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Manufacture of tips for diamond burnishing and dressing probes for abrasive wheels with a diamond composition thermal material AKTM®

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A thermally sound composite material, consisting of polycrystalline diamond and silicon carbide, namely the AKTM® aggregate, was developed at the Institute for Superhard Materials of the National Academy of Ukraine. Its improved physical and mechanical properties make it suitable for a wide range of material removal operations. In the present paper the manufacture and the performance of the material on industrial applications are discussed.

1. Introduction

Diamond burnishing is the method of burnishing by surface plastic deformation, encompassed by the sliding on it of a burnisher, i.e. an insert made of natural or synthetic diamond of the "balas" or "carbonado" components with a fine-grained polycrystalline diamond microstructure, similar to the crystalline structure of the natural diamond carbonado. Note that, the high values of hardness of the diamond enable the processing of almost all plastically deformed metals and low strength materials, quenched up to a hardness HRC 60–65. A schematic diagram of a spherical surface burnisher is shown in Fig. 1. The small radius of curvature of the diamond burnisher, 0.75–4 mm, results in a small burnishing force, 50–300 N, that allows for the treatment of thin-wall, no rigid components, where requirements for machine tool rigidity are not necessary. Low strength workpiece materials employed are synthetic corundums, sapphire and hard-face alloys, however, stability of such burnishers is rather insignificant.

The roughness of the plastically deformed surface and the work-hardening of the material depend on the parameters of diamond burnishing, i.e. the contact pressure and surface, the magnitude of the normal force applied by the devise to the surface, the radius of curvature of the burnisher, the machining parameters and the lubricant used.

In the present paper, the improvement of the operational properties of diamond polycrystalline materials, used as inserts of dressing probes, tips for diamond burnishing and wear-resistant components is considered. For such industrial applications a thermally sound composite material, consisting of diamond and silicon carbide, namely the AKTM®, has been developed at the Institute for Superhard Materials of the National Academy of Ukraine in Kiev; its properties and applications are discussed.

2. Fundamentals of burnishing

For shaping surface microcontours at burnishing of metals and coatings, especially rigids see Fig. 1, natural diamonds may be considered as more preferable, than polycrystals from synthetic diamonds, such as "balas" or "carbonado," with the friction coefficient of the former being 2.5–4 times lower of the latter. Note that, the synthetic polycrystalline materials contain a great quantity of metals, i.e. Ni and Cr, up to 10% of mass, considerably aggravating their frictional properties; their thermostability (700°C), consisting of diamond grains of different sizes, results in a high porosity of the worked surface. Note, also, that, the thermostability of both the natural diamond and the synthetic diamond polycrystalline materials is very important for the manufacturing of the burnishers and, also, during processing.

The burnishing process is due to the inconvertible external abrasive at the contact of the workpiece and the burnisher, accompanied by plastic deformation and adhesion welding of the surface layers. The effect of the size of the intruding burnisher and the horizontal toughness of the adhesion are determined by the friction coefficient, consisting of the deformation, f_{def} and the adhesion, f_{adh} components. Note, however, that, the frictional deformation component, f_{def} does not depend on the burnisher type, influencing only the adhesion frictional component, f_{adh}, related, more or less,

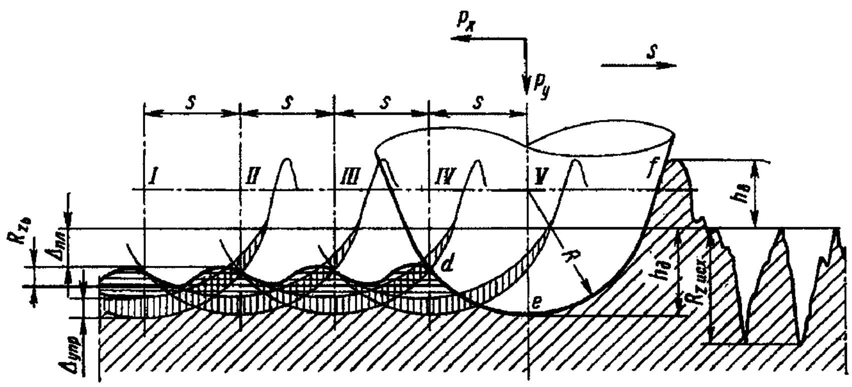


Figure 1 A schematic diagram of a surface microcontour deformation by a spherical burnisher.

to frictional natural diamonds. Therefore, by using synthetic diamonds, the passage from the plastic deformation regime to microcutting is observed at smaller values of the relative intrusion, $h\Sigma/R_{sph}$, see Fig. 1, which is associated to the higher porosity and roughness of the worked surface of the synthetic diamonds, and, also, to the higher values of $d\tau/dh$, reducing the threshold of the external abrasive processing.

