# The Effect of Boron Carbide Amount on Microstructure and Electrical Properties of Cu-$B_4C$ Composite Materials

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***Abstract*- In this study, the effects of boron carbide ($B_4C$) addition on mechanical and physical properties such as microstructure, hardness and density of hot pressed copper-boron carbide (Cu-$B_4C$) composites were investigated. To improve the mechanical properties of commercial copper (C) powders having a particle size of 40µm, $B_4C$ having a particle size of 40µm, of 2,5, 5, 7,5, 10% by weight was added. Cu-B4C composites were sintered to argon atmosphere at $650^0$C, $750^0$C and $850^0$C for 4 minutes. The electrical conductivity values of the sintered products were measured after examination with the presence of $B_4C$, optical microscope, X-ray diffraction analysis technique and SEM-EDS. In the images obtained, $B_4C$ was found to be homogeneously dispersed in the copper matrix. As the ratio of $B_4C$ increased, the hardness of the composites increased and the density decreased.**

***Keywords*- Metal Matrix Composites, Cu, $B_4C$, Hot Pressing, Electrical Conductivity**

## I. INTRODUCTION

The new material, which is formed by combining at least two different materials in such a way that they can not dissolve in order to develop some properties (strength, elasticity, hardness etc.) that are not present in the components alone, is called "composite material" [1]. Due to its high abrasion resistance and strength and good thermal expansion coefficient, metal martial composites (MMK) formed from metal matrix and ceramic reinforcements lead to increased use in aerospace, automotive and defense industries [2]. The high electrical and thermal conductivities of copper (Cu) and its alloys can be shown to be low cost compared to gold (Au) and silver (Ag) and as a reason for preference due to easy manufacturing. Since the 1930's bronze bearings and porous bronzes have been made of copper alloys. Copper and its alloys also include brake pads, clutches, electrical contacts, shock absorbers, etc. It is also used in industrial applications. [3-4]. On the other hand, the fact that Cu is low-strength and resistant to abrasion makes it necessary to form an alloy. The strength can be increased by adding many ceramic materials to the copper material. SiC, $Al_2O_3$ and $B_4C$ are excellent reinforcing materials in terms of removing the negative properties of copper. Known properties of silicon carbide (SiC) are very hard, excellent thermal shock resistance, oxidation resistance, abrasive and high creep strength [5]. $Al_2O_3$ is a material resistant to mechanical and chemical degradation at low temperatures due to the melting temperature of $1200^0$C. Properties such as boron carbide ($B_4C$), high hardness (2900-3900kg/mm$^2$), high neutron absorption section and low density (2.52 g/cm$^3$), high melting point (~ 2450°C), high elastic modulus (448GPa) it is a potential reinforcing material to make the composite material it possesses. $B_4C$ reinforced metal matrix composites; blasting nozzles, metal processing tool tips, nuclear reactor control rods, and nuclear waste storage systems. Due to its covalent structure, boron carbide sintering requires very high temperature and high pressure. Additive materials such as C, Al, Fe, Ti, SiC, $TiB_2$, $Al_2O_3$, $Y_2O_3$, $ZrO_2$ reduce the sintering temperature and also have a positive effect on the mechanical properties [6]. Despite its superior properties such as high mechanical properties, good wear and corrosion resistance, $B_4C$ has a low thermal conductivity. Cu-$B_4C$ has been produced in studies to improve the low thermal conductivity of $B_4C$ based composites [7].

## II. EXPERIMENTAL STUDY

In this study, copper powder, 99,9% purity and 40µm diameter and boron carbide ($B_4C$) powder, 99.5% purity and 40µm diameter were used. SEM images of Cu powder and $B_4C$ particles used in this study are shown in Figure 1.a and Figure 1.b. The Cu powder is spherical, and the $B_4C$ particle is sharp-edged.

