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The Effect of B_4C Reinforcement on Microstructure and Hardness in Waste Chip CuSn10 Matrix with BN Additive

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ABSTRACT

In this study, CuSn10 chips which are mostly recycled in the industry were used as matrix material. Metal matrix composite material was produced by pressing boron nitride (BN) with solid lubricant and B4C at room temperature and under high pressure (800Mpa) and sintering. Matrix/reinforcement powder mixtures prepared with B4C powder content and BN (1% by weight) at certain ratios (5%, 10%, 15% by weight) were subjected to mechanical mixing and grinding. After this process, the powder metal part production process was started by using the powder mixtures prepared. For this purpose, powder mixtures were subjected to pressing, sintering and density measurement processes, respectively. Then, the hardness values of the powder metal parts were investigated after microstructural characterization.

Keywords: Powder Metallurgy, Composite, Metallic chips, Recycling, B_4C

1. INTRODUCTION

The material and energy needs which are increasing with the developing technology have enabled the production of much higher qualified products [1]. In particular, this has necessitated the development of journal bearing materials that have high energy efficiency in terms of both material and production cost and tribological properties they have in the conditions of use. In the last 50 years, technological advances emerging at an untraceable pace in the manufacture of bearings and gear elements have led to an increase in interest in metal matrix composites [2].

Due to the fact that composite materials have superior mechanical properties, studies conducted in this field are of interest. Bearings working in these systems are usually designed with features that can perform under difficult conditions. In the selection of journal bearing elements, whose majority are made of metallic materials (Bronze and Tungsten, etc.) and a very small part is made of polymers and ceramics, many important parameters such as load, speed, temperature, humidity, and corrosive environment to be exposed to must be taken into account. Material and production costs are also very important in this selection [3].

"Powder Metallurgy (P/M)" is an advanced manufacturing method that is very convenient for the production of technological materials and ensures a large number and economical production of small parts [4]. Nowadays, when cost and quality become the goal, the production of parts with powder metal techniques is becoming increasingly important. The importance of powder metallurgy is due to the fact that parts that are quite difficult or impossible to shape by casting and machining can be easily and economically produced in mass productions using this method [5]. Production of parts by Powder Metallurgy consists of stages such as powder preparation, pressing, sintering, and post-sintering processes [6]. The production of powders used in the powder metallurgy technique is quite difficult and expensive. This situation has a restrictive effect on the use of powder metallurgy. In this study, it was shown that as an alternative to the powder metallurgy technique, similar materials with sufficient structural integrity and strength could be produced by using metal chips, which are considered waste, instead of metal powders and applying a similar production technique. Since it will not be possible to melt different types of chips in the same pot when the melting and casting process is used in the recycling of waste metal chips, the classification process should be applied. Thanks to the Powder Metallurgy production method, it is possible to produce different types of metals in the desired composition and materials can be easily brought to the desired final dimensions [7].

In this thesis study conducted in this context, metal matrix composite samples were produced using waste chips (CuSn10 metal matrix), solid lubricant (BN), and ceramic particle (B4C) at different reinforcement rates. As a continuation of the studies, density, microstructure, and micro hardness measurements of the produced composite samples were carried out. Thus, with the recovery of waste metal chips, studies focusing on the production of metal matrix composite materials were carried out using the powder metallurgy method, unlike the conventional melting and casting process.

2. MATERIAL AND METHOD

In this study, CuSn10 (as chips; matrix), BN (as the solid lubricant), and B_4C (as reinforcement) powders were used as starting materials, respectively. The chemical composition of the matrix CuSn10 material is given in Table 1. Some physical and mechanical properties of the Boron Nitride material [8] used as the solid lubricant are shown in Table 2, while some mechanical properties of Boron Carbide material [9] used as reinforcement material are shown in Table 3.