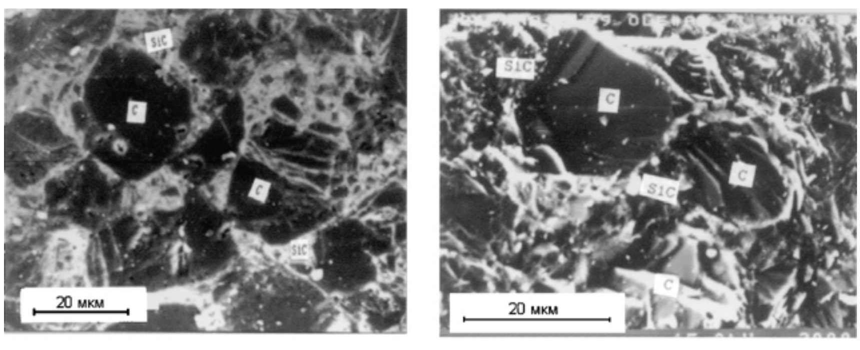
The relative intrusion, $h\Sigma/R_{sph}$, under optimal burnishing conditions, varies within small limits, probably stipulated by the operation of the resilient component intrusions; with the other components being equal, the plastic component varies slightly. Experimentally, it was found, that the magnitude of the relative intrusion, $h\Sigma/R_{sph}$ for steels and alloys is $1.5–2.2 \times 10^{-2}$, and for nitride and carbon saturated steels $2.8–3.2 \times 10^{-2}$. From Table I, it is indicated, that the conditions and requirements of burnishing do not have as essential effect on f_{adh}, which is 0.3–0.6 f_{fric}. Hence, the development of a new tool material, ensuring low adhesion frictional coefficient component at burnishing, constitutes an actual problem, see also [1].

3. Manufacturing of composite material AKTM®

Nowadays, wide application in industry is gained by thermally sound synthetic polycrystalline materials, consisting of classified flours of diamond and silicon carbide, fabricated by impregnation of diamond grains by silicon at high-pressures and temperatures [2]. A such widely used material is the Sindaks-3 produced by De Beers Co [3], whilst at the Institute for Superhard Materials of the National Academy of Ukraine (ISM) the AKTM® aggregate was developed, with improved physical, mechanical and operational characteristics, primarily used for fabricating drilling tools of high performance [4].

The microstructure of the material is shown in Fig. 2; it consists of a matrix of particles, ca. 85–90% of mass, dispersed with particles of silicon carbide and disconnected crystalline silicon (1–2% of mass). Note, however, that, the brittleness of the material is very high, leading to a low output, mainly due to the dissimilarity of the SiC structure and the presence of the disconnected silicon. It is known that, at solidification, the silicon results in an increase in volume by approximately 10%, in the development of flaws after baking and consequent cooling. Examinations revealed that, by adding silicon in an imbuing stratum of nanograins of diamond or carbide, the above-stated deficiency may be eliminated [4]. The microstructure of this new material indicated, that the component of diamond nanograins in an imbuing stratum at baking of an aggregate "diamond—carbide of silicon" results in the formation of a homogeneous dispersible connecting phase SiC and in a sharp diminution of the content of the disconnected silicon [5].

The physical and mechanical properties of the AKTM® depend on the baking conditions (pressure, p – temperature, T) and on the arrangement of the initial diamond grains. From measurements, it can be stated that the compressive strength of the AKTM® aggregate exceeds the strength of similar material by 30% [5].



(a) (b)

Figure 2 Microstructure of a diamond—SiC aggregate obtained on a raster electron microscope (a) at fracture (b) on the surface [4].

