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IMPURITIES AND INCLUSIONS IN DIAMOND GRAINS AS A FACTOR TO BE CONSIDERED WHEN USING DIAMOND GRINDING POWDERS IN DIAMOND TOOL

The article presents the results of the influence of the content of impurities and inclusions in diamond grinding powders synthesized in the Ni-Mn-C and Fe-Si-C systems. As a result of their separation in a magnetic field, powders of magnetic and non-magnetic fractions are obtained, the magnetic susceptibility of which differs by an order of magnitude. It is shown that diamonds obtained in the Fe-Si-C system have well-defined magnetic properties; ferromagnetic elements of solvent alloys in inclusions (Ni+Mn for the Ni-Mn-C system and Fe for the Fe-Si-C system) predominate and make up 77.9–84.0% of the total number of inclusions present in diamond powders of the non-magnetic fraction, and in the magnetic fraction it is slightly higher and amounts to 94.5–93.1% for diamonds of both growth systems. The strength of diamonds of the magnetic fraction of both systems is higher in comparison with the strength of diamonds of the non-magnetic fraction, the heat resistance of diamonds of the non-magnetic fraction of both systems is higher in comparison with the heat resistance of diamonds of magnetic fractions. After the separation of diamond powders in a magnetic field into a number of fractions with different specific magnetic susceptibility, the homogeneity of the powders increases in strength compared to the homogeneity of the original powders before their separation. The performance of grinding wheels, with processing productivity (200 mm^3/min), is more effective when using diamond powders of the magnetic fraction with a higher content of impurities and with greater strength. At a higher processing productivity (400 mm^3/min), the wear resistance of wheels equipped with diamonds of the magnetic fraction decreases due to a decrease in their heat resistance. The wear resistance of diamonds of the magnetic fraction compared to the wear resistance of diamonds of the non-magnetic fraction for the Ni-Mn-C system will increase by a small amount, and for the Fe-Si-C system - by approximately 1.7 times.

Key words: *synthetic diamond grinding powders, physical and mechanical characteristics, separation in a magnetic field, magnetic susceptibility, heat resistance.*

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ДОМІШКИ ТА ВКЛЮЧЕННЯ В АЛМАЗНИХ ЗЕРНАХ, ЯК ФАКТОР, ЯКИЙ НЕОБХІДНО ВРАХОВУВАТИ ПРИ ЗАСТОСУВАННІ АЛМАЗНИХ ШЛІФПОРОШКІВ В АЛМАЗНОМУ ІНСТРУМЕНТІ

У статті приведені результати впливу вмісту домішків та включень в алмазних шліфпорошках, синтезованих в системах Ni-Mn-C і Fe-Si-C. В результаті розділення їх у магнітному полі отриманні порошки магнітних та немагнітних фракцій, магнітна сприйнятливість яких відрізняються між собою на порядок. Показано, що алмази, отримані в системі Fe-Si-C, мають добре виражені магнітні властивості; феромагнітні елементи сплавів-розчинників у включеннях (Ni+Mn для системи Ni-Mn-C та Fe для системи Fe-Si-C) переважають і складають 77,9–84,0 % від загальної кількості наявних включень в порошках алмазу немагнітної фракції, а в магнітній фракції трохи вище і складають 94,5–93,1 % для алмазів обох ростових систем. Міцність алмазів магнітної фракції обох систем вище в порівнянні з міцністю алмазів немагнітної фракції, термостійкість алмазів немагнітних фракцій обох систем вище в порівнянні з термостійкістю алмазів магнітних фракцій. Після розділення порошків алмазу в магнітному полі на ряд фракцій з різною питомою магнітною сприйнятливістю збільшується однорідність порошків за міцністю в порівнянні з однорідністю вихідних порошків до їх розділення. Працездатність шліфувальних кругів, при продуктивності обробки (200 мм^3/хв) більш ефективна при використанні порошків алмазу магнітної фракції з більшим вмістом домішок і з більшою міцністю. При більш високій продуктивності обробки (400 мм^3/хв) зносостійкість кругів, оснащених алмазами магнітної фракції, знижується внаслідок зменшення їх термостійкості. Зносостійкість алмазів магнітної фракції у порівнянні із зносостійкістю алмазів немагнітної фракції для системи Ni-Mn-C зросте на малу величину, а для системи Fe-Si-C – приблизно в 1,7 разів.

