EVALUATION OF SURFACES ROUGHNESS, DIMENSIONAL AND SHAPE ACCURACY OF Al_2O_3 CERAMICS IN HARDENED STATE AFTER MILLING

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Abstract

The article evaluates the effect of technological parameters of machining on surface roughness, dimensional and shape accuracy in the process of milling Al_2O_3 ceramics in hardened state. The unique properties of ceramic materials cause more and more interest in them in various branches of industry. Ceramics in the hardened state can be processed using unconventional methods and conventional methods while maintaining the appropriate technological parameters. Ceramics cutting tests were carried out in a hardened state (face and shape milling) on a CNC milling machine using PCD tools. Geometric surface structure study and measurements of geometric dimensions were made.

Keywords: Ceramics machining, ceramics milling, hard ceramics, Al_2O_3 milling

1. INTRODUCTION

Ceramic technical materials due to their unique property are constantly used in various industries, such as the electrical, chemical or food industries. Ceramic materials are used in the production not only as a machining material, but also as cutting tools (cutting inserts or brushes for deburring) [1-3]. Ceramics is used to produce protective surface layers [4,5], but also requires conductive modification with metal coatings [6,7].

The choice of ceramic materials for manufacturing processes depends on their physical and chemical properties, as well as on the possibility of giving them dimensional and shape accuracy and ensuring proper surface quality. One of the main difficulties in the treatment of ceramic materials is their brittleness and hardness [16,17]. During processing, greater brittleness of ceramic materials in relation to metal materials is manifested by the occurrence of cracks at the edges, while the higher hardness of ceramic materials in relation to metals results in a limited number of tools enabling processing [8]. In recent times, the most popular methods of machining ceramic materials are electro-erosive machining, abrasive machining and laser-assisted machining (LAM - Laser Aided Manufacturing) [9,14,15]. The article evaluates the technological parameters in milling operations on a CNC machine. Previous research confirmed the need to process ceramic materials using a CNC milling machine.

2. TEST CONDITIONS

The ceramic material used for the tests is aluminum oxide (Al_2O_3) with purity of 99 % and 97 % (**Figure 1**) in the hardened state (after firing). The choice of this type of ceramics is dictated by its popularity in the industry due to its properties such as: high compressive strength, thermal resistance, resistance to chemical agents, corrosion resistance and electrical insulation [10].

The tests were carried out on the Cincinnati Arrow 500 vertical milling center. The ceramic material used was in the form of a cylinder with a diameter of 8 to 15 mm and a height of 30 mm. The processed samples were mounted in a three-jaw chuck (**Figure 2**) screwed to the machine tool table. End milling and contour milling were performed.

Figure 1 Ceramic material Al_2O_3 in the form of a cylinder

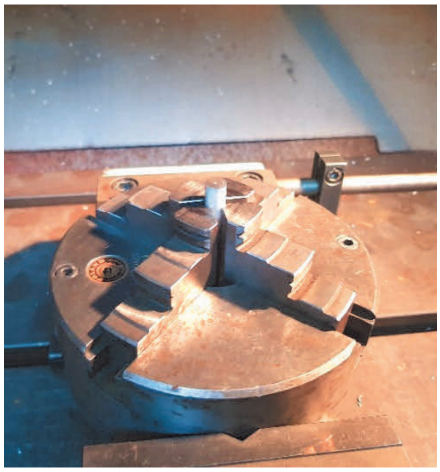

Figure 2 Fixing the blank in a four-jaw chuck

For the tests, cutting tools equipped with a polishing plate with a polycrystalline diamond corner (PCD) from different manufacturers were used. The first tool will be marked as PCD10, the second as PCD05. Before carrying out the tests, it was decided to attach one PCD plate in the tool and a second plate with a grounded corner as a counterbalance. In both cases, they are cutting inserts with a polycrystalline diamond corner. The PCD10 tool has 2.2 mm of leading edge length and 4 mm of effective cutting edge, PCD layer thickness is 0.625 mm, it is shown in **Figure 3**. For PCD05 tool, the leading edge length is 2.4 mm, the effective cutting part has a height of 6.5 mm, while the thickness of the PCD layer is 0.82 mm (**Figure 4**).