TABLE I Influence of burnishing conditions on friction coefficient [1]

Elemental composition of steel								R_{sph} (mm)	Optimal force P_y, (N)	Microhardness H_{max} (MPa)	f_{adh}	f_{adh}/f_{fric}
C 0.30%	Si 0.27%	Mn 0.65%	Cr < 0.25%	Ni < 0.25%	Cu < 0.25%				130	3200	0.043	0.52
C 0.38%	Si 0.3%	Mn 0.5%	Cr 1.5%	Mo 0.2%	Al 0.9%				150	3500	0.040	0.49
C < 0.12%	Si < 0.8%	Mn < 0.8%	Cr 17.0%	Ni 5.0%	Cu < 0.2%				170	4500	0.037	0.48
C < 0.12%	Si < 0.8%	Mn < 2.0%	Cr 18.0%	Ni 9.0%	Ti 0.7%				190	4600	0.038	0.48
C < 0.08%	Si < 0.6%	Mn < 0.6%	Cr 15.0%	Ni 35.0%	Ti 2.8%	Al 1.0%	W 3.1%	1.5	200	4600	0.040	0.50
C < 0.07%	Si < 0.6%	Mn < 0.4%	Cr 20.0%	Ti 2.6%	Al 0.8%	Fe 1.0%			220	5450	0.035	0.46
C 0.18%	Si 0.27%	Mn 0.4%	Cr 1.5%	Ni 4.2%	W 1.0%				200	5600	0.034	0.47
C 0.31%	Si 1.1%	Mn 1.0%	Cr 1.0%	Ni 1.0%					240	5600	0.026	0.38
C 0.14%	Si < 0.8%	Mn < 0.5%	Cr 17.0%	Ni 2.0%					240	6300	0.032	0.45
C 0.31%	Si 1.1%	Mn 1.0%	Cr 1.0%						240	6400	0.032	0.45
C 0.9%	Si < 0.8%	Mn < 0.8%	Cr 18.0%	+ nitration					220	9270	0.021	0.35
C 0.12%	Si < 0.6%	Mn < 0.6%	Cr 2.0%	Ni 1.0%	Mo 0.2%	+ saturated carbon		1.2	220	9300	0.021	0.35
C 0.12%	Si < 0.6%	Mn < 0.6%	Cr 12.0%	Ni 4.0%	+ saturated carbon				240	10500	0.018	0.32
		Coverage by chrome							260	10800	0.017	0.30
C 0.38%	Si 0.3%	Mn 0.5%	Cr 1.5%	Mo 0.2%	Al 0.9%	+ nitration			260	12000	0.010	0.30