Ключові слова*: шліфпорошки синтетичного алмазу, фізико-механічні характеристики, розділення у магнітному полі, магнітна сприйнятливість, термостійкість.*

Introduction and statement of the problem. At the present stage of production development, the main factor of technical progress is the improvement of production process technology. For the development of mechanical engineering, the use of effective abrasive grinding tools based on synthetic diamonds is an important area. In industrial conditions, diamond abrasive processing is one of the most common methods of surface treatment of workpieces [1]. During diamond abrasive processing, the wear resistance and performance of a grinding tool are influenced by the properties of diamond powders, which are formed during the synthesis of diamond, its extraction from the synthesis product, as well as during classification and sorting. As a rule, diamond powders after synthesis are heterogeneous in their main characteristics and properties.

When processing products made of hard alloy, ceramics, glass and other brittle materials, synthetic diamond powders of low-strength grades AC6 - AC32 are widely used. The synthesis of diamond powders of these grades, as a rule, is short-term and occurs at high growth rates, which facilitates the capture of all side phases present in the reaction chamber by the growing diamond crystal, which have a significant impact on the physical, mechanical and operational properties of diamonds. Therefore, the goal was to study the influence of the content of impurities and inclusions in diamond grinding powders of the AC6 and AC20 grades, synthesized in various growth systems, on the wear resistance of diamond grinding tools.

Analysis of the latest research and publications. For diamond abrasive machining processes, diamonds from the low strength range of grades are preferably used in grinding tools. From previous studies it is known that the properties of synthetic diamonds mainly depend on the amount of impurities and inclusions in them, as well as on their magnetic properties [1, 2].

Due to the peculiarities of the diamond crystal structure, in which all 4 valence electrons of carbon atoms are tightly bound, an ideal diamond crystal (without impurities and lattice defects) should be a dielectric transparent to visible light. In real crystals there is always a certain amount of impurities and lattice defects. Even in the purest jewelry diamonds, the impurity content reaches 1018 atoms per 1 cm3. The distribution of impurities in a diamond may be uneven; for example, there are more impurities at the periphery than at the center. The strong bonds between carbon atoms in the diamond structure mean that any imperfection in the diamond crystal lattice affects its physical properties.

For synthetic diamonds (especially low-strength grades AC4–AC32), attention was drawn to the fact that the grains of diamond powders contain impurities and inclusions both on the surface and in defects (pores) of this surface, and porosity is a distinctive feature of such diamonds (see Fig.1).

Diamond, when synthesized in the metal (Me)-carbon (C) system, is obtained in special apparatus under high p, T conditions. To reduce the desired high synthesis characteristics, a catalyst in the form of a solvent alloy is used. The process of synthesizing diamonds of the above-mentioned low-strength grades occurs at high rates of crystal growth, which, during their growth, capture all the secondary phases present in the reaction chamber. These phases (inclusions) are of different sizes: from atomic to macroscopic sizes. Inclusions that are completely preserved in a diamond crystal are volumetric defects that affect the thermal stability of the crystals, which directly affects the performance characteristics of the diamond tool.

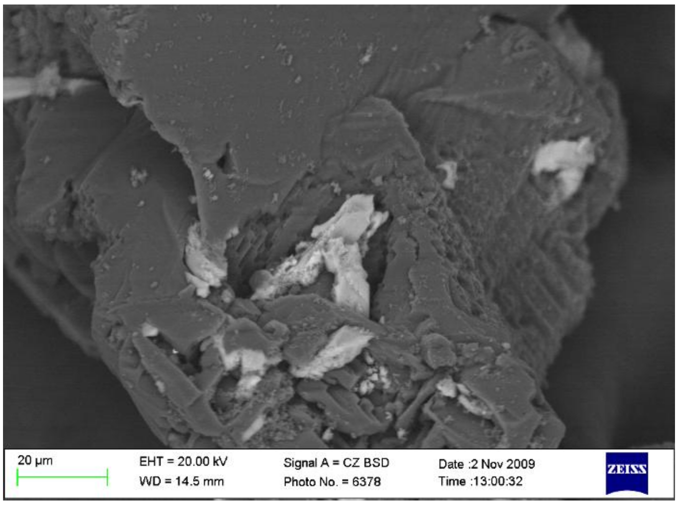


Fig.1. **An example of the presence of inclusions on the surface and pores of AC6 125/100 diamonds in original condition**

Domestic and foreign researchers A.A. Shulzhenko, M.V. Novikov, S. Evans, G.P. Bogatyreva, G.F. Nevstruev, Yu.I. Nikitin et al. made a great contribution to the study of the properties of synthetic diamond powders and convincingly demonstrated the significant influence on the strength characteristics of diamond grinding powders from the content of impurities and metal inclusions of the carbon solvent alloy [2, 3].