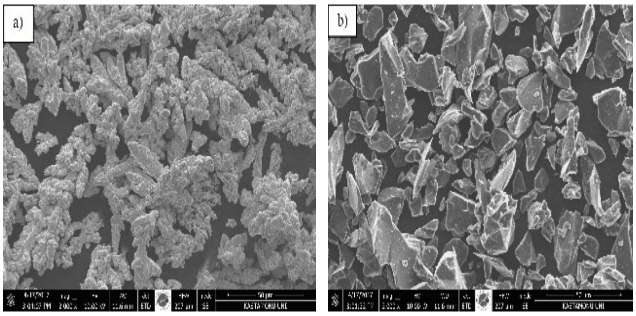



Fig. 1 SEM Micrographs of a) Cu, b) $B_4C$ powders

2,5%, 5%, 7,5% and 10% $B_4C$ were mixed with Cu powders, respectively. The Cu-$B_4C$ powders were subjected to mechanical powder mixing at a speed of 45 r/min and for 45 minutes. The copper(Cu) powder and Cu-$B_4C$ powder mixtures were sintered at 650$^0$C, 750$^0$C and 850$^0$C for 4 minutes under 35 MPa load pressure in argon atmosphere. Totally 15 samples were produced in 3 different temperature and 5 different mixing ratio. The parameters are given in Table 1.

TABLE I

HOT PRESSING PARAMETERS APPLIED TO CU-B4C POWDER MIXTURES PREPARED AT DIFFERENT RATIOS

| Sample no | % $B_4C$ Amount | Pressing Press | Sintering Time (min) | Pressing temperature ($^0$C) |
|---|---|---|---|---|
| N01 | 0 | 35 | 4 | 650 |
| N02 | 2,5 | 35 | 4 | 650 |
| N03 | 5 | 35 | 4 | 650 |
| N04 | 7,5 | 35 | 4 | 650 |
| N05 | 10 | 35 | 4 | 650 |
| N06 | 0 | 35 | 4 | 750 |
| N07 | 2,5 | 35 | 4 | 750 |
| N08 | 5 | 35 | 4 | 750 |
| N09 | 7,5 | 35 | 4 | 750 |
| N10 | 10 | 35 | 4 | 750 |
| N11 | 0 | 35 | 4 | 850 |
| N12 | 2,5 | 35 | 4 | 850 |
| N13 | 5 | 35 | 4 | 850 |
| N14 | 7,5 | 35 | 4 | 850 |
| N15 | 10 | 35 | 4 | 850 |

The surfaces of the composite samples were grinded with 220, 320, 400, 600, 800, 1200, 1500 and 2000 mesh grinders and polished by 3µm and 1µm diamond solution. After polishing, the samples were cauterised by 90% water- 10% nitric acid solution for 3 seconds, then rinsed with etil alcohol and dried. Composite samples were analyzed by XRD technique. The microstructures of samples were examined by a Nikon Eclipse MA100 optical microscope. EDS analysis was performed to detect Cu, $B_4C$ and possible copper oxides in Cu-$B_4C$ interfaces. The relative density of the samples were measured according to the Archimed method. The hardness of samples were measured by a Brinell Hardness test machines with a load of 31,25 kg on different 5 points and average hardness values of 5 points were used to determine the hardness. Electrical conductivity coefficients were measured in TUBITAK-MAM by a Sigmatest 2.067 model instrument.

## III. RESULTS

It is seen that the $B_4C$ particles in Cu matrix have homogeneous distribution (Fig.2.a, b,c). The SEM images of composites sintered at 650$^0$C, 750$^0$C and 850$^0$C are given in Figure 2a,b,c.. Dark, angular shapes indicate the $B_4C$ particules and gray colored areas indicate copper matrix (Fig.2.a, b,c).

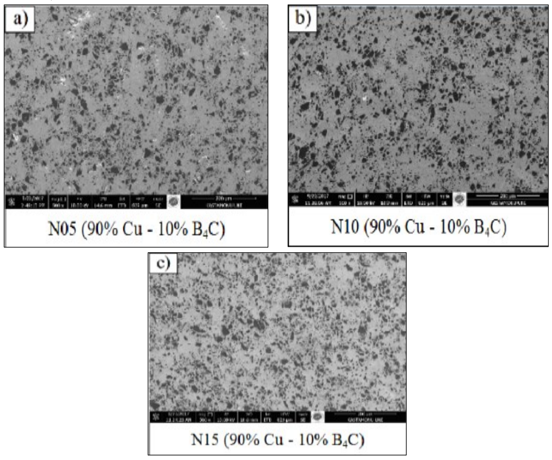



Fig. 2 SEM images of Cu-$B_4C$ composites sintered at different temperatures a) 650$^0$C b) 750$^0$C c) 850$^0$C

