# Properties of composites with nanodiamonds of detonation synthesis

Evgenii Petrov

Biysk Technological Institute of Altai State Technical University named after I.I. Polzunov, Biysk city[1]
SC Federal Research and Production Center "Altai" Biysk city[2]
E-mail: htemi@bti.secna.ru

***Abstract:*** *Modern metals, alloys and polymers, using in mechanical engineering, now have such high-temperature and strength properties that do not meet the advanced requirements. One of the methods to improve their physico-mechanical properties is the method of hardening by dispersed additives. Nanodiamond (ND) and diamond-carbon -containing material (NDC) of detonation synthesis, having nano-structure and high surface energy, impact structurally on any materials contacting with them. Detonation synthesis is a fundamentally new and productive type of basic technology for producing nanostructures and nanomaterials. ND of detonation synthesis is a unique material that combines the properties of diamonds and the advantages of nanostructures. Industrial development of the given method made it possible to actually reach large-volume production and consumption of ND in a number of industries. The effectiveness application of ND and NDC in industrial lubricants, polishing, composite galvano-chemical coatings, metal and polymer-based composites has been shown.*

***Keywords****: NANODIAMOND, DIAMOND CARBON MATERIAL, POLYMER COMPOSITES, METAL-DIAMOND COATINGS, MICRO HARDNESS, WEAR AND TEAR, LUBRICANTS, POLISHING MATERIALS*

## *1. Introduction*

Artificial diamonds are considered to be strategic materials all over the world, as they play a vital role in the development of the industry. With the establishment of a new detonation method for the synthesis of diamonds, there appeared fundamentally new opportunities for the implementation of advanced technologies [1,2]. The synthesis is carried out by detonation of explosives in an explosion chamber, while nanocarbon (NDC) and nanodiamonds (ND) are formed in condensed detonation products with a high mass yield [3,4]. The diamonds are generated from explosives by chemical reactions under rather non-equilibrium conditions, whereupon their structure becomes defective and the particle size is small. The average size of the diamond microcrystallites is between 4 and 6 nm, and the specific surface area of the powders ranges between 300 and 400 $m^2/g$ [5].

Possessing nanoscale and high surface energy, diamonds have a structural and dispersion-strengthening effect being in contact with any materials. By morphology, microstructure, element composition, and reactivity, NDC and ND are close to each other. Therefore, as products of detonation synthesis, NDC powders themselves can be attractive both scientifically and practically.

NDC and ND is currently applied as anti-friction additives to motor, industrial oils and greases; in pastes and suspensions for super finishing material polishing; in wear-resistant electrochemical and chemical metal-diamond coatings; as dispersion-strengthening additives in composite materials based on polymers, metals, alloys and rubbers; as effective sorbents, catalyst carriers, biomarkers, transporter of medicinal substances and etc. [6].

In this work, the properties of composites with nanodiamonds of detonation synthesis are presented.

## *2. Industrial lubricants*

Figure 1 shows the comparative results of research info the tribotechnical characteristics of oil at various loads *(P)* in the friction zone. Compared to pure oil, a *NDC* additive reduces the friction coefficient (***f***) and, consequently, the oil temperature *(T)* in the friction and pad wear *(I)* zone. In addition, the limit load increases by three times. Concentrated carbon properties such as the nano size and round shape of particles, adsorption, and sedimentary stability in oil suspensions fully manifest themselves here. Solid particles with an oil film on their surface to avoid dry friction are always present in the friction zone. Therefore, this effect reached in all lubricants: motor and technological oils; plastic and hard lubricant.

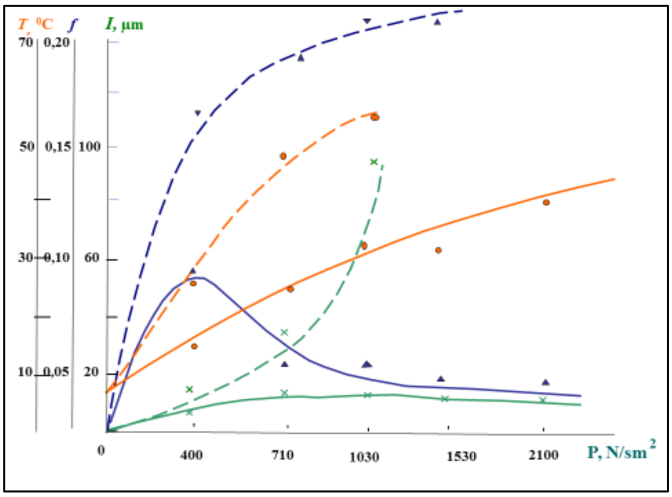
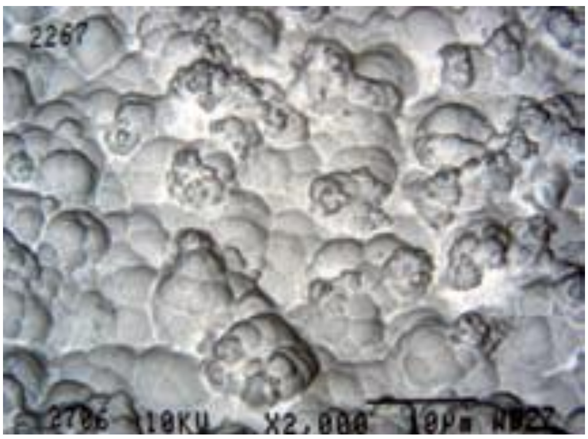