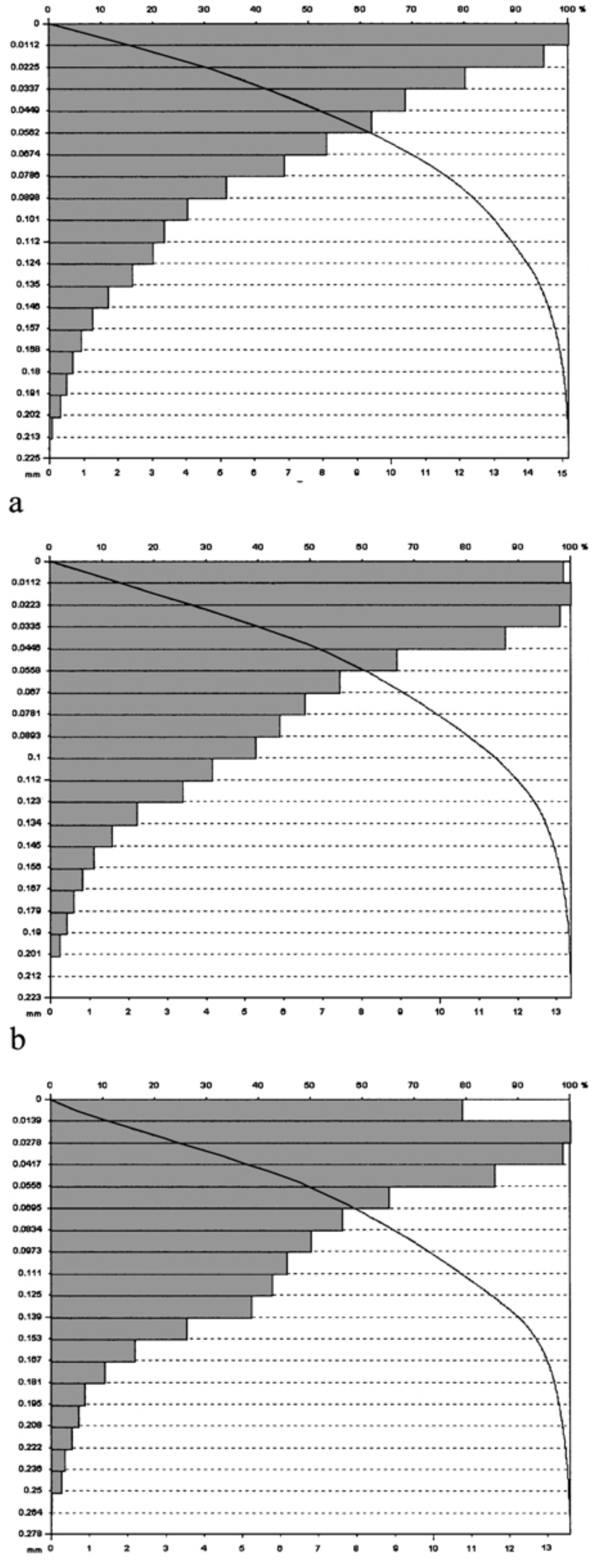


Figure 3 Abbott-firestone curve for the spherical surface of AKTM® burnisher in dependence of the grains maximum size (a) 20 μm (b) 40 μm (c) 60 μm.

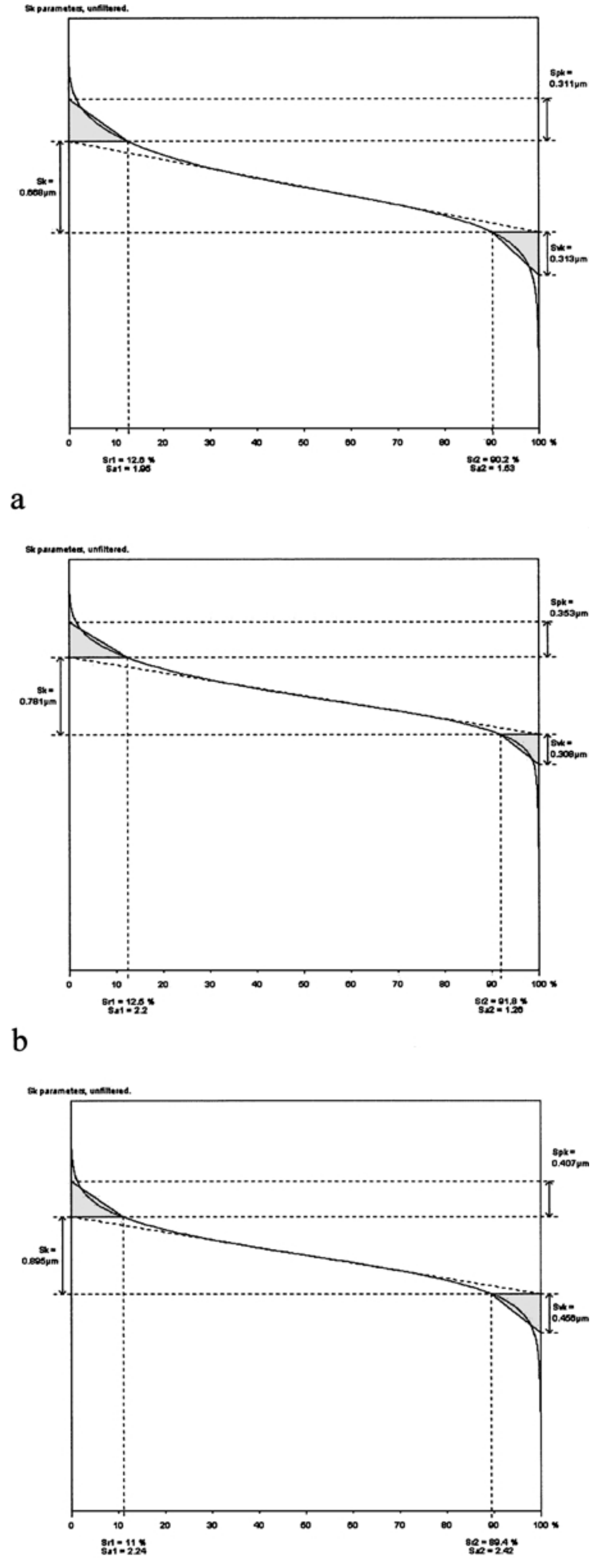


Figure 4 Graphical study of Sk's (ISO 13565) for the spherical surface of AKTM® burnisher in dependence of the grains maximum size (a) 20 μm (b) 40 μm (c) 60 μm.

