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MORPHOLOGICAL QUALITATIVE CLASSIFICATION OF SYNTHETIC DIAMOND MICROCRYSTALS

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Abstract. The paper presents a morphological qualitative classification of statically synthesized diamonds, based on microscopic studies. Investigations of the internal structure and habit of crystals and of their surface structure were carried out on a variety of diamond grains representing different commercial brands. Five distinct forms were determined for each of the two parameters, and three typical grains representing each of these forms were selected and listed in Plates I and II. These tables serve as a basis for the qualitative evaluation of diamond grains and, together with Table 1B, allow the selection of an appropriate diamond abrasive for tools with different binders, ensuring their optimum service parameters. The indisputable advantage of the presented classification is that it is based on non-destructive methods of evaluation of diamond grains, determining at the same time the mechanical strength of diamonds, which depends on the structure of grains.

INTRODUCTION

This paper is an attempt at the morphological qualitative classification of synthetic abrasive diamond grains produced by static synthesis. It is a result of extensive comparative studies carried out on a variety of products with a view to developing a comparative system that would enable the evaluation of the product of synthesis, after its granulometric and shape segregation, for definite uses in abrasive tools with organic, metallic or ceramic binders.

The only available system of functional classification, the „Triefus Abrasive Codings — TAC" (1965) includes the following factors: mineral hardness (10 for diamond), durability factor — toughness of the particle (varying from 9—0), grain form indicator — shape of the particle (warying from 0, A, B... to R), and surface texture characteristics — nature of the surface of the particle (varying from 0—9). When considering diamond, the TAC system can be simplified as hardness, being always 10 for diamond, can be left out of account. Moreover, from the extensive comparative studies of natural and statically synthesized (on press) diamonds (Ba-

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koń 1980) it appears that the durability factor is closely associated with the grain form indicator, and the two may be considered jointly as the „crystal habit and internal structure". The other important factor still to be considered is the surface texture characteristics.

EXPERIMENTAL

Microscopic examination was carried out with a Leitz—Wetzlar AMOP optical microscope and a JEOL JSM SI and Cambridge Stereoscan 180 scanning microscopes. The optical microscope used allowed the examination of samples in reflected, transmitted or polarized light. Prior to electron microscope studies, the samples were coated with a layer of gold or carbon (the latter in the case of qualitative microanalysis) several dozen nanometers thick to give a conducting surface. The Stereoscan 180 microscope was equipped with a Link Systems attachment for X-ray microanalysis. The microanalytical system contained a detector capable of detecting elements heavier than sodium. Microscopic images were described and recorded on photographic plate. In view of the limited scope of this paper, the photographic documentation and data presented are only a fraction of the results obtained. Only grains and fragments of their structure characterizing certain morphological types of abrasive diamond were shown.

A comparison of the form of diamond grains was made on the basis of the following criteria devised for that purpose:

— crystal habit and internal structure of single grains,
— form of faces of single grains,
— form of cutting edges of single grains,
— colour, lustre, translucence and transparence of single grains,
— linear parameters of single grains,
— mechanical strength of single grains.

The data presented are a result of examination of 100—150 grains at different angles using photographic technique, due to which it was possible to determine the dimensions of faces, the length of edges, and the angles between faces. An ateempt was also made to assess the irregularities of the grain surface and to investigate the internal structure of single grains.

RESULTS

Natural abrasive diamond grains appeared to be spherical mono- or polycrystals. The present results only partly confirmed the earlier observations of Semko (1978) and Bakul et al. (1974, 1976, 1977) concerning Russian diamonds. Single natural and synthetic diamond grains of various commercial brands show wide differentiation in their structure. Therefore, the inferences of Semko, Bakul et al. are relative. Nautral grains of the RPD, EMB or DEBDUST type were characterized by a smaller amount of sharp-edged crystals, more spherical shapes and a less developed surface than the synthetic grains recommended for tools with resin binders. The structure of single grains of the NRBT and SNDMB types was similar to that of electrocorundum abrasives obtained by crushing large electrocorundum blocks (Maślankiewicz, Szymański 1976). Such form of diamond grains suggests that the NRBT and SNDMB types were obtained

by crushing of larger natural crystals. Natural grains obtained in this way had the surface characteristics similar to those of synthetic grains recommended for tools with a metallic binder, or their surface was better developed than that of synthetic grains.

