Research Article

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Experimental Determination of the Surface Geometrical Structure Parameters and Tool Wear During Turning the Polymer Concrete

Abstract: The paper presents the results of experimental determination of the Surface Geometrical Structure (SGS) parameters and tool wear during turning the polymer concrete. Until now, all literature reports have shown that the smoothness and roughness of the mineral cast surface was obtained directly from the mold. However, new applications of polymer concrete, even for some parts of the machine tools, forced the producers to carry out machining, which would improve the parameters of the surface layer. The topic of machining ceramic-based composite materials is a new chapter in the field of machining, which has not been sufficiently researched so far. The article describes the process of experimental determination of dependence of surface layer and tools wear parameters from cutting parameters during longitudinal turning of polymer concrete. The turning was carried out using plates made of a cubic boron nitride (CBN). After machining, the surface roughness and the maximum width of the flank wear were measured. On this basis, the mathematical model of the surface layer and tools wear parameters versus cutting parameters were defined. The authors also attempted to explain the phenomena occurring in the machining zone using variable cutting parameters. Microscopic pictures of CBN plates after machining were also performed. After the study, the final conclusions about the machining of mineral cast material were formulated.

Keywords: polymer concrete, mineral cast, turning, tool wear, surface layer parameters

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1 Introduction

Increasing requirements on the accuracy of the manufacturing items have made that polymer composites have been introduced as a construction material in the field of machine tool construction [1]. Mineral cast (PC – polymer concrete) is a material based on a mixture of inorganic aggregates, whose dimensions reach up to over a dozen millimeters, while the binder is usually a polymer resin [1, 2]. Parts made of mineral cast are manufactured in various types of molds [3]. PC's are used in the production of a variety of products, such as precast members, structures, acid tanks, manholes, drains, highway median barriers, and coating repair materials or parts of machinery such as guides, tables, or beds [4]. What is more, in order to improve the dynamic properties of machine tool, polymer concrete with addition of styrene-butadiene rubber can be used [5]. Therefore, to obtain the appropriate surface layer parameters, the elements made of mineral cast must be machined after removal from the mold. An extensive description of polymer cements, mineral casts and resins used in the castings' processes of ceramic matrix composites has also been included in the scientific articles [3–9].

Current trends in the development of machine tool construction include using mineral cast instead of cast iron [10–16]. In some cases, for instance in the precision industry, mineral casts are used only for selected machine tool assemblies, for example, guides. This is due to inadequate strength properties of mineral casts [3, 17]. In other cases of machining, where the accuracy of the workpiece does not have to be so high, the whole beds are made of mineral cast [18, 19]. During machining of the hard-to-machine materials, high stiffness of the machine tool, handle, workpiece, and tool is required. From this point of view, the construction process as well as the construction materials play a big role.

The article describes the process of experimental determination of surface layer parameters and tool wear during turning of polymer concrete. The treatment was carried out using plates made of cubic boron nitride (CBN)

WNGA 060408 S01030A 7015. These plates gave the best results in preliminary research [20]. After the treatment, the surface roughness was measured as well as the maximum width of flank tool wear. The results of the performed experiments were the basis for drawing conclusions on the optimal parameters of mineral material turning so as to achieve the lowest wear of the tool, the lowest cutting forces and the best machined surface roughness parameters. On this basis, equations describing the functions of the surface layer and tools wear parameters versus cutting parameters were defined. The authors also attempted to explain the phenomena occurring in the machining zone using variable cutting parameters. Microscopic pictures of CBN plates after machining were also performed. After the study, the final conclusions about the machining of mineral cast material were formulated. Table 1 presents the nomenclature used in the manuscript.

