Chemical deposition of nickel with inclusion of ultradispersed diamonds

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In this paper the state-of-the-art technology of deposition of diamond–nickel coatings on synthetic diamond surfaces is described. Owing to the presence of nanodiamond particles, the coating is extremely hard and can be effectively used when manufacturing superabrasive tools.

Keywords: coating, diamond wheel, grinding, nanodiamond, ultradispersed diamond

1. Introduction

Many scientists are inclined to believe that in the XXI century nanotechnologies will have an impact upon the economic and social life of mankind, will open new possibilities and will allow improvements in the classical approaches to manufacturing. The set of techniques or procedures based on manipulating separate atoms and molecules at the scale from 1 to 100 nm is consensually called nanotechnology. New materials created with nanotechnologies promise to achieve breakthroughs in manufacturing industry, the IT sphere, medicine, the design of precision devices, etc. Ultradispersed diamond (UDD) is a brilliant example of a modern nanomaterial (the term "nanodiamond" is generally accepted internationally).

Diamond nanopowders have unique physical and chemical properties, in particular high surface energy and adsorption activity, a large specific surface area, various functional groups on a surface, etc.[1] Synthesis of diamonds by the method of detonation of explosives with an oxygen deficiency is one of the most interesting and promising directions in the field of

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[1] Gogotski, Y. (ed.). *Nanomaterials Handbook*. pp. 204 ff. Taylor & Francis (2006).

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diamond nanopowder production.[2] Nowadays diamond nanopowders are widely used in many branches of industry. It is especially interesting and promising to apply ultradispersed diamonds for the improvement of the physicomechanical properties of diamond grinding tools.[3]

2. Principle

The diamond abrasive tool is nowadays one of the most effective means to machine metals, synthetic materials (plastics) and minerals (stone, marble, granite, etc.). Nickel coatings deposited on diamond emery powders have been used to appreciably increase the working capacity of diamond abrasive tools due to the modification of their structure.[4, 5]

The most widespread among the methods of generation of nickel coatings is chemical reduction of nickel from an aqueous solution as it allows coatings with the highest yield, the best operating performance, the lowest cost and a very wide range of superior physicomechanical properties (roughness, hardness, abrasive wear resistance, etc.) to be obtained.[6]

However, evidence is now available of the possibility of further considerable improvements of the properties of such coatings due to supplementary additives and through the deposition of new composite coatings, which differ advantageously in their physicomechanical properties from purely nickel coatings. One should pay special attention to chemically reduced nickel coatings with the inclusion of ultradispersed diamonds (Figure 1).

a b c

Figure 1. Nanodiamonds made by dynamic synthesis, in powder form (a) and in the form of an unstable (left) and stable (right) water suspension (b,c).[2]

The composite coatings, incorporating UDD, have significantly improved performance compared with traditional nickel coatings; namely, they have increased strength, wear

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[2] Danilenko, V.V. Synthesis and sintering of diamond by explosion. *Energoatomizdat* **272** (2003) 135–142.

[3] Kulakova, I.I. Chemical properties of nanodiamond. In: J. Lee and N. Novikov (eds), *Innovative Superhard Materials and Sustainable Coatings for Advanced Manufacturing*, pp. 365–368. Springer (2005).

[4] Greene, K., Egan, D., Kelly, S., Nailer, S. and Melody, S. Metal coatings on synthetic diamond and their application areas. *Industrial Diamond Review* **66** (2006) 57–65.

[5] Egan, D. and Engels, J.A. The use of coated diamonds in diamond impregnated tools. *Industrial Diamond Review* **64** (2004) 34–38.

[6] Vyshenkov, S.A. Chemical and electrochemical deposition of metal coatings ways. In: *Mechanical Engineering*, pp. 103–119. Moscow: Vysshaya Shkola (1975).

resistance, microhardness, antiadhesive and antifriction properties (i.e., the coefficient of friction is diminished), load-carrying capacity, heat resistance, etc. The UDD particles, as opposed to the usual finely dispersed powder fillers, are not a filler agent but a specific structure-forming material.