The present studies confirmed the earlier observations of Stolin and Gwoździara (1971) indicating that synthetic diamonds occur in several characteristic forms. However, no regular crystals in the form of cubes were found among commercial diamonds subject to investigation, and neither were regular synthetic grains in the form of orthorhombic dodecahedra described by Semko (1978), which habit is typical of large natural diamond crystals (Orłow 1963, 1973).

Synthetic monocrystals occurring as a combination of octahedron and cube predominated quantitatively in the brands used in tools with metallic binders of De Beers and General Electric and in Polish MDS *. As shown by chemical analyses, these diamonds were synthesized in the So—C or Co—Fe—C system. Grains of this type were regular monocrystals with the relatively large and smooth $\{111\}$ and $\{100\}$ faces, and in a lesser degree, in the form of twin, parallel or irregular intergrowths, or fragments of larger mono- or polycrystals. Grains recommended for tools with metallic binders, e.g. saws, dressing wheels, drills, (MBS, MSD, MBS-70, MBS-750, SDA, SDA 100, MDAS) exhibited a compact, nearly spherical structure and the angles between faces with a common edge not less than 90°. The amount of grains in this form ran up to 90%. Sporadically crystals with rounded or chipped-off corners and edges were noted. In other commercial brands used in tools with metallic binders, there were fewer regular monocrystals.

Grains with rounded corners and edges were observed primarily in synthetic abrasives recommended for tools with galvanic metal binders (more than 40% of grains).

Octahedral monocrystals were present in the ACB, ACK and Polish DSK grains. As suggested by chemical analysis, these diamonds were synthesized in the Ni—C or Ni—Mn—C system. A comparison of the ACO, ACP, ACB and ACK grains showed that they were characterized by the increasing amounts of grains with a compact structure and contained more and more regular monocrystals with the smooth and larger $\{111\}$ faces. In the ACB, and particularly ACK grains, not fully grown crystals were found as a combination of octahedron and cube.

Comparing the grain habit and the range of brands of one producer, from diamonds for tools with resin, ceramic, metallic (for grinding and superfinish, for granding wheels and files) and galvanic metal binders to tools with metallic binders for the working of rocks, concrete and refractories and for the dressing of grinding wheels (for saws, drills, dressing wheels), it was found that the samples contained more and more compact grains in the form of monocrystals with a less developed, smoother surface. The samples of grains for tools with a resin binder consisted entirely of polycrystals and monocrystals showing a complex irregular habit, with the faces grown differently near the edges and corners compared with

* All symbols for synthetic diamond samples are given according to the designation of their producers. Polish grains have symbols: MDS — monocrystalline synthetic diamond, PDS — polycrystalline synthetic diamond, DSK=PDS (different producer, Ni catalyst).

the central parts, or grown unevenly in different directions. Characteristic were also grains with a platy habit and grains that were irregular intergrowths of fine crystals of various sizes, generally less than 40 μm (smallest grain size). It was found that in these types of diamond grains the well developed flat faces frequently concealed the layered structure and pores in the grains. Such structure of diamond was presumably due to the presence of a large number of crystal nuclei in the process of synthesis.

The transparence, translucence and the colour of grains are affected by the internal structure of diamond crystals (Maślankiewicz, Szymański 1976; Orłow 1973). Grains more than 100 μm in size containing nickel were green-grey or black. Dominant were dark-green grains, commonly with black opaque inclusions, or grains of grey colour resulting from the considerable development of the surface, or from fractures. Most grains (more than 70%) were non-translucent. Grains containing cobalt were dark-green to light-yellow, the colour varying with their size. In the RVG, RDA, DSK, DSP, PDS and ACO brands more light, colourless and translucent grains were found in the RDA, RVG, DSP and PDS samples. Samples of smaller grain size contained more translucent grains. Micrograins less than 20 μm in size appeared to be translucent white-grey or colourless monocrystalline fragments. Their lighter colour was presumably due to the increased amount of monocrystals and the decrease in the number and size of inclusions in grains. Natural grains were mostly translucent colourless crystals with lustrous or mat surfaces. The SNDMB and NRBT samples contained transparent crystals, about 1/6 of the total amount of NRBT grains being black and non-translucent diamonds. In the SNDMB and NRBT grains, single crystals of light-yellow colour were present.

