Agronomy Research **12**(1), 269–278, 2014

Machining quality when lathing blanks with ceramic cutting tools

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Abstract. The article deals with the problems of improving quality of parts machined on lathe type machine tools. Improvements are suggested by predicting the operability (tool life parameter) of cutting tools equipped with replaceable ceramic inserts. It is proposed to forecast the operability of ceramic tools on the ground of relation between operational characteristics of the ceramic and microstructural parameters of the ceramic material. Microstructural parameters of ceramic inserts are determined by non-destructive testing method, evaluating them by estimating the specific electric resistance of the material.
As a result of research, a relation has been detected between operability of the inserts and the specific electric resistance of the insert material.
Obtained results permit one to determine the stability range borders for lathing blanks with tools equipped by ceramic cutting inserts and to predict flawless work.

Key words: metals cutting, ceramic cutting inserts, machining precision.

INTRODUCTION

Advancement of production engineering is one of the significant factors in state-of-the-art mechanical engineering. Feature of the present-day production includes the use of new tool materials having high cutting properties. Cutting ceramics belong to those materials.

High efficiency of machining, tool-life gain, reduction of costs at the expense of replacement of grinding procedures with cutting, and reduction of processing time at the expense of significant cutting speed increase are the main reasons of cutting ceramics use on production of exact elements of machine parts. Moreover, using cutting tools equipped with ceramic inserts, one can process hardened steels and other hard-to-cut materials.

At present, the amount of cutting ceramics on the whole of used tool materials does not exceed 5–8%. According to forecasts, the rate of ceramics will increase up to 15% in near future (Bandony & Buljan, 1988). It could occur due to the fact that known hard alloys will be replaced by cutting ceramics from straight forward economic considerations.

Moreover, using cutting tools equipped with ceramics one can process not only cast iron and structural steel, but also heat-resistant and hardened steels and other hard-to-cut materials.

All the types of cutting ceramics combine the properties of ceramic and metal constituents. They differ from other materials in higher strength characteristics, lower toughness and tendency to crack initiation, having high cutting properties. Ceramics use is bounded in the practice of metal cutting as yet since it is considered as too «high-speed» for standard conditions of processing and brittle for wide use.

Investigation of one of the main components of processing system – a cutting tool – is the main task on control of turning process quality. Control of handling process quality is directly connected with information on the ability of tool to carry out processing with specified accuracy parameters in the specified time period, i.e. with information on the working ability of cutting tool (Margules, 1980).

Different behavior of cutting plates made of ceramics of the same type was observed on their use under the same conditions of processing. Half-finished products processed with tools equipped with same cutting plates made of ceramics of the same type at the constant parameters of cutting modes had various indices of dimensional accuracy, surface roughness, and geometrical deviations. Life period of the tool equipped with identical cutting plates also varied on the preservation of constant parameters of cutting modes. Above-mentioned circumstances dictate the necessity to find parameters influencing the distinction of behavior on cutting with ceramics, which is an urgent question since, in particular, the problem of control of treatment process quality and working ability of tool equipped with cutting ceramics is in a formative stage.

At present, the methods of control of the working ability of cutting tool equipped with ceramics are in the stage of study and therefore require further development and improvement. To develop such methods it is necessary to have verified, reliable information on the structural parameters of cutting ceramics, detection and validation of which can give the clear idea of the most rational use of cutting tool for the definite processing conditions, which enables us to realize the control of working ability of ceramic cutting tool. Problems arising on the investigation of such objects as cutting tools determine the reasonability of experimental techniques use.

MATERIALS AND METHODS

Structural composition of tool material qualitatively influences its mechanical properties and wear during cutting. The better the structure is, the better the cutting properties. This dependence is true also for cutting ceramics; therefore it is required to determine the relationship between ceramic structure and the working ability of tool which is equipped with it. It is known (Margules, 1980), that cutting ceramics is a conducting material and being structurally inhomogeneous material it has a definite value of resistivity. Investigations showed (Maksarov et al., 2008a; 2010) that ceramic plates with resistivity value approaching $R = 100\ \Omega$ have the best cutting properties. Ceramic plates with resistivity value approaching $R = 10\ \Omega$ have the poorest cutting properties. From this one can conclude that ceramic plates with $R = 100\ \Omega$ have the microstructure of higher quality in comparison with ceramic plates with $R = 10\ \Omega$.

