776. Correlation between shape errors in flat grinding

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Abstract. Correlation between shape errors of the tool and ceramic work-pieces are presented in the paper. A new tool, on which different shape errors of convexity or concavity can be set, was used during experiments. Results from flat grinding, such as the shape errors, are presented and analyzed. Computational calculations concerning the local shape errors of the tool and the technological effects such as surface roughness and waviness parameters as well as the work-piece plane-parallelism are also presented.

Keywords: flat grinding, shape errors, ceramics.

Introduction

Grinding of ceramics is widely used for reducing the workpiece roughness from preceding processes and can be carried out with different tool-workpiece configurations. Lapping is the basic flattening process which allows for achieving a high degree of flatness and parallelism of machined parts. It is still one of the most common processes to flatten e.g. the sliced silicon wafers [7]. Apart from lapping also grinding operations are carried out for parts flattening with two basic tool-workpiece configurations: single side grinding (SSG) and simultaneous double side grinding (SDSG) [13]. These processes have some advantages comparing with lapping e.g. lower cost and higher throughput although there is still a problem with effective waviness removal by SSG and with a dimple in the center of the wafer after SDSG [13]. Most suitable for processing the workpieces with coplanar functional areas are manufacturing technologies which allow for both areas to be processed at the same time. Grinding (flat honing, fine grinding) with the use of grinding wheels mounted on a double-disk lapping machine is widely used in practice [1, 5, 12]. Special machines for high speed grinding are available now [2]. Single-disk machines can be also used for single side grinding [4] but its conventional configuration needs the modification - the leading ring rotational velocity should be higher and set independently unlike on conventional machines, where the conditioning (leading) rings rotate with workpieces without any additional drive. When grinding wheel is used on a lapping machine, dressing influences the grinding process significantly, depending on how it is done [11].

Grinding with lapping kinematics ensures a very good flatness due to the fact that the active surface of the tool is simultaneously the machining datum surface. In consequence of such configuration, there is a very close correlation between the tool and the machined part flatness errors. During the process both surfaces: active surface of the tool and the surface of the workpiece change the profile shape due to the abrasive wear. The active surface of the tool usually is not flat and can be either concave or convex. This exerts the main influence on the shape accuracy of the workpieces. Kinematical analysis of grinding marks was used in a mathematical model for the wafer shape prediction proposed by Wangping Sun et al. [13]. Influence of a double-side lapping kinematics on the face grinding was studied by Uhlmann and Ardelt [12]. The proposed and used in this paper model for the theoretical shape error estimation [7] is also based on the kinematical relations and additionally on local shape errors of the tool. This kind of relation must be considered when the tool surface is simultaneously the machining (fixturing) datum.

Results of grinding of ceramics flat pieces when submitted to single-disc lapping kinematics are the subject of this paper. The grinding tools were electroplated with diamond grains D64 and D107. Different tool profiles were set for each tool to check the correlation between the shape errors. Results from the computational simulations concerning the local shape errors of the tool are presented to predict the correlation between shape errors in flat grinding. Technological effects such as surface roughness and waviness parameters as well as the workpiece plane-parallelism were also checked during experiments.

Experimental procedure

Experiments were carried out on a modified single-disk lapping machine with the independent drive of a leading ring realised with the use of a stepper motor [3]. Placed in a separator ceramic workpieces were loaded against a rotating tool and rotated together with a leading ring. The rotational velocity of the tool was set to n_t = 63 rpm and the rotational velocity of a ring was set to n_2 = 120 rpm in the opposite direction of the tool rotation. Cutting fluid (based on kerosene and machine oil) was introduced drop by drop into the contact region between the workpieces and the diamond electroplated tool. To check the correlation between the tool and the workpiece shape errors, tool radial profiles were measured along eight paths on the CNC measuring machine as well as with the use of a digital indicator - Fig. 1 [6]. The design of the tool allows for setting required profiles and is a subject for the polish patent law. After the measurements of two tools, the average profiles were calculated (Fig. 2) and used for numerical analysis. The tool #1 was covered with diamond grains D107, and the tool #2 with grains D64.