On the basis of microscopic examination, the authors classified abrasive diamond grains into groups characterizing their internal and morphological structure from the viewpoint of their application in tools with various binders. Seventeen extreme forms of abrasive diamond grains were distinguished (Table 1A). In respect of the internal structure and crystal habit, the following grains were distinguished:

— regularly formed monocrystals,
— monocrystals grown unevenly in various directions,
— coarse polycrystals,
— fine polycrystals,
— skeletal crystals.

Table 1

Extreme forms of diamond abrasive grains (A) and interrelation between form of grain, commercial sorts as well as field of application (B)

A

SURFACE / INTERNAL STRUCTURE AND CRYSTAL HABIT	Grains with flat, smooth faces	Grains with flat, rough faces	Grains with very rough surface	Fragments of larger grains	Ovalized grains
Regularly formed monocrystals	A (1)	A (2)		A (3)	A (4)
Monocrystals grown unevenly in various directions	A (5)	A (6)		A (7)	A (8)
Polycrystals composed of coarse crystals	A (9)	A (10)	A (11)	A (12)	B (13)
Polycrystals composed of fine crystals			A (14)	B (15)	
Skeletal crystals			A (16)	B (17)	

B

Extreme forms of diamond grain growth (according — A)	Sort of grain: synthetic, I				II	III							IV							V			natural, III+				
	ACO	ACP	ACB	ACK	DSP	RDA	MDA	MDAS	MDASE	MDAE	SDA	SDA-100	RVG	MBG II	MBG-P	MBG-T	MBS	MBS-70	EP-100	DSK	PDS	MDS	SNDMB	NRBT	RPD I	EMB	DEBDUST
1							A	A	B	B	A	A		A	B	A	A	A	B			A					
2			B	A			B	B	A	A	B	B		B	A	A	A	B	A			A					
3							A	A	A	A	B	B		A	A	A	B	B	A			A	A	A			
4							B	A	A	A				B	B	B			A			B			A	A	A
5							A	A			A	A		A	A	A	A	A			B	A					
6			A	A	B	B	A	B	B		B	B	B	A	A	A	B	B	B		B	A					
7	B	B	B	A	B	B	A	A		A	B	B	B	A	B	B	B	B	B	B	A	A					
8				B			B	B	B	A									B						A	A	
9	A	B	A	B	A	A	B						A	A	A						A	A					
10	A	B	A	A	A	A							A	B	B						A	B					
11	A	A	A		B	A	B						A		B					A	B						
12	A	B	B	A	A	A							A	A	B					B	A	B					
13																				B							
14	A	A	B		B	A							R		B					A	B						
15	B	B	B		B	B							B							B	B						
16	B	B	B		B	B														A							
17	A																			A							
Suggested by producer type of binder in tools (+)																											
Binder:																											
resinoid	+	+			+	+							+		+					+	+			+			
ceramic		+	+										+														
galvanic									+	+						+			+								
metallic			+	+			+	+			+	+			+		+	+				+	+		+	+	+

Grains with this forms to appear:
A — in majority,
B — sporadically.
+) Producer or distributor I. USSR; II. Czechoslovakia; III. De Beers; IV. General Electrgic; V. Poland.

Taking into consideration the surface structure, the grains were divided into:

— grains with flat, smooth faces,
— grains with flat, rough faces,
— grains with very rough surface,
— fragments of larger grains,
— ovalized grains.

Plates I and II give a more detailed characterization of the terms used, along with descriptions and examples of certain relative standards for each grain form. Since single diamond grains with a definite internal structure show a diversified morphological structure, they should be described in a complex way. Table 1A presents the extreme forms of abrasive diamond grains distinguished on the basis of microscopic examination, which characterize the morphological and internal structure of grains.

DISCUSSION

The commercial brands of diamond were evaluated from the point of view of occurrence of grains showing the defined extreme forms. As appears from Table 1B, there is a correlation between the form of a single diamond grain, the composition of samples from different brands as regards the amount of grains with a similar structure, and the optimum, i.e. recommended by the producer, application of diamond in tools. A comparison of the composition of diamond brands in respect of the form of single grains with the range of application of these brands suggests that the kind of binder in a tool, and thereby the kind of mechanical working, requires the use of grains with an appropriate structure.

