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Processing and Mechanical Properties of B_4C/Diamond Impregnated Fe/Co MMC

K.E Öksüz*, M. Şimşir

Department of Metallurgical Materials Eng., Cumhuriyet University, 58140, Sivas, Turkey

Cobalt is currently used in the production of diamond reinforced metal matrix composites (i.e. stone-cutting tools). Herein, how sintering temperature and matrix composition influences the material properties of diamond reinforced MMCs was explored. The aim of this work is to produce diamond reinforced metal matrix composites based on Fe-Co compositions with and without B_4C are processed by a PM method using a hot pressing technique. The effects of Fe and B_4C additions on the characteristic of diamond impregnated Co matrix composites have been investigated. Samples reinforced with and without B_4C having two different compositions (different Fe/Co ratio) were produced under 25 MPa pressure and sintered at 1000 °C temperature. After sintering, hardness tests were carried out and wear tests were performed by pin-on-disc. The results showed that addition of Fe caused slightly decrease in the hardness of the matrix. However, reinforcing with B_4C increased the hardness of the matrix. It is observed that wear resistance of B_4C reinforced Fe-Co metal matrix composite was greater than that of composites without reinforcement. SEM and EDX techniques were used to characterize the composites.

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1. Introduction

The advantages of using diamond cutting tools often include improved work piece quality, increased productivity, and reduced costs. High hardness and wear resistance result in good surface finishing over long production runs, consistent control of dimensions for extended periods, and long tool life [1–4]. Cutting tools can be produced using methods [5–6] such as cold pressing and sintering, hot pressing, brazing and infiltration. PM is the only viable method for manufacturing these tools because the solid state prevents excessive chemical interaction between the metal phase and the diamond, thereby avoiding graphitization [7]. Metals (Co, Ni, Ti, and W) with a high chemical affinity to carbon have been used for bonding diamonds in composites. When diamond reinforced MMCs are heated, the metals attack the diamond surface and bonds are formed between the diamond surface and metal powder. These particular metals (Co, Ni, Ti, and W) in diamond reinforced composites are commonly used as binders due to their good wettability and chemical compatibility that holds the diamonds together and forms chip flow grooves via rapid wear during cutting. However, Cu, Sn, brass and bronze metals have lower chemical affinity to carbon, [7] and these metals are used as filler metals to fill the pores formed during sintering. The diamonds are primarily responsible for the grinding process and therefore the bonding type of the diamonds in the metal matrix is of essential relevance because the interfacial region has to bear up the developing forces at each diamond particle [8]. The existence of a chemical bonding between matrix and diamond in tools is preferred in contrast to the always given mechanical bonding [9–10]. The chemical bonding type results in higher durability, better grinding performance and longer lifetimes [11]. Thus, it is of fundamental interest to gain information about this interfacial area, e.g. if it consists of metal carbides, solid solutions of carbon in metal, or even graphite. Even if there is a big variety of a matrix system today, cobalt is often used as a constituent of diamond tools. This is due to the fact that cobalt offers a good combination of ductility, compatibility, abrasion resistance and hardness associated with a stable embedding of diamonds [8]. However cobalt is an expensive, hazardous and strategic metal; therefore, over the last fifteen years, researchers have focused on methods to develop alloy powders that could serve as an alternative to cobalt or reduce the content of cobalt in diamond tools. Spriano *et al.* [12] worked on several titanium alloys as matrices for diamond tools. In addition, Fe metal can be used for bonding purposes instead of Co as Fe is easy to apply, inexpensive and not a hazardous material [13–16]. The aim of this study was to investigate the effects of addition of Fe into matrix on hardness and wear resistance of diamond reinforced MMCs; to improve the mechanical properties (hardness and especially wear resistance) by adding B_4C.

2. Experimental procedure

Polycrystalline diamond grits of 297–420 μm (LS4750+, LANDS), a B_4C (H.C. Stärck) powder with average particle size less than 10 μm, a carbonyl iron powder with an average particle size less than 75 μm (Baymed Inc.), a cobalt powder with an average particle size of 37 μm (Umicore) and a bronze (Cu-15 wt.% Sn) powder with average particle size 44 μm (Pometon) were selected as precursors for this study. The composition of

*corresponding author; e-mail: kerimemreoksuz@gmail.com

the composite samples denoted as A, B, A-B_4C, B-B_4C and their composition of matrix are given in Table I.