***Fig. 1*** *Tribotechnical characteristics of industrial oil. Dotted lines for pure oil, solid lines for oil with an addition of 0.1% NDC.*

## *3. Composite galvano-chemical coatings*

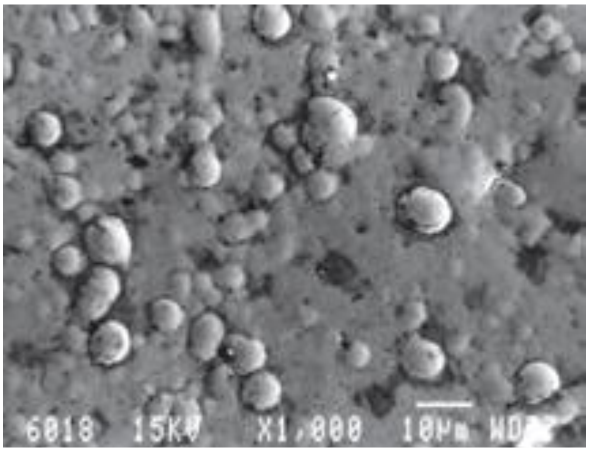
Nanodiamond properties such as resistance to acidic media and sedimentary stability made it possible to improve the properties of composite coatings produced by chemical and electrochemical deposition of metal films. As ND are introduced into the process for various metals, the same picture is observable: the grain size decreases (fig. 2,3), the micro hard ness increases, and the wear resistance of coatings is improved (table 1).



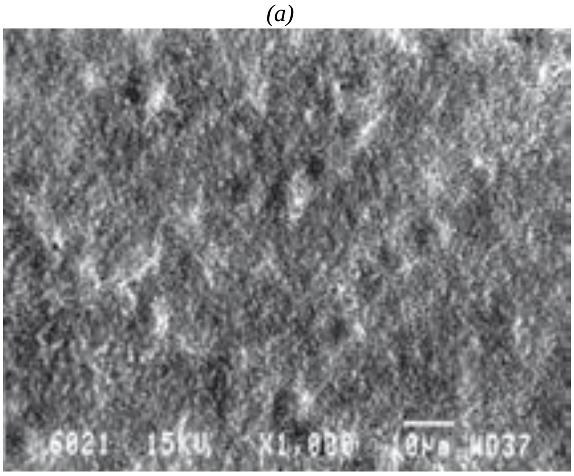

(a)

(b)

***Fig. 2.*** *Microstructure of electrochemical coating of chromium (a) and chromium with ND (b)*




*(a)*




*(b)*

***Fig. 3.*** *Microstructure of chemical coating of nickel (a) and nickel with ND (b)*

Wear reduction cannot be explained only by *ND* inclusion, since the *ND* content in a coating, for example, electrochemical nickel, does not exceed 1.5% and in a chromic coating it does not exceed 0.05%. Thanks to their surplus surface energy, *ND* have a structuring effect on deposited metal films, reducing the grain size and disordering the chromium structure to the limit at maximum micro hardness values. The use of this effect in industrial technology has confirmed the efficiency of metal-diamond coatings at 200 factories Russian. This technology is used company by Armoloy, USA. The implementation of the process does not require the remodeling of electroplating equipment, since the electrolyte is modified by adding an *ND* aquatic suspension to the initial plating tank.

