Friction and Wear Changes of Boron Carbide Cermets Depending on the Structure

L. Kommel*, E. Kimmari

In this work we present the technology features of boron carbide cermet processing. Synergetic dependent the structure condition of cermet and behaviour of specimens weight loss during sliding and slurry testing were studied. The wear mechanism and friction of cermets were investigated.

Keywords: wear, friction, boron carbide cermet, sliding and slurry testing.

1. INTRODUCTION

Boron carbide (B$_4$C) is the hardest ceramic material known in nature after diamond and cubic boron nitride [1]. The boron carbide is excellent hard (HV 45000 MPa) and low density ($d = 2.51$ gr/cm$^3$) material. It has high chemical stability in hostile environment and high resistance to wear by sufficiently higher mechanical strength [2]. The melting temperature of boron carbide is 2450°C. The chemical stability temperature in barium and sodium salts is not higher than at 700°C. At temperature over 1000°C it reacts with chlorides and all non transitions metals and this oxidation by which generated the according brides. It is known, that boron carbide in temperature range at 298 – 2300°C is very chemically attractive with transition metals and as a result formes refractory compounds and carbides.

In works [3 – 4] the manufacturing of super lightweight composites and cermets on base of boron carbide and aluminum alloy was done. For composites manufacturing self-propogating high temperature synthesis (SHS-process) with densification and heat treatment was used. Depending on starting components and processing regimes, it is possible formation in composites of aluminum carbide, boron nitride, boron aluminum carbide, aluminum boron carbide and other chemical refractory compounds [3 – 6]. These formation chemical refractory compounds in binder phase of cermets define their mechanical and tribological properties. Boron carbide based cermets is a metal/ceramic hard material with the interest properties for several tribological applications [6, 7].

2. EXPERIMENTAL

2.1. Specimens manufacturing

The production of wrought cermets consists of many steps, including powder disintegration or attrition milling, their densification during (or after) SHS-processing, heat treatment by different temperatures and environments. The materials for testing were worked out from boron carbide and aluminum alloy powders. At starting the boron carbide has mean grain size in range from 17.2 µm (specimens N1 – N3 and N9) up to 200 nm (specimens N4 – N8). For comparison of test results the tungsten (VK 15-35) and titanium (TH 30B-9) carbides based cermets (specimens N10 and N11) were tested by using identical test parameters. The milled powders of boron carbide and aluminum alloy were mixed by proportion of 50 % and closed in steel capsules. The capsules with mixed powders were heated in furnace by temperature at 850°C up to SHS-process starting. The heat densification of powder was carried out under strength up to 110 – 120 MPs. From these materials polished specimens were worked out with measurements of 6 × 12 × 20 mm. The specimens were heat treated at different surroundings and different temperatures up to at 1500°C.

2.2. Testing

Characterisation of these processed materials included analysis of density, microstructure, grain size, crystallographic texture, micro, Vickers, Rockwell and universal hardness measuring. The structure of cermets was studied on optical (Nikon CX) and scanning electron (JOEL JSM-840 A) microscopes. The mechanical properties of composites on universal hardness tester (Zwick Z 2,5/TS 1 S) were measured.

The weight loss and friction coefficient were measured according to ASTM-B 611-85. The specimens testing were made in dry sliding system of cermet/steel. The testing parameters were accordingly: linear velocity 2.3 m/s, distance up to 8 km and normal force at 150 N. The effect of processing on slurry erosion were carried out during 144 hours in 3.5 % sodium chloride (NaCl) solution.

3. RESULTS

The experimental wear testing results of boron carbide based cermets have shown on Fig. 1. Depending on the cermets density these volume wear rates is very different. The results of friction coefficient measure are shown in Fig. 2.

The cermets of N1 and N2 (Fig. 1) wear rate is higher depending on distance increases. These materials have large grain size (without milling) and have low temperature of heat treatment. The grains of hard phase
have not bonded with soft binder phase. The microhardness of binder phase is minimal, about \( HV = 200 \text{ kg/mm}^2 \). The composite binder phase consists of aluminum alloy without refractory compounds. The cerments (N3 – N8) wear rate decreases with the testing distance increase. These materials were heat treated at higher temperatures and they have a binder phase containing different refractory compounds.

![Graph](image1)

**Fig. 1.** The cerments volume wear rate change

![Graph](image2)

**Fig. 2.** The friction coefficient change

The material friction coefficient distribution is identical to the volume wear rate distribution. The friction coefficient depends on hard phase grain form. During the heat treatment of this hard phase, the boron carbide grain sharp corners change due to dissolution and refractory carbides formation. These changes in microstructure shown in Fig. 3.

![Image](image3)

**Fig. 3.** The microstructure of cerment with changed hard phase grains and formed refractory compounds in binder phase

Depending on the binder phase mechanical properties the wear mechanism by dry sliding is different. These changes of wear mechanism were studied using microscopic investigation of wear surfaces after testing. The steel disc material was soiled on specimen sliding surface and other specimen was taken from the sliding surface of cerment during testing in result of adhesion wear. The specimen testing surface microphotograph (Fig. 4.) showed the adhesion wear mechanism. There are zones with soiled steel disk materials, gains of hard phase, refractory compounds of binder phase and black zones. These zones were formed after tribofilm pull out from cerment sliding surface.

The nanocrystalline hard phase cermet (Specimen N5) has a minimal wear rate and minimal friction coefficient (Fig. 1 and 2).

![Image](image4)

**Fig. 4.** The sliding surface of cermet after testing

The comparison testing of mass wear rate results with tungsten and titanium cerments are shown in Fig. 5.

![Graph](image5)

**Fig. 5.** Effect of structure condition on comparison diagram on mass wear rate of boron-, titanium- and tungsten carbides based manufactured wear resistant hard materials depending on testing distance

The mass wear rate was in range of 0.1 – 0.5 mg/km distance. The titanium carbide cermet had a mass wear rate in range of 0.2 – 0.4 and tungsten carbide cermet up to 0.5 – 1.5 mg/km distance. As shown these results of mass wear rate testing the lightweight boron carbide based cerments maybe used in quality as tribomaterial.

The slurry testing results of this materials are shown in Fig. 6. The minimal loss of weight during 144 hours has titanium carbide based cermet. Little higher loss of weight has boron carbide based cerment after low temperature heat treatment in zirconium oxide environment.

The highest loss of weight during slurry erosion testing has tungsten carbide cermet (Specimen N10). The nanostructured cerments have the mean loss of weight. The cermet (Specimen N9) was manufactured on the base of
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REFERENCES


4. CONCLUSIONS

1. The boron carbide cermet friction coefficient and wear rate have identical distribution.
2. The nanocrystalline boron carbide cermet friction coefficient and wear rate is minimal.
3. The lightweight cermet on boron carbide and boron nitride base has best tribological properties.
4. The comparison test results shows that mass wear rate is minimal for boron carbide based cermet and it is maximal for tungsten carbide cermet.
5. Depending on density of cermets the volume wear rate is opposite.
6. The friction coefficient depends on the hard phase grain and its shape.