Several ceramic plates of grade VOK63 with various values of resistivity were selected to confirm the theory.

Plates of cutting ceramics were prepared in special way to carry out the structural investigations of material using microscope. The samples were subjected to microgrinding according to the specially developed technique (Maksarov et al., 2008b). Up-to-date ceramics of grade VOK63 taken for the investigation consists of 75% of Al_2O_3 + 25% of (Ti, W) C, which is proved out on computing of image obtained using metallographic microscope (Fig. 1).

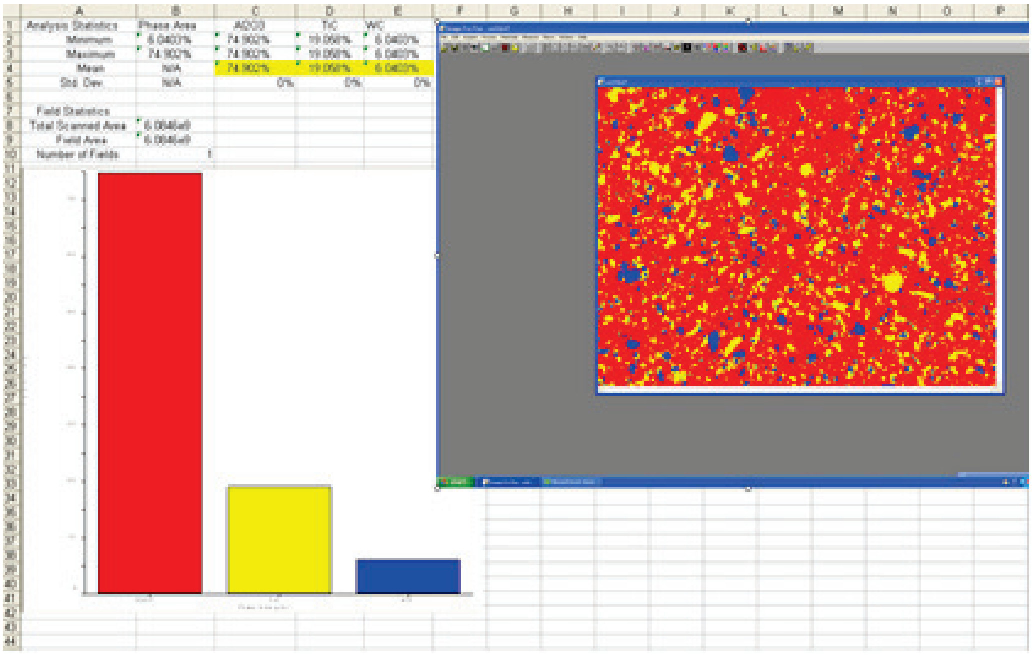
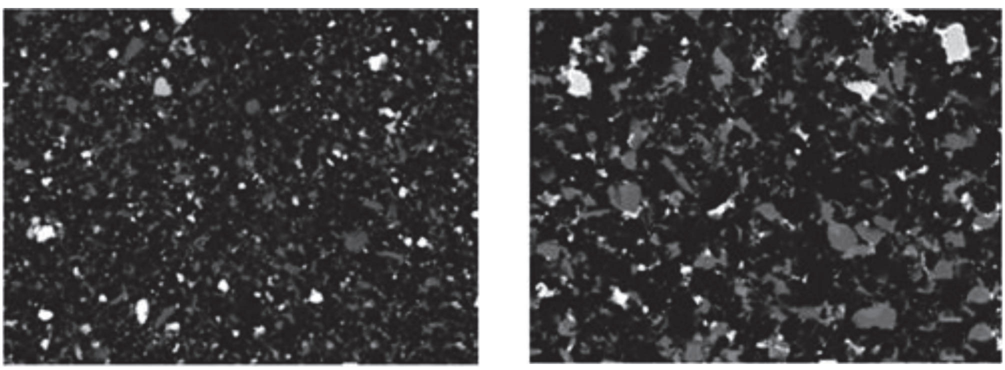


Figure 1. Percent distribution of Al_2O_3, TiC, and WC in VOK63 ceramics.