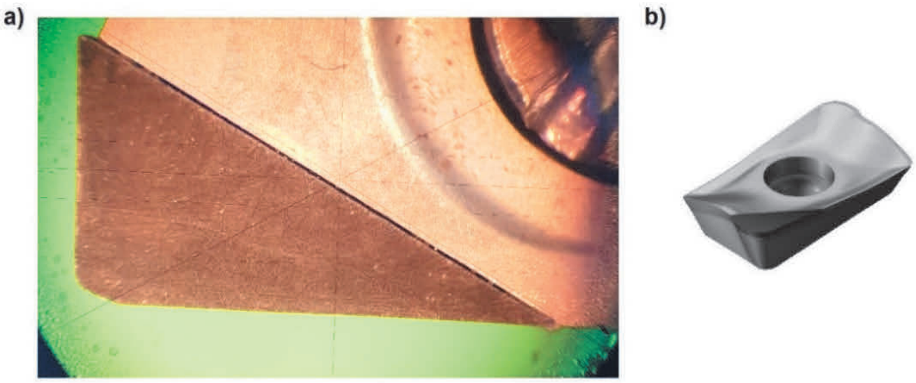

Figure 3 a) microscopic view of the PCD corner in cutting insert PCD10, b) visualization of the entire insert [12]

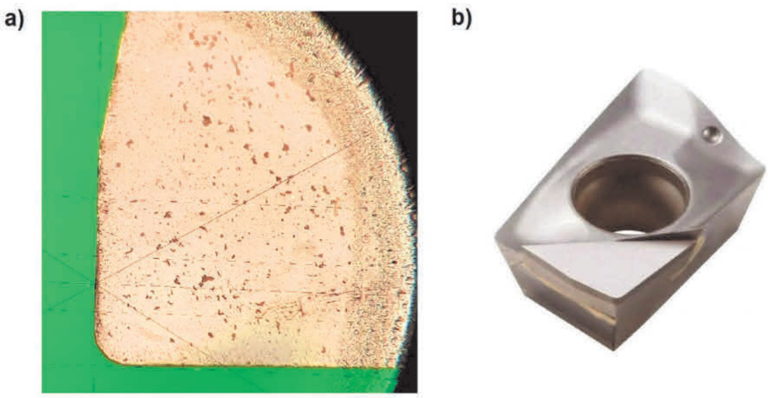

Figure 4 a) microscopic view of the PCD corner in cutting insert PCD05, b) visualization of the entire insert [13]

The PCD10 tool was used to test the surface milling of blanks with various machining parameters. **Table 1** contains surface roughness parameters before and after machining with various technological parameters.

Table 1 Surface roughness parameters and machining parameters

Face milling					Roughness before processing		Roughness after processing	
Insert	Sample no.	v_c [m/min]	f_z [mm/rot]	a_p [mm]	Ra [µm]	Rz [µm]	Ra [µm]	Rz [µm]
nr 1 PCD10	1a	120	0.05	0.05	0.86	7.16	0.493	4.83
nr 2 PCD10	1b	60	0.05	0.05	1.15	11.92	0.337	2.99
nr 3 PCD10	2a	180	0.05	0.05	1.06	8.00	0.622	4.66
nr 4 PCD10	2b	120	0.075	0.05	0.9	11.65	0.377	2.91
nr 4 PCD10	3a	120	0.025	0.05	0.75	8.32	0.325	2.59

Samples were subjected to topography analysis using a Talysurf 10M profilometer. In each case the roughness of the surface layer has been improved relative to the roughness before processing.

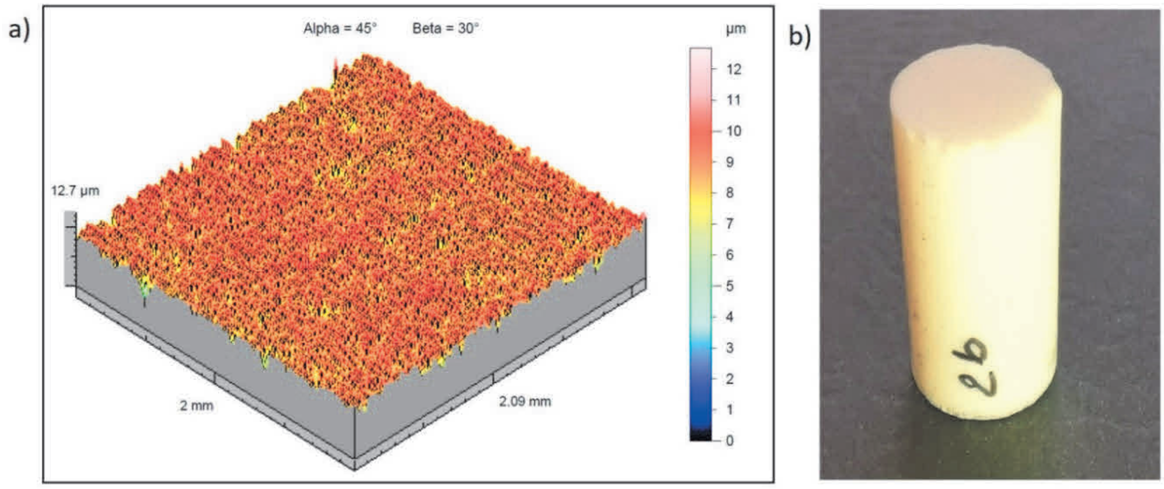

Figure 5 a) Stereometric image of the 2b sample surface (v_c = 120m/min, f_z = 0.075 mm/rot, a_p = 0.05 mm), b) view of sample 2b after processing