Table 1: Nomenclature

v_c	cutting speed
f	feed
a_p	depth of cut
Ra	surface roughness
Rz	height of roughness
VB	width of flank wear land

1.1 Mineral Cast Material

The material used for the study was the mineral cast material offered by RAMPF, commercially available under the name EPUCRET 140/5 [21]. This material is used for casting small parts of machines, that is, guides, tables or beds, whose mass does not exceed 500 kg. This material consists of aggregates measuring from micrometers up to 5 mm. All
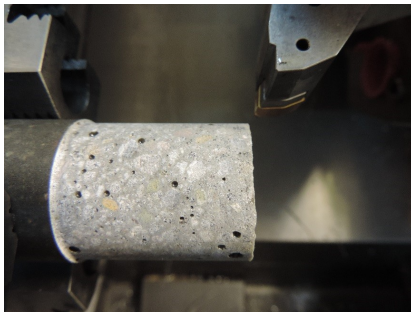

Figure 1: View of the sample mounted in the three-jaw chuck of a CNC lathe

the aggregates were at the beginning mixed thoroughly and then epoxy resin was added to them. The whole mineral cast material was thoroughly mixed. Cylindrical specimens of diameter $d = \varnothing 40\ mm$ and height $h = 60\ mm$ were prepared for research. Figure 1 shows a view of a test specimen mounted in a three-jaw chuck of a CNC lathe.

2 Methodology

The research was carried out on the HAAS lathe SL10, which is located in the Institute of Machine Tools and Production Engineering at the Lodz University of Technology. The tool plates from Sandvik Coromant with the designation WNGA 060408 S01030A 7015 were chosen for the tests. These plates are made of cubic boron nitride (CBN) and used for the treatment of hard-to-machine materials.

In order to find a suitable machining parameters of mineral cast material, the longitudinal turning tests were planned with the following parameters:

- cutting speed $v_c = 25 \div 200\ m/min$
- feed $f = 0.05 \div 0.3\ mm/rev$
- depth of cut $a_p = 0.25 \div 2\ mm$

The purpose of the study was to determine the Surface Geometrical Structure (SGS) parameters and tool wear. Additionally, the appropriate cutting parameters by performing turning tests with variable machining parameters: cutting speed (v_c), table feed (f), and axial depth of cut (a_p), and analyzing the surface roughness and tool wear were determined. In the scientific literature, there is no information on the machining parameters during the turning of mineral casts. Therefore, the intention of these experiments was to determine the most convenient cutting parameters in order to obtain the smallest values of surface roughness and tool wear.

During each test, a new plate was mounted on the tool. The cutting distance during the machining of polymer concrete was $L = 60\ mm$. Turning tests were repeated three times.

After each machining pass, the roughness values Ra and Rz of the machined surface were measured parallel to the longitudinal feed direction (according to the PN-EN ISO 4287:1999 [22]). A portable Mitutoyo SJ-210 roughness gauge was used for this purpose.

During the cutting process, the cutting fluid was supplied into the treatment zone. Thanks to its lubricating properties, the fluid caused the decrease of machining temperature and less dustiness. In addition, the cutting fluid caused better drainage of the microchips from the tool.

Table 2: Results of longitudinal turning tests of mineral cast material

	Parameters	**Ra [μm]**	**Ra [μm]**	**VB [mm]**
Test	**Raw cast**	**13.343**	**67.080**	**—**
1	v_c = 50 m/min f = 0.05 mm/rev a_p = 0.25 mm	3.768	25.817	0.685
2	v_c = 50 m/min f = 0.1 mm/rev a_p = 0.25 mm	4.251	26.734	0.470
3	v_c = 50 m/min f = 0.2 mm/rev a_p = 0.25 mm	5.975	33.703	0.310
4	v_c = 50 m/min f = 0.3 mm/rev a_p = 0.25 mm	8.173	44.010	0.290
5	v_c = 100 m/min f = 0.2 mm/rev a_p = 0.25 mm	6.238	34.112	0.360
6	v_c = 200 m/min f = 0.2 mm/rev a_p = 0.25 mm	4.330	25.156	1.375
7	v_c = 25 m/min f = 0.2 mm/rev a_p = 0.25 mm	5.425	31.750	0.325
8	v_c = 50 m/min f = 0.2 mm/rev a_p = 0.5 mm	7.339	39.242	0.350
9	v_c = 50 m/min f = 0.2 mm/rev a_p = 1 mm	7.016	38.677	0.360
10	v_c = 50 m/min f = 0.2 mm/rev a_p = 2 mm	8.178	45.665	0.485

3 Results and discussion

Table 2 shows the results of the individual tests with variable machining parameters. The average values of the selected roughness parameters and width of tool flank wear were given.

