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SINTERING OF HYBRID DIAMOND COMPOSITES WITH CARBIDE-FORMING ADDITIVES

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Abstract. *The effect of carbide-forming additives on the sintering and properties of hybrid diamond polycrystals has been studied. Carbide-forming additives were applied to the CVD diamond surface using magnetron sputtering. It has been established that metallization of CVD diamond plates, which form part of a hybrid diamond composite, with carbide-forming elements such as titanium and iron, increases the strength of the material by up to two times. At the same time, wear resistance is increased by at least 20%. This improvement in operational properties is due to the formation of carbide interlayers at the interface between the CVD diamond and polycrystalline diamond shell, which leads to additional hardening at the interface.*

Key words: *diamond composite, carbide forming additive, high pressures, sintering*

Introduction.

Creating materials for various functional purposes and optimizing their properties to improve their efficiency is a constantly evolving field of science with a high innovation potential. The knowledge gained in this area is essential for basic industries, particularly for mechanical engineering, mining, and oil and gas production. An example of this is rock-cutting tools, which, depending on their properties such as hardness, strength, crack resistance, and wear resistance, significantly impact the cost of production.

For the successful development of modern tool materials, it is crucial to have a detailed understanding of the conditions under which the tool operates. This knowledge will allow us to ensure properties such as resistance, cutting speed, and reduced tool wear due to high hardness, increased fracture toughness, and high compressive strength. These properties will ultimately extend the service life of the tool and improve its economic efficiency.

Since the 1960s, there has been a steady increase in interest in the use of diamonds for tools that operate in particularly challenging conditions. At the same time, significant efforts have been made to develop technologies for producing working elements from polycrystalline diamonds. This is because the distinguishing feature of polycrystalline diamonds, as opposed to single diamond crystals, is the anisotropy of their physical and mechanical properties.

Polycrystals are produced by sintering diamond micropowders under high pressure and temperature conditions. The use of this high-pressure sintering technique is associated with the need for a continuous network of diamond particles, as it results in the formation of strong diamond-diamond bonds and a dense, finely dispersed granular structure.

The main factor in the formation of these diamond-diamond bonds is the plastic deformation of the diamond particles. Research has shown that effective consolidation of the particles through plastic deformation requires high pressure and temperatures that correspond to the thermodynamic stability of diamond [1].

One of the most common methods for sintering diamond powder at high pressures and temperatures is to use additives that activate the sintering process within the charge. This results in the formation of a diamond polycrystalline structure, which has a second phase present in its composition, making it a composite material.

The effectiveness of this process is reduced when using metal and alloy additives, as they have a lower heat resistance compared to other carbon solvents. To overcome this issue, it is important to exclude metal components from the polycrystalline material that can initiate the reverse transformation of diamond into graphite. Additionally, the use of micro- and nanopowders based on refractory compounds such as carbides, nitrides, and borides can activate the sintering process, significantly improving the physical and mechanical properties of the sintered composite and polycrystalline diamond materials [2].

The purpose of this study is to investigate the impact of carbide-forming additives on the sintering process and properties of hybrid diamond composite materials.

Main text.

Currently, a new approach to creating superhard materials is being actively developed: polycrystalline superhard composite materials with a hybrid diamond base [3]. In particular, a superhard material with a hybrid diamond base, known as "hybridite", has been developed. It is a plate of monocrystalline or polycrystalline chemical vapor deposition (CVD) diamond surrounded by a shell of diamond composite heat-resistant material. This is shown in Figure 1.

