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QUALITY IMPROVEMENT OF PRODUCTS MADE OF HIGHLY RIGID CERAMICS FOR HEAVY-LOADED FRICTION PAIRS

The paper shows that one of the ways of getting non-porous ceramic materials based on silicon carbide can be using aluminum oxide as an additive. The paper also offers the quality assessment forecast method for highly rigid and brittle ceramic materials using the criterion of their surface fragility.

Keywords: *silicon carbide, aluminum oxide, micro-indentation, hot pressing (clinkering), surface fragility, diamond polishing, highly rigid ceramics, non-porous materials.*

The practice of designing and making machinery shows that further development of scientific and technological progress is impossible without the use of high-tech, high-strength and wear-resistant materials and ingenious engineering solutions.

The issue of increasing the dependability and durability of individual components, assemblies and whole complexes is particularly urgent in the petroleum and chemical industries, as well as in the construction industry, where the equipment operates in extremely unfavorable conditions, corrosive environment, abrasives, high contact temperature, etc. We believe that ceramics can be considered as the most promising material for use in these industries.

Our studies have shown high efficiency of products made of hard ceramics in heavily loaded subassemblies (friction pairs). However, the dependability and durability of ceramics articles is largely determined by the quality of the working surface formed at the final stage of product machining.

From field experience it is known that in the chip-cutting operation during diamond grinding of ceramics individual diamond grains together with an aggregate of wheel bond take place in the process. However, basically the removal of outsize from stock surface is defined by the action of diamond grains themselves, which play a major role in the dispersion of the material [1 – 2]. We carried out a study of cutting-scratching by a single-point diamond in the form of a diamond pyramid, as well as by a raw single-point diamond of natural geometry with the original submicroscopic relief.

It was found that at the beginning and at the end of scratching the grain leaves a clear trace with no apparent chipping at the edges, and a sliding zone preceding the penetration of the diamond grain is absent (fig.1.). Possessing the high hardness, the diamond grain begins to cut the chip immediately upon contact with the material, and the middle part of the scratch has a large tear-out on the edges of its entire length so that the scratch edges are delineated by a broken line in the their middle part.

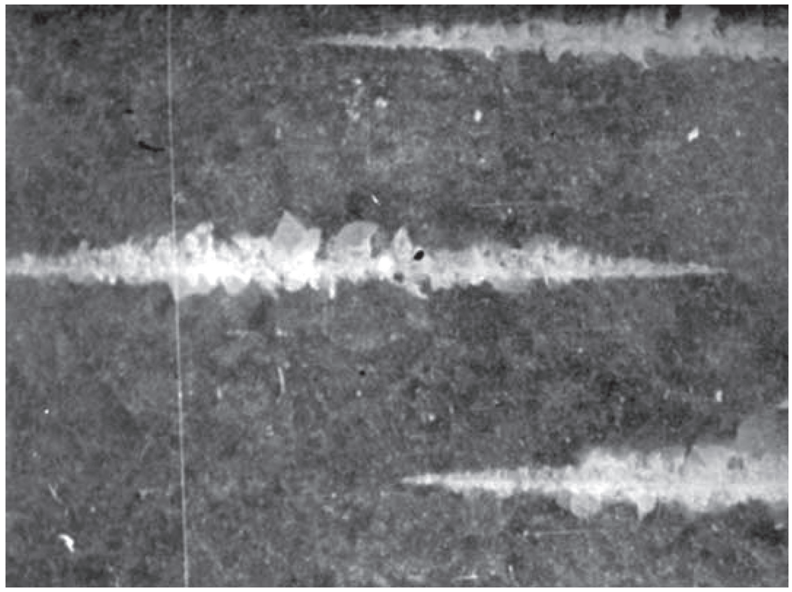


Fig. 1. The view of scratch on the surface of silicon carbide ceramics
In case of cutting $V_{пр}$ = 38 m/s by a single diamond grain, x 300

Chips emerge when the grain reaches a certain depth of penetration. This can be explained by the fact that with increasing depth of cutting, new edges of the diamond grain come into play and here micro-cutting forces increase in the area of the grain contact with the sample material: large sections of tear-outs and the formation of highly dispersed chips are observed.

