Effect of tungsten nanoparticles on interaction of Sn-Cu-Co metallic matrices with diamond

A V Ozolin, E G Sokolov and D A Golius

Kuban State Technological University, 2, Moskovskaya St., Krasnodar, 350072, Russia

E-mail: ozolinml@yandex.ru

Abstract. The effect of tungsten nanoparticles on interaction of sintered Sn-Cu-Co metallic matrices with diamond has been studied. Nanoparticles were obtained by grinding standard tungsten powder in a planetary-centrifugal mill. Commercially pure tin, copper, and cobalt powders were mixed with synthetic diamonds and the milled tungsten. Samples were shaped by static pressing in a mold and sintered in vacuum at 820°C. The sintered samples were subjected to static compression test, and hardness of the metallic matrices was measured. The structure of fractures and distribution of the elements over them were explored by the SEM and energy dispersive X-ray microanalysis methods. It has been determined that introducing tungsten nanoparticles into the composite material contributes to dispersion hardening of the metallic matrix and higher strength of its adhesion to diamond.

1. Introduction
Diamond abrasive tools with metallic matrices are widely used in construction and mechanical engineering industries. One of the principal technologies for obtaining diamond abrasive tools is powder metallurgy. Using it, diamond cutting and grinding wheels, drill bits, and other tools are manufactured. Operational properties of such tools depend on physical and mechanic properties of the metallic matrices and the strength of diamond-to-matrix adhesion.

An efficient method for improving physical and mechanic properties of composite materials with metallic matrices is to introduce nanosized particles into them [1-6]. For this purpose, particles of metals, oxides, carbon materials, etc. are used [2, 3]. The effect of nanoparticles on the structure and properties of composite materials is associated with several causes. The presence of distributed finely dispersed particles in the material leads to hardening under the Orowan mechanism [2]. In sintering of some materials, finely dispersed high-melting particles play the part of crystallization centers, which ensures the formation of a fine-grained structure contributing to improvement of mechanical properties [6]. According to works of RAS academian I. F. Obraztsov’s school and some other researchers [5, 8, 9], nanosized particles present in the composite matrix have an essential effect on properties of the interfacial layer. This phenomenon allows scaling up physical and mechanic properties of composite materials massively.

In a number of works, it is demonstrated that introducing nanosized additives allows significantly improving operational properties of diamond metallic composite materials [6, 10-15] used for abrasive tools. The positive effect described in these works is achieved by enhancing mechanic properties of the metallic binder of the composite material mostly under the Orowan mechanism.
The contemporary studies show that nanoparticles in diamond-containing composite materials influence interfacial interaction. In particular, in work [14] it has been found that nanosized particles of tungsten carbide influence the interaction of cobalt and iron micro-powders with diamond grains: they separate these particles and thus block catalytic graphitization of diamond. In work [15], it is demonstrated that modification of the Next100 metallic matrix with tungsten carbide nanoparticles provides stronger fixation of boron nitride crystals in the binder.

At present, there are almost no information in literature about the effect the size of finely dispersed high-melting particles has on adhesion activity of the liquid phase to diamond in sintering of composite materials. The effect of finely dispersed high-melting particles on the formation of structure of metallic binders in liquid phase sintering and, in particular, on the structure and properties of interfacial layers, is studied little, too. However, findings of the above research works give grounds for assuming that the liquid phase containing finely dispersed particles features a higher adhesion activity to diamond. They also make possible the hypothesis about better strength properties of the resulting diamond-containing composite material at the expense of modified properties of interfacial layers in its structure.

The objective of this work is to study the effect of tungsten nanoparticles on the interaction of the Sn-Cu-Co metallic matrices with diamond.

2. Materials and methods

For preparation of the samples, commercially pure metal powders were mixed at the following proportion, % (wt.): 20 of Sn, 43 of Cu, 30 of Co, and 7 of W. The authors used tungsten of grade W16,5 (TU 48-19-417-8) which they grounded in a planetary-centrifugal mill. The technology and ball milling modes were used as described in work [16]. A part of the samples were prepared with ground tungsten (particle size of 25 nm–0.8 µm), the other part – with non-ground tungsten (particle size of 19–24 µm). Into the resulting mixtures, the SDB1065 diamonds (grain fineness – 50/60 mesh) were added at the quantity of 25% of volume of the metal powders. The samples of 10 mm diameter and 25 mm height were compacted by static pressing in a mold and sintered in vacuum at 820°C for 20 min exposure time. The sintered samples were then subjected to static compression test. Hardness of the matrices was measured by the Rockwell method, scale "B". The fracture structure of the samples, as well as distribution of elements in them were studied by methods of scanning electron microscopy and energy dispersive X-ray microanalysis using the EVO HD 15 (Zeiss) scanning electron microscope.

3. Results and discussion

With the said proportion of the components, the sintered matrices consist of the following phases: cobalt and tungsten particles, solid solution of tin in copper (Cu), and intermetallic compound Cu₃Sn [17]. Sintering of the matrices was accompanied by the formation of a considerable amount of the liquid phase which was crystallized as solid solution (Cu) and intermetallic compound Cu₃Sn during the subsequent cooling down [18]. Particles of cobalt and tungsten remained in the solid state during sintering. After sintering, tungsten nanoparticles were distributed within copper and tin phases mainly, with a certain part of them being inside cobalt particles.

The study of the external surface of the sintered samples has shown that the binders containing ground tungsten wet and cover the diamond grains better (figure 1). Nanoparticles of tungsten distributed in the liquid phase feature a high surface energy, which ensures more intensive chemical interaction of the liquid phase with the surface of diamond.
Figure 1. Surfaces of sintered composites: (a) containing tungsten particles sized 1–8 µm; (b) containing tungsten particles sized 25 nm–0.8 µm.

The hardness of the matrix containing non-ground tungsten amounts to 96–98 HRB. The binder with ground tungsten features a higher hardness of 103–105 HRB, which is apparently explained by dispersion hardening according to the Orowan mechanism. Under static compression, the samples were deteriorated by brittle fracture, spalling along inclined and longitudinal planes. So, compressive strength of the samples containing non-ground tungsten is 206 MPa, that of the samples with ground tungsten – 243 MPa.

Figure 2 shows fractures of diamond-containing composite materials sintered with non-ground and ground tungsten, respectively. In both cases, there are particles of the metallic matrix on the surface of diamonds, which gives evidence about strong adhesion of the matrix to diamond. Destruction took place not only along the diamond-matrix interface, but also along the matrix itself.

Figure 2. Elements distribution over fractures of composites containing tungsten particles sized (a) 19–24 µm and (b) 25 nm–0.8 µm.

In figure 2a, the residues of matrix substance on diamond grains are copper and tin phases (colored green) and individual cobalt particles (colored red). In figure 2b, alongside the matrix substance residues of similar composition, one can also observe finely dispersed tungsten particles sintered to the surface of diamond. It can be seen that the size of cobalt particles is different in these materials: in the material with non-ground tungsten, it is 9–15 µm, and in the one with ground tungsten – 3–10 µm. In sintering,
tungsten nanoparticles prevent recrystallization of cobalt through the liquid phase and growth of cobalt particles [19]. Owing to dispersion and uniform distribution of adhesion active tungsten and cobalt particles, a large area of their contact with the surface of diamond is achieved.

4. Conclusion
Thus, introducing tungsten nanoparticles into the composite material contributes to dispersion hardening of the metallic matrix and higher strength of its adhesion to diamond.

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