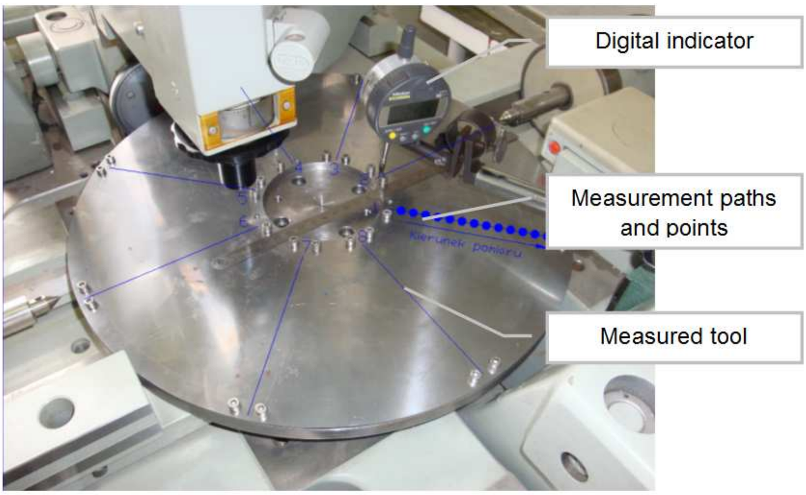

Fig. 1. Measurement of the tool shape

Computational results

Numerical simulations are based on the developed model for the shape error estimation during machining with flat lapping kinematics [7, 8, 10]. During the simulations, the theoretical distance between the workpiece and the tool is calculated [9]. The analyzed tool shapes, set and measured before experiments (Fig. 2) and for which the calculations were carried out are presented in Fig. 3. The workpiece area is divided into elementary areas and the orientation of an adjacent plane containing the workpiece is found. This orientation depends not only on the shape error of the lap but also on the shape and size of the workpiece [7]. During the computational calculations the active tool surface is limited to the area containing the analytical points for each discrete location of the workpiece. The movement of the circular workpiece is analyzed and some its discrete locations are shown in Fig. 3.

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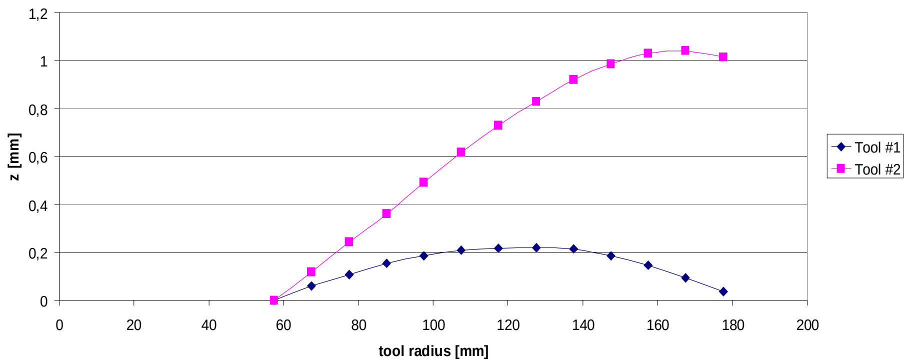


