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EXPERIMENTAL INVESTIGATION OF WEARING GRINDING WHEELS AFTER MACHINING SINTERED CARBIDE

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Abstract

Solid cutting tools are widely applied in the machining of shape parts and mainly fabricated using the grinding operations. Solid cutting tools are of specific geometry and shape. The tool geometry is created by mutual movement grinding wheels and stock. In the grinding of its manufacturing, grinding wheels are worn out gradually with the grinding number increasing. The wearing grinding wheel has a significant influence on the accuracy-geometry of the tool produced. The paper focuses on the wear of the grinding wheels based on diamonds, and the grinding wheels based on cubic boron nitride. The wear rate of the grinding wheels is affected by the properties of a grinding wheel, grinding conditions, and type of cutting material. A measure of the ability of a grinding wheel to remove material is given by the Grinding ratio. The grinding ratio (G ratio) is defined as the volume of material removed (V_w) divided by the volume of wheel wear (V_s). Periphery grinding wheels were used in the experiments. Cylindrical face grinding was used for the machining of sintered carbide stock with a diameter of 20 mm. The results of the experiment show that the diamond-based grinding wheels are more suitable for grinding sintered carbide.

Key words

Grinding ratio, grinding wheel, grinding, sintered carbide

INTRODUCTION

Recently, with an increase in the demand for the manufacturing of the shape parts using solid cutting tools, the production of solid cutting drilling and milling tools has increased. The combination of hard carbide particles and a tough metallic binder provides a perfect cutting material with high wear resistance and fractural toughness [1]. Grinding represents the basic operation in the production of solid cutting tools. The materials like sintered carbide and cutting ceramics are difficult to grind. Grinding of those cutting materials causes high grinding heat and force, generation of thermal cracks on the ground surface, and wheel wear. The grinding wheels are worn out gradually with the ground tool number increasing. The wear leads to errors in the ground tool profile. Generally, a cutting tool manufacturer evaluates the quality of grinding, the surface finish of the end-mill, and then the geometrical profile. The grinding precision of cutting tools is determined by the surface roughness and accuracy geometry of the cutting tools [2].

The author Liu [3] investigated compensation for a worn grinding wheel in the solid cutting tool flute grinding. The authors propose an error compensation method by considering a boundary condition determination of a worn wheel. The method was implemented using C#. The author Karpuschewski [4] presents an algorithm of searching for a wheel position in flute grinding for the grinding wheel profile and shape of the helical flute. The algorithm is based on the simulation flute profile by splitting the grinding wheel into many thin disks. The principle of algorithm is based on the computation of the intersection points between the plane of flute profile for all positions of the grinding wheel and all circles on the grinding wheel. The author Uhlmann [5] analysed kinematical simulation for the grinding of end mill cutting tools made of cutting ceramics and cemented carbides. The tool geometry was created by mutual movement grinding wheels and stock. In this paper, grinding wheels of different sizes of abrasive grains were used. The tools were used for machining Inconel 718. The tools manufactured of cutting ceramic machined about 10 times faster than the conventional coated cemented carbide tools. The author [2] describes the grinding temperature characteristics and grinding forces during creep-feed grinding of cermet (Ti (C, N) alloy). The measurement of grinding temperatures was conducted using a thermocouple. The experiments were carried out to investigate the impact at the wheel speeds, the worktable speed, and the wheel diameter. The article described the process burnout that is responsible for high grinding temperatures in contact arc. During grinding, the forces were measured using a piezoelectric dynamometer. It has been observed that, as the wheel speed increases, the grinding force decreases, and the wheel wear rate also decreases. Gao et al [6] examined the cutting-edge damage mechanisms in the grinding of cemented carbides micro mills. The surface quality of micro mills is strongly affected by the tool material property. The author investigated the impact of the size of grain and composition of cemented carbides on the damage of the cutting edge. The results showed that the micro-cracks and microfractures are generated in the cutting edge. The author Denkena [7] investigated the novel continuous grinding process. The modified continuous grinding process allows for the simultaneous manufacture of all cutting edges of the cutting tools. The author described the manufacturing cutting tools using gear grinding wheel. Moravcikova and Lipa [8] deal with experimental comparison of conventional and highly abrasive abrading agent in plunge-cut grinding with the goal to find the optimal setting of the abrasive and dressing parameters allowing to achieve the best qualitative and economical parameters of machined surface of a work piece. The criterion is the surface roughness and economy of production. Kundrák [9] researched 3D modelling of the diamond grain and its bearing layer when sintering diamond grinding wheels. It is necessary to increase the reliability and quality when manufacturing the diamond-abrasive tools, which is indispensable for its effective application in manufacturing processes. The research described in this article used the FEM simulation for the production of diamond grinding wheels, dealing with the optimal conditions for the production of diamond grinding wheels. The FEM simulation is also used for the grinding process itself. The simulation model [10] was used to assume the formation of temperature at the grinding point during wet grinding process. The grinding wheel was approximated as a cylindrical milling cutter with a large number of cutting edges. The author discussed the used parabolic and triangular heat flux distributions, and found that better results were obtained using parabolic heat flux.