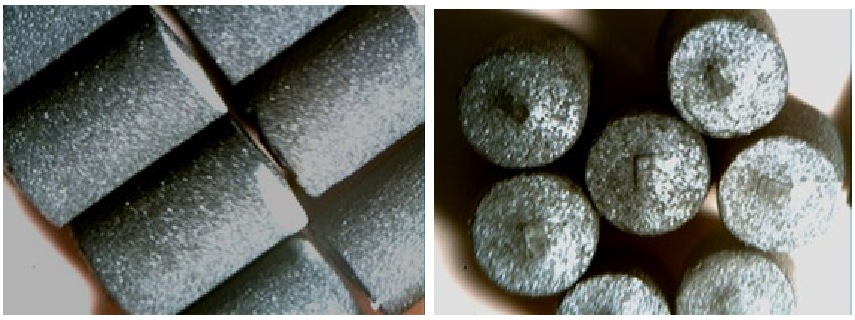


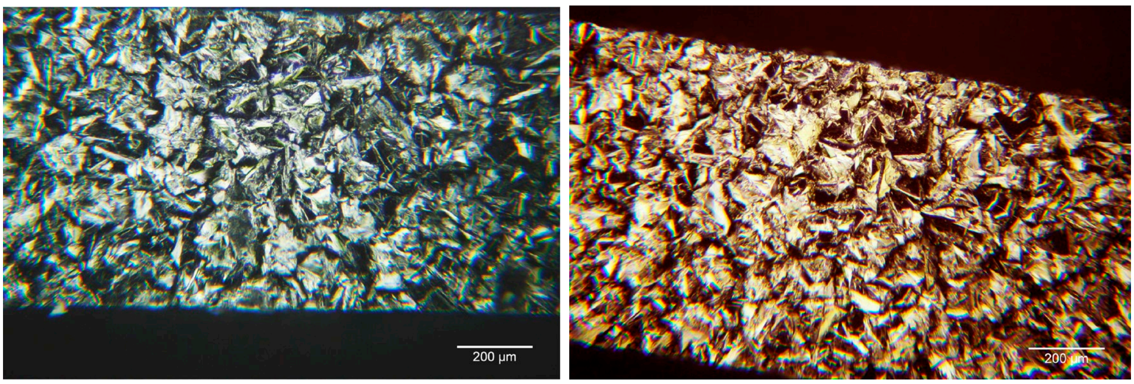
Figure 1 – The appearance of a hybrid polycrystalline diamond material.

Thus, the material combines the unique physical, mechanical, and thermal characteristics of CVD diamond with the high hardness, strength, and heat resistance of a polycrystalline shell made from static synthesis diamonds. A characteristic feature of this hybrid material is the presence of a continuous, rigid framework of fused diamond grains that are formed in the region where it is thermodynamically stable. These grains, which make up the framework, are actually single crystals of diamond that have unique physical, mechanical, and thermal properties. The degree to which these properties manifest themselves in a polycrystal depends on the strength of the diamond-diamond bond.

Experimental studies have shown that there is no chemical bond between the CVD diamond and the polycrystalline diamond shell in the hybrid material. Instead, these two components are connected through a silicon carbide interlayer. The strength of this connection determines the physical, mechanical, and operational properties of the entire hybrid material. Therefore, it is essential to study the effect of additives that can form carbides on the sintering process and the properties of the diamond-polycrystal hybrid. Carbide-forming additives, such as transition metals from the IVB-VIB groups (Ti, Cr, V, Mo, Zr, Fe, and W), can react with carbon atoms and form metallic carbides, which act as additional bonding links between the CVD diamond and the polycrystal shell.

One effective method for applying a carbide-forming additive to the CVD diamond surface is metallization. This process involves depositing a thin layer of metal onto the diamond surface, which can then react with the carbide-forming elements to form a strong bond. This approach has the potential to improve the overall performance and durability of the hybrid diamond material.

There are several methods of metallization, including physical deposition from the gas phase, chemical deposition from the gas phase, vacuum slow deposition from the gas phase, the molten salt method, magnetron sputtering, and laser cladding [4]. In this study, we used a carbide-forming additive to apply a coating to the surface of a magnetron-sputtered CVD diamond [5]. The sputtering was done using a VUP-5M vacuum universal post, and titanium and iron were used as carbide-forming additives. The coating thickness was no more than 100 nanometers. Figure 2 shows a CVD diamond plate before and after titanium metallization.



a **b**

Figure 2 – The appearance of the surface of a chemical vapor deposition (CVD) diamond plate: a – initial surface; b – after applying a titanium coating.

The hybrid diamond composite was sintered under a pressure of 7.0-7.5 GPa and at a temperature of 1250-1350 °C, following a two-step process [6]. The sintering process took approximately 100 seconds.

Figure 3 illustrates the fracture of the sintered hybrid material.