The composition of produced composite samples. TABLE I

Material types	Composition of matrix, [wt.%]
A	[Fe/Co = 2.6]+10 wt.% Bronze
B	[Fe/Co = 1]+10 wt.% Bronze
A-B_4C	[Fe/Co = 2.6]+10 wt% Bronze+0.75 wt.% B_4C
B-B_4C	[Fe/Co = 1]+10 wt% Bronze+0.75 wt.% B_4C

Composite samples having two different compositions with and without B_4C were produced. The concentration of the diamond grits in these composite samples was kept constant and maintained at a concentration of 20% (a concentration of 100% diamond grits was designated as 4.4 carat/cm^3). Fe, Co, Bronze and diamond powders were blended for 45 min in a T_2F turbula mixer with alcohol with 2 wt.% glycerine to obtain a uniform and homogenous mixture. For each composition, the mixture was placed in carbon moulds with dimensions ($24 \times 10 \times 10$ mm^3). After setting the mould, the powder mixture was cold compacted, and the green product in the mould was placed in a sintering machine. The hot zone was evacuated to remove air from the chamber, and sintering then was conducted using the hot press machine (Dr. Fritsch DSP 510 Sinter Machine) under nitrogen. The glycerine was heated up to 500 °C and held for 100 sec, and a brown product was produced and heated up to the sintering temperature. After brown product was obtained at of 500 °C, the composite samples were heated to the selected sintering temperature (1000 °C) under a compression load of 25 MPa and cooled in the sintering machine. Figure 1 shows the sintering regime. The sintering temperature must be maintained below 1150 °C to keep the diamond from reverting to graphite and the tool from losing its cutting capability [17]. Density (ρ) measurements of sintered composites were performed in accordance with Archimedes' principle. Brinell hardness values were measured under a load of 100 kg-f for each sample, and the average hardness values and standard deviation were calculated. A pin-on-disc type of apparatus was employed to evaluate the wear characteristics of MMC's. Wear tests were carried out at RT without lubrication. In wear tests; normal loads on the pin were 10, 25 and 40 N at a constant sliding speed of 1 m s^{-1}, and a constant sliding distance of 60 m for each composite sample. Each test was performed with a fresh SiC papers 180 grits, which is corresponds to ~70 μm. The wear pin was cleaned in acetone prior to and after the wear testing; it was then dried and weighed on a microbalance with 0.1 mg sensitivity. Wear tests were carried out for three samples per unique composition and the average weight loss and standard deviation were calculated.

3. Results and discussion

The hardness values, experimental and theoretical densities of the composites are shown in Table II and the

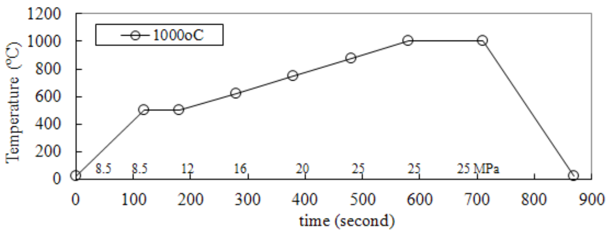


Fig. 1. Applied sintering procedure to the composite specimens.

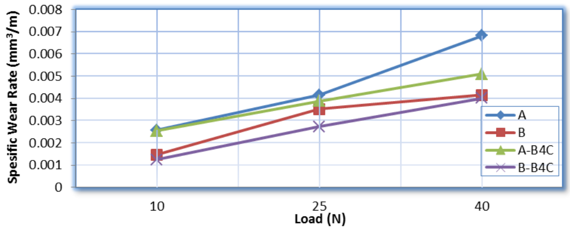


Fig. 2. Specific wear rate vs load curves of the composite samples with and without B_4C.

wear test results are shown in Fig. 2. It was observed that there is a linear increase in hardness and density with increasing Co content (decreasing Fe content). Maximum hardness values were measured from B composition samples with and without B_4C. This is attributed to presence of a Co-Fe solid solution which causes strengthening. A and A-B_4C composite samples have the lowest hardness value.

