Precision processing of ceramics by the raster machine

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Abstract. Ceramic materials processing techniques have been briefly presented in the article. The process of grinding, lapping as well as the stages of technical ceramics processing have been reported. Up to 80% of the material to be removed at the first stage, where a rough tool was utilized for machining at high speed. At stage second, the fine grain instrument was employed for the grinding process. Thus, the volume of the grinded material is reduced. At the third stage, lapping is performed by diamond abrasive flour grains and pastes of the necessary granularity. After the stage of lapping the polishing of the surface is done to achieved high accuracy and elegant finish. The investigation of abrasive lapping of the parts made of VSH-75 oxide ceramics material. It has been found that the efficiency of the diamond flour grains is 15-30 times greater than the efficiency of Al_2O_3 and SiC flour grains. With the increasing of granularity, the volume of the total material removal and surface finish enhances. In order to obtain the highly finished surface (Rz=0.8 μm), it is recommended to use ASM20 synthetic diamond flour grain. The influence of the part's contact pressure (range 25-150 KPa)on the lap has also been investigated. The volume of the total removal is distinctly increased with the increase of contact pressure from 25 to 50 KPa, while the diamond discharge intensity and the processed surface finish reduces. Further, the contact pressure increases up to 150 KPa exhibited deep scratches and machining marks on the tool surface which seriously impairing the tool. The optimal contact pressure for the superior ceramics lapping on the cast-iron lap SCH-28 should be in between 50-100 KPa

1 Introduction

Ceramics is a polycrystalline material and its products present the compound of nonmetallic (III-IV) groups in the periodic table. Such compounds are obtained by molding and burning of the feedstock. The natural substances such as silicate, clay, quartz, etc., are used as a feedstock. Moreover, artificial substances such as pure oxide, nitride and carbide are also utilized in the respective field. [1]. In the engineering industry, technical ceramics is the material that producing structural high-temperature and fireproof components (body structures, crucibles, gears, turbine blades). Ceramic has enormous applications in the cutting tool industry such as tool plates manufacturing, whereas, in the chemical industry,

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ceramics serves for production dies and components that working in the corrosive medium [2].

Mechanical treatment of ceramics is a labor-intensive and complex process aiming of the production of goods with the necessary degree of accuracy and quality of the machined surface. Different techniques of ceramics mechanical treatment are used:

1. Grind process
2. Electroerosion machining and electrochemical working
3. Ultrasonic machining
4. Hydrodynamic treatment
5. Laser processing

The process of grinding and lapping is the most widely used technique of ceramics mechanical treatment. Such abrasive materials viz. natural and manufactured corundum, silicon carbide and boron carbide are used for grinding and lapping of ceramics depending on its properties. Application of diamond grinding is reasonable for processing germanium, silicon, glass, quartz, ceramics and hard alloys. The main characteristic features of the diamond treatment are less wear and excellent tool resistance. According to the Japanese researchers the cost of ceramics processing dozens of times higher than that of the structural steels [3, 4].

The development of modern engineering and instrumentation associated with the development of new materials and advanced technological processes of their processing. Currently, the abrasive finishing process and the destruction of plastic materials are well known while the destruction behavior of brittle material requires further research.

New composite materials have found wide application in industry thanks to their physicomechanical properties. Application of this materials allowed to solve long-standing problems of mechanical engineering.

For example, ceramic materials are widely used in various fields of technology. The unique properties of ceramics allow to use it as a cutting tool, machine parts, instruments, electronic equipment, widely used in the chemical and oil and gas industry, in aviation and rocket technology, for applying heat-shielding coatings; hip joint endoprostheses that are used in traumatology and orthopedics; and dentistry. Refractory products, structural parts, thermal coatings, translucent ceramics, variators in the field of strong currents (lightning arresters) are made of such ceramics. Also this material is suitable as heating elements that can be used at high temperature under oxidation conditions. Due to the high hardness of the material, processing of the workpieces is possible only with an abrasive tool. A synthetic diamonds application allowed to intensify the processing of ceramics drastically. [5, 6].

1.1 Design diagram

Mechanical treatment of ceramics depends on the characteristics such as hardness, brittleness, strength, porosity, surface condition, thermal stability and on the properties of abrasive material and instrument. Also, it is influenced by the speed of removal rate, pressing force, grinding product cooling and by other processing conditions. Usually, mechanical abrasive processing of ceramics is performed in three stages: roughing, finishing and lapping (Fig. 1).