Nanodiamonds have a complex set of unique properties, which differentiates them from both known filling agents and known carbon materials. The ultradispersed diamonds have very small sizes (4–6 nm),[7] their shape is close to oval or spherical (without cusps or branches; hence the nanodiamonds do not exceed the bounds of a surface of cutting edges), they have a very large specific surface (up to 450 m^2) and a high surface energy.

The UDD particles have a complex structure:[8] a nucleus of classical cubic diamond and a carbon coat around the nucleus with a transition to Roentgen-amorphous structures of carbon with a thickness of 4–10 ångström (Figure 2). This coat, consisting of sp^2-hybridized atoms of carbon, is nonhomogeneous according to the criterion of the degree of structural order of fragments. The surface layer, which contains heteroatoms in addition to the atoms of carbon, is saturated by a wide spectrum of various, mainly oxygen-bearing functional groups. Thus, the nondiamond components of the pure UDD are not impurities, but they are the organic components of the product formed by the detonation of carbon, substantially defining the special properties of the surface.

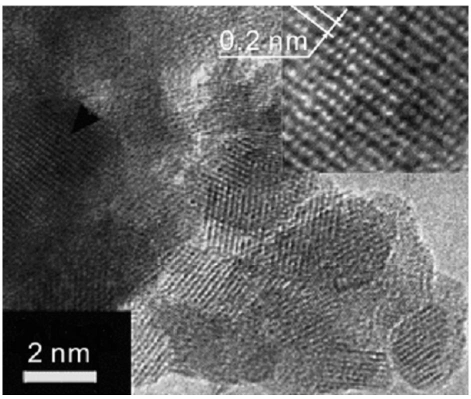

Figure 2. High resolution transmission electron micrograph of nanodiamond particles.[2]

3. Experimental

In order to obtain in practice a composite coating based on chemically deposited nickel and nanodiamonds, we have elected to use the already known technique of nickelized synthetic diamond manufacture. It includes the following stages:

1. Preparation of diamond surface: activation realized by processing synthetic diamond powder in a solution of sodium hypophospite at $T = 70$ °C, resulting in a phosphate film being formed on the surface of the diamond grains.

[7] Burkat, G.K. and Dolmatov, V.Yu. Application of ultrafine-dispersed diamonds in electroplating. *Phys. Solid State* **46** (2004) 703–710.

[8] Aleksenskii, A.E., Baidakova, M.V., Vul, A.Ya., Davydov, V.Yu. and Pevtsova, Yu.A. Diamond–graphite phase transition in ultradisperse diamond clusters. *Phys. Solid State* **39** (1997) 1007–1015.

2. Chemical deposition of the first layer of metallic nickel from aqueous solutions of a nickel salt.

3. Deposition of the second layer of nickel and subsequent layers according to the same technique. The number of layers is determined by the desired final degree of metallization.

The nickelizing process was carried out on synthetic diamond powder of Ukrainian AC-6 brand, the mean size of the grains of which was 90 μm. The nanodiamonds were used in the form of an aqueous suspension of 5% concentration. The final concentration of the nanodiamond particles in the nickel coating was 0.7–1.4% of the nickel volume. Note that as nanodiamond particles are very small, a dense, uniformly distributed packing in the final coating is reached at a very small mass or volume fraction of the host material, in the range of one tenth of a percent.[9]

4. Results and discussion

The presence of nanodiamond in the coating was verified by scanning electron micrography (SEM), from which one can see the presence of nonmetallic nanoparticles of irregular shape (Figures 3 and 4).

