Development of binding based on b-n-ti-al system compounds for creating a composite instrumental material for a final raining of railway parts

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Abstract. Studying methods for producing new composite materials based on compounds of the B-N-Al-Ti system using high pressure (up to 5 GPa) and temperatures (up to 1800 K), studying their physical characteristics to create tool materials based on them. Studying the prospects for the further development of research and the practical use of the results.

1 Introduction

The current level of technology development requires the use of new materials. To create units, mechanisms, and aggregates operating for a long time at high speeds and increased loads, it is necessary to use materials with improved characteristics (strength, hardness, wear resistance, and others). Such materials include cubic boron nitride - the second in hardness after diamond; it surpasses it in chemical, thermal, and radiation resistance. However, obtaining cubic boron nitride is associated with the use of high pressures and temperatures (5-8 GPa and 1500-2200 °C). In addition, the production of single crystals is associated with additional technological difficulties. Therefore, to simplify the manufacture of tools, the processes of sintering cubic boron nitride powders with a binder are used. Recently, the attention of researchers all over the world has been focused on the use of titanium- and aluminum-containing bonds.

The obtained fundamental knowledge will allow to develop and implement at the production site of the State Scientific and Research Center of the National Academy of Sciences of Belarus for Materials Science technologies to produce tools using the developed bundle. The manufactured products will make the products of specialized enterprises of the Republic of Belarus and the Republic of Uzbekistan more competitive. Simultaneously with this fact, the issues of import substitution and export orientation will be resolved. Established marketing will help modernize and expand the existing infrastructure and attract Belarusian and Uzbek toolmakers to subcontracts, creating jobs. All these steps will help to revive the instrumental directions of the two countries.

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2 Methods.

Investigation of methods for obtaining new composite materials based on compounds of the B-N-Al-Ti system using high pressure (up to 5 GPa) and temperatures (up to 1800 K), investigation of their physical characteristics for the creation of instrumental materials on their basis are described below.

When exposed to high pressures of 5.5 GPa and temperatures of 1750-1800 °C, monocrystalline powder superhard materials are formed with specified characteristics depending on their further use (cutting, grinding, or polishing tools).

Nano- and micro-structure of cubic boron nitride is used to create composite materials for instrumental purposes, formed under thermobaric action.

A pilot experiment for the synthesis of composite materials was carried out at pressures of 5 GPa and temperatures up to 1500 °C. The installation for the synthesis of BNc at high pressure and temperature includes a hydraulic press up to 137 A, a high-pressure apparatus (AHP), a power transformer for electric heating of the reaction volume of the high-pressure chamber, and an OPTRON synthesis programmer. The synthesis was carried out in an HPD with hard-alloy matrices of the "anvil with a hole" type (Figure 1).

Fig. 1. High-pressure device for the synthesis of superhard materials

1 are carbide dies with a container and a heating element; 2 are steel supporting rings; 3 are carbide base plates with supporting rings; 4 is housing for water cooling (arrows indicate the direction of water inlet and outlet).

In the reaction cell of the HPA, as a rule, there is an uneven distribution of pressure over the volume. To study the real pressure distribution in the cell of an apparatus of the "anvil with a hole" type, the method of two simultaneously operating pressure sensors is successfully used. One of the sensors (zero) is installed in each experiment in a certain position, and the second (wandering) is placed at different points of the reaction volume. This allows the sensor signals to be distinguished by the magnitude of the jump in electrical resistance. According to the readings of these two sensors, the accuracy of determining the difference in pressure values is ± 0.01 GPa.

The pressure gradient from the zero gauge to the center of the cell in graphite reaches 0.75 GPa / mm. Considering the degree of compression, the real gradient is estimated to be over 0.1 GPa / mm.

The reaction mixture for synthesis, consisting of powders, was stirred for 20 h in a mixer with an offset axis. Then, under a pressure of 0.25 GPa, cylindrical tablets with a diameter of 10 and a height of 2 mm were pressed from the mixture in a steel mold at room

temperature and placed in a composite heater pressed from a charge consisting of graphite and BN_g, located in a high-pressure chamber, after what the synthesis was carried out.