***Table 1.*** *ND electrolyte additive effect on various metal sediment properties*

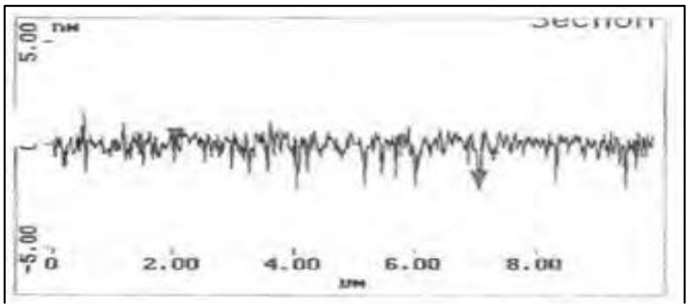
| Sediment type | ND in electrolyte, g/l | Micro hardness, GPa | | Wear resistance increase, times |
|---|---|---|---|---|
| | | Initial | with ND | |
| Chromium electrochemical | 13,0÷15,0 | 9,8÷11,1 | 13,2÷14,6 | 3.0 ÷4.0 |
| Nickel electrochemical | 9,5÷10,5 | 2,8÷3,0 | 4,6÷5,8 | 2.4 ÷4.2 |
| Copper electrochemical | 5,0÷10,0 | 2,0÷2,1 | 3,2÷3,3 | 4,8 ÷7,0 |
| Cobalt–phosphorus electro chemical | 0,5÷2,0 | 5,0÷5,25 | 6,8÷7,0 | 3,6 ÷4,1 |
| Copper chemical | 2,0÷6,0 | 1,9÷2,1 | 6,4÷6,6 | - |
| Nickel chemical | 4.5÷5.5 | 4,2÷4,4 | 6,1÷6,3 | 3,7 ÷4,0 |

## *4. Composite material for super-finish polishing*

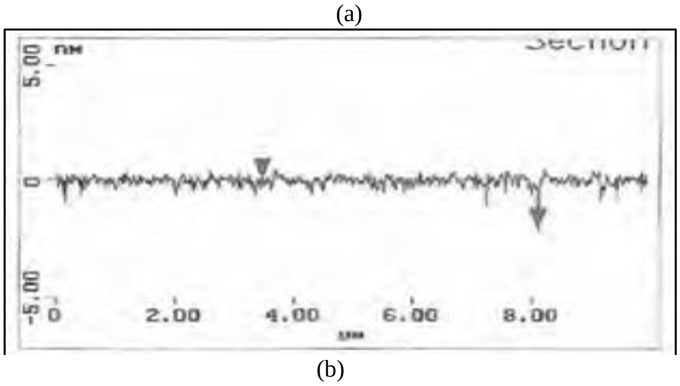
Polishing is a traditional sphere of diamond application. The best polishing abrasives have particle sizes no less than 0.1 μm. Thanks to its homogeneous granulomeres size composition, *ND* as the finest abrasive has turned out to be indispensable for super finish polishing. Nanodiamond suspensions and pastes allow surface finishes of several angstroms (table 2, fig. 4), which is an order of magnitude higher than the best international results in this sphere.

***Table 2.*** *Results of the polishing*. Suspension ND (4%) in ethyleneglycoles.

| Material | Roughness (Ra), nm |
|---|---|
| Hard alloy | 1÷5 |
| Steel; Sapphire | 5÷6 |
| Quartz; Silicon | 0,5÷1,5 |
| Molten silicon oxide | 0,5÷1,0 |
| *NaCl; KBr* crystal | 2÷3 |




(a)




(b)

*Fig. 4. Roughness of silicon plate before polishing (a) and after (b)*

Multi-level *ND* particle aggregation involves a specific polishing mechanism. The impact of the polishing system *(ND-carrier)* on the treated surface on the one hand is mitigated, and on the other is intensified by the generation of new diamond surfaces. *ND* is effective where the main result of the polishing process is a surface frequency class, not performance.

## 5. Composites

Nanodiamonds with developed surfaces and high surface energy have dispersion strengthening and structuring effects on any material that contacts them. Dispersion strengthening can explain the proper ties of metals and polymers with *ND* additives. Thus, the micro hardness of aluminum samples improves as the *ND* content increases (table 3), approaching that of low-grade steels but still preserving the advantages of a light metal. The wear resistance of aluminum compacts increases by 1.3 times from 2% *ND*, and from 10% to 1.8 times. Similar results were obtained when *ND* was introduced into magneto-uggy amorphous alloys used in magnetic heads of digital magnetic recording systems.

The wear resistance of fluoroplastic (Teflon) approaches bronze in wear resistance (table 4), and the friction coefficient is preserved at the level of pure fluoroplastic. In terms of the degree of impact in comparison with known dispersed additives, NDC takes the leading place (table.5).

The performance of polyamide samples with a 0.5% *ND* supplement is maintained when the maximum load increases from 20 to 150 kg/cm2. Increased strength and wear resistance are also obtained on polyacrylamide, polymethylmethacrylate, polyethylene.

