Study of the machining quality of CMC ceramic composite during high-speed grinding

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Abstract. Ceramic matrix composites (CMC) are now an increasingly popular choice of materials used to manufacture critical parts for a variety of engineering applications. Due to the complex heterogeneous structure of CMC and the high hardness of at least one of the components (fiber or matrix) - processing such materials becomes an extremely difficult task. In addition, the heterogeneous structure and brittleness of CMC leads to different material removal mechanisms during machining, resulting in unique surface defects that reduce the quality of the machined surface. This article deals with the issues of ensuring the quality of the machined surface of samples made of SiC/SiC ceramic composite with ceramic matrix, by selecting the characteristics of the grinding tool and cutting modes during high-speed grinding.

1. Introduction
Composite materials have attracted industrial attention because of their better strength-to-weight ratio compared to traditional heat resistant steels and alloys. Depending on the type of matrix material, composites are usually divided into PMC (polymer matrix composites), MMC (metal matrix composites) and CMC (ceramic matrix composites) [1].

Ceramic matrix composites (CMC) are relatively new and promising materials for many high-tech engineering applications. They can perform under harsh conditions due to properties such as: high strength, heat resistance, low thermal conductivity, corrosion resistance, wear resistance and low density. These properties provide a significant increase in service life compared to traditional metal and ceramic materials [2]. Like most ceramic materials, CMC are manufactured by sintering. CMC parts are made to tight tolerances for dimensions and quality of machined surfaces. However, after sintering, the parts undergo considerable shrinkage, which makes subsequent machining unavoidable.

The hardness of sintered CMC significantly limits material removal processes by machining. Grinding with diamond tools and subsequent finishing and polishing are the most frequently used methods for achieving dimensional accuracy and the desired surface quality of ceramic parts, including CMC parts. The cost of such a machining process can reach 60-80% and sometimes even up to 90% of the total production cost [3, 4]. It follows that despite all the above-mentioned advantages, the use of CMCs is hampered by the high cost of their machining. More and more new CMC composites with unique properties are being developed every day. Many of these new materials are very difficult to process with traditional technologies, which means that improving the existing process (or creating new methods) of processing is necessary and extremely important.
2. Problem statement
Many papers have been devoted to the problem of CMC processing [5-7]. For example, in [5], the authors have attempted to provide an informative review of the literature on the research carried out on conventional and unconventional CMC machining, with the main emphasis on a critical evaluation of how different machining methods affect the machined surfaces. However, high-speed CMC grinding is not considered among the works presented.

There are known works [8, 9], where the authors study the process of high-speed grinding of ceramic materials, but we are talking about ceramics without a matrix, which casts doubt on the possibility of using the processing modes proposed in these studies for CMC ceramic composite.

Machining of new types of composite materials is a complex task that requires solving the problems of selecting the characteristics of grinding tools and determining the rational modes of cutting.

The main objective of the study is to select the characteristics of the grinding tool and determine the machining modes to achieve the best quality of the machined surface.

3. Research methods
Many papers have been devoted to the problem of CMC processing [5-7]. For example, in [5], the machining was performed on a stand based on an upgraded special CNC grinding and sharpening machine of model VZ-326 F4 at constant modes: depth of cutting \( t = 3 \, \mu \text{m/dv stroke and feed } S = 600 \, \text{mm/min} \). The cutting speed in the experiments was \( V = 20 \, \text{m/s} \) (this speed is considered classical when grinding ceramic and composite materials) and \( V = 100 \, \text{m/s} \). Studies of CMC ceramic composite were carried out with AW ACN type grinding heads on the M2-01 metal bond and B1-1 Bakelite bond with grit sizes 40/28 and 20/14. In this case, all experiments were carried out without the use of coolant, which is a feature of the method of high-speed grinding.

A workpiece made of SiC/SiC ceramic composite material, the main technical properties of which are listed in Table 1, was set up in a special vise, providing its protrusion based on the machining allowance (about 0.5...1.0 mm), so that the machined surface was parallel to the cutting plane of the grinding wheel.

| Name of characteristic     | Value          | Unit of measure |
|---------------------------|----------------|-----------------|
| Geometric dimensions      | □(30.0±0.52)x(2.0±0.25) | mm             |
| Density                   | 2.82±0.1       | g/cm³           |
| Open porosity             | 1.2±0.2        | %               |
| Volumetric fiber filling  | 20±2           | %               |

The surface quality after machining was evaluated with a Carl Zeiss Axio Observer.A1m microscope, and the roughness was measured with a MarSurf PS1 profilometer.