Fig. 2. High-pressure apparatus DO 137A.

The synthesis was carried out at a pressure of 5 GPa (taking into account the thermal pressure increase equal to ~ 0.8 GPa) and temperatures of 1670-1910 K in high-pressure carbide chambers of the "anvil with a hole" type in containers made of lithographic stone. With the given synthesis parameters, 5 identical experiments were carried out.

Phase formation studies were carried out using DRON-3 and DRON-3 M diffractometers in Cr-K α - and Cu-K α -radiation at room temperature. A graphite monochromator was used to cut off the K β radiation components. The scanning step was no more than 0.03 degrees; the exposure time was no less than 5 seconds. The data was recorded automatically. The crystal structure studies were carried out by the Rietveld full-profile analysis of X-ray structural data. The spectra were refined using the FullProf software package.

The samples of the Al-Ti system were obtained from the elementary components Al and Ti (ratio 50: 50% by mass) at a pressure of 5 GPa (taking into account the thermal pressure increase equal to ~ 0.8 GPa) and at a temperature of 1500°C in high-temperature carbide chambers. Pressure type "anvil with a hole" in containers made of lithographic stone. The selected synthesis conditions make it possible to obtain solid solutions of the specified system with a high degree of phase purity.

Fig. 3. X-ray diffraction spectra of Al-Ti system compounds obtained at a high pressure of 5.0 GPa from elementary components at a temperature of 1400 °C

The X-ray diffraction data obtained immediately after the synthesis of compounds of the Al-Ti system at a high pressure of 5.0 GPa and at a temperature of 1400 °C indicate the presence of the AlTi phase. AlTi - has a tetragonal structure with crystal lattice parameters $a = 4.0050 \text{ \AA}$, $c = 4.0700 \text{ \AA}$, $a / b = 1.0000$ $b / c = 0.9840$ $c / a = 1.0162$. The diffractograms were refined in a single-phase model using the space group $P4 / mmm$ (123).

Samples of the Al-BN system were obtained from elemental Al and the hexagonal modification of the BN compound (in the ratio Al: BN = 0.1: 1 and Al: BN = 0.2: 1 by mass) under a high pressure equal to 5.0 GPa and at a temperature of 2500 °C with a duration synthesis 3 minutes in high-pressure carbide chambers of the "anvil with a hole" type in containers made of lithographic stone. The duration of the synthesis was established experimentally. The selected synthesis conditions make it possible to obtain compounds of the specified system with a high degree of phase purity.

The X-ray diffraction data (Figure 4-5) of the obtained samples of the Al-BN system indicate that the AlN phase is formed in the samples when exposed to high pressure of 5.0 GPa and at a temperature of 2500 °C. Along with the AlN phase, the samples contain other binary (Al_xB_y) compounds of the Al-BN system. This is due to the non-stoichiometric ratio of the initial charge. The obtained compound AlN (Aluminum Nitride) - has a hexagonal structure with crystal lattice parameters $a = 3.1130 \text{ \AA}$, $c = 4.9810 \text{ \AA}$. The diffractograms were refined in a single-phase model using the space group $P 6_3 / m c$ (186).

Fig. 4. X-ray phase analysis of the X-ray diffraction spectra of the obtained samples of the Al-BN system in the stoichiometric ratio Al: BN = 0.1: 1 under high pressure of 5.0 GPa at a temperature of 2500 °C with a synthesis duration of 3 minutes

Fig.5. X-ray phase analysis of the X-ray diffraction spectra of the obtained samples of the Al-BN system in the stoichiometric experiment Al: BN = 0.2: 1 under high pressure of 5.0 GPa at a temperature of 2500 °C with a synthesis duration of 3 minutes

Figure 6 shows the effect of the concentration of the initial elements (namely, aluminum) in the charge on the course of chemical reactions in the sample and the reactions' final products.