From the above studies it follows that the introduction of the criteria of grain structure and the standards of extreme grain forms allows an evaluation of natural and synthetic diamonds of various provenance from the viewpoint of their optimum uses. The analyses have shown that such evaluation is a non-destructive and unequivocal method of investigating the grain structure, permitting one to define readily the optimum range of application of grains in tools, and to determine their mechanical strength. On the other hand, it should be noted that an assessment based on microscopic studies is in some measure subjective and fails to determine fully the physico-chemical properties of a grain. The classification of diamond grains presented in this paper does not exhaust all the possibilities. In the authors' opinion, it is satisfactory for comparisons of diamond grains from the point of view of their use in tools with various binders. It may also serve as a basis for detailed analysis of individual grain forms (for example, monocrystalline grains with rough faces may be evaluated from the viewpoint of the diversity of their surface structure; fine- and coarse-crystalline grains consisting of polycrystals may be divided according to the size and habit of diamond crystals making up single grains; the linear parameters of grains may be estimated, etc.).

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REFERENCES

BAKOŃ A., 1980: Doctor degree dissertation. Technical University Wrocław.

BAKUL W. N. et al., БАКУЛЬ В. Н., 1976: Синтетические алмазы в машиностроении. Наукова Думка, Киев.

Catalogue. De Beers Ind. Diamond Division, 1979.

Diamond Abrasives Classified in Triefus Codings — TAC. London 1965.

MAŚLANKIEWICZ K., SZYMAŃSKI A., 1976: Applied mineralogy (in Polish). Wydawnictwa Geologiczne. Warszawa.

ORŁOW J. Ł. ОРЛОВ Й. Л., 1963: Морфология алмаза. Изд. АН СССР. Москва.

ORŁOW J. Ł. ОРЛОВ Й. Л., 1973: Морфология алмазов. Наука. Москва.

SEMKO M. F. СЕМКО М. Ф., 1978: Основы абразивного шлифования. Техника. Киев. Синтетические алмазы в промышленности. Наукова Думка. Киев 1977.

STOLIN O., GWOŻDIARA P. СТОЛИН О., ГВОЖДИАРА П., 1971: Алмазы 6, 28. *Синт.*

SZYMAŃSKI A., 1966: System TAC. *Mechanik* 4, 230.

Andrzej BAKOŃ, Andrzej SZYMAŃSKI

JAKOŚCIOWA KLASYFIKACJA MIKROKRYSZTAŁÓW DIAMENTOWYCH NA PODSTAWIE CECH MORFOLOGICZNYCH

Streszczenie

W artykule przedstawiono opracowaną na podstawie badań mikroskopowych morfologiczną klasyfikację jakościową diamentów syntetyzowanych metodami statycznymi. Badania prowadzono na diamentach wytwarzanych przez głównych producentów światowych porównując ziarna pod względem budowy i pokroju kryształów oraz struktury ich powierzchni. Dla obydwu parametrów określono po pięć odmiennych postaci dla których wytypowano po trzy charakterystyczne formy, zestawione na planszach I i II. Tabele te stanowią podstawę do praktycznej oceny jakości produktów syntezy i łącznie z tabelą 1B pozwalają na zalecanie określonego typu spoiwa do ścierniwa diamentowego dla wytwarzania narzędzi o optymalnych parametrach eksploatacyjnych.

Zaletą przedstawionej klasyfikacji jest ocena diamentu metodami nieniszczącymi, które dobrze różnicują diamenty również pod względem wytrzymałości, ściśle związanej z budową poszczególnych ziarn.

OBJAŚNIENIA PLANSZ

Plansza I. Charakterystyka form ograniczających strukturę i pokrój krystaliczny diamentu.

Plansza II. Charakterystyka form ograniczających powierzchnię struktury kryształów diamentu.