Photographs obtained using microscope (Fig. 2) show that microstructural parameters of the samples with different resistivity differ from each other.



a b

Figure 2. Structure of ceramics of grade VOK63: a – $R \approx 100\ \Omega$, b – $R \approx 10\ \Omega$.

Samples with resistance close to $R = 100\ \Omega$ have better structural parameters than others. As computing showed (Fig. 3), the samples of ceramic plates with relatively low resistivity ($R = 10\ \Omega$) are characterized by large diameter of grains ($D_{CP} = 2.21$ µm), high percentage of porosity ($\Pi = 14\%$), low value of cumulative line of grain boundary extension ($C = 7.76 \cdot 1\ \text{mm}^{-2} \cdot 10^{2}$), and small quantity of grains ($H = 21.5$). The samples of ceramic plates with relatively high resistivity ($R = 100\ \Omega$) are characterized by the following parameters: $D_{CP} = 1.51$ µm, $\Pi = 8\%$, $C = 5.186 \cdot 1\ \text{mm}^{-2}\ 10^{2}$, $H = 46.76$.

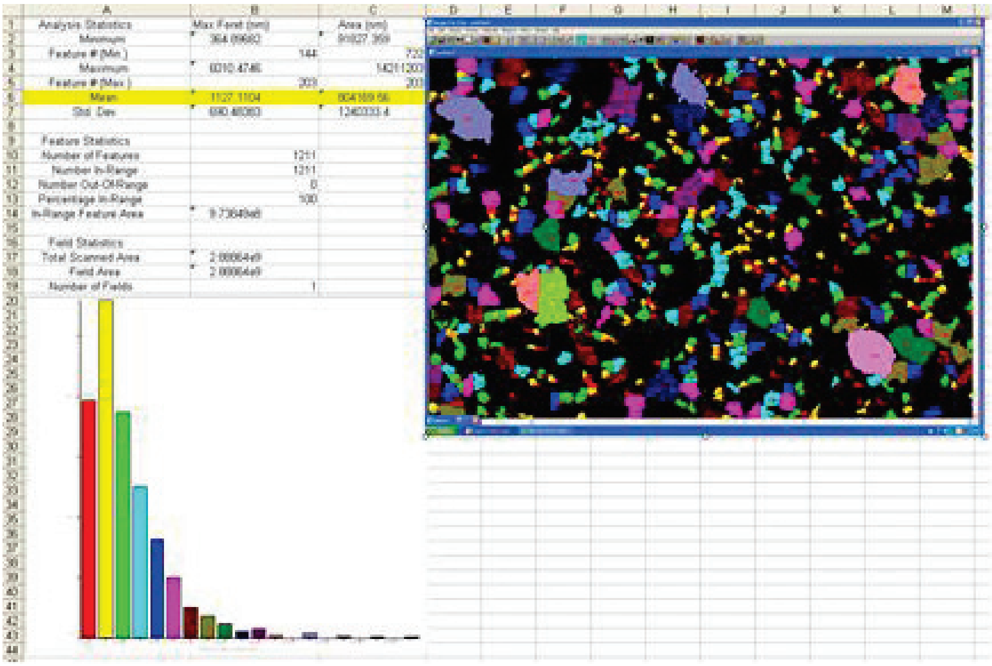


Figure 3. Structural parameters of ceramics of grade VOK63.