Fig. 2. Measured and analyzed tool profiles

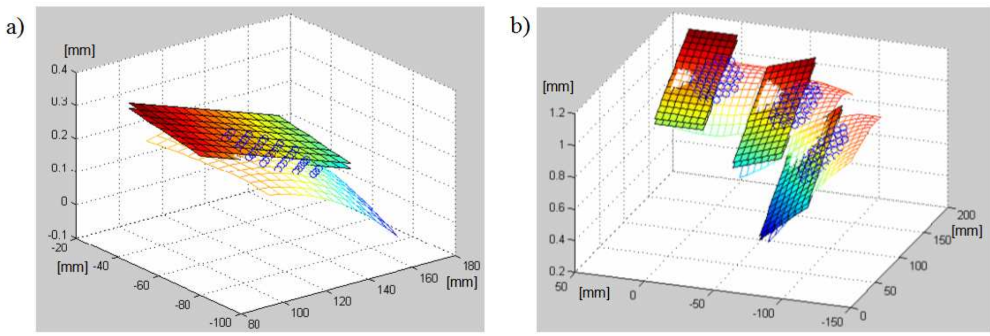


Fig. 3. Workpiece orientation on the tool surface:
a) tool #1 - one discrete location, b) tool #2 - three workpiece discrete locations

The average distance (during the cycle time T_z) between the elementary work-piece area A_{1i} and the tool surface is the main variable in a computer model developed for the estimation of the work-piece shape [7]. Distributions of the distance d_2 for a circular work-piece (ϕ34) and for analyzed tool shapes (Fig. 3a, b) are shown in Fig. 4. The average distribution along the work-piece radius is presented in Fig. 4c, d. The results indicates that the work-piece shape errors should be higher when the tool #2 (Fig. 2 and Fig. 3b) is applied.

Grinding results

Ceramic work-pieces were pre-grounded before experiments with the initial average surface roughness parameters: R_a = 1,96 µm, R_z = 22,7 µm, measured within the central area of the radius R = 6 mm, with the initial and final biggest shape errors. The average initial plane-parallelism was T_p = 0.062 µm. Surface roughness and waviness parameters were measured with the profilometers Hommel Tester T500 and ME10 on each sample after each test along three paths. Additionally these parameters were measured and the work-piece surface was inspected with the FRT non-contact measuring instrument (from Fries Research & Technology Company, Germany) - Fig. 5. Plane-parallelism was checked with a micrometer of sensitivity 1 µm (from Mitutoyo Company, Japan, Kawasaki). The height of the samples Δh_w reduced by grinding was measured individually after each test.

The first three tests were carried out on ceramics work-pieces (Al_2O_3) with the use of a tool #1 with diamond grains D107 and with the radial profile presented in Fig. 2 and in Fig. 3a. The required velocity of the tool (n_t = 62 rpm) and of the work-piece holder (n_2 = 120 rpm) as well as the load on the contact were set (p = 2.7 kPa), and tests ($T_1 \div T_3$) were run for total machining time of 3 minutes for each test. Every three minutes, five work-pieces were removed from the separator and, after cleaning, the plane-parallelism, surface roughness and waviness parameters were measured. Results show the reduction in the shape errors from the initial state (Fig. 6, Fig. 7) to the final one (Fig. 7 and Fig. 8) for each work-piece.