***Table 3.** Aluminum composite with ND*. Characteristics*

| ND content, % | Micro hardness, GPa | Density, g/cm$^3$ | Porosity, % | Thermal conductivity, W/(m K) |
|---|---|---|---|---|
| 0 | 0,76 | 2,73 | 0 | 162 |
| 2,5 | 1,81 | 2,71 | 0,5 | 141 |
| 10 | 1,97 | 2,69 | 1,1 | 101 |
| 20 | 2,68 | 2,71 | 1,9 | 64 |
| 50 | 5,22 | 2,6 | 1,5 | 9,2 |

** Hot pressing at temperature 793-803K and pressure 1,0 GPa*

***Table 4**. Fluoroplastic composite* with coal powder and NDC. Characteristics*

| Additive, % | Compressive modulus, MPa | Friction coefficient | Wear resistance increase, times |
|---|---|---|---|
| Without additive | 4,2 | 0,21 | 1,0 |
| Coal powder, 20 % | 11,5 | 0,32 | 25,0 |
| NDC, 5 % | 4,9 | 0,21 | 70,0 |

** Hot pressing at temperature 643K*

Rupture strength of composite plastic made of fiber glass filament and binder on the basis of epoxy resin increases with 1.0% additive by 1.3 times for *NDC* and by 1.5 times for *ND*. Moreover, carbon nano-additives effectively influence on crack resistance of the composite.

In rubbers, *NDC* has a structuring effect already at 0.5%, increasing the vulcanization rate by 1.3 times. The best results were obtained at *NDC* doses of 1–3 phr. Within this range, we observe the growth of indicators such as wear resistance (2.5–4.5 times), gap resistance (1,3-1,4 times), conditional strength at rupture (1,1–1,2 times), and (very importantly), elasticity; other indicators remain unchanged.

***Table 5.** Wear resistance of Fluoroplastic with different additives*

| Additive (5%) | Surface area (additive), m$^2$/g | Surface wear area, mm$^2$ |
|---|---|---|
| NDC | 344 | 7,2 |
| NDC | 468 | 5,9 |
| ND | 282 | 10,6 |
| $SiO_2$ | 400 | 19,0 |
| $Si_3N_4$ | 28 | 13,7 |
| $Co[Al_2O_4]$ | 10 | 17,5 |
| Soot | 15 | 19,7 |
| Graphite | 10 | 28,2 |
| $MoS_2$ | 0,2 | 28 |

Bench and performance tests show that industrial rubber parts last 1.3–2 times of their guideline life; tires last 1.3 times of their standard run.

## 6. Conclusion

ND of detonation synthesis is a unique material that combines the properties of diamonds and the advantages of nanostructures. Possessing nanoscale and high surface energy, diamonds have a structural and dispersion-strengthening effect being in contact with any materials. The effectiveness application of ND and NDC in industrial lubricants, polishing, composite galvano-chemical coatings, metal and polymer-based composites has been shown. Currently, the detonation method allows to receive ND with grain size 60-90 nm [7]. Their use will increase the range of composites with new properties.

**Acknowledgments**

The study was carried out with the financial support of the Russian Federal Property Fund in the framework of a scientific project No. 18-29-19070 MK.

## References

[1] A. I. Lyamkin, E. A. Petrov, A. P. Ershov, G. V. Sakovich, A. M. Staver, and V. M. Titov, “The way to produce diamonds from explosives,” Dokl. Akad. Nauk SSSR **302**(3), 611–613 (1988).

[2] F. E. Griener, B. S. Phillips, J. D. Johnson, and F. Volk, “Diamonds in detonation soot,” Nature **333**(172), 440–442 (1988).

[3] A. L. Vereshchagin, E. A. Petrov, G. V. Sakovich, V. F. Komarov, et al., RF Patent 2051092RU (25.12.1991); Europe. Patent 05745587 ER (25.12.1991); Japan Patent 2799337 (25.12.1991), USA Patent 5.861.349 USA (18.11.1993); Canada Patent 2.104.867 (26.06.1993); Belorussian Patent 3075BY (25.12.1991).

[4] A. L. Vereshchagin, E. A. Petrov, G. V. Sakovich, V. F. Komarov, et al., RF Patent 2041165 RU (12.02.1993); USA Patent 5.916.955 USA (23.12.1996); Belorussian Patent 1687BY (12.02.1993).

[5] A. L. Vereschagin, G. V. Sakovich, V. F. Komarov, and E. A. Petrov, “Properties of ultrafine diamond clusters from detonation synthesis,” Diamond and Relater Materials, No. 3, 160–162 (1993).

[6] E.A. Petrov, “ Detonation synthesis of nanomaterials. Nanodiamonds and nanotechnology.” Biysk, Russia: Technological Institute of the Altay State Technical University, 259p (2015).

[7] E.A. Petrov, A. A. Kolesova, A. B. Pribavkin, “Properties of nanodiamonds of industrial detonation synthesis”: International scientific journal "Machines. Technologies. Materials." 13(8) 373-375 (2019)