The studies on diamond synthesis known from the literature were mainly carried out using the Ni-Mn-C system. Currently, diamond synthesis is carried out in the presence of metal melts of different compositions. Ni, Fe, Mn, Co are most often used. The use of alloys helps to increase the degree of conversion of graphite into diamond. Industrial production of synthetic diamond powders is most often carried out in the presence of nickel or cobalt, the cost of which is an order of magnitude higher than the nominal cost of iron. At the same time, there is some interest in the use of a cheaper solvent alloy - Fe-Si. It has been revealed that the effect of silicon on Fe-Si alloys is similar to the effect of nickel, which makes it possible to reduce the thermodynamic parameters of diamond production [4].

Therefore, it is of great interest to study the possibility of using iron alloys and, in particular, the Fe-Si alloy as carbon solvents.

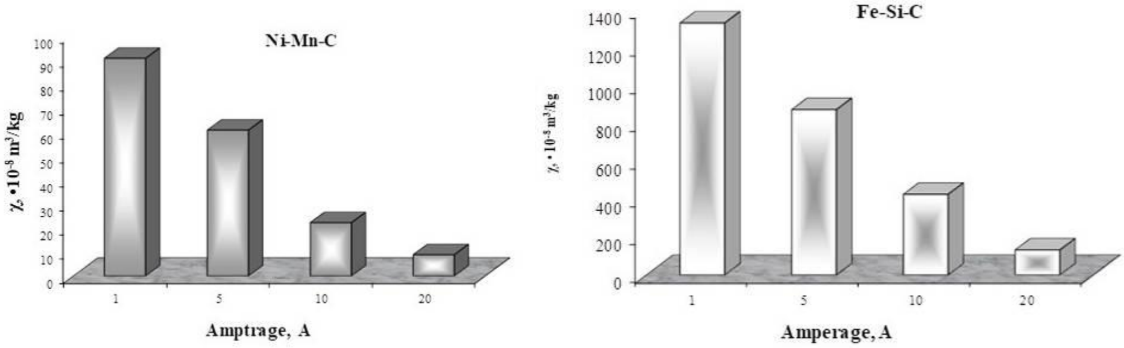
Materials and methods of research. The study of the influence of impurities and inclusions in the grains of diamond grinding powders was carried out on diamonds of the AC6-AC20 grade, grain size 160/125, obtained in the Ni-Mn-C and Fe-Si-C systems. In this work, AC6 diamond grinding powders were subjected to mechanical crushing in a planetary mill, as well as ultrasonic treatment, to improve their quality. Mechanical and ultrasonic selective crushing ensures the destruction of crushed stones, intergrowths and grains that have shells and inclusions, resulting in an increase in the isometry of the powders. Diamond grinding powders of the AC6 grade with a grain size of 160/125, synthesized in the Ni-Mn-C and Fe-Si-C systems, after physical and mechanical treatment were separated in a magnetic field with amperage of 5 to 20 A to obtain magnetic and non-magnetic diamond powders . fractions differing in magnetic susceptibility.

The physical and mechanical characteristics of the powders were determined: strength in the form of breaking load under static compression at room temperature (P, N) and after heat treatment at 1100 C, heat resistance was calculated in the form of the thermal stability coefficient (K_{TS}), strength uniformity coefficient (Kunif.p); We measured the specific magnetic susceptibility (χ) using methods developed at the Institute of Superhard Materials of the Academy of Sciences of Ukraine.

In diamond grinding powders with a grain size of 160/125, synthesized in the Ni-Mn-C and Fe-Si-C systems, the initial and after their separation in a magnetic field, the elemental and general composition of intracrystalline impurities and inclusions was determined by X-ray fluorescence integral analysis using scanning electron micro BS -340" and an energy-dispersive X-ray spectrum line analyzer "Link-860". To determine the elemental composition of inclusions and impurities (β, % (by mass), a modified ZAF-4FLS quantitative analysis program developed by Link (England) was used.