Table 1: Chemicalcomposition of CuSn10 material (% byweight)

Malzeme	Cu	Sn	Pb	Ni	Fe	Zn	Si	P	Mn
CuSn10	87,95	10,45	0,36	0,67	0,025	0,45	0,053	0,012	0,026

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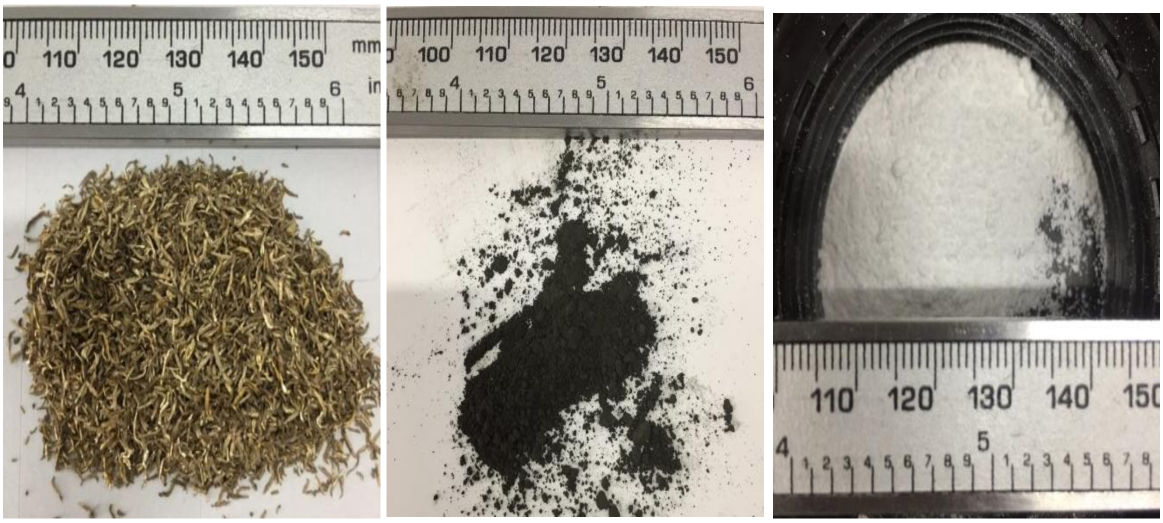
Table 2: Properties of Boron Nitride material

Resistivity	DielectricConstant	ThermalConductivity	Young'smodulus	Strength
10^{12}–10^{14} Ω cm II	4.97 II	550±75Wm^{-1}K^{-1} II	810 GPa	130 GPa
10^{12} – 10^{14}⊥	2.89 ⊥	3.5±0.8Wm^{-1}K^{-1}⊥		

Table 3: Properties of Boron Carbide material

Tensile strength	Density	Thermalconductivity	Modulus of elasticity
(MPa)	(g/cm2)	(W/m-K)	(GPa)
261	2.3	30 - 42	362



a b c

Figure 1: Starting powder materials; a) CuSn10, b) B_4C, c) BN

The images of the starting powder materials used for the production of metal matrix composite materials in experimental studies are given in Figure 1. A total of 5 different composite material samples were prepared for experimental studies. The contents of the prepared starting powder materials are shown in Table 4.

Table 4: Mixingratios of test samples

CS-1	100% CuSn10 (Reference)
CS-2	90% CuSn10 - 10% B_4C
CS-3	94% CuSn10 -1% BN - 5% B_4C
CS-4	89% CuSn10 -1% BN - 10% B_4C
CS-5	84% CuSn10 -1% BN - 15% B_4C

Since the CuSn10 matrix material is a product that appeared after the machining process, it was used by performing the necessary cleaning process. As the first stage of the material production process, mixtures were obtained by weighing metal powders in certain proportions. Then CuSn10 metal chips were ground with a high-energy grinding device, and it was ensured that the powders were mixed homogeneously within each other. Powder mixing and grinding operations were carried out for 30 minutes at a speed of 400 rpm using a planetary type grinder. The prepared powder mixtures were subjected to the pressing process. The pressing process was carried out under a pressure of 800 MPa. Then the pressed powders were sintered for 1 hour at a temperature of 800 ℃. The sintered samples were subjected to sanding, polishing and etching processes, respectively. Then optical microscope and Scanning Electron Microscope (SEM) studies were performed to examine the material microstructure. Finally, microhardness measurements were performed to be able to compare the samples with each other as a mechanical property after the microstructure studies.

3. RESULTS AND DISCUSSION

After the pressing process, the density measurement results (raw densities) of the reference sample (Cs-1) and the other composite samples (Cs 2-5) were determined as approximately 8.1 g/cm^3. Sintered density values generally tend to decrease compared to raw density in composite samples, while density values increased in the Cs-1 reference sample. The density value after sintering was measured as 8.65g/cm^3 in this sample. The distribution of the added solid lubricant (BN) and B_4C material at the grain boundaries and their effects of stopping the shrinkage of the pores can be shown as the reason for the decrease in the density values, especially in the composite materials [10]. In this case, it was found that there is a decrease in the density of the composite materials. In Figure 2, the density values of the experimental samples after sintering are given comparatively. Also, relative density measurement results were obtained both in the reference sample and in other composite samples.