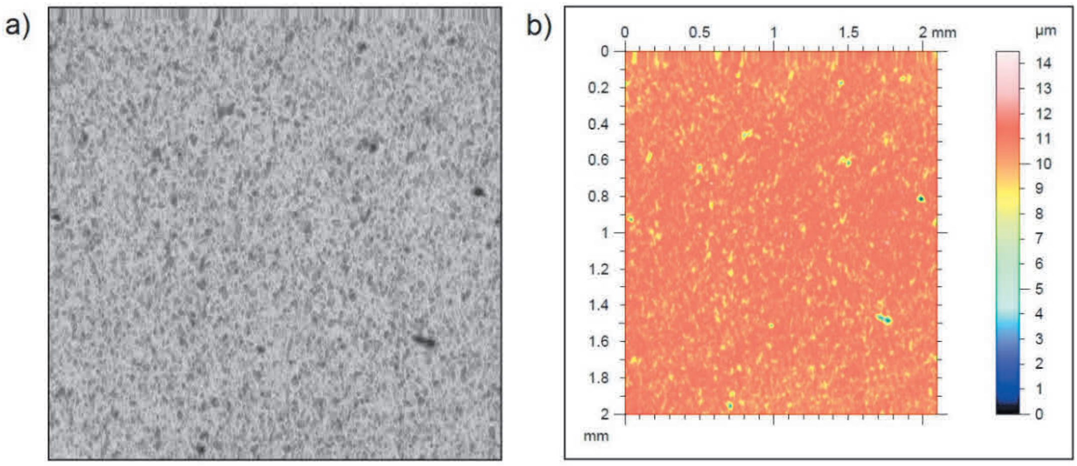

Figure 6 a) the frontal surface of sample 1a (v_c = 120m/min, f_z = 0.05 mm/rot, a_p = 0.05 mm), b) 2D topographical view of sample 1a

Figure 7 shows the plot of the load bearing area in sample 1a. The bearing capacity of the surface is described by the following parameters [6]:

- S_{pk} - reduced summit height [μm],
- S_k - core roughness depth [μm],
- S_{vk} - reduced valley depth [μm],
- S_{r1} - ppper bearing area [%],
- S_{r2} - lower bearing area [%].

The S_{pk} parameter allows you to evaluate the surface resistance to abrasion. The low value of the S_{pk} parameter means high abrasion resistance. The parameters S_{vk} and S_{r2} provide information on the lubricating properties of the surface (keeping the fluid through the sliding surfaces). In the case of the S_k parameter, its low value indicates the ability to withstand high mechanical loads, which confirms the large difference between the S_{r2} and S_{r1} pairs, proves the high surface load capacity [11].

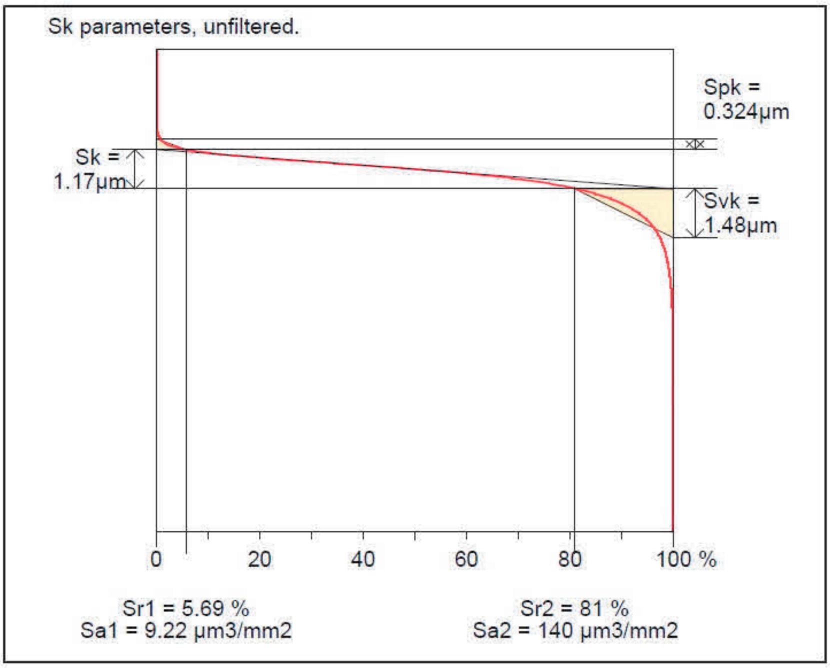

Figure 7 Material ratio curve of 1a sample (v_c = 120m/min, f_z = 0.05 mm/rot, a_p = 0.05 mm)