The relevant performance of diamond composition materials is their thermostability, i.e. the ability of the material to maintain the physical and mechanical characteristics up to a particular temperature after cyclic heating. By heating at temperatures between 800–1400°C (with a step of 100°) it was found, that the properties of the aggregate practically did not vary up to 1200°C. For temperatures higher than 1200°C, the values of the physical and mechanical characteristics of the material were considerably reduced [2].

The high values of a thermostability and strength are ensured from the following technological advantages of

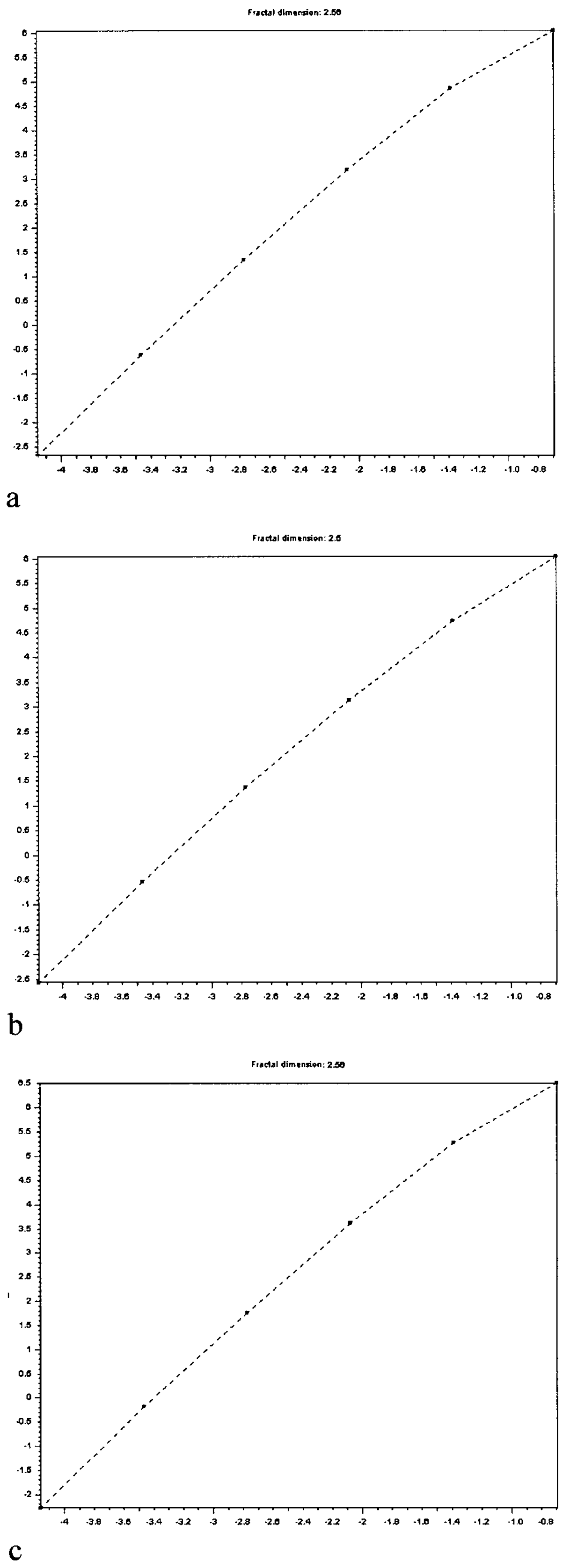


Figure 5 Fractal analysis for the spherical surface of AKTM® burnisher in dependence of the grains maximum size (a) 20 μm (b) 40 μm (c) 60 μm.

the AKTM®, as compared, in particular, to the synthetic diamond polycrystalline material "carbonado":

- Control of the physical and mechanical properties, by using at baking of the AKTM® diamond grains of different speckles and marks; note that, in the case of "carbonado" graphite is converted into diamond at high pressures, p and temperatures, T.
- Formation of different shapes and sizes of the material.

These result in a wide area of applications of the AKTM®. Nowadays, this material is used for rigging a drilling tool (for moderate drilling), for fabricating dominative pencils and manifold valves (for editing half-hard abrasive wheels for end measuring), wear-resistant legs and for burnishing. Practically, in every application of this material, it is required to adjust the structure of the aggregate, i.e. to change its thermostability, or strength, by constructing new marks of the aggregate for specific requirements; for example, the material due to be used for rigging of the dominant device, must have high values of thermostability (1300°C) and thermal conductivity. For deriving an aggregate with such a performance, in order to be used for baking, grains of natural or synthetic diamonds with a minimum quantity of metal inserts and admixtures are required.