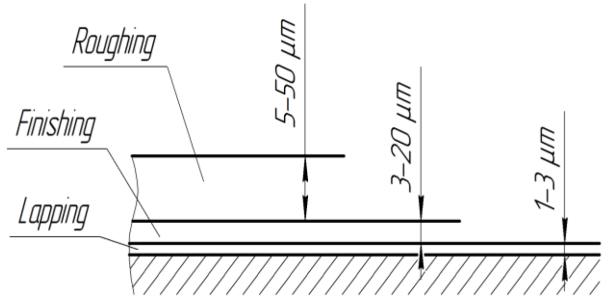


Fig. 1. Stages of ceramics mechanical processing

The stages are shown in Fig. 1. These are compared on the basis of the volume of grind ceramics and roughness of the processed surface (Table 1) [7].

Table 1. Stages of ceramics finishing

Stage	Excess material, μm	Dimensional allowance, μm	Roughness of the surface according to Rz, μm
Roughing	300	± (5-50)	6,3-1,6
Finishing	50-100	± (3-20)	1,6-0,8
Lapping	3-10	± (1-3)	0,8-0,032

As a rule, it is removed up to 80% of material during the first stage; the processing is carried out by the large-grained instrument at high speed, and as a result, deep scratches and cleavage remain on the surface. Detail dimensional allowance may be equal to 0.3-0.5 mm; it may be one-sided or double-sided and its dimensions influence the allowance. The volume of the grinded material becomes less, during the second stage. The second processing stage is carried out by the fine grain abrasive tool surface. At the third stage of the experiment, lapping up to the reference dimension is usually performed by the diamond tool with abrasive flour grains and pastes of necessary granularity. It is quite often to operate surface polishing after the stage of lapping. In this case, a higher class of accuracy is achieved.

The character of ceramics surface fracture is different at various stages of grinding. Thus, in the process of the preparatory diamond, grinding dominates the brittle failure. It could be observed two types of such failure: the first is the cleavage due to the abrasive tool pressing force; the second is the breakaway (chipping) of separate crystals (grains) from the binding phase under the impact of tangential forces appearing at the relative movement of ceramics and abrasive.

Under the influence of these forces partial abrasion of the diamond occurs and chip or bluntness of its angles and edges are possible. After preparatory grinding, still, the defects such as scratches and cleavage remains, which depends on the size, form and behavior of the diamond grain. At the stage of finish grinding, the abrasive tool with the smaller grains are used. As a result, reduced brittle fracture and the grinding action causes plastic deformation, as well as the, flattened the ceramics surface. The diamond with abrasive micro powders and fine grain pastes are used in the stage of lapping.

Thus, machining of ceramic products by grinding is a complicated process which depends on properties of ceramics, characteristics of grinding tool, parameters of grinding and other factors. In this work, the process of the lapping of VSh-75 ceramics models (HRC 90-93) has been investigated. It is observed that low strength and extreme brittleness are the main defects of VSh-75 ceramics. Tools with chip members made of VSh-75 ceramics remain hard in the process of operation is heated up to 1200°C. Therefore, VSh-75 ceramics are used in conditions of non-impact loading and finish or semi-finish machining of steel, iron fabrication, non-ferrous metals and their alloys, at high-speed operation with shallow depth of cut and feed.

2 Experimental Study

Complex investigation of abrasive lapping of the material parts which includes VSh-75 oxide ceramics (HRC 90-95) has been carried out. In the experiment, the plane smoothing machine "Raster" has been used [8]. The required roughness Rz of the parts' surface was less than 0, 9 µm.

Plane smoothing machines of the "Raster" model (Fig. 2) are utilized in individual and series manufacturing which is characterized by change of small kits of parts and their wide range. A unique feature of these machines is the translation movement of the tool (lapping tool) along the non-recurrent path. At that, the traverse speed of all points of the lapping tool work surface is identical.

a) b)

Fig. 2. Plane smoothing machines: a) Raster-220; b) Raster-350

Complexity and uniqueness of the tools relative path and the parts working surface along with the possibility to regulate their parameters to control the process of machining effectively and to produce a surface with the predetermined performance characteristics of macro- and microrelief shown in Fig. 3.