Table 2 Selected parameters of material ratio curves

Sample no.	v_c [m/min]	f_z [mm/rot]	a_p [mm]	S_{pk} [μm]	S_{vk} [μm]	Sa [μm]	Sz [μm]
1a	120	0.05	0.05	0.324	1.48	0.569	9.55
1b	60	0.05	0.05	0.288	1.12	0.417	10.6
2a	180	0.05	0.05	0.385	1.09	0.445	7.32
2b	120	0.075	0.05	0.37	1.51	0.596	9.55
3a	120	0.025	0.05	0.304	1.28	1,1	10.7

In the case of profiled machining, it was decided to make a cube (**Figures 8 a and b**) and to make a pyramid with a quadratic base (**Figure 8 c**). In the case of milling the first cube (**Figure 8 a**), no material chipping at the edges was noted as opposed to the second cube (**Figure 8 b**). In the first case, the material was extended 6 mm above the jaws, in the second case the material was extended 10 mm above the jaws. The appearance of material chipping may be due to material trembling in the machining chuck.

For the first and second samples, the processing time was about 1h and 10 minutes. In both cases, only the deburring on the leading edge in the cutting inserts was observed. Therefore, it is necessary to consider the correct tool wear bandwidth. During milling a pyramid-shaped sample, the PCD corner breaks off the milling plate and prematurely completes the machining. In the case of the third sample (**Figure 8 c**), the working time of the tool until the corner was broken off was about 1 hour and 40 minutes. New cutting insert was used to make any machining.

Figure 8 Samples after shape milling, a) sample made with PCD05 insert (v_c = 120m/min, f_z = 0.05 mm/rot, a_p = 0.05 mm), b) sample made with PCD10 insert (v_c = 120m/min, f_z = 0.05 mm/rot, a_p = 0.05 mm), c) sample made with PCD05 insert (v_c = 120m/min, f_z = 0.05 mm/rot, a_p = 0.05 mm)

After machining, the samples were subjected to measurements on a Zeiss CMM Acurra 7. **Figure 9** presents the measurement scheme, the results of measurements are in **Table 3**.

Table 3 Dimensions of samples after shape milling

Sample made with PCD05 insert			
v_c = 120 m/min	f_z = 0.05 mm/rot		a_p = 0,05 mm
	Direction 1 - 3	Direction 2 - 4	Height
Assigned dimension	6 mm	6 mm	6 mm
Measurement 1	5.960 mm	5.939 mm	6.05 mm
Measurement 2	5,978 mm	5,965 mm	
Difference in dimension	0.018 mm	0.026 mm	0.05 mm
Sample made with PCD10 insert			
v_c = 120 m/min	f_z = 0.05 mm/rot		a_p = 0.05 mm
	Direction 1 - 3	Direction 2 - 4	Height
Assigned dimension	6 mm	6 mm	6 mm
Measurement 1	5.985	5.950	6.05 mm
Measurement 2	5.990	5.975	
Difference in dimension	0.015	0.025	0.05 mm

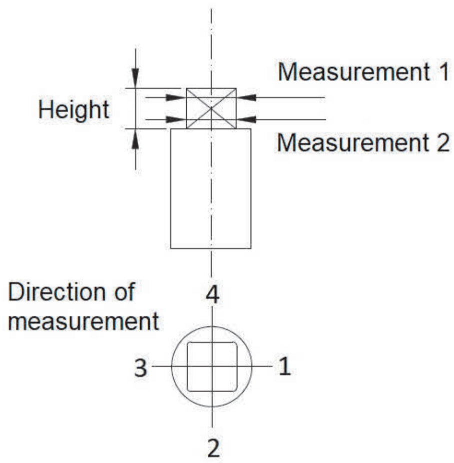

Figure 9 Diagram of measurements of cubes made of Al_2O_3 (99 %) ceramics in hardened state

3. CONCLUSION

The cutting tests carried out showed the effectiveness of using polycrystalline diamond blades in ceramic processing. The obtained roughness values of Ra = 0.3 - 1.2 μm testify to the high quality of the geometric structure of the surface.

The method of fixing the blank affects the accuracy of the material processing. A small overhang of the blank should be used above the fixing, which results in less vibrations of the blank.

As a result of the vibrations of the blank, chipping occurs at the edges of the milled material during the exit of the tool from the material.

The first milling tests allow for the initial determination of the recommended intervals of the technological values of the cutting parameters (v_c = 100÷200 m/min, f_z = 0.025 ÷ 0.075 mm/rot, a_p = 0.05 mm).

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