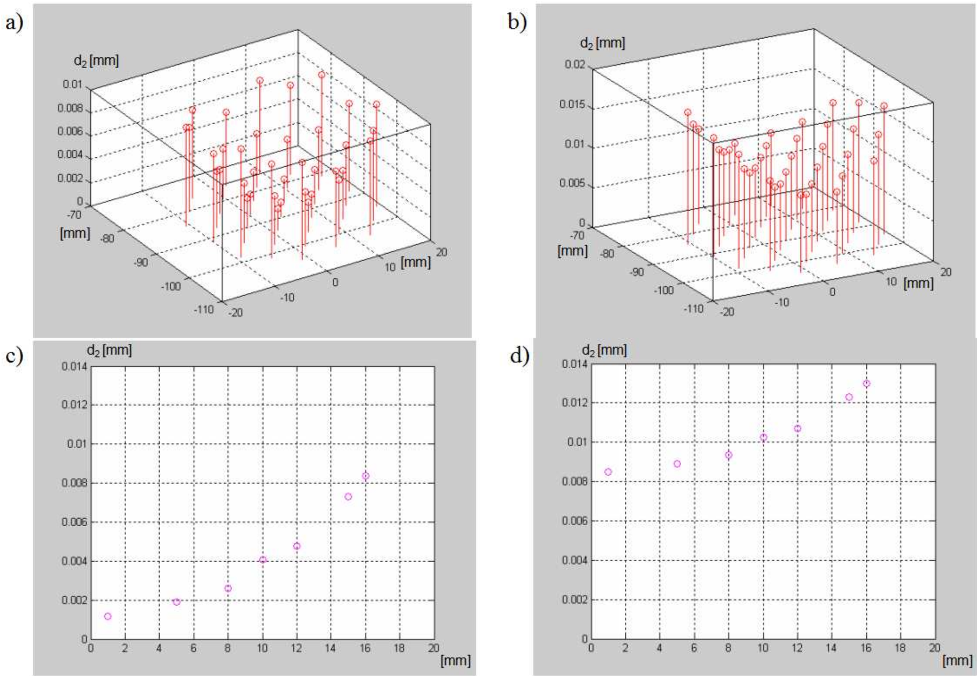
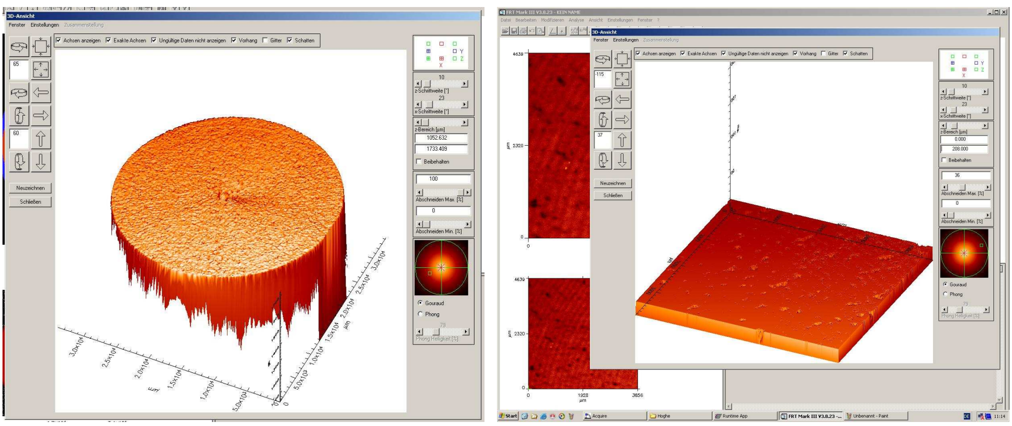


Fig. 4. Distribution of the distance d_2 between the work-piece and the active surface of the: a) tool #1, b) tool #2, c) average radial distribution for the tool #1, d) average radial distribution for the tool #2



a) b)

Fig. 5. Machined ceramic workpiece: a) analyzed total surface b) filtered image with porosity

Next tests ($T_4 \div T_6$) were carried out also on ceramics work-pieces (Al_2O_3) with the use of the electroplated diamond tool #2 with grains D64 and with the radial profile presented in Fig. 2 and in Fig. 3b. The required velocity of the tool (n_t = 62 rpm) and of the work-piece holder

(n_2 = 120 rpm) as well as the load on the contact (p = 2.7 kPa) were set. The first test (T_4) was run for total machining time of 3 minutes and next tests T_5 and T_6 for 2 minutes. The machining time was reduced in order to minimise the wear of a single-layer electroplated diamond tool which was higher comparing to the previous set of tests, because of smaller grains - D64. Results show the increase in the shape errors from the initial state (after the test T_3) to the final one (Fig. 9 and Fig. 10) for each work-pieces. That was expected after the numerical calculations (Fig. 4), which indicated the higher work-piece shape errors for the tool #2 applied.