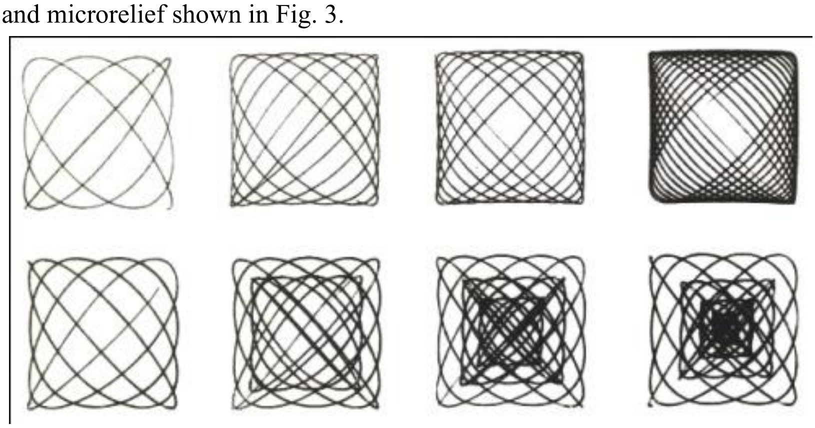
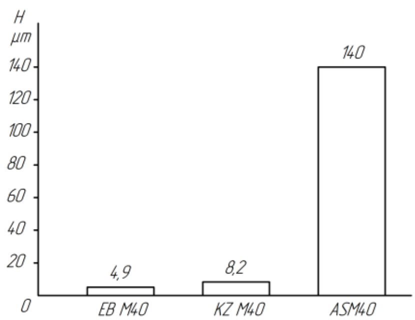


Fig. 3. Tool working path (unitary abrasive grain) on the machine with raster kinematics.

The structure and density of the tool working path (Fig. 3) allows forming the micro-relief of the machined surface with optimal statistic parameters for the specific operating ability of products. At that, the volume of roughness according to *Rz* parameter could be reached in 10 to 35 nm; according to the *Ra* parameter, it is equal to 6-2 nm.

Research of the oxide ceramics lapping has been carried out at PNRPU. The results of this research are given below.

It is known that the properties of abrasive micro powder used in lapping greatly influence the results of machining. Such effect becomes especially apparent in the process of lapping ceramics as of the incredible material. Comparative study of fused alumina white (EBM40), silicon carbide green (KZM40) and human-made diamond (ASM40) with micro powders' confirmed that the cast-iron lap (SCh-28 type) enhance the efficiency in the process. During 4 minutes of machining, it is found that the human-made diamond powder ASM40 removes 15-30 times higher material as compared to EBM40 and KZM40 micro powders (Fig. 4a). It could be explained by the fact that hardness of the worked material is practically the same as the hardness of fused alumina white EBM40 and silicon carbide green KZM40 micro powders but it is considerably less than the hardness of the man-made diamond ASM40. The roughness of the machined surface is practically independent of the type of abrasive material and it modifies in the limits of one class (Fig. 4b).



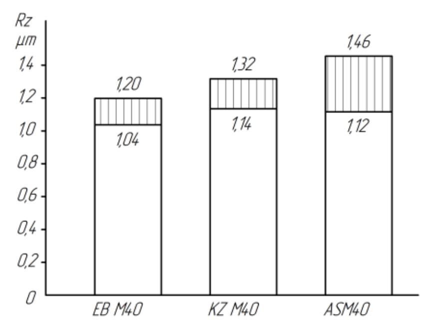
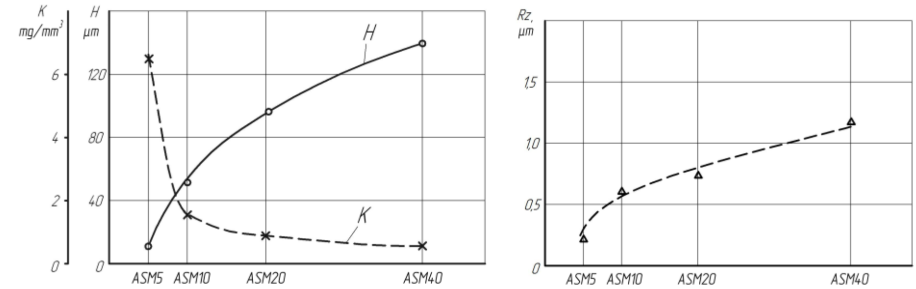


Fig. 4. Comparative study of abrasive material during the lapping of VSh-75 oxide ceramics, processing time T=4 min: a) total removal of material (H, μm); b) roughness of the worked surface according to the Rz parameter, μm

Taking into account, extremely high efficiency of human-made diamond micro powder by the amount of removal. It should be preferentially used in the lapping of very hard materials as oxide ceramics.