In this case, inclusions and impurities have different sizes, ranging from an atom to macroscopic sizes. Depending on the size of elements captured by the diamond lattice or the internal structure of the crystal, the name “impurities and inclusions” is accepted. There is no clear dividing line between these concepts. It is practically impossible to separate them based on the results of modern methods of studying the elemental composition of the side phases present in diamond, therefore the total content of atoms of the element being studied is determined.

Presentation of the main research material. The results of the distribution in a magnetic field of the initial diamond grinding powders of grain size 160/125, synthesized in the Ni-Mn-C and Fe-Si-C systems, after physical and mechanical treatment are presented in Fig. 2 (a and b).



a) **b)**

Fig.2. **Separation of grinding powders of AS6 grade 160/125 diamond synthesized in the Ni-Mn-C (a) and Fe-Si-C (b) systems.**

As can be seen from fig. 2 diamond grinding powders of both systems are divided into four separation fractions that differ among themselves in terms of specific magnetic susceptibility. Magnetic susceptibility of diamonds of both systems of extreme fractions of magnetic and non-magnetic fractions differ by an order of magnitude. For diamonds synthesized in the Ni-Mn-C system (Fig. 2a), χa is from 90.3 to 8.8 ×10-8m3/kg, and for diamonds synthesized in the Fe-Si-C system (Fig. 2b) χa from 1327 to 132.0 ×10-8m3/kg.

The total and elemental composition of impurities and inclusions was determined in diamond grinding powders synthesized in the Ni-Mn-C and Fe-Si-C systems, initial and obtained after distribution in a magnetic field. The elemental composition was estimated as the sum of elements of metals of carbon-solvent alloys.

Magnetic methods were used to obtain more extensive information when studying impurities and inclusions. As a rule, pure unadulterated diamond is a dielectric with an almost constant specific magnetic susceptibility (χ = –0.62×10-8 m3/kg), and the carbon solvent alloys used in the synthesis have strong magnetic properties, so all the variety of magnetic properties of crystals diamond is related to the amount and magnetic state of the metal or alloy of metals present in the diamond in the form of impurities and inclusions.

The sum of all detected elements corresponds to the total content of inclusions and impurities in the diamond, and the sum of the elements of the solvent alloy makes it possible to estimate their content in the diamond powder. The measurements and determination of the elemental composition of impurities and inclusions make it possible to calculate the specific magnetic susceptibility of inclusions χincl, [5].

The obtained results of measurements and calculations are presented in table. 1.

Table 1.

Characteristics of the properties of diamond grinding powders with a grain size of 160/125 and after distribution in the magnetic field, synthesized in the Ni-Mn-C and Fe-Si-C systems

Separation fraction	Ni-Mn-C				Fe-Si-C			
	β, % (by mass)		χ, m^3/kg		β, % (by mass)		χ, m^3/kg	
	General	Ni+Mn	χ_{init}, ×10^{-8}	χ_{incl}, ×10^{-8}	General	Fe	χ_{init}, ×10^{-8}	χ_{incl}, ×10^{-8}
magnetic	3,631	3,337	90,3	2503	7,360	6,828	1327	18038
non-magnetic	2,014	1,569	8,8	467	2,129	1,733	132	6229
initial	3,413	2,901	16,8	630	4.557	3,965	342	7518

From the table data it follows those ferromagnetic elements of solvent alloys in inclusions (Ni+Mn for the Ni-Mn-C system and Fe for the Fe-Si-C system) predominate and account for 77.9–84.0% of the total number of inclusions present in diamond powders of the non-magnetic fraction, and in the magnetic fraction it is slightly higher and amount to 94.5-93.1% for diamonds of both growth systems.

Thus, diamonds obtained in the Fe-Si-C system have well-defined magnetic properties, therefore the specific magnetic susceptibility of diamonds and their inclusions of the magnetic fraction is χa = 1327 × 10-8 m^3/kg and χ incl = 18038 × 10-8 m^3/kg , according.

In grinding powders in the magnetic and non-magnetic fractions of both systems, the physical and mechanical characteristics were determined: strength (P, N) and after heat treatment at 1100 °C, thermal resistance was calculated in the form of the thermal stability coefficient (K_{TS}), the results are added in table 2.