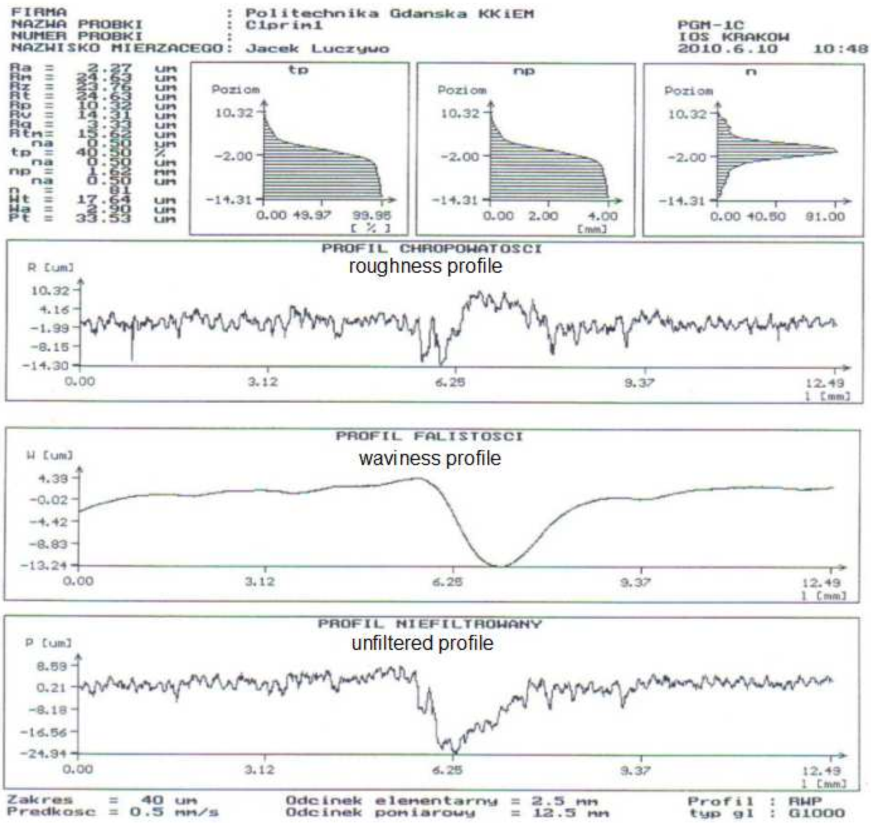


Fig. 6. Exemplary results from the measurement of the initial state of a ceramic sample

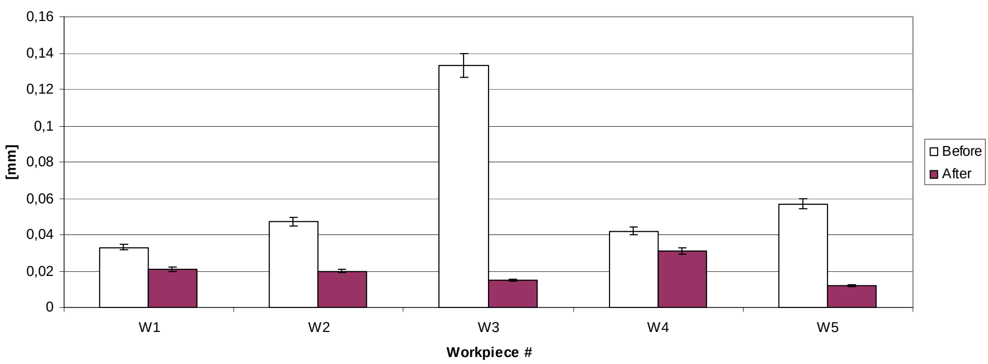
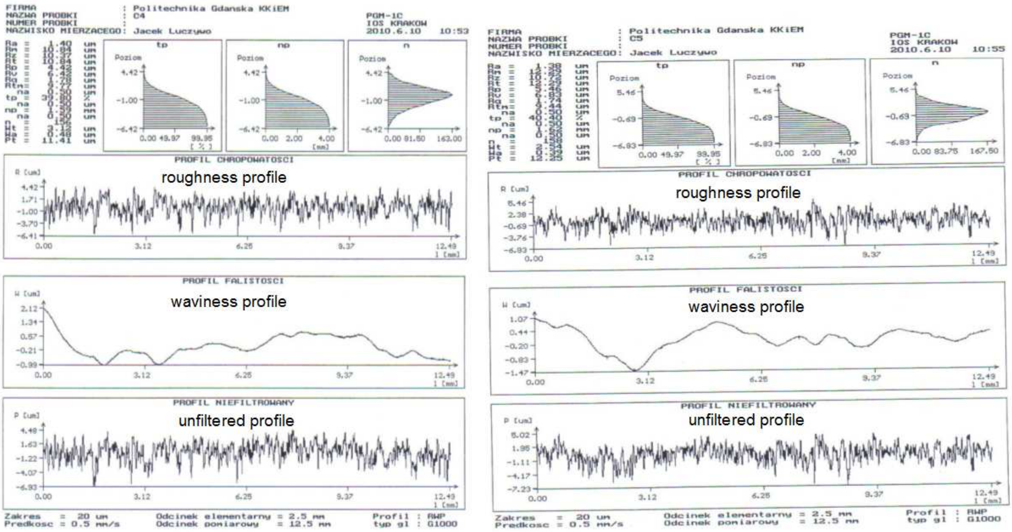


