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The Formation of Structure and Change of Properties During Heat Treatment of Boron Carbide Composites

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In this work, we present a new method of heat treatment to change structure and properties of boron carbide composites. During self-propagating high temperature synthesis (SHS-process), pressing and heat treatment of composites on base of boron carbide and aluminum alloy refractory compounds with specific properties were formed. These new formed nano- and microstructured refractory compounds change the structure and as a result, mechanical, physical and protective properties of the composites.

Keywords: boron carbide based composites, self-propagating high temperature synthesis, structure and properties.

1. INTRODUCTION

Boron carbide is chemically inert, excellent light-weight and hard technical material [1]. It has high thermal neutrons attenuation factor [2], and high elasticity.

At present time production of the boron carbide composites or cermets is limited, because the boron carbide grains do not wet with metal of binder phase at sintering temperatures. Only by using self-propagating high temperature synthesis (SHS) process, the manufacturing of composites or cermets on base of boron carbide and aluminium alloy powders is possible [3]. The formed structure and as a result, the properties changes are possible only during heat treatment before [4] or after [5] SHS-process.

In this work we study the composites structure formation and properties changes depending on temperature, time and environment of the heat treatment.

2. EXPERIMENTAL

In this work the composites were produced from boron carbide and aluminum alloy powders by self-propagating high temperature synthesis (SHS) with hot pressing and subsequent step-by-step heat treatment under high temperatures up to 1500 °C in different environments and in vacuum. The specimens for testing were produced from the SHS-processed polished billets with dimensions of 6 × 12 × 20 mm and 5 × 6 × 19 mm.

The composite structure was studied by optical (Nikon CX) and scanning electron microscopes (JOEL JSM-840 A). X-ray diffraction analyser (D5005, Bruker AXS) was used for determination of phase composition. The mechanical properties of composites were measured by universal hardness tester (Zwick Z 2,5/TS1S). The Rockwell and Vickers hardness testers were used for hardness testing of composites. For the microhardness testing the "Mikromet-2001" was used. To define yield stress and flexural modulus by three-point, the bend testing on the Instron Corporation Series IX Automated Materials Testing System INSTRON-8516 was used.

3. RESULTS

After SHS-process the microstructure of boron carbide cermet is typical, as for cermets on tungsten or titanium carbide base (Fig. 1. a). This microstructure consists of grains of hard phase and binder phase between these grains. The boron carbide grains have a view of white angular grit. These grains are ambient from boron aluminum carbide thin layers.

Between these grains aluminum alloy is filled as the binder metal. The structure of composite is shown in Fig. 1. a. The chemical composition of this material is shown in Fig. 2. (curve A). Only boron carbide (1), aluminum (2) and graphite (3) can be seen.

After the heat treatment of densified powder at temperatures over 600 °C the only Al_4BC was formed on the boron carbide and aluminum base.

By heat treatment of densified powder at temperature up to 800 °C the substantially free AlB_{12}, $AlB_{12}C_2$ and Al_4C_3 were formed.

After SHS-process and heat treatment at temperature of 1080 °C during 5 – 10 h BN, Al_4C_3 and Al_3BC chemical compounds (Fig. 2., curve B) were formed in boron carbide/aluminum composites.

As result of temperature increase up to 1300 – 1500 °C hard phase carcass from this refractory compounds (Fig. 1, c) was formed.

These compounds were aluminum oxide (Al_2O_3) and aluminum boron carbide ($Al_8B_4C_7$), as shown in Figure 2 (curve D). This structure changes from initial boron carbide aluminum content (a) up to refractory carbides formation (b) and the hard carcass formation (c).

Curve A (initial) corresponds to the heat pressed powders of boron carbide and aluminum alloy; curve B – after SHS-process and heat treatment at temperature 1080 °C during 5 hours; curve C – after heat treatment in vacuum at temperature 1150 °C during 30 minutes; curve D – after dual-temperature heat treatment at 1150 and 1300 – 1500 °C during 15 minutes.

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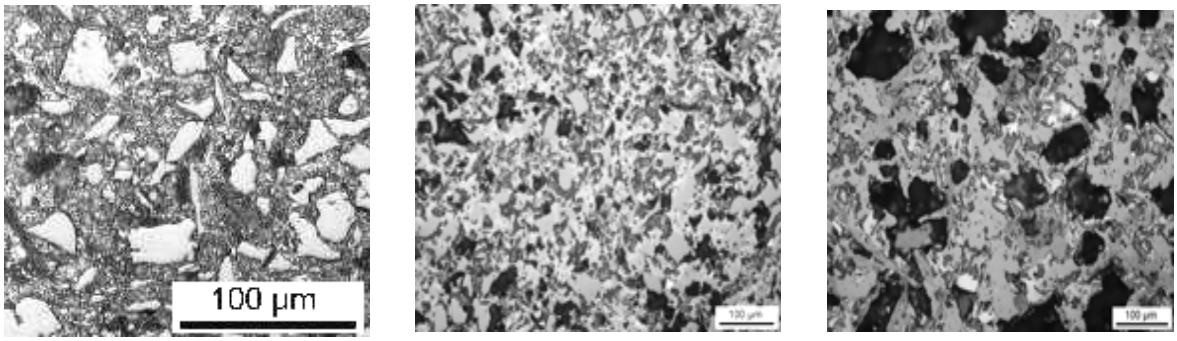

a b c

Fig. 1. View of the microstructures as function of heat treatment temperatures and modes: a – after SHS-process, b and c – after heat treatment at 1150 °C (b) and 1300 – 1500 °C (c)