On the basis of the results obtained, the analysis of the impact of parameters of cutting process on the selected parameters of the surface layer and tool wear was carried out. Considering the average roughness and wear values of the tool, it has been found that the convenient cutting parameters are: cutting speed v_c = 50 m/min, feed rate f = 0.2 mm/rev and depth of cut a_p = 0.25 mm.

Figures 2, 3 and 4 show the effects of machining parameters (f, v_c, a_p) on the values of the selected roughness parameters (Ra and Rz) and width of flank wear land (VB). In addition, the equations describing the course of dependencies of the surface layer parameters and tool wear on the cutting parameters were determined experimentally.

From the graph above, it can be concluded that the lowest values of roughness Ra and Rz were obtained at the low feed rate f. In addition, for the lowest feed rate f, the maximum width of flank wear land VB has been reached. With an increase of feed rate f, the width of flank wear land VB decreased, and the Ra and Rz parameters increased. At feed rates f = 0.2 mm/rev and f = 0.3 mm/rev, slight variations in width of flank wear land VB were obtained. On the other hand, in the same feed range, a significant increase

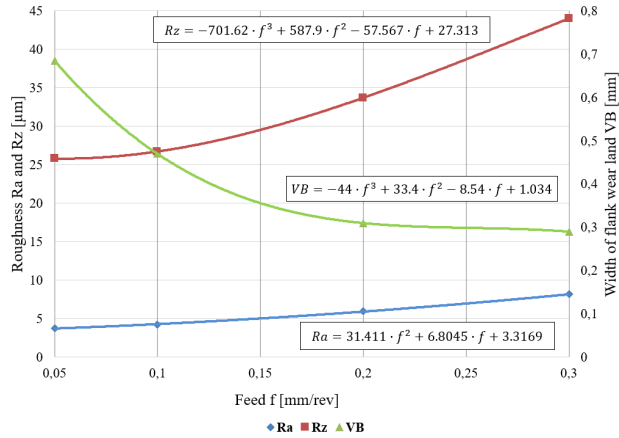**Figure 2:** Equations describing the course of dependence of surface layer parameters and tool wear versus feed

Figure 3: Equations describing the course of dependence of surface layer parameters and tool wear versus cutting speed

Figure 4: Equations describing the course of dependence of surface layer parameters and tool wear versus depth of cut

of the *Rz* value was observed. For high feed rates, high cutting force are expected. The amplitude of vibration in the mass-damping-elastic system decreases its value with cutting force increase, which results in lowering waviness (unlike roughness) of the machined surface. That dynamical behavior may be the reason of rapid decrease of the width of flank wear land *VB* with the increase of the feed rate *f*. Equations describing the course of dependence of surface layer parameters and tool wear on feed speed were also determined. For the *Ra* parameter, the equation describing dependence on the feed rate has taken the form (1).

$$Ra = 31.411 \cdot f^2 + 6.8045 \cdot f + 3.3169 \qquad (1)$$

For the *Rz* parameter, the course of the curve was described by equation (2).

$$Rz = -701.62 \cdot f^3 + 581.9 \cdot f^2 - 57.567 \cdot f + 27.313 \quad (2)$$

However, for the parameter *VB*, the description of the curve was represented by equation (3).

$$VB = -44 \cdot f^3 + 33.4 \cdot f^2 - 8.54 \cdot f + 1.034 \qquad (3)$$

As a result, the *Ra*, *Rz*, and *VB* parameters can be determined for any feed rate *f* between the extreme values of the feed parameters from the range used in the tests.