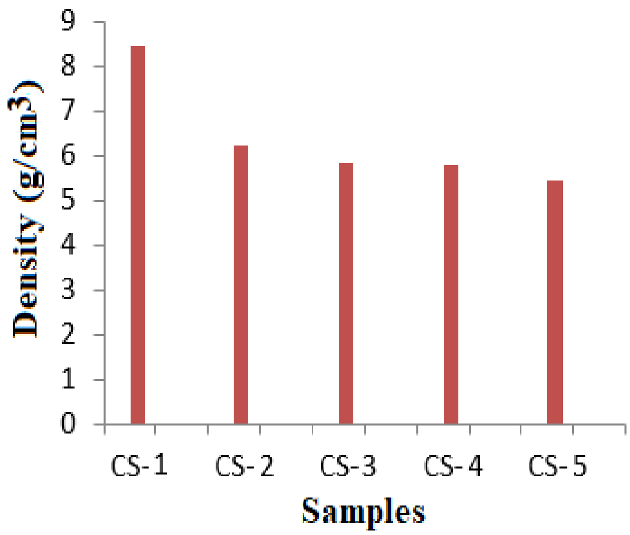


Figure 2: Density results after sintering process

Figure 3 shows the optical and SEM images of the CuSn10 experimental sample. When microstructure images of the CuSn10 material were examined, it was determined that there were pure CuSn10 structure and twin crystal formations (region No. 1). In addition, it can be seen in the figure that there are eutectoid inclusions in the sintered CuSn10 microstructure. By comparing the material density values and optical microscope microstructure images, it can be understood that the pore morphology is quite small in the material and there is a positive course of the sintering mechanism.

This situation shows parallelism when SEM images are also examined. However, it was found that there were also pore formations, albeit rarely (region No. 2). Optical and SEM microstructure images of the composite experimental samples produced by adding boron nitride and boron carbide to CuSn10 material are shown in Figure 4 and Figure 5, respectively.