Fig. 7. Plane-parallelism errors recorded after grinding tests $T_1 \div T_3$



a) b)

Fig. 8. Exemplary results from the roughness and waviness measurements of the ceramic samples after grinding tests T_3: a) workpiece #4, b) workpiece #5

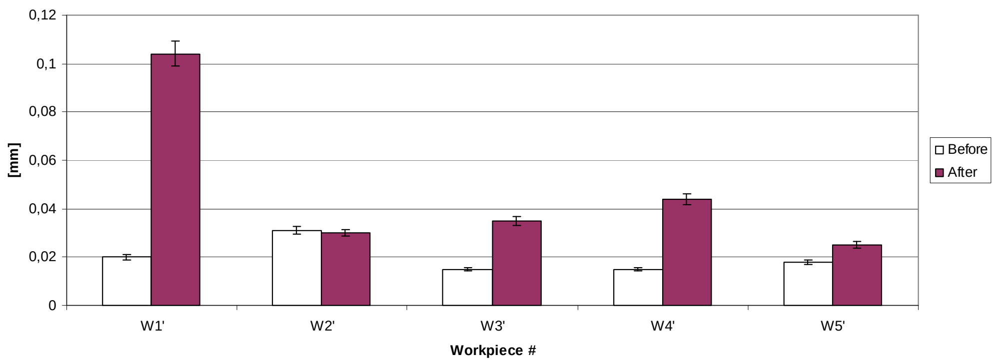


Fig. 9. Plane-parallelism errors recorded after grinding tests $T_4 \div T_6$

Surface roughness and waviness parameters achieved after grinding tests and measured within the central area of the radius R = 6 mm, with the initial and final biggest shape errors, are presented in Fig. 11. All parameters are below the initial values but the change in the grain size from D107 to D64 does not influence considerably the surface finish - *Ra*, *Rz*, *Rt*. The increase in the waviness parameters (*Wt*, *Wa*), which are also below the initial values as it is seen from Fig. 11, is caused by the bigger tool shape error set for the tool #2. This shape results in higher values of the distance between the work-piece elementary areas and the active tool surface what is seen in Fig. 4.

Conclusions

The results of experiments enable formulation of the following conclusions:

(i) There is a close relationship between shape errors of the tool and the work-pieces in flat grinding with lapping kinematics. As expected from computational calculations, higher workpiece shape errors were induced by grinding with the tool of bigger shape error.