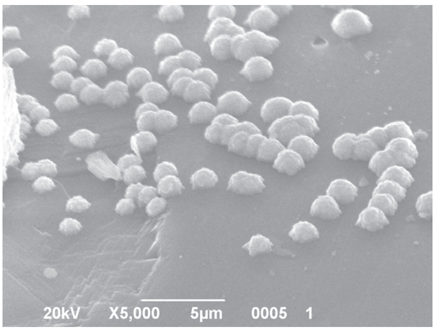

Figure 3. Growth centres of nickel on a diamond surface.

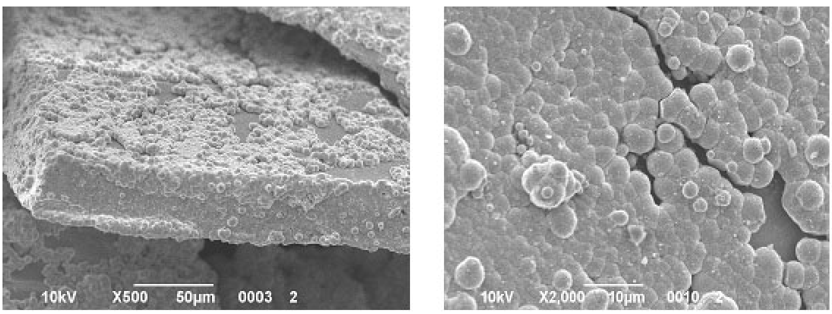

Figure 4. Diamond grain with nickel–diamond coating deposited on its surface (scanning electron micrographs).

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9 Dolmatov, V.Yu., Burkat, G.K., Saburbaev, V.Y., Salko, A.E. and Veretennikova, M.V. Preparation and properties of electrochemical composite coatings of precious and nonferrous metals with ultradispersed detonation-synthesized diamonds. *J. Superhard Materials* **2** (2001) 49–55.

Presumably, deposition of the nickel–diamond coating leads to enhancement of the adhesion of nickel to the diamond surface, owing to the presence of areas of localized nickel growth. As opposed to the conventional chemical or electrochemical nickelizing, the obtained coating is not delaminated and strongly adheres pointwise to the diamond grain surface. High productivity and wear resistance due to strong bonding of nickel on the grain surface distinguish the diamond powder with a nickel–diamond coating from diamond. The powder is characterized by high performance and durability due to strong retention of nickel on the surface of the grains.

In the following stage of the investigation, samples of the diamond-bearing layer of the grinding wheel have been sintered; they consist of the organic resin B2-01 and diamond grains coated by the nickel–diamond composite. At first, the AC6 diamonds were nickelized (with the addition of nanodiamonds), then they were mixed with the resin (organic material). The grinding wheel was sintered out of nickelized diamond (AC6 type) and the resin bond. The composition of the diamond-bearing layer (i.e., the volume fraction of UDD) was varied in manufacturing the samples. Presently, comprehensive testing of the physico-mechanical properties of the obtained brand of the organic bond is being undertaken. Our proposition that the increase in productivity of diamond wheels in the structure of which there are diamonds with nickel–diamond coatings should of course be corroborated experimentally. Our preliminary testing has shown that wear resistance[10] of the nickel coating has been increased by 1.2–1.8 times, which has been confirmed by tool lifetime tests using of 20 samples of diamond-bearing layers (with B2-01 resin bond). Grinding wheels with 100% diamond concentration[11] (grain size 90 μm) were used.

5. Conclusion

For the first time, a technique for the deposition of a diamond–nickel coating containing UDD particles on a synthetic diamond surface has been developed. This technique of *chemical deposition* of the diamond coating has practical applications. The theoretical expectation of an increase in the wear resistance of the coating owing to the addition of the ultradispersed diamond was confirmed by testing samples made up into tools.

[10] Comparative tests of the resistance of coatings to abrasion were carried out on an apparatus with a reciprocating sample (coated diamonds) under conditions of dry friction. Measurement error ± 6%.

[11] I.e., the weight of diamond is 4.4 carats per cubic centimetre of the diamond layer.