It is seen that, in lower sintering temperature higher sintering gaps were detected.The amount of voids in the sample sintered at 650$^0$C(the lowest temperature) is maximum. Additionally, increasing $B_4C$ ratio in matrix results in inceasing sintering gaps (Fig.3.a,b,c,d).

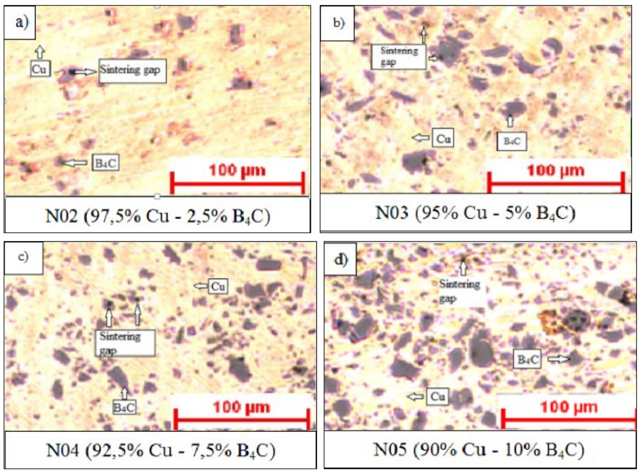



Fig. 3. Optical microscope image of Cu / $B_4C$ composites containing $B_4C$ at different ratios sintered at 650$^0$C a)2,5% $B_4C$ b) 5% $B_4C$ c) 7,5% $B_4C$ d) 10% $B_4C$

By examining optical images of samples sintered different temperature, it is also seen that increasing amount of $B_4C$ ratio causes higher sintering voids. Contraversly, higher sintering temperature decrases the amount of sintering gaps (Fig.4.a,b,c).

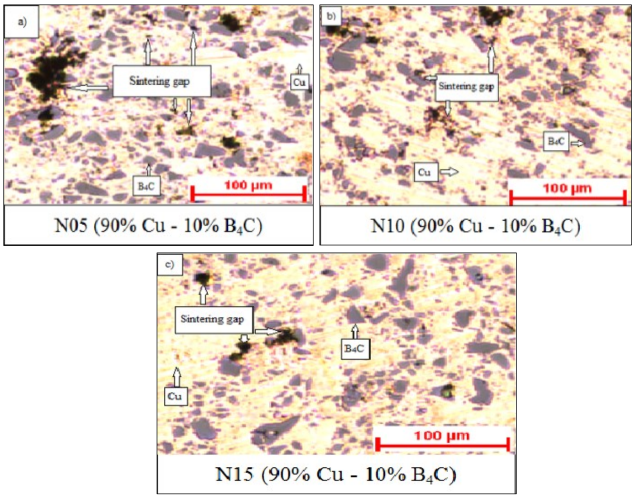
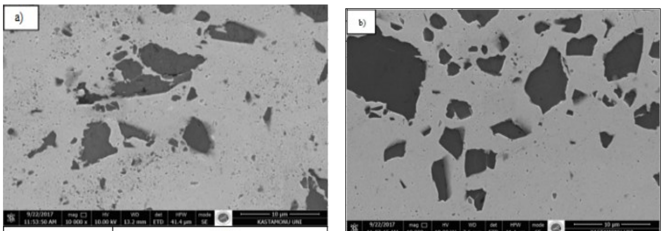



Fig.4 Effect of sintering temperature on sintering clearance a) 650$^0$C, b) 750$^0$C, c) 850$^0$C

Figure 5.a and 5.b show SEM images and EDS analyzes of Cu-$B_4C$ composites. The EDS analysis show that there is a small amount of oxygen in the samples of copper and composites. This is probably due to the oxidation of the matrix during sintering and/or surface cauterisation.



