15% B_4C reinforced composite materials under 5N load.

- It was determined that as the B_4C reinforcement ratio increased, the calculated wear track depth decreased and thus the wear resistance increased.
- It was observed that as the B_4C reinforcement ratio increases, the lubricating feature on the abraded surface increases. It was observed that B_4C increases the wear resistance of the composite material due to the decrease in the calculated wear track depth and the friction coefficient with the increase of lubricity.
- When the friction coefficient values of composite materials were examined, it was determined that the friction coefficient value of unreinforced Ti6Al4V material is higher than all composite materials and as the amount of B_4C increases, the friction coefficient values decrease.

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