Анджей БАКОНЬ, Анджей ШИМАНЬСКИ

КАЧЕСТВЕННАЯ КЛАССИФИКАЦИЯ АЛМАЗНЫХ МИКРОКРИСТАЛЛОВ НА ОСНОВАНИИ МОРФОЛОГИЧЕСКИХ ПРИЗНАКОВ

Резюме

В статье представляется качественная морфологическая классификация синтезированных статическими методами алмазов, разработанная на основании микроскопических исследований. Исследования проводились на алмазах, получаемых главными производителями в мире, причем сопоставлялись зерна в отношении строения и габитуса кристаллов, а также структуры их поверхностей. Для обоих параметров определено по пять разных видов, для которых намечены по три характерные формы, показанные на таблицах I и II. Эти таблицы являются основой для практической оценки качества продуктов синтеза и вместе с таблицей 1В позволяют рекомендовать определенный тип цемента алмазных абразивов для производства инструментов с оптимальными эксплоатационными параметрами.

Преимущество представленной классификации заключается в проведении оценки алмаза методами без его разрушения, которые хорошо различают алмазы также в отношении сопротивляемости, тесно связанной со строением отдельных зерен.

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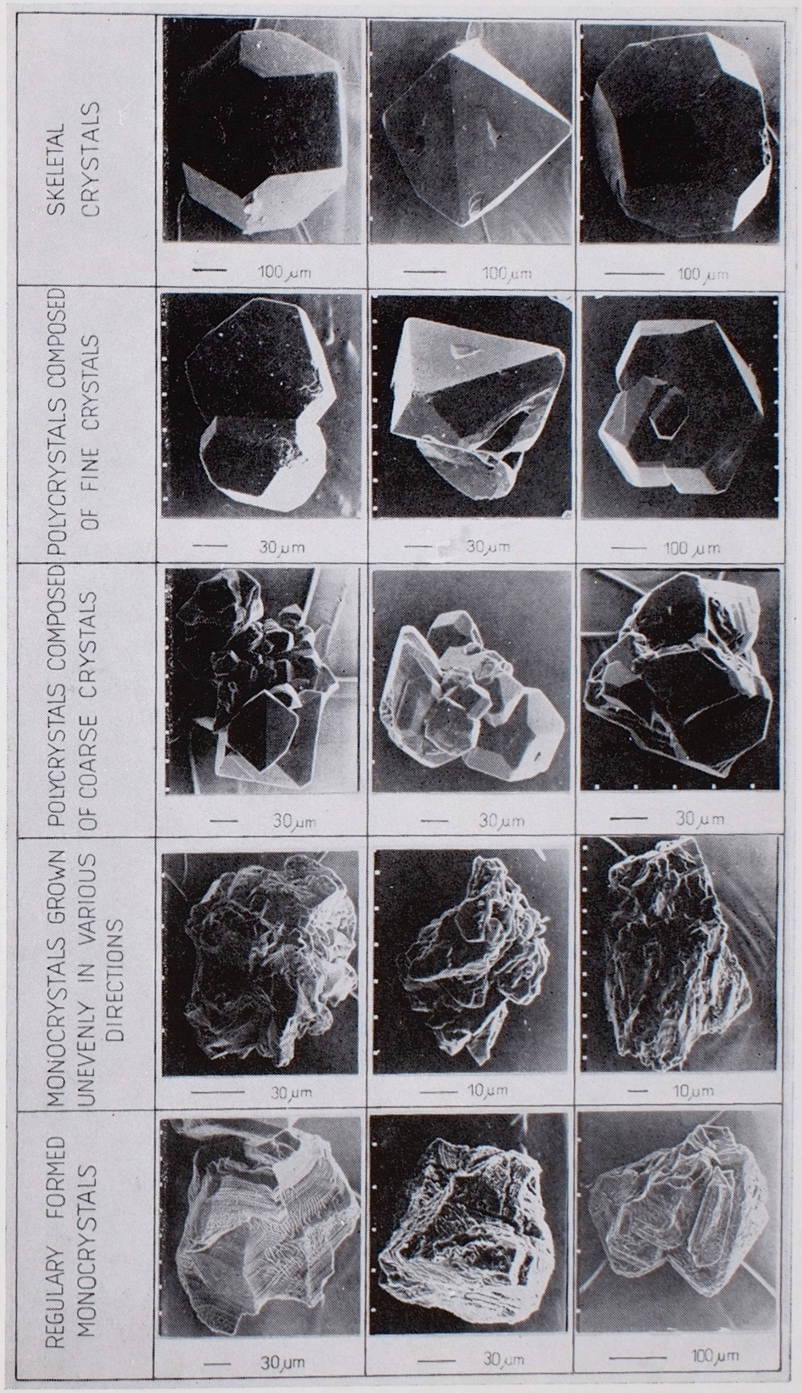
ОБЪЯСНЕНИЯ К ТАБЛИЦАМ