| SAMPLE | wt. % | | | |
|---|---|---|---|---|
| | B | C | O | Cu |
| N09 (92,5% Cu-7,5% $B_4C$) | 44.10 | 9.88 | 1.86 | 44.16 |

| SAMPLE | wt. % | | | |
|---|---|---|---|---|
| | B | C | O | Cu |
| N12(97,5%Cu-2,5%$B_4C$ | 43.89 | 9.6 | 1.49 | 45.02 |

Fig. 5 SEM images and EDS analyzes of Cu/$B_4C$ composites a) N09 sample b) N12 sample

Hardness graph of pure copper (Cu) and Cu-$B_4C$ composites produced at different ratios and temperature are shown in Fig.6. By examining the graph, it is observed that there is a small increase in hardness up to 2.5% $B_4C$ contents,higher increasing ratio between 2.5% -5% $B_4C$ content. Increasing ratio in hardness between 5%-7.5% $B_4C$ contents are getting lower and after 7.5% $B_4C$ content decreases rapidly. After the 7.5% $B_4C$ content sintering temperature has more effect on decreasing ratio on hardness, lower sintering temperature results higher decreses(Fig.6). Briefly it can be said that up to 2.5% $B_4C$ content, the amount of $B_4C$ content has no significiant effect than others.

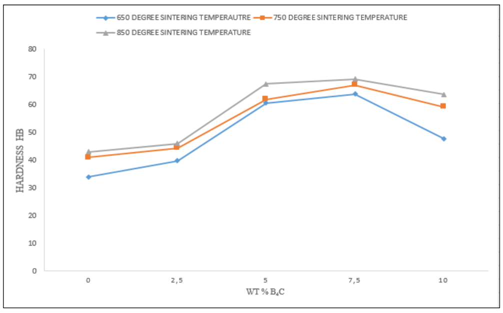



Fig.6 Hardness of Cu-$B_4C$ composite samplesaccording to sintering temperature and $B_4C$ content

Figure 7 shows the change in the density of Cu/$B_4C$ composites. It can be seen in Fig.7, increasing ratio of $B_4C$ results decrasing of the density in all $B_4C$ composites. The sintering temperature has clear effect on density, low sintering temperature means low densitiy at the same $B_4C$ ratio. Decrasing in density in all samples are nearly parallel to each other. Difference between the density is small in higher temperature( between 850$^0$C -750$^0$C ) and higher in lower sintering temperature(between 750$^0$C-650$^0$C) relatively. The reason can be thought that the sintering voids which increase in parallel with the increasing $B_4C$ ratio are effective on it.

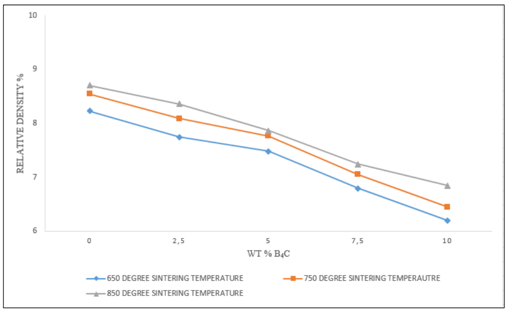



Fig.7 The change in the density of the Cu/$B_4C$ composites depending on the $B_4C$ ratio it contains

Figure 8 shows the change in the electrical conductivity of the composites depending on sintering temperature and $B_4C$ ratio. It has been determined that the Cu-$B_4C$ composites sintered at 650$^0$C have sharp decreasing ratio than others parallel to $B_4C$ ratio. Electrical conductivity of the samples sintered at 850 $^0$C and 750 $^0$C are very closer to each other.