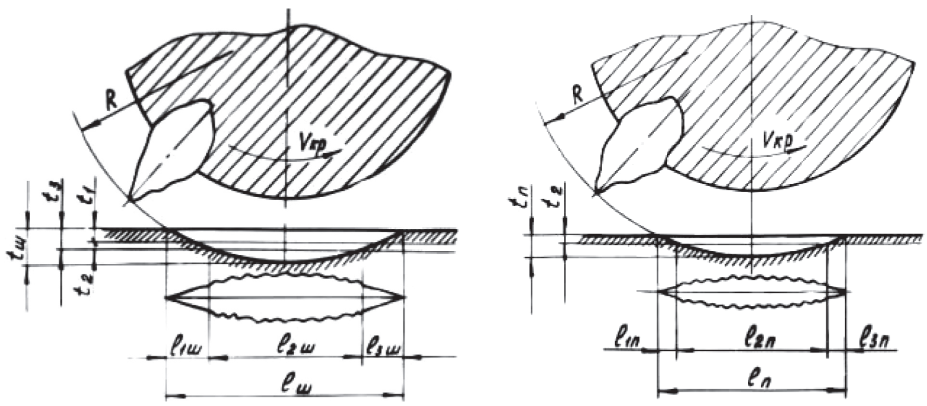
The penetration depth of a diamond grain in which the chips are beginning to appear on the scratch sides, depends on many factors. It is determined by the strength properties of the machined material and the condition of its working surface, all other things being equal. That is, at the same cutting speed characteristics of a diamond grain should not depend on the depth of cutting, except for an insignificant effect of a slight change in a front angle at start and change of a cutting angle. To verify this statement, we carried out measurements of the length of scratch marks $l_{ш}$ (fig. 2) on the preliminary ground samples and $l_{п}$ on the preliminary polished samples and the length of the middle section of marks with chips $l_{2ш}$ on the preliminary ground and $l_{2п}$ on the preliminary polished samples. Using these data, the actual depth of the mark $t_{ш}$ ($t_{п}$) and the depth of grain penetration, in which chips $t_2(t_3)$ appear, have been calculated by the following formulas:

$$t_{ш,п} = R - \frac{\sqrt{4R^2 - l_{ш,п}^2}}{2};$$

$$t_{2,3} = \frac{\sqrt{4R^2 - l_{2ш,2п}^2} - \sqrt{4R^2 - l_{ш,п}^2}}{2}.$$

The results of the calculation are presented in table 1 and table. 2.

In the process of variance analysis to determine the significance of the obtained results, the action of two factors has been revealed: the first factor – micro-cutting depth – the depth of the indenter penetration into the scratched surface (factor *A),* the second factor – the surface condition of the scratched surface – ground or polished ones (Factor *B).* Factor *B* has two levels, and 16 levels were adopted for factor *A* – a total range of depth of mark-scratches on ground and polished surfaces. The values of the bedding depth of the chipless part of mark-scratches for the grain going in and out of contact with scratched surface were calculated by parallel observations.



a *b*

Fig. 2. Scheme of cutting-scratching by a single diamond grain corresponding to surface grinding by diamond wheel periphery: *a* – on the preliminary ground samples, *b* – on the preliminary polished samples

Table 1. The results of determining the chipless depth of scratches in case of micro-cutting of ground ceramic surface

Depth of scratching mark, micron	The depth of the bedding depth of the chipless part of mark-scratch	
	in, micron	out, micron
13.1	12.3	11.3
22.2	6.4	12.7
20.1	17.6	13.3
25.3	19.9	17.9
20.6	9.9	20.2
20.8	9.5	16.9
32.7	23.6	12.3
21.8	14.5	13.2
11.0	8.1	9.2
16.0	7.4	7.6
24.0	9.1	23.2
17.9	11.1	12.9
15.2	14.7	9.5
38.2	9.3	17.2
45.6	18.2	4.5
57.8	4.8	30.1
50.4	20.0	23.2
44.2	24.1	20.2

Thus, this problem is a classic example of the use of two-factor analysis of variance with the assessment of the effect of the interaction of factors *A* and *B*.