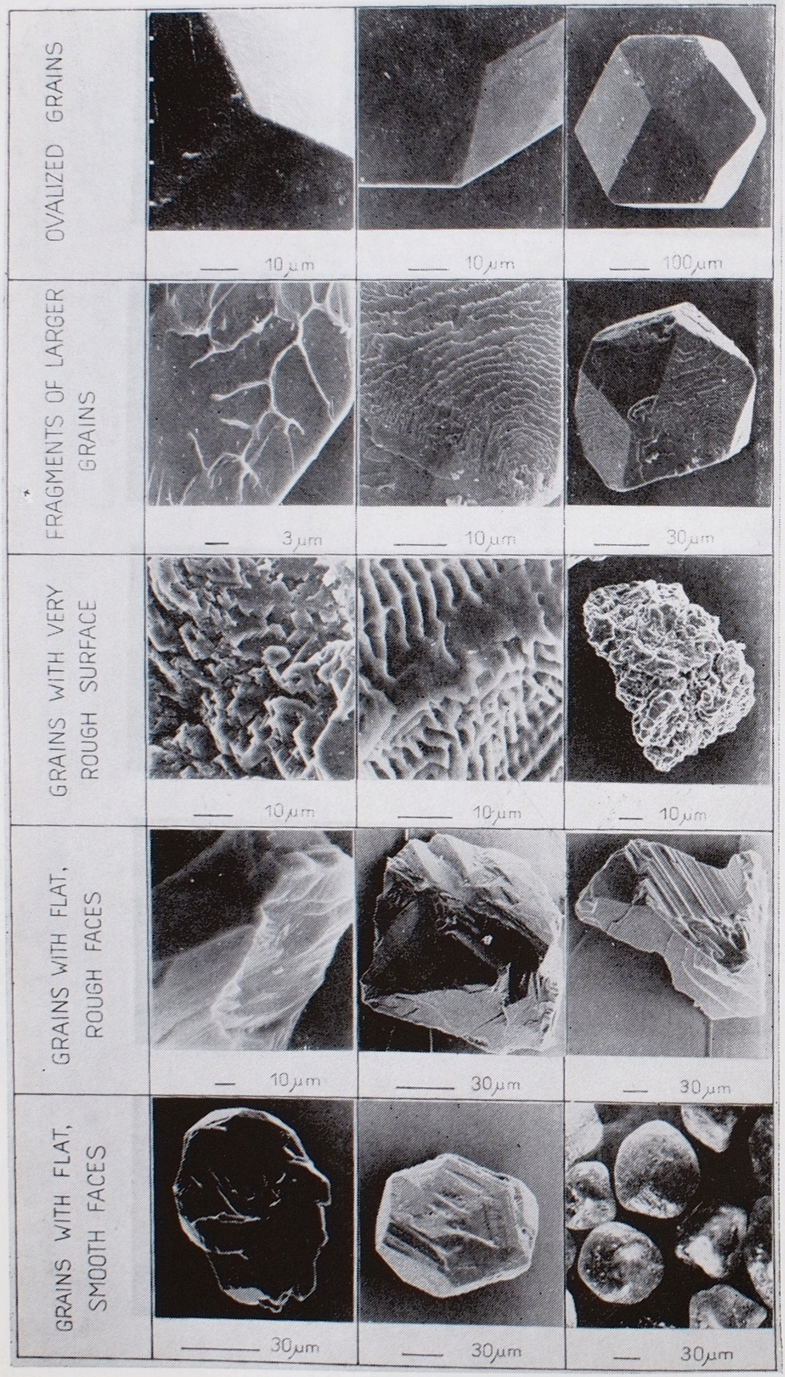
Таблица I. Характеристика форм ограничивающих структуру и кристаллический облик алмаза.

Таблица II. Характеристика форм ограничивающих поверхность структуры кристаллов алмаза.



Characteristics of limiting forms of the structure and crystal habit of diamond

Andrzej BAKOŃ, Andrzej SZYMAŃSKI — Morphological qualitative classification of synthetic diamond microcrystals



Characteristics of limiting forms of the surface structure of diamond crystals