4. Experimental results
When processing the sample with diamond grinding heads on a metal bond of M2-01, a grid of cracks was formed on the machined surface of the plate (Figure 1).
Results of processing at cutting speed $V = 100$ m/s, cutting depth $t = 3$ mkm/dv. stroke and feed $S = 600$ mm/min using diamond grinding heads type AW ASH 40/28 on bakelite binding B1-1 are shown in Figure 2 and at cutting speed $V = 20$ m/s in Figure 3.

Figure 1. Cracks on the plate after machining with heads on metal-bonded M2-01

Figure 2. Sample surface at a) x2.5; b) x10; c) x50
Figure 3. Sample surface at x2.5

Results of processing at cutting speed $V = 100$ m/s, depth of cut $t = 3$ µm/dv. stroke and feed rate $S = 600$ mm/min with usage of diamond grinding heads type AW ASN 20/14 on Bakelite binding B1-1 are shown on figure 4. It is established that roughness of the processed surface is $Ra = 0.03...0.06$ µm.

Figure 4. Sample surface at a) x2.5; b) x10; c) x50

Figure 5 shows the treated surface at 100x magnification.
Figure 5 clearly shows that there are no chips and tears at the boundary between the matrix and the aggregate after machining. This may indicate that the high-speed grinding method can be applied to heterogeneous layered or fiber-reinforced materials.

Figure 6 shows the dependency of surface roughness of the machined surface on the cutting speed with the use of diamond grinding heads AW ACN 20/14 on the bakelite bond B1-1, at a cutting depth of $t = 3$ microns/dv stroke and the feed $S = 600$ mm/min.
According to the results of the experiment with the use of diamond grinding heads AW ACN 20/14 on a bakelite bond B1-1 as the grinding tool that provides the best result, the following dependence is obtained:

$$Ra = -0.07 \ln(V) + 0.2079$$ (1)

The reliability of the approximation is $R^2 = 0.9707$. On the Cheddock scale, the quantitative measure of closeness of the of the strength connection of 0.9...0.99 corresponds to a very high qualitative characteristic of the strength of the connection.

5. Discussion of results

The results of machining samples from CMC ceramic composite with grinding heads on metal and bakelite bonds showed that bakelite bond is more suitable for machining this type of material, which can be explained by the rigidity of the grinding tool elements and its possible damping of the bond.

At cutting speeds of $V = 20$ m/s with the use of AW ASN 40/28 diamond grinding heads on the B1-1 bakelite bond it can be seen that there are no cracks on the machined surface, the roughness is $Ra = 0.12...0.20 \mu m$, which is explained by the large number of grain micro-ruptures from the surface of the ceramocomposite.

After processing at cutting speed $V = 100$ m/s with the use of grinding heads of type AW ACM 20/14 on a bakelite bond B1-1 the roughness of the processed surface was $Ra = 0.03...0.06$ microns, that in 3.3...4 times lower in comparison with machining at cutting speed $V = 20$ m/s, at the same time there are no cracks and tears as the base (ceramics), and reinforcing fibers, which may indicate a decrease in cutting forces and contact temperatures. From the studies we can conclude that reducing the grit size of the grinding material and increasing the cutting speed has a positive effect on the quality of the machined surface of CMC ceramic composite.

6. Conclusions and Conclusion

The dependence of the roughness of the machined surface when grinding samples from CMC ceramic composite on the cutting speed allows us to conclude that an increase in speed has a positive effect on the quality of the machined surface. Also, reducing the grit size of sanding heads significantly reduces the number of breaks and has a positive effect on the quality of the machined surface.
disadvantage of machining with the use of fine-grained tools is their high consumption, to solve this problem, processing of samples should be carried out in two stages - roughing with the use of grinding heads of type AW ACM 40/24 B1-1 and finishing with the use of grinding heads of type AW ACM 20/14 B1-1.

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