Treatment of experimental data enabled us to establish relationship between resistivity and structural parameters of ceramics, as a result of which we obtained the following dependence:

$$R = 542.9 \frac{H^{2.35}}{C^{1.14} \cdot D_{\text{SR}}^{3.029}}, \Omega \qquad (1)$$

This points to the fact that the better the microstructure of cutting ceramic plates (relatively small-sized grains, small their quantity, high values of cumulative line of grain boundary extension, and low porosity of material), the more the value of their resistivity. The data obtained is the base to determine the cutting properties of ceramics depending on the structural parameters of material, data about which one can obtain by determination of the resistivity of each plate before its use.

RESULTS AND DISCUSSION

A number of experiments, in which the final treatment of identical half-finished products was carried out with running values of cutting modes, were carried out to determine the cutting properties of ceramics of grade VOK63 with different values of resistivity (Maksarov et al., 2008a; 2008b). According to the results, we have found the connection between the wear of cutting plate and cutting modes, based on the parameters of plate wear on rear face $h_Z = f(t, S, V)$, where t is cutting depth, S is tool feed, and V is cutting speed. Ceramics wear mechanism turned out to be peculiar. Plate bluntness occur mainly on clearance face in the form of typical strokes of wear located at right angle to main cutting edge in the region contacting with cutting surface. Wear of the rake face is negligible in comparison with wear of clearance face (Maksarov et al., 2010).

Dependence of wear of clearance face on the duration of cutting path showed significant difference in reaching of wear equal to 0.5 mm. Correlation of traversed path lengths for VOK63 with $R = 100\ \Omega$ and VOK63 with $R = 10\ \Omega$ turned out to be 8/6 and the functional dependences of wear on cutting modes look as follows:

- for BOK63 with $R = 100\ \Omega$:

$$h_Z = 0.08\frac{V^{0.38} \cdot S^{0.17}}{t^{0.66}}, \text{ mm,} \tag{3}$$

- for BOK63 with $R = 10\ \Omega$:

$$h_Z = 0.04\frac{V^{0.22} \cdot S^{0.023}}{t^{0.11}}, \text{ mm.} \tag{4}$$

The next important step in the investigations was to determine accuracy margin Ψ on the processing of half-finished articles with VOK63 ceramics with different values of resistivity and to determine the relationship between accuracy margin and mode parameters (Maksarov et al., 2010). To determine this relationship we used the results of previous experiences, on treatment of the results of which we derive the dependences $\Psi = f(t, S, V)$ which enabled us not only to determine accuracy margin on processing (Fig. 4), but also to predict the tool work without defective products at the expense of use of optimal processing modes and rational selection of cutting ceramic plates.

Thus, the question of ceramic tool working ability control and the question of turning process quality control in whole reduce to the determination of optimal working characteristics of the tool used (Maksarov et al., 2008). Knowing of these characteristics and starting from the definite accuracy margin of material enables us to calculate the optimal parameters of processing modes and, accordingly, to predict the work without defective products. These dependencies were proved using out-of-round gage (Fig. 5) which is a measuring device for determination of roundness, i.e. the largest distance from the points of real profile of cylindrical surfaces in cross-section up to abutting (female) circle.

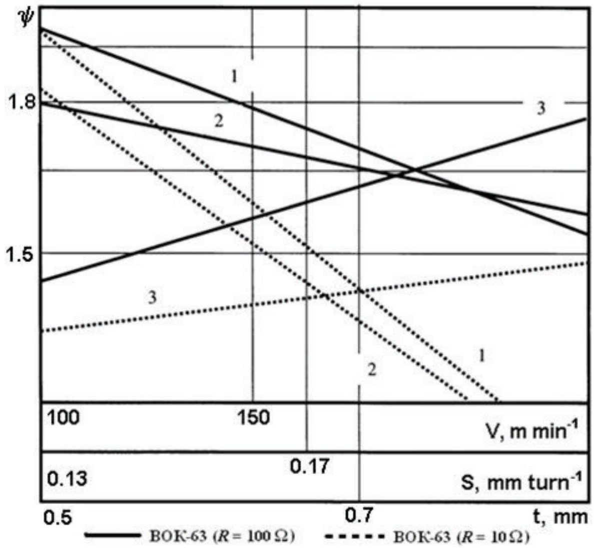


Figure 4. Graphical dependence $\Psi = f(V, S, t)$: 1 – $\Psi = f(V)$, 2 – $\Psi = f(S)$, 3 – $\Psi = f(t)$.