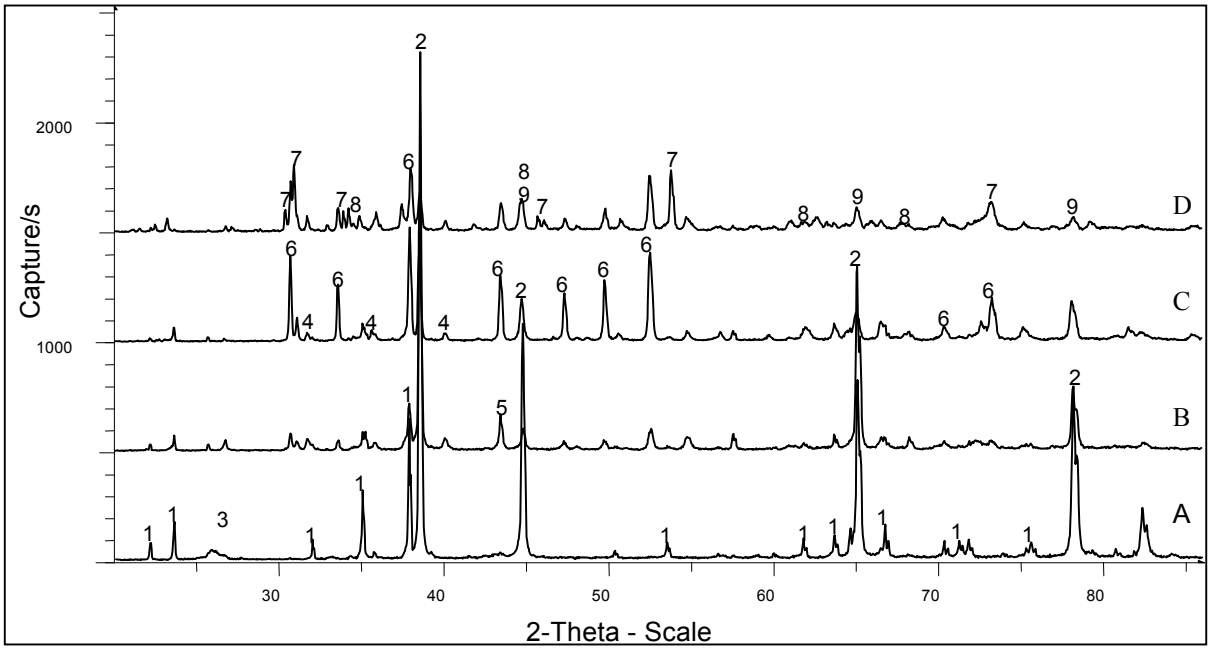

Fig. 2. Changes of the X-ray diffraction patterns of the boron carbide/aluminum alloy composite as a function of temperature and mode of the heat treatment

Chemical elements and refractory compounds numbers are as following: 1 – B_4C, 2 – Al, 3 – C, 4 – Al_4C_3, 5 – BN, 6 – Al_3BC, 7 – $Al_8B_4C_7$, 8 – AlB, 9 – AlN.

The composites with density in range of 2 – 2.5 g/cm^3 have Rockwell hardness in range of *HRA* = 50 – 70 kgf/mm^2 and universal hardness up to $HU_{plast}100 = 5000 \pm 100$ N/mm^2. These results are shown in Fig. 3 – 4.

The Rockwell hardness increases up to 70 HRA at temperature 1150 °C of heat treatment. Up to this temperature the material have no pores (Fig. 1., b). The binder phase consists of refractory compounds without free aluminum content.

The universal hardness is identical with Rockwell hardness dependence. The flexural module of boron carbide cermets, measured by three-point bend test method and indentation (or plastic modulus) have identical character of dependence (Fig. 5 – 7).

The yield stress testing results show, that during temperature increase this parameter decreases from 530 MPa up to 120 MPa at 1350 °C. At this heat treatment the hard phase carcass in cermet was formed. The chemical composition of this material is shown on curve D in Fig. 2. This material consists of aluminum boron, aluminum nitride and boron aluminum carbon.