Table 2.

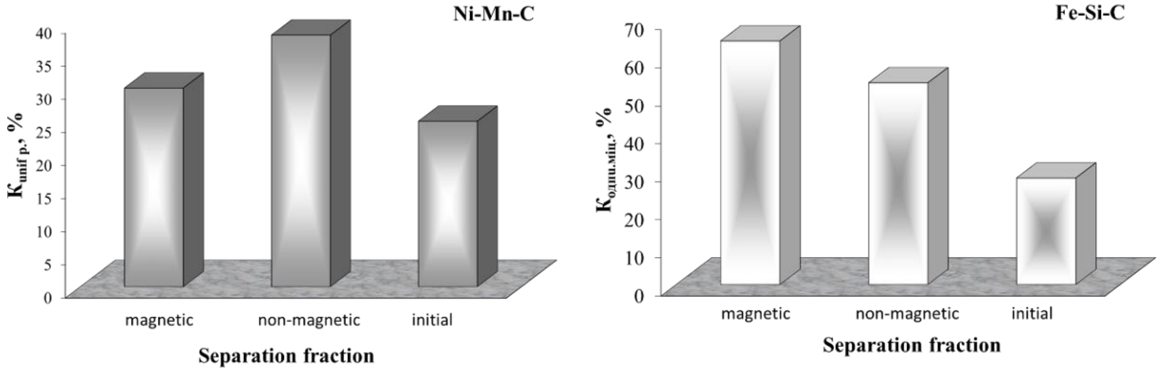
Physical and mechanical characteristics of AC6 diamonds, grain size 160/125

Separation fraction	Ni–Mn–C		Fe–Si–C	
	P, H	K_{TC}, %	*P*, H	K_{TC}, %
magnetic	7,4	44	12,7	35
non-magnetic	6,0	78	4,1	57
initial	7,2	61	11,7	55

Analysis of data in table. 2 shows that the strength of diamonds of the magnetic fraction of both systems is higher compared to the strength of diamonds of the non-magnetic fraction. Yes, the strength of diamonds obtained in the Ni-Mn-C system, the magnetic fraction is 1.2 times higher compared to the strength of diamonds of the non-magnetic fraction. The strength of magnetic fraction diamonds synthesized in the Fe-Si-C system increases by 3.1 times compared to the strength of non-magnetic fraction diamonds. The heat resistance of diamonds of non-magnetic fractions of both systems is higher compared to the heat resistance of diamonds of magnetic fractions: for diamonds of the Ni-Mn-C system it is 1.8 times, and for diamonds of the Fe-Si-C system it is 1.6 times.

Moreover, after dividing diamond powders in a magnetic field into a number of fractions with different specific magnetic susceptibility, the uniformity of the powders in strength increases compared to the homogeneity of the original powders before their separation. For diamonds synthesized in the Ni-Mn-

C system, homogeneity increases by 1.2–1.5 times, and for diamonds synthesized in the Fe-Si-C system – by 1.9–2.3 times (Fig. 3) .



a) **b)**

Fig. 3. **Changes in the homogeneity coefficient in terms of the strength of diamond grinding powders of grain size 160/125, synthesized in the Ni-Mn-C (a) and Fe-Si-C (b) systems, obtained after distribution in a magnetic field: magnetic and non-magnetic fractions.**

AC6 grade diamond powders with a grain size of 160/125, synthesized in both systems, magnetic and non-magnetic fractions, were used for the manufacture of experimental grinding wheels on the B2-01 polymer bond when grinding hard alloy samples of the VK8 grade. Processing productivity was 200 and 400 mm3/min. The wear resistance of the tool was determined by the relative consumption of diamonds qp [1]. The test results are presented in Table 3.

Table 3.

Physico-mechanical and operational characteristics of AS6 diamonds of grain size 160/125 synthesized in the Ni-Mn-C and Fe-Si-C

Separation fraction	Ni–Mn–C			Fe–Si–C		
	K_{TS}, %	q_p, mg/g at processing productivity, mm/min		K_{TS}, %	q_p, mg/g at processing productivity, mm3/min	
		200	400		200	400
magnetic	44	3,25	4,15	35	2,31	4,65
non-magnetic	78	3,33	3,70	57	1,64	2,75
initial	61	-		55	-	

It was found that the performance of grinding wheels equipped with AS6 diamonds of 160/125 grain size, synthesized in both systems, at processing productivity (200 mm3/min) is more effective when using diamond powders of the magnetic fraction with a higher content of impurities and with greater strength. The wear resistance of diamonds of the magnetic fraction compared to the wear resistance of diamonds of the non-magnetic fraction is higher for the Fe-Si-C system - approximately 1.4 times, and slightly higher for the Ni-Mn-C system.