By analyzing the obtained results of the cutting speed v_c influence on surface and tool parameters (Figure 3), it can be concluded that the cutting speed $v_c = 100$ m/min was the limit at which the value of width of flank tool wear land *VB* and values of the roughness *Ra* and *Rz* were not significantly changed. Above this value of v_c, the *VB* tool increases drastically, causing a sudden and irreversible damage to the cutting edge, as illustrated in Figure 5b. Such unfav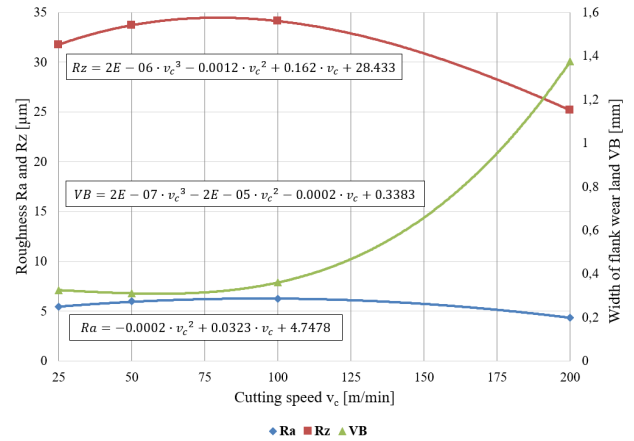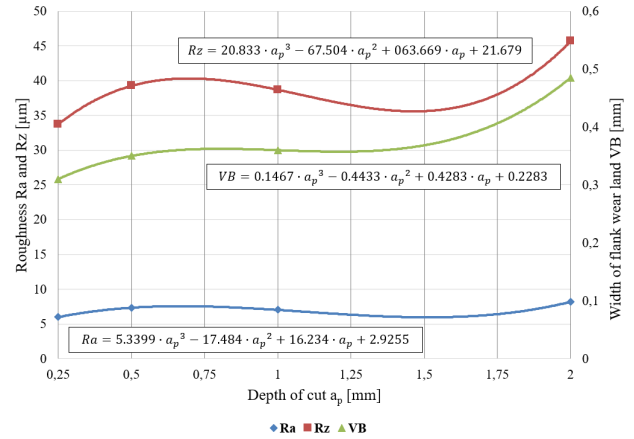orable phenomena may be caused by kinetic energy of the interacting elements of the workpiece (aggregates) on the material of the cutting plate. The energy of mineral aggregates impacting the cutting plate increases with square of value of the cutting speed v_c, which results in complete and irreversible damage of the tool corner by the mineral cast material. Equations describing the course of dependence of surface layer parameters and tool wear on the cutting speed were also determined. For the *Ra* parameter, the equation describing the course of the curve took the form (4).

$$Ra = -0,0002 \cdot v_c^2 + 0,0323 \cdot v_c + 4.7478 \qquad (4)$$

For the *Rz* parameter, the course of the curve was described by equation (5).

$$Rz = 2E - 06 \cdot v_c^3 - 0.0012 \cdot v_c^2 + 0.162 \cdot v_c \qquad (5)$$
$$+ 28.433$$

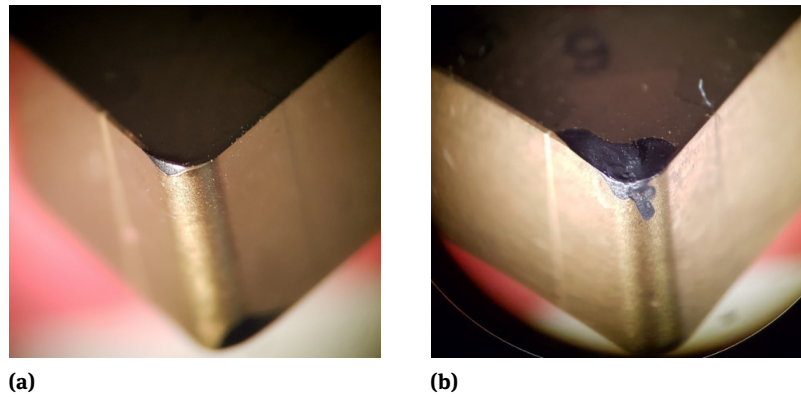**(a)**   **(b)**

Figure 5: View of width of flank tool wear land VB depending on machining parameters: a) the favorable conditions v_c = 50 m/min, f = 0.2 mm/rev, a_p = 0.25 mm; b) the worst conditions v_c = 200 m/min, f = 0.2 mm/rev, a_p = 0.25 mm