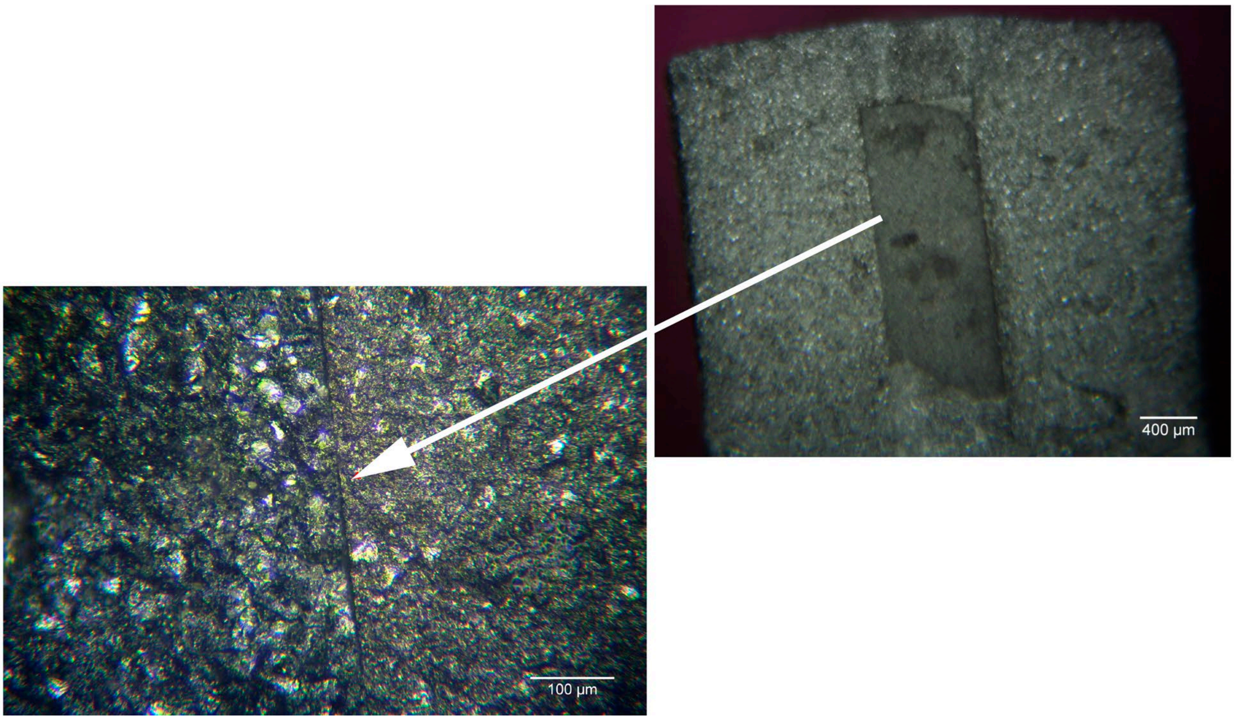


Figure 3 – A split sample of a sintered hybrid diamond material with a titanium-coated CVD diamond.

Comparative tests of the samples for compressive strength showed that the average strength of the sample with a titanium-coated CVD diamond plate was 2180 ± 224 MPa, while the average strength of CVD diamond samples without metallization was 1815 ± 98 MPa. This indicates that pre-metallization of the CVD diamond plate resulted in a 20% increase in strength of the hybrid diamond composite.

The improvement in physical and mechanical properties is attributed to the formation of a TiC layer at the interface between CVD diamonds and the polycrystalline diamond shell. This layer contributes to additional hardening at the interface, leading to enhanced strength.

This conclusion is supported by the results of a comparative test on manufactured samples of the IX category sandstone in terms of drilling ability. It was found that the composite polycrystalline material with a titanium-coated CVD (chemical vapor deposition) diamond plate is more than twice as wear-resistant as a material with a non-metallized CVD diamond plate. Similar results were obtained for the hybrid composite version with an iron-coated CVD diamond plate.

Summary and conclusions.

As a result of studying the effect of carbide-forming additives on the sintering process and properties of hybrid diamond polycrystals, the following was established:

1. The magnetron sputtering method can successfully be used for metallizing the diamond surface with carbide forming elements.

2. The metallization of CVD diamond plates with carbide-forming elements such as titanium and iron, which are part of a hybrid diamond composite, leads to an increase in material strength up to two times, while wear resistance increases by at least 20%.

3. The improvement of operational properties is due to the formation of carbide layers at the interface between CVD diamond and polycrystalline diamond shells, which leads to additional hardening at this interface.

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