At a higher processing productivity (400 mm3/min), the wear resistance of wheels equipped with diamonds of the magnetic fraction decreases due to a decrease in their heat resistance. The wear resistance of diamonds of the magnetic fraction compared to the wear resistance of diamonds of the non-magnetic fraction for the Ni-Mn-C system will increase by a small amount, and for the Fe-Si-C system - by 1.7 times.

Thus, it was established that in order to increase the efficiency of the grinding tool, it is necessary to separate grinding powders of synthetic diamond in a magnetic field with an intensity of 5 to 20 A/m, which makes it possible to obtain powders that differ significantly in terms of the content of metal intracrystalline inclusions and impurities, the specific magnetic susceptibility, indicators of the strength of grinding powders under static compression of diamond grains, uniformity in strength, which contributes to the impact on the wear resistance of the grinding tool.

Conclusions.

1. It is shown that as a result of separation in a magnetic field of different voltages from 5 to 20 A/m of diamond grinding powders of grain size 160/125 synthesized in the Ni-Mn-C and Fe-Si-C systems, the obtained powders of magnetic and non-magnetic fractions, magnetic the receptivity of which differ by an order of magnitude. It was established that the diamonds obtained in the Fe-Si-C system have well-defined magnetic properties, therefore the specific magnetic susceptibility of diamonds and their inclusions of the magnetic fraction is χa=1327×10-8m3/kg and χвкл= 18038×10-8m3/kg , respectively.

2. It was established that ferromagnetic elements of solvent alloys in the inclusions (Ni+Mn for the Ni-Mn-C system and Fe for the Fe-Si-C system) predominate and make up 77.9–84.0% of the total number of inclusions present in in diamond powders of the non-magnetic fraction, and in the magnetic fraction it is slightly higher and amounts to 94.5–93.1% for diamonds of both growth systems.

3. It is shown that the strength of diamonds of the magnetic fraction of both systems is higher compared to the strength of diamonds of the non-magnetic fraction. Thus, the strength of diamonds obtained in the Ni-Mn-C system, the magnetic fraction is 1.2 times higher compared to the strength of diamonds of the non-magnetic fraction. The strength of diamonds of the magnetic fraction synthesized in the Fe-Si-C system increases by 3.1 times compared to the strength of diamonds of the non-magnetic fraction.

4. It was established that the heat resistance of diamonds of non-magnetic fractions of both systems is higher compared to the heat resistance of diamonds of magnetic fractions: for diamonds of the Ni-Mn-C system by 1.8 times, and for diamonds of the Fe-Si-C system by 1.6 times.

5. It is shown that after the separation of diamond powders in a magnetic field into a number of fractions with different specific magnetic susceptibility, the homogeneity of the powders in terms of strength increases compared to the homogeneity of the original powders before their separation. For diamonds synthesized in the Ni-Mn-C system, the homogeneity increases by 1.2–1.5 times, and for diamonds synthesized in the Fe-Si-C system – 1.9–2.3 times.

6. It was found that the performance of grinding wheels equipped with AS6 diamonds of 160/125 grain size, synthesized in both systems, at processing productivity (200 mm3/min) is more effective when using diamond powders of the magnetic fraction with a higher content of impurities and with greater strength. The wear resistance of diamonds of the magnetic fraction compared to the wear resistance of diamonds of the non-magnetic fraction is higher for the Fe-Si-C system - approximately 1.4 times, and slightly higher for the Ni-Mn-C system.At higher processing productivity (400 mm3/min), the wear resistance of wheels equipped with magnetic fraction diamonds decreases due to a decrease in their heat resistance. The wear resistance of diamonds of the magnetic fraction compared to the wear resistance of diamonds of the non-magnetic fraction for the Ni-Mn-C system will increase by a small amount, and for the Fe-Si-C system – by 1.7 times.

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