Table 2. The results of determining the chipless depth of scratches in case of micro-cutting of polished ceramic surface

Depth of scratching mark, micron	The depth of the bedding depth of the chipless part of mark-scratch	
	in, micron	out, micron
11.7	6.2	6.2
48.3	3.3	3.3
47.6	3.2	4.6
42.9	3.3	3.3
34.2	3.2	3.4
26.3	3.0	3.2
21.2	2.4	2.4
14.5	5.6	5.5
7.0	5.2	5.1
14.2	3.2	3.1
11.9	5.0	3.0
9.9	1.8	1.5
20.7	3.1	3.0
16.0	3.5	3.3
15.2	5.7	5.8
16.9	1.8	2.2
27.6	2.9	2.3
26.8	2.0	2.4

The order of variance comparison has been performed in accordance with the recommendations by Fisher's criterion:

$$F_{\text{эмп}} = \frac{\sigma_{x^2}}{\sigma_{y^2}},$$

where σ_{x^2} and σ_{y^2} are variances of the first and the second sample respectively.

According to the criterion, the quantity of the numerator should be greater than the quantity of the denominator, therefore $F_{\text{эмп}}$ F will always be equal to or greater than 1.

The performed analysis showed the significance of factor *B* with a minor impact of factor *A* and their interaction:

$$\frac{nS_0^2}{S_2^2} = 1{,}13 \prec 2{,}1,\ F(0{,}95;15;32) = 2{,}1;$$

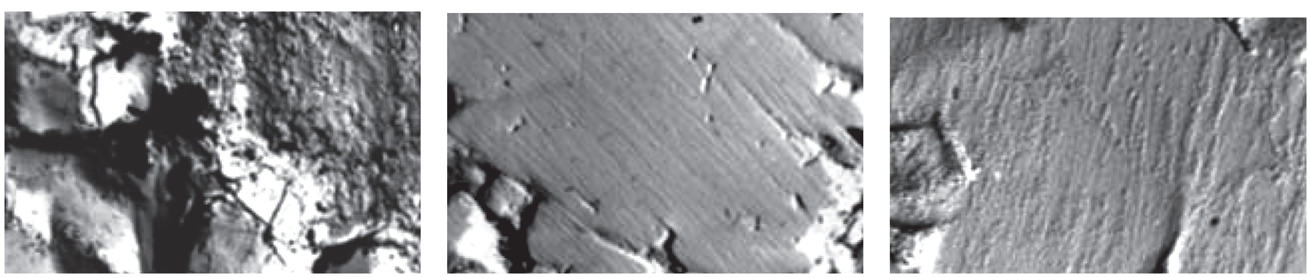
$$\frac{S_A^2}{S_0^2} = 0{,}55 \prec 1{,}6,\ F(0{,}95;15;15) = 1{,}6;$$

$$\frac{S_B^2}{S_0^2} = 85 \succ\succ 1{,}8, F(0{,}95;1;15) = 1{,}8;$$

where S_0^2 is combined variance of reproducibility and interaction; S^2 is variance of reproducibility; S_A^2, S_B^2, are sample variances.

Thus, we obtained a statistically significant influence of the factor of surface preparation method (grinding or polishing) on the chipless depth of a mark-scratch. At the same time, we did not detect any statistical significance of the influence of the factor ─ the scratch depth – on the same parameter, that, in turn, confirmed the proposal made above. It was found that the maximum grain depth of penetration at which the chips are formed on the mark edges of ground samples makes up at the average 14 microns, and in case of polished samples – 4 microns. The electroscope study of the surface layer and the determination of its micro-hardness were carried out on micro-hardness testing machine.

The studies described above have revealed the presence of the defective layer in the surface layer of grounded samples (fig. 3), which has a higher viscosity and reduced fragility. In case of the sample, the outer defect layer of which was removed by polishing, the maximum depth of chip formation makes up t_2, but in case of the ground sample the maximum depth is formed by the sum of the defect layer depth t_1, the material of which is more inclined to the viscous plastic flow rather than to brittle fracture and the depth of penetration in source material t_3, corresponding to t_2 for the polished sample. From these considerations, the depth defective layer was determined as $t_3 = t_1 - t_2$, which made up at the average 10 microns.



a *b* *c*

Fig. 3. The surface of silicon carbide ceramics after various surface treatment:
a – after grinding, x 7800; *b* – after polishing, x 7800 *c* – after polishing, x 7800

Thus, based on the Fisher criterion, the relation of influence of the method of highly rigid ceramics surface preparation (grinding, polishing) on chipless depth of grinding mark at diamond polishing has been theoretically determined and practically established.

The maximum depth of grain penetration, which leads to chips' formation on the trace edges for various methods of ceramic surface pretreatment makes up 4 – 14 mm, which is quite acceptable in the manufacture of high-precision articles and components.

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