Hardness values, theoretical and experimental densities of the composites. TABLE II

Material types	Theoretical density [g/cm^3]	Experimental density [g/cm^3]	HB [100 kg-f]
A	8.2	8.05	100 ± 3.3
B	8.408	8.025	101.8 ± 1.5
A-B_4C	8.2	7.816	101.5 ± 2.6
B-B_4C	8.408	7.893	103.5 ± 0.8

Abrasive wear test were conducted to evaluate the wear resistance and mechanism. For the composite sample without B_4C, one can observe increase in weight loss with increasing applied load for each sample. Second observation is increase in weight loss with increasing Fe content in composites. The specific wear rates of the composite specimens A, B, A-B_4C, B-B_4C sintered at 1000 °C under 40 N loads were measured as 0.00683, 0.00415, 0.00511 and 0.0411 mm^3/m, respectively. The weight loss of composite samples under 40 N applied load was measured as 0.002 g for B (45 wt.%Fe-45 wt.%Co), and that is 0.65 times lesser than weight loss for the composite with A (65 wt.%Fe-25 wt.%Co) composition. Similar observations are valid for the composite samples with B_4C. Finally, the composite samples without B_4C have higher weight loss than the composite sample with B_4C

for all the compositions. B_4C contribute to the wear resistance of the composite due to high hardness of B_4C material. Besides the diamond, B_4C can be used as the wear rate controller of the composites used in natural stone sawing. It is observed that wear occurs with abrasive wear mechanism and this result was obtained by other researchers [10–14].

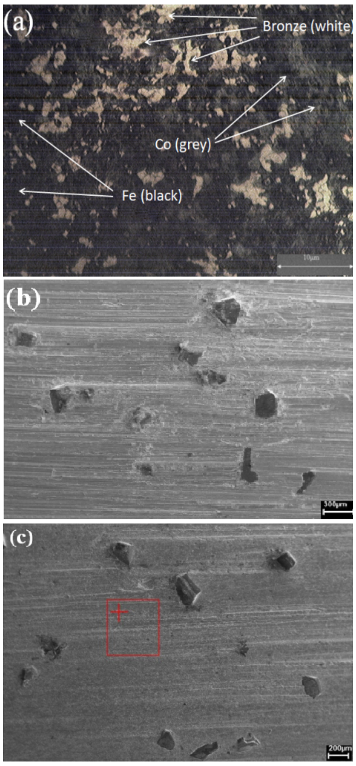
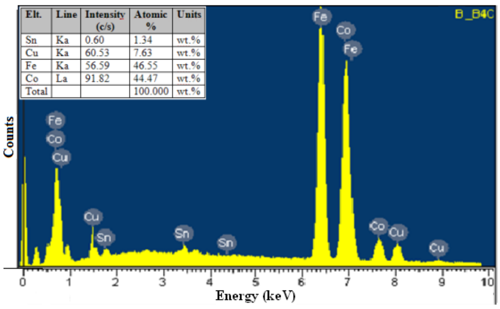


Fig. 3. (a), (b), (c) SEM micrographs of B-B_4C composite.



Elt.	Line	Intensity (c/s)	Atomic %	Units
Sn	Ka	0.60	1.34	wt.%
Cu	Ka	60.53	7.63	wt.%
Fe	Ka	56.59	46.55	wt.%
Co	La	91.82	44.47	wt.%
Total			100.000	wt.%

Fig. 4. EDX analysis of B-B_4C composite.

The microstructure of the composite was examined using an optical microscope and scanning electron microscope. Figure 3a shows the microstructure of the matrix; after etching with the solution of $(NH_4)_2S_2O_3$. The retention of the diamond by the metal matrix is important for determining the mechanical properties (i.e. wear, transverse rupture strength). It is observed that the diamond was not pulled out of the metal matrix for the B-B_4C samples. Figure 3b and 3c shows the general view of diamond in matrix for B-B_4C composite sample. Microstructure observation demonstrates a relatively homogenous distribution in matrix of diamonds. As it is seen in Fig. 3b, that is the evidence of the good bonding between matrix and diamond. The bond strength between matrix and diamond acts an important role in the cutting process. It is desired that matrix must hold the diamond tightly and diamond grits must not fall down from the matrix during the cutting process. Figure 4 shows the EDX compositional pattern of the B-B_4C composite sample.

4. Conclusions

In this experimental study, the effects of Fe and boron carbide (B_4C) additions in Co matrix composites have been investigated. Diamond impregnated Fe-Co matrix composites were produced at 1000 °C, under 25 MPa by PM using hot pressing. It can be concluded that B-B_4C type composite samples can be used in the sawing of natural stone depending on the properties of natural stone. Hardness and wear loss of the produced composites are compared with that of unreinforced composites and better results are obtained in the reinforced composites. Addition of Fe caused decreasing in the hardness of the matrix. It is observed that wear resistance of B_4C reinforced Fe-Co metal matrix composite was greater than that of composite without reinforcement (B_4C). Addition of B_4C contributes to the wear resistance of the composites. B_4C can be used instead of diamond used in the segment design for sawing of natural stone.

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