Fig. 6. X-ray phase analysis of the X-ray diffraction spectra of the obtained samples of the Al-BN system under high pressure of 5.0 GPa at a temperature of 2500 °C with a synthesis duration of 3 minutes
(a - stoichiometric ratio Al: BN = 0.1: 1; b - stoichiometric ratio Al: BN = 0.2: 1)

Fig. 7. microstructure of cBN samples, sintered at a pressure of 8 GPa

Table 1. Mechanical properties of composite materials based on cubic boron nitride.

№	Name	Value	
1	Hardness	30-45	GPa
2	Crack resistance	12-16	MPa•m ^{1/2}
3	Resistance when turning hardened steels (HRC 52-54)	60	min.
4	Grain size	5-30	mcm
5	Depth of cut up to	0,5	mm
6	Feed	0,05 - 0,15	mm / tur.
7	Cutting speed	200 – 125	m / min.

Fig. 8. Obtained high-pressure synthesis samples (without machining)

Experimental studies of the cutting properties of cutters based on B-N-Al-Ti system joints were carried out at the Tashkent Diesel Locomotive Repair Plant and the Tashkent Foundry and Mechanical Plant. The studies were carried out by changing the cutting tool operating mode parameters during the finishing of parts.

At the "Tashkent Diesel Locomotive Repair Plant", the shaft Ø 57 mm of a blower made of steel grade 12XN3A with a hardness of 56 HRC, with the parameters of the cutter operating mode: cutting feed 0.05 mm / rev, cutting depth 0.1 mm, cutting speed 285 m / min. The working time of the cutter was 88 minutes (Figure 9).

Fig. 9. Turning a shaft $\varnothing$ 57mm from steel grade 12XN3A with a cutter feed of 0.05 mm / rev and a cutting speed of 285 m / min.

External longitudinal turning of a shaft $\varnothing$ 57 mm was carried out with the following mode parameters: tool feed 0.15 mm / rev, cutting depth 0.1 mm, cutting speed 229.1 m / min. The working time of the cutter was 82 minutes (Figure 10).

Fig. 10. External longitudinal turning of a shaft $\varnothing$ 57mm from steel grade 12XN3A cutter feed 0.15 mm / rev and cutting speed 229.1 m / min.

Also, impact tests were carried out on a shaft $\varnothing$ 60 mm of a blower with a length of the grinded surface of 70 mm made of steel grade 12XH3A, with a hardness of 56 HRC. Shaft turning mode parameters: cutter feed 0.05 - 0.1 - 0.15 mm / rev, cutting depth up to 0.5 mm, cutting speed 125 - 200 m / min. The working time of the cutter until complete wear was 15-30 minutes (Figure 11). According to the tests' results on the processing of toothed surfaces, the following turning mode is recommended: cutting feed 0.05 mm / rev, cutting depth up to 0.1 mm, cutting speed 125 m / min.

Fig. 11. Machining by impact on the shaft $\varnothing 60$ with the length of the turned toothed surface 70 mm made of steel grade 12XN3A

At the DP "Tashkent Foundry and Mechanical Plant" when turning parts made of steel grade 5XNM with hardness > 52 HRC with the parameters of the cutter operating mode: cutter feed 0.05 - 0.1 - 0.15 mm / rev, cutting depth up to 0.5 mm, cutting speed 242.1 - 210.7 - 194.3 m / min.

Fig. 12. Shaft turning $\varnothing 100$ mm from steel grade 5XNM

The experiments carried out showed that, subject to the cutting conditions, the working time of the cutters was 78 - 88 minutes (Figure 12).

4 Conclusions

The obtained composite compounds are a prerequisite for creating a binder based on the Ti-Al system for specific industry tasks.

Based on several connections of the system, changing the composition, and not significantly adjusting the technological process, it is possible to quickly obtain instrumental composite materials of various directions.

Several mechanical tests have been carried out on various grades of steel. At the same time, the working time of the cutters (durability) was 78 - 88 minutes.

Experimental studies of cutting properties of cutters based on B-N-Al-Ti system joints have been carried out. Recommendations on rational conditions and modes of cutting tools using superhard composite tool materials have been developed.

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