Figure 5. Roundness tester, Roundtest RA–120.

Results of measurements presented as a cross-section of the part were obtained using Roundness tester Roundtest RA–120 with device to extract the harmonic components of roundness (out-of-roundness profiles) and with devices to exclude the inaccuracy of initial centering of the part from the measurement results. It is determined on the analysis of images obtained that deviations of the parameter of nonroundness of the processed part on processing using tool equipped with cutting ceramics with resistivity $R = 100\ \Omega$ (Fig. 6) are less than on processing using tool with $R = 10\ \Omega$ (Fig. 7).

Thus, one can finally conclude that the half-finished product processing accuracy under the same cutting modes with VOK63 ceramics with the parameters of resistivity $R = 100\ \Omega$ is higher than on processing using ceramics with $R = 10\ \Omega$, which is proved by the analysis of investigations carried out and calculated dependencies obtained on their treatment and testing carried out using out-of-round gage (Maksarov et al., 2010).

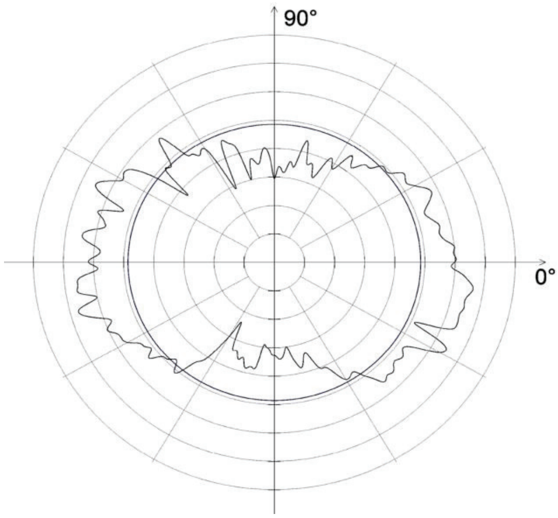


Figure 6. Out-of-roundness profile obtained on processing a part with VOK63 ceramics with $R = 100\ \Omega$.

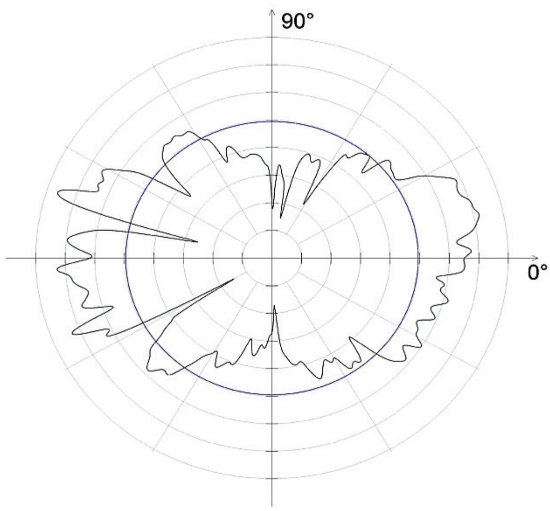


Figure 7. Out-of-roundness profile obtained on processing a part with VOK63 ceramics with $R = 10\ \Omega$.

On control of turning process quality it is necessary to ensure the stability of technological system of mechanical operation. Stability is a necessary criterion of operational integrity and the principal dynamic criterion of processing quality. Boundaries of stability region of cutting tool equipped with plates made of cutting ceramics of grade VOK63 with different values of electrical resistance depending on cutting speed and the depth of cut layer of half-finished workpiece were determined on the basis of data obtained.