Manufacturing of AKTM® dressing sticks of a type diamond in a casing, basically assigned to one profile editing of abrasive wheels with a split-hair accuracy and, also of AKTM® diamond burnishers have been developed at the ISM. Influence of the arrangement of the initial diamond grains on a roughness parameters of spherical surface of AKTM® burnisher is indicated in Table II. Abbott-firestone curves (roughness and waviness), graphical study of Sk's (ISO 13565) and fractal analysis for this surface in dependence of the arrangement of the initial diamond grains are shown in Figs 3–5. The surface roughness of the burnishers depends on the mark and speckle of a wheel and, mainly, on the material structure.

The depth of the hardened layer at diamond burnishing, is related to the specific pressure exerted on the contact area, which depends on the force of the holder, the size of the burnisher, the properties of the material and the size of the workpiece. The degree of hardening and the distribution of the residual stresses developed

TABLE II Influence of a size of the initial diamond grains on a roughness parameters of spherical surface of AKTM® burnisher

Roughness parameters (μm)	Maximum size of the initial diamond grains (μm)		
	20	40	60
R_z	2.54	3.23	4.08
R_p	1.23	1.37	1.81
R_v	1.77	2.78	2.98
R_t	3.00	4.15	4.79

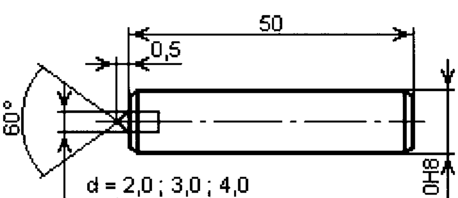
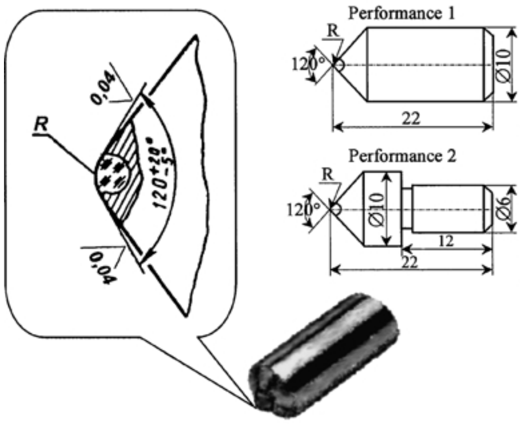


Figure 6 Principal dimensions of the dressing stick for editing abrasive wheels (diamond in casing).



Type and size	
Performance	R (mm)
1	0.5
	1.0
	1.5
	2.0
	2.5
	3.0
	3.5
	4.0
2	0.5
	1.0
	1.5
	2.0
	2.5
	3.0
	3.5
	4.0

Figure 7 Principal dimensions of the diamond burnisher.

depend only on the applied pressure and the amount of repeated straining of the worked surface; hardening depends on the machining speed. It is to be noted, however, that the same parameters, which are related to hardening, influence the amount and the degree of heat generated, due to the plastic deformation and the thermoplastic stresses developed, which may change magnitude and, sometimes, the character of the resulting stresses. The temperature distribution has its maximum value at the surface layer and gradiently drops in the sub-surface layers. The intensive pressure, the instantaneous heat and the prompt cooling of the worked surface result in a change of the microstructure of the metal of the hardened surface layer and the development of high temperatures in a thin surface layer. Therefore, the properties and the thermostability of the AKTM® burnishers are necessary in the case of machining hardened steels with medium and low hardness, or high-resistance steels, not prone to temperature changes of the metal structure.

It is to be noted that, for the AKTM® burnishers, it is necessary to define the optimum size of the initial diamond grains and also to define links between the hardness of the treated surface and the physical and mechanical properties of the AKTM® aggregate.

4. Conclusions

Summarising the main results reported, pertaining to the development at the Institute for Superhard Materials of the National Academy of Ukraine, of the AKTM® material, i.e. a thermally sound composite aggregate, consisting of diamond and silicon carbide, it may be concluded that, due to the improved physical and mechanical characteristics, this aggregate is suitable for manufacturing components and machine tools for a wide range of industrial machining operations.

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