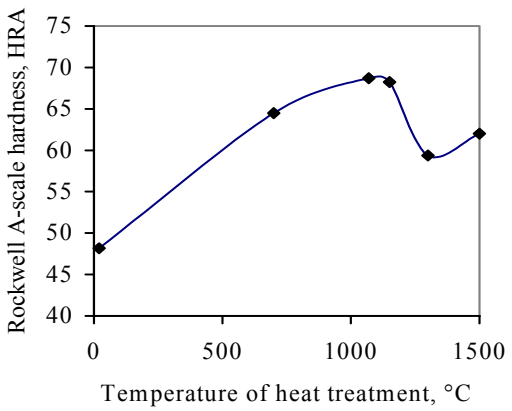

Fig. 3. Rockwell A-scale hardness as function of heat treatment temperature

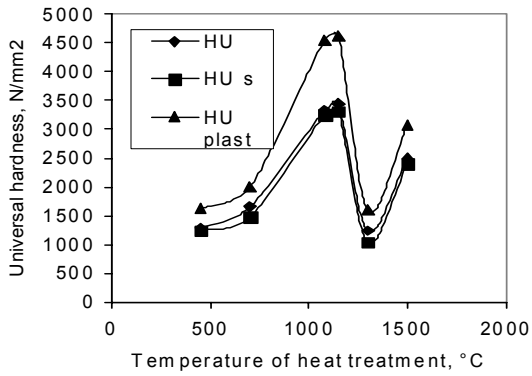

Fig. 4. The universal, plastic and elastic part of hardness changes as function of structure and heat treatment temperature

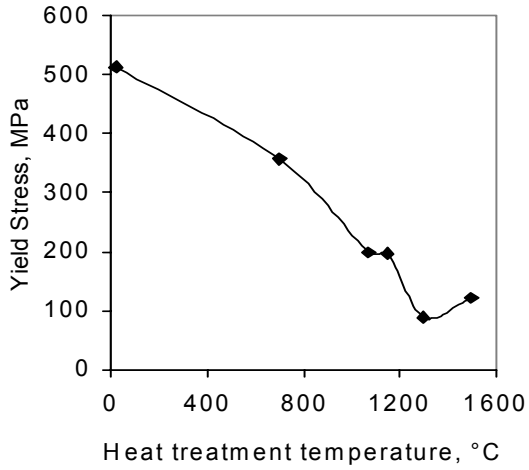

Fig. 5. The yield stress dependence on the heat treatment

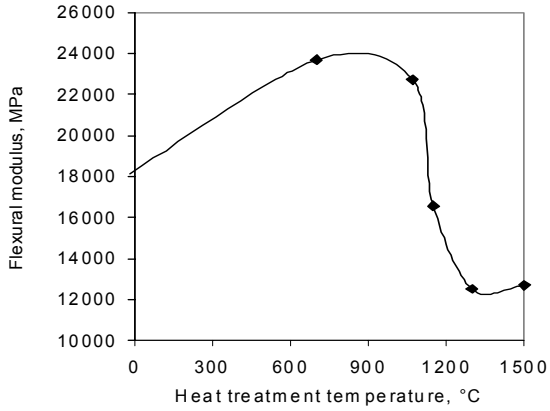

Fig. 6. Flexural modulus variations as function of temperature during heat treatment

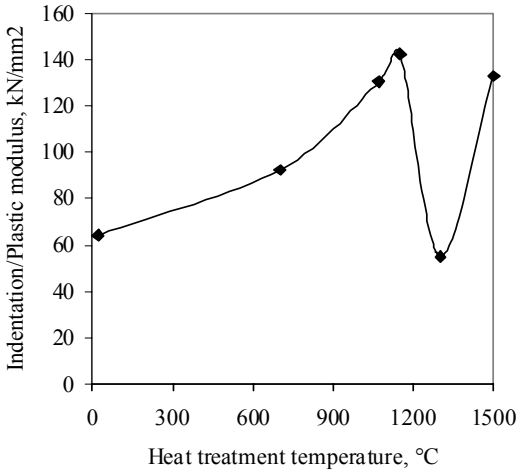

Fig. 7. Indentation or plastic modulus of cermet depending on heat treatment temperature

4. CONCLUSIONS

1. The mechanical, physical, characteristics of developed boron carbide cermet are in synergetic dependence on the structure, of refractory compounds and binder phase status, formed during SHS-process and heat treatment.
2. The cermet also can find application as high-temperature dry sliding bearing material in pairs with Ni-based superalloy.

Acknowledgements

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REFERENCES

1. **Kisly, P. S., Kuzenkova, M. A., Bodnaruk, N. I., Grabchuk, B.L.** The Boron Carbide. *Naukovo Dumka, Kiev* 1988: 216 p.
2. http://ds.dial.pipex.com/jouncaunt/thermal_neutron_attenuation_factors.htm.
3. **Kommel, L. A.** The Method of Metal/ceramic Product Manufacturing and Container for their Manufacturing *USSR Patent* No. 1836190 A3, 1991
4. **Pyzik, A.** Boron Carbide/aluminum Cermets Having Microstructures Tailored by a Post-densification Heat Treatment *US Patent* No. US5298468, 1994.
5. **Kommel, L., Hussainova, I., Kimmari, E.** The Structure and Properties Forming in Boron Carbide/aluminum Composites during Processing. *Advanced Materials & Processes* (in press).