Fig. 8 shows the calculated boundaries of stability region corresponding to various states of parameters of the system: R_1 for cutting ceramics of grade VOK63 with parameters of resistivity $R = 10\ \Omega$ and R_2 for cutting ceramics of grade VOK63 with $R = 100\ \Omega$.

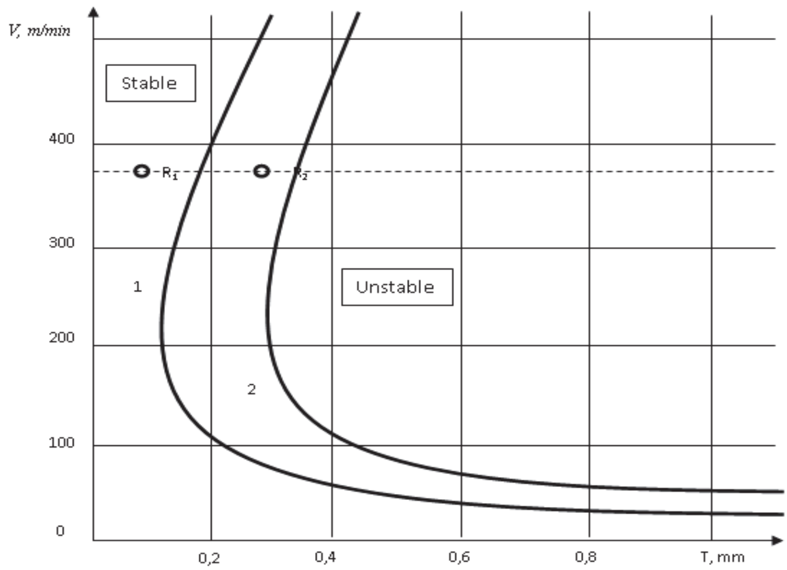


Figure 8. Boundaries of stability region of cutting tool equipped with plates made of cutting ceramics with various values of resistivity.

Significant displacement of stability region boundary found for cutting ceramic plates with low value of electric resistance is clear visible in comparison with multi-ohm ceramic plates.

It is suggested to control the working ability of cutting tool equipped with cutting ceramics starting from data obtained on the previous stages of the work, according to the following model (Fig. 9). This model is based on the dependence of working ability on the value of electrical resistance of each ceramic cutting plate and the parameters of processing quality, including *T* (tool life period), *IT* (dimensional tolerance), and *Ra* (surface roughness class).

Ceramic plates of the same grade have different values of electrical resistance *R* which depend on material porosity (*П*), cumulative line of carbide grain boundary extension (*C*), diameters of carbide grains (D_{CP}), and quantity of carbide grains (*H*). Relationship between the value of electrical resistance and structural parameters manifests itself as follows: plates with electrical resistance close to $R = 100\ \Omega$ have microstructural parameters of more quality as compared with others. They have smaller average diameter of carbide grains, the largest length of boundary line of carbide grains, greater quantity of carbide grains, and at the same time low percentage of surface porosity. Structural parameters of ceramic plates have a great influence on the working ability of cutting tool equipped with them and the processing quality in whole. The smaller the carbide grain size, larger the cumulative line of carbide grain boundary extension, lower the percentage of material porosity, and more the quantity of carbide grain in the definite bulk of material, the higher the wear-resistance of the cutting tool.