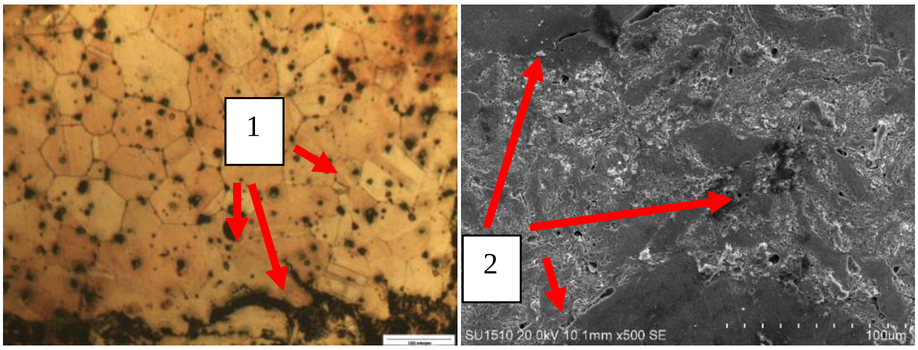


Figure 3: Microstructureimages of CS-1 test specimens

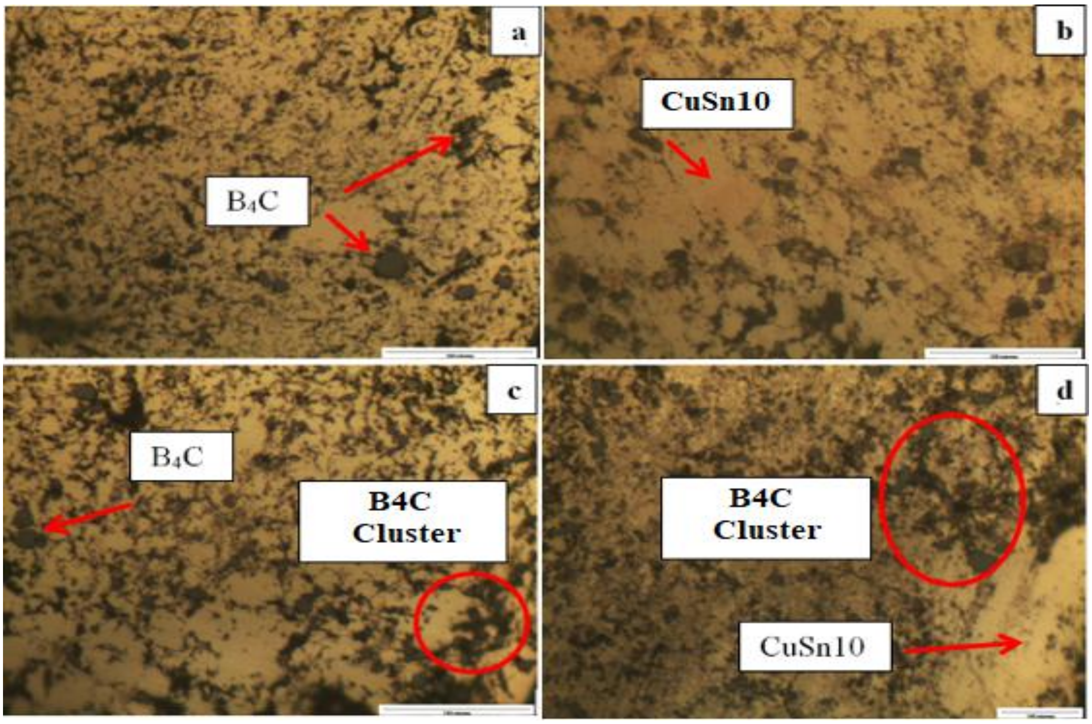


Figure4. Microstructure images of composite test specimens; a) CS-2, b) CS-3, c) CS-4, d) CS-5

In the composite experimental samples' microstructures given in Figure 4, the yellow regions on the ground refer to the CuSn10 matrix phase, while the structure in the polygonal grayish structure with sharp corners shows the distributions of the B_4C ceramic particle phases. However, it is seen that especially as a result of the increasing amounts of ceramic particle reinforcement (10-15%), the ceramic phase tends to agglomerate or cluster at the grain boundaries.

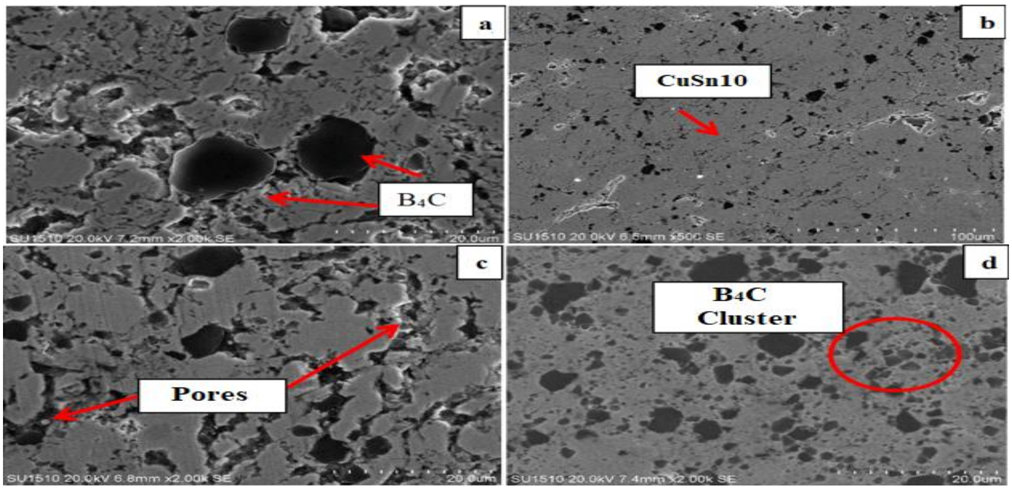


Figure 5: Microstructure images of composite test specimens; a) CS-2, b) CS-3, c) CS-4, d) CS-5

In the SEM images in Figure 5, it was determined that B_4C ceramic particles were observed in the black regions in the polygonal structure and that they were distributed especially at the grain boundaries. It was found that they exhibited a homogeneous distribution in the microstructure depending on the increasing amount of ceramic phase reinforcement. However, in some regions, ceramic particle agglomerations occur, albeit slightly. It is also believed that this situation negatively affects sintering in terms of shrinking of the pores, grain joining, and high-temperature resistance.