With other things being equal the size and the amount of the diamond grains involved in work modify together with the modification of the diamond micro powder granularity. Therefore, modification of micro powder granularity influences the conditions of micro cutting, lapping capability, specific consumption of diamonds (K mg/mm^3) and roughness of the machined surface. Research of VSh-75 oxide ceramics lapping by micro powders of different granularity has shown that the amount of total removal (H μm) increases with the rise of micro powder granularity from ASM5 to ASM40 (Fig. 5a). It is explained by the fact that as the dimensions of the diamond grains increases, their total number becomes less, every grain load grows, the grain itself penetrates deeper the worked material and cuts microchips of the large size. When granularity increases, the specific consumption of diamonds (K mg/mm^3) becomes lower, and it is especially strong in granularity change from ASM5 to ASM10 (Fig. 5a). When the granularity of the diamond micro powder increases from ASM5 to ASM40, the roughness of the lapped surface rises from *Rz*=0, 27 to 1, 14 μm (Fig. 5b).

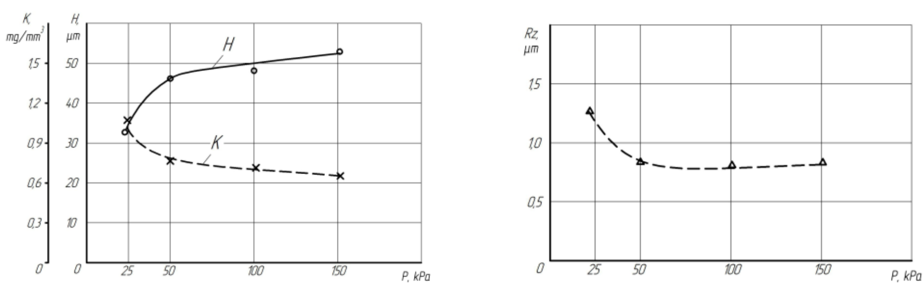


a) b)

Fig. 5. Comparative study of the influence of the diamond micro powder granularity in the process of ceramics lapping: a) specific consumption of the diamonds (*K mg/mm³)* and total removal (*H* µm*)*;b) roughness of the machined surface according to the *Rz* parameter*,* µm.

Taking into consideration that in the process of lapping by ASM20 micro powder, it is provided sufficiently high productive capacity, low specific consumption of diamonds and required surface roughness (Rz=0.7-0.8µm). Further, research has been carried out with the application of this micro powder.

In the process of ceramics lapping by ASM20 diamond micro powder on SCh-28 cast-iron lap, it has been studied the effect of contact pressure in the range of 25 – 150 kPa. It has been found experimentally that the total amount of material removal (H) becomes higher with the increase of contact pressure from 25 to 50 kPa but there is a little change with its further increase up to 150 kPa (Fig. 6a).



a) b)

Fig. 6. Comparative study of the contact pressure effect in the process of ceramics lapping by ASM20 diamond micro powder:a) total removal (H) and specific consumption of diamonds (K); b) roughness of the machined surface (Rz).

The last fact could be explained by the intensive diamond micro powder grains refinement under the impact of high load. Specific consumption of diamonds reduces when the contact pressure becomes higher. Diamond consumption is lowered with the contact pressure in the range of 25 – 50 kPa (Fig. 6a).

The roughness of the machined surface *Rz* reduces from 1.28 to 0.70 µm with the increase of contact pressure from 25 to 50 kPa and is practically unchangeable with its further increase up to 150 kPa (Fig. 6b). Thus, the assumption of intensive destruction – diamond grains refinement with a rise in pressure has been proved. It is necessary to mention that in the process of lapping with contact pressure equal to 150 kPa, scratches and marks appear on the tool surface (SCh-28 cast iron lap) and make its appearance seriously worse. So, it should be considered the contact pressure equal to 50-100 kPa to be optimal in the process of ceramics lapping on the SCh-28 cast-iron lap.

4 Conclusions

- The granularity of the human-made diamond micro powders exercises a significant influence on the capacity of machining and the roughness of the machined surface. When granularity becomes higher the total removal and roughness of the machined surface increase as well. To obtaining granularity (Rz=0.8 μm), it is recommended to use ASM20 human-made diamond micro powder.
- Part's contact pressure on the lap influences the results of lapping. With the increase of contact pressure from 25 to 50 KPa, the amount of the total removal distinctly rises; specific consumption of diamonds and roughness of the machined surface become substantially lower. However, the influence of contact pressure on process parameters reduces after the value of 150kpa. The contact pressure in the process of ceramics lapping on SCh-28 cast-iron lap should be in between 50-100 kPa.

5 Discussion and Application

The research of operation parameters of the "raster" tool path machine (amplitude and frequency of the lap vibration) and their influence on the qualitative and numerical characteristics of ceramics machining will be carried out based on the obtained results.

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