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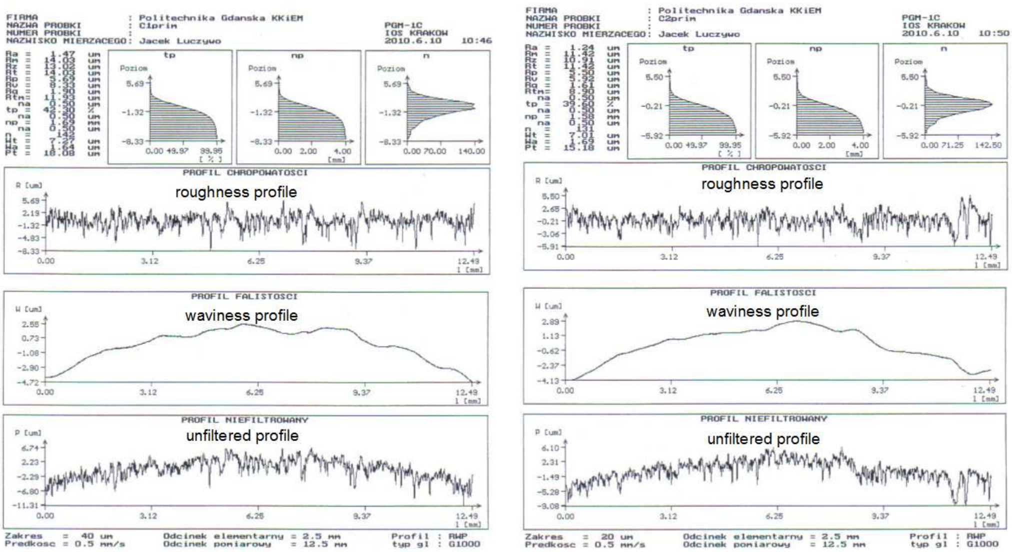
(ii) Surface finish was improved by flat grinding with the roughness and waviness parameters lower than the initial values, although the grain size from D64 to D107 does not influence considerably the surface finish - *Ra*, *Rz*, *Rt*. The increase in the waviness parameters (*Wt*, *Wa*), which are also below the initial values, is caused by the bigger tool shape error set for the tool #2. This shape results in higher values of the distance between the work-piece elementary areas and the active tool surface.

(iii) Plane-parallelism was also improved by single-side flat grinding with the correlation to the tool shape error.

(iv) Presented in the computer simulations assumptions could be included in a more sophisticated model to predict the work-piece shape machined with grinding or lapping configurations.



a) b)

Fig. 10. Exemplary results from the roughness and waviness measurements of the ceramic samples after grinding tests T_6: a) workpiece #1', b) workpiece #2'

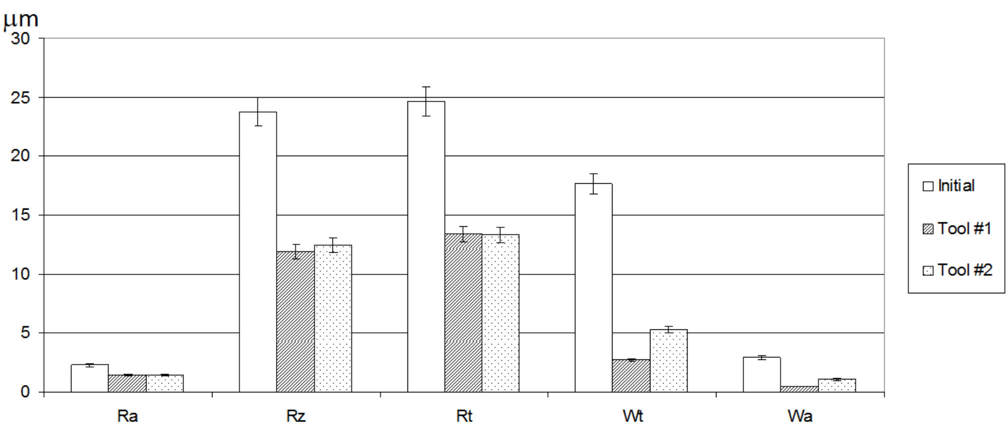


Fig. 11. Average surface roughness and waviness parameters achieved after grinding experiments

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