However, for the parameter *VB*, the description of the curve was represented by equation (6).

$$VB = 2E - 07 \cdot v_c^3 - 2E - 05 \cdot v_c^2 + 0.0002 \cdot v_c \quad (6)$$
$$+ 0.3383$$

As a result, *Ra*, *Rz*, and *VB* parameters can be determined for any cutting speed v_c in the range used during experimental research.

The best surface and the lowest wear were observed at the lowest depth of cut *a_p = 0.25 mm*. However, at depths of cut *a_p = 0.5 mm* and *a_p = 1 mm*, no significant increase in the values of these parameters was observed in contrast to *a_p = 2 mm* depth. With such a high depth of cut, the values of *Rz* and *VB* are significantly deteriorated. This phenomenon was caused by the machining of much larger volume of material than at the lower depths of cut *a_p*. The equations describing the course of dependence of surface layer parameters and tool wear from the depth of cut were also determined. For the *Ra* parameter, the equation describing the course of the curve took the form (7).

$$Ra = 5.3399 \cdot a_p^3 - 17.484 \cdot a_p^2 + 16.234 \cdot a_p \quad (7)$$
$$+ 2.9255$$

For the *Rz* parameter, the course of the curve was described by equation (8).

$$Rz = 20.833 \cdot a_p^3 - 67.504 \cdot a_p^2 + 63.669 \cdot a_p \quad (8)$$
$$+ 21.679$$

However, for the parameter *VB*, the description of the curve was represented by equation (9).

$$VB = 0.1467 \cdot a_p^3 - 0.4433 \cdot a_p^2 + 0.4283 \cdot a_p \quad (9)$$
$$+ 0.2283$$

As a result, *Ra*, *Rz*, and *VB* parameters can be determined for any depth of cut a_p in the range from *a_p = 0.25 mm* to *a_p = 2 mm*. From the width of flank tool wear land *VB* analysis, it can be concluded that machining of mineral castings is very difficult. Many of the mineral aggregates contained in the mineral cast impacted the plate of a tool, which resulted in larger damage of cutting corner. Figure 5 shows the microscope images of the CBN wear of plate working in favorable conditions (a) and the worst conditions (b). The photos have been taken after *L = 60 mm*. For plate working in convenient conditions, the width of flank tool wear land was *VB = 0.310 mm* (Figure 5a). For plate working in the worst conditions, the width of flank tool wear land was *VB = 1.375 mm* (Figure 5b).

As it can be observed, with the cutting speed *v_c = 200 m/min*, the tool of wear is very fast, so the plate is not suitable for further processing. Also, on the plate, various types of cracks and crushes are visible – the plate has been completely and irreversibly destroyed.

4 Summary

During longitudinal turning, the mineral cast material with cutting parameters: cutting speed *v_c = 50 m/min*, feed rate *f = 0.2 mm/rev* and depth of cut *a_p = 0.25 mm*, good surface properties (low roughness) and comparatively the lowest wear of tool were obtained. The roughness values were obtained at a satisfactory level of *Ra = 5.975 μm* and *Rz = 33.703 μm*, which can be described as a satisfactory result from a technological point of view. For this parameters, the width of flank tool wear land was *VB = 0.310 mm*. Additionally, the courses of the surface layer parameters and tool wear against the machining parameters were de-

termined. The courses obtained are not linear courses. The second and third degree equations were used to describe these, which in a significant way allowed approximating the estimated values of *Ra*, *Rz*, and *VB* to real values. As a result, *Ra*, *Rz* and *VB* parameters can be determined for any value of machining parameters in the ranges of cutting parameters used during experimental investigations.

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