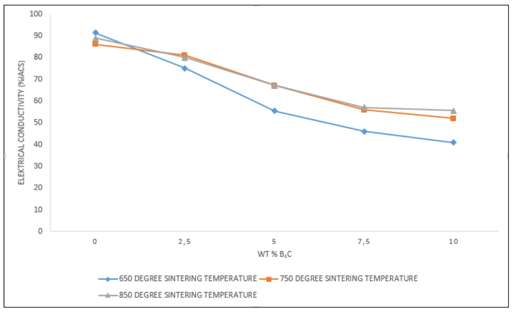



Fig.8 Change in the electrical conductivity of Cu / $B_4C$ composites at different sintering temperatures

## IV. CONCLUSION

The following results can be obtained as a result of analyses made on Cu-$B_4C$ composites with different Cu-$B_4C$ ratio:

Increasing $B_4C$ ratio in Cu-$B_4C$ composites causes higher sintering gaps. Low sintering temperature also increases the sintering gap ratio and it efects the density, electric conductivity and hardness. Highest sintering gaps observed at 650 $^0$C and 10% $B_4C$ ratio.

Maximum hardnesses were measured on 7.5% $B_4C$ containing samples. At this $B_4C$ ratio, the samples which is sintered at higher tempereature showed higher hardness level. Over the 7.5% $B_4C$ ratio, hardness decrease in all sintering tempereature, probably, due to high sintering gaps. Empty spaces(sintering gaps volume)are also higher depending on the sintering tempereature.

It is seen that(Fig.6) the effect of $B_4C$ on hardness very high between 2.5% and 5% acording to other $B_4C$ ratio. The effect of $B_4C$ looses its effect from 5% to 7.5%, rises slowly and hardness tend to decrease. The sample which contains 10% $B_4C$ and sintered at 650 $^0$C shows faster decline on hardness.

In the other hand, density also decraeses depending on both sintering temperature and $B_4C$ ratio, higher $B_4C$ ratio or lower sintering temperature causes lower density.

Electric conductivity coefficients of cCu- $B_4C$ composites depend on both $B_4C$ ratio and sintering temperature. The samples that sintered at 650 $^0$C show lowest electric conductivity. There is no significant difference between sintered samples at 750- 650 $^0$C.

Briefly, sintering gaps are relatively higher in the 7.5%-10% $B_4C$ containing samples that reduce some properties like electric conductivity and hardness.

Studying on the effect of sintering pressure and time in producing Cu-$B_4C$ composites can be useful.

## ACKNOWLEDGMENTS

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## REFERENCES

[1] (2016) The DEU.EDU website. [ONLINE]. Available: http://kisi.deu.edu.tr/userweb/mehmet.zor/composite%20materials/2-Genel_bilgiler.pdf

[2] A.R.Motorcu. E.Ekici, "Al/$B_4C$ Kompozitlerin Karbür Matkaplarla *Delinmesinin Değerlendirilmesi*." Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi, Vol. 22.4, p. 259-266. 2016.

[3] E.Turan, "Bor Karbür-Silisyum Karbür Kompozitlerinin Sıcak Presle*me ile Elde Edilmesi*," thesis, İstanbul Teknik Üniversitesi Fen Bilimleri Enstitüsü. İstanbul. May. 2004

[4] H.Ipek. H.Çuvalci C.Celebi, "Tribological Properties of Boron Carbide Reinforced Copper Based Composites." Ejens European Journal of Engineering and Natural Sciences. Vol.2.1.,p.102-107.2017.

[5] E.Çağlar. "Bor Karbür/ Bor Karbür Silisyum Tabakalı Kompaozitlerin Spark Plazma Sinterleme Tekniği ile Üretimi ve Karakterizasyonu".thesis, İstanbul Teknik Üniversitesi Fen Bilimleri Enstitüsü.İstanbul,Turkey. Jan.2015.

[6] T.Yener. I.Altınsoy. S.C.Yener. F.G.Çelebi Efe. I.Özbek. C. Bindal, "*An Evaluation of Cu-$B_4C$ Composites Manufactured by Powder Metallurgy*". Proceedings of the International Congress APMAS2014,1045-1047, Fethiye,Antalya.2014.

[7] I.Altınsoy. F.G. Çelebi Efe. D.Aytaş. M.Kılıç. İ.Özbek. C.Bindal, "*Some Properties of Cu-$B_4C$ Composites Manufactured by Powder Metallurgy.*" Periodicals of Engineering and Natural Sciences, Vol.1.1, p. 34-38. 2013.