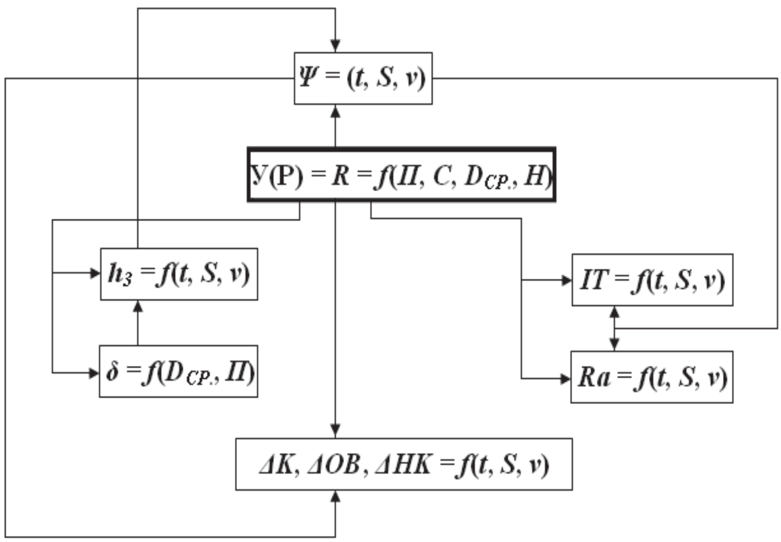


Figure 9. Working capacity control model for tool equipped with cutting ceramics.

All other things being equal such a tool will have larger life period (*T*), it can be used to process the more critical surfaces of half-finished articles with high-performance dimensional accuracy (dimensional tolerance *IT*), surface roughness class (*Ra*) and the accuracy of form and location of surfaces (cone shape *ΔK*, ovality *ΔOB*, nonroundness *ΔHK*).

Influence of the value of electrical resistance on the wear of clearance face of ceramic plate (h_3) and thus on the working ability of tool is also specified by the structural parameters of the sample. The more the value of the electrical resistance of ceramic plate is, the better microstructural parameters are. According to them, the tool performance time under the constant processing modes (*t*, *S*, *v*) rises considerably, that is the tool life period (*T*) increases, which enables us to correct essentially the processing speed increasingly and thus to increase the working ability of tool on the preservation of standard wear value.

CONCLUSIONS

Plates made of cutting ceramics have definite resistivity, ceramics structure is characterized by the following main parameters: grain quantity, average diameter of carbide grains, cumulative line of carbide grain boundary extension, and material porosity.

Ceramic plates with relatively low electrical resistance have larger grain diameter, higher percentage of porosity, low value of cumulative line of grain boundary extension, and small grain quantity; and vice versa, structural parameters have inverse values in samples with high value of electrical resistance.

Comparison test showed that the wear-resistance of ceramics of grade VOK63 with R = 100 Ω is 1.56 times high in comparison with VOK63 ceramics with R = 10 Ω on steel cutting under the same parameters of cutting modes v, S, t.

Dimensional wear of cutter with cutting ceramics has a significance influence on the accuracy and geometry of parts processed. Analysis of graphical dependences obtained enables us to conclude that ceramics with R = 100 Ω ensures higher accuracy and better geometric shape of the finished piece surface in comparison with ceramics with R = 10 Ω. Derivation of that dependence enables us not only to determine the accuracy margin of the part, but also to predict work without defective products.

Capability to control the working ability of cutting tool equipped with cutting ceramics at the expense of selection of parameters of cutting modes on the processing using the tools with different electroconductivity is determined.

REFERENCES

Baldony, J.K. & Buljan, S.T. 1988. Ceramics for machining. *J. Am. Ceram. Soc. Bull.* **67**(2), 381–38. (in Russian).

Maksarov, V.V., Olt, J. & Khalimonenko, A.D. 2010. *The quality management of the process of turning the instrument of the cutting ceramics.* NWTU, SPb. 172 pp. (in Russian).

Maksarov, V.V., Olt, J., Laatsit, T. & Khalimonenko, A.D. 2008a. Control of working capacity of the cutting tool, equipped with removable inserts of the cutting ceramics. SPb. Polytechnika. *Metal-working* **6**(48), 50–58 (in Russian).

Maksarov, V.V., Olt, J., Laatsit, T. & Khalimonenko, A.D. 2008b. A study of tools, equipped with removable inserts of the cutting ceramics. SPb. *Tools and technology* **30–31**, 132–136. (in Russian).

Margules, A.U. 1980. *Cutting metals cermets*. Mechanical Engineering, Moscow, 160 pp. (in Russian).