Wear of grinding wheel is an important factor that negatively affects the shape and accuracy of the resulting surface. Wear of grinding wheel is due to the grain fracture rubbing wear, bond fracture, and grain pull-out. The wear is caused by the interaction of the grain with the workpiece material causing physical and chemical reactions to take place. The cutting edges are distributed randomly on the top surface grinding wheels. If the grain is blunted, grinding becomes ineffective and, at the cut point, a high temperature is generated. The grains break off all or at least a part of them, and thus the new grains are formed continuously during grinding. This phenomenon is called re-sharpening [11]. The use of unsuitable grinding conditions may result in loading or wheel clogging. In that case, the surface material adheres to the tips the abrasive grains. The adhered workpiece material is brought into repeated contact with the material. The consequences of clogging and loading are the increased grinding wheel wear and increased grinding forces. Loading and clogging of the wheel can be avoided by using a suitable coolant, increased cutting speed or reduced depth of cut [12]. Li and Wang [13] researched wear of the diamond grinding wheels and material removal rate of silicon nitrides. The authors observed the wear mechanism of the diamond tool through wear tests and observation of the surface of the diamond grinding wheels. During experiments, observed were normal and tangential grinding forces, material removal rate, and wear grinding grain independent of the depth of cut. Mamalis [14] investigated the application of the advanced precision grinding process, elaborating continuous wheel dressing based on electrochemical principles, namely the ECDM process. The author found that continuous wheel dressing using the ECDM process can be used effectively in precision ceramic grinding. Material removal can be significantly increased, while providing improved surface integrity.

MATERIALS AND METHODOLOGY OF EXPERIMENT

The grinding wheels with the diamond and cubic boron nitride are used for grinding the hard and brittle materials e.g. glass, stone, ceramics, and cemented carbides. The grinding wheels are tools of undefined geometries. The wear of the grinding wheel is an important factor that negatively affects the shape and accuracy of the resulting surface. Wheels behave very differently, depending on the grain size of abrasive, type of bond, type of abrasive, and concentration of abrasive. The periphery grinding wheels (1A1) were used in experiments. Abrasive wheels for grinding the cutting materials usually have a diamond or CNB abrasive grains, which are embedded in a matrix. The matrix materials are either made of polymeric resin or metals. Table 1 shows the properties of grinding wheels used in the experiments.

Table 1 The properties of grinding wheels

	The diamond-based grinding wheel	**The cubic boron nitride grinding wheel**
Size of abrasive grain	D 64	B 126
Application	For medium grinding, cutting tools sharpening	For efficient grinding and roughing operation
Surface roughness Ra	0.4	0.8
Amount of abrasive	0.88	0.88
Type of bond	Resinoid	Resinoid
Concentration of abrasive	K 100	K 100
Cooling	Yes	Yes
Wheel of diameter	100 mm	100 mm
Width of wheel	10 mm	10 mm

The cemented carbide rods were used for the experiments. Owing to their high hardness, mechanical strength and wear-resistant, cemented carbides are of great importance in the manufacturing industry. Cemented carbides are used in the applications such as cutting, grinding and drilling process. The grade of cemented carbide was K20-K30 by ISO. The material is used for the machining steel, cast iron, stainless steel and special alloys. The properties of cemented carbide are shown in Table 2. The cemented carbide rods have dimensions of Ø20h6. Fig. 1 shows a diagram of the experiment implementation.

Table 2 The properties of cemented carbide

Grain size μm	Co ± 0.5%	Hardness HV300	Hardness HRA	Density g/cm^3	TRS N/mm^2
0.7	10.0	1580	92.0	14.35	3800

The experiments were carried out on the Reinecker WZS 60 grinding machine by ULMER WERKZEUGSCHLEIFTECHNIK Company. The grinding machine is used for production of solid cutting tools. The production of tools in small to medium series up to a diameter of 25 mm is efficient. The spindle with two grinding wheel clamps provides the maximum grinding power with the minimum kinematics limitations. The workpiece spindle achieves a rotational frequency of up to 1,200 rpm, which is equipped with a direct cooling drive. Pätoprstý [15] was engaged in the production of milling tools. For manufacturing, we used the Reinecker WZS 60 grinding machine. The scheme of the experiment implementation is shown in Figure 1.