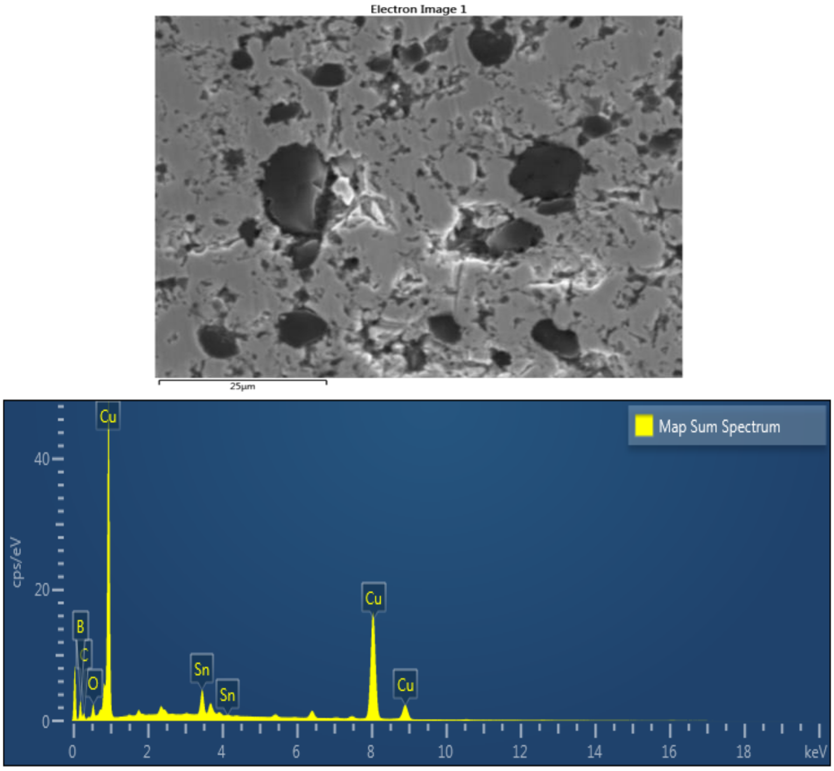


Figure 6: General EDS analysis of CS-4 test sample

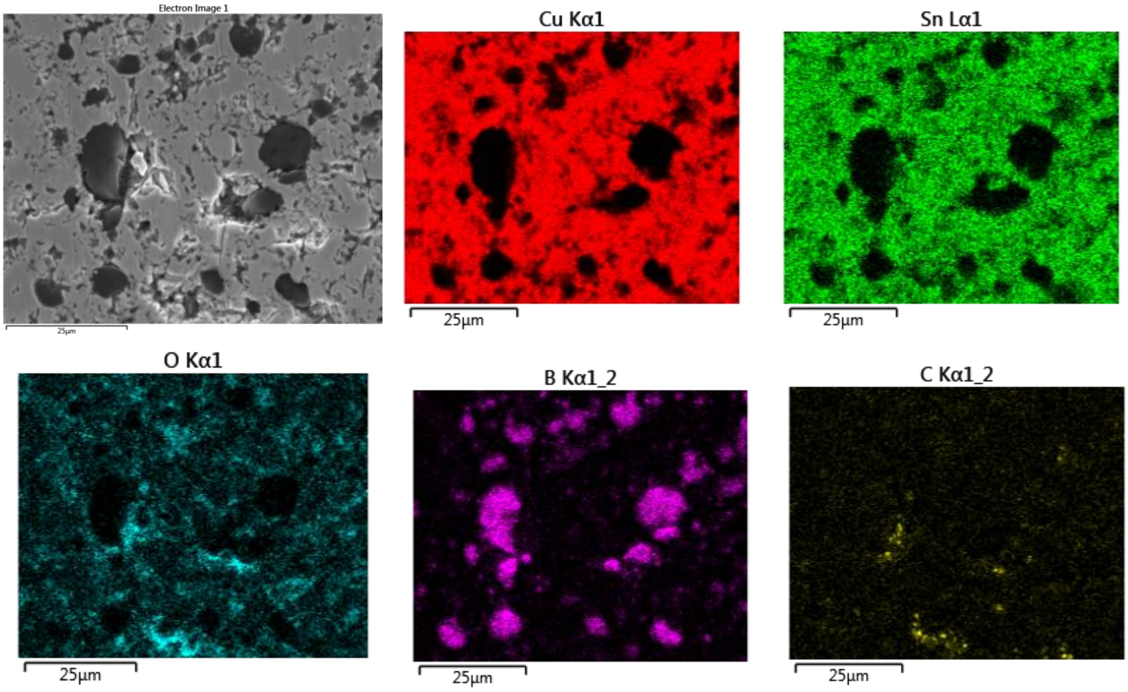


Figure 7. Elemental map of the CS-4 test sample

The general EDS analysis and elemental map distributions of the 10% B_4C-reinforced sample, which is among the composite experimental samples, are shown in Figure 6 and Figure 7, respectively. When the general EDS analysis given in Figure 6 is examined, it is seen that the analysis result defines the matrix and reinforcement-phase components. In addition, in Figure 7, the distributions of these elements are revealed with different colorings. The

Brinell hardness results obtained for the comparison of the pure CuSn10 material and the composite experimental samples produced using different proportions of B_4C ceramic reinforcement in the CuSn10 metal matrix structure by applying the powder metallurgy method are shown in Figure 8. Since it is a reference compared to composite experimental samples, the hardness value of CuSn10 material was measured as 68.32 HBN after the pressing and sintering processes. In a similar study, scholars measured the CuSn10 hardness value obtained in the sintered bronze-based composite material production studies as 60 HBN. They noted that depending on the increased amount of ceramic phase reinforcement, the composite material hardness values they produced were 1.2-1.6 times higher compared to the CuSn10 material [11].

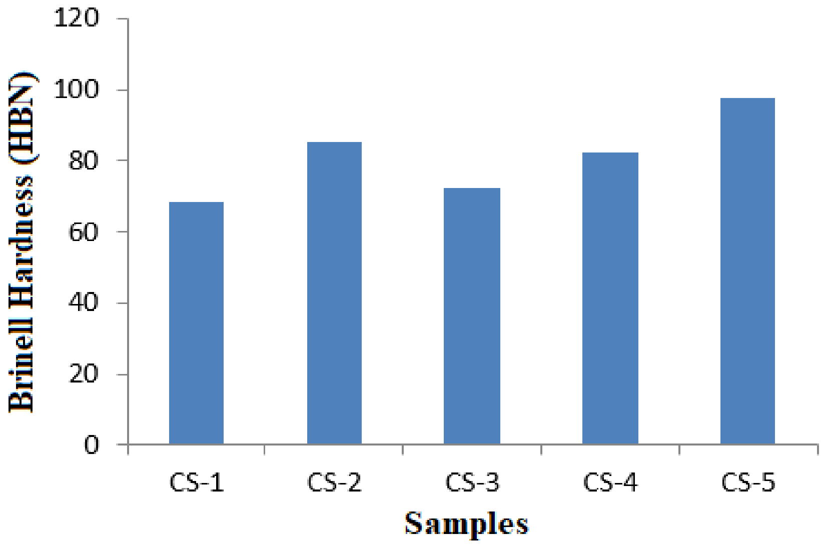


Figure 8:Hardnessresults of test specimens

Accordingly, it was found that hardness values increased in the composite experimental samples produced with B_4C reinforcement compared to the CuSn10 matrix material. The highest hardness value was obtained in the composite experimental sample produced with 15% B_4C reinforcement, and this hardness value was measured as 97.52 HBN. Based on this, it can be said that the hardness value of the CuSn10 material increased by about 1.5 times further.

CONCLUSION

The results obtained within the scope of the production of metal matrix composite materials using CuSn10 waste chips are as follows;

The highest relative density value after sintering was determined as 97% in the CuSn10 experimental sample produced without reinforcement. When the microstructure images were examined, it was observed that there were twin crystal formations in the CuSn10 structure. The presence of B_4C ceramic particles, which tended to cluster mostly at grain boundaries, was detected in the composite experimental samples. It was observed that the hardness values increased as the proportion of the reinforcement element in the obtained composite samples increased. The highest hardness value was obtained as 97.52 HBN in the metal matrix composite experimental sample containing 15% B_4C reinforcement. This value was about 1.5 times higher compared to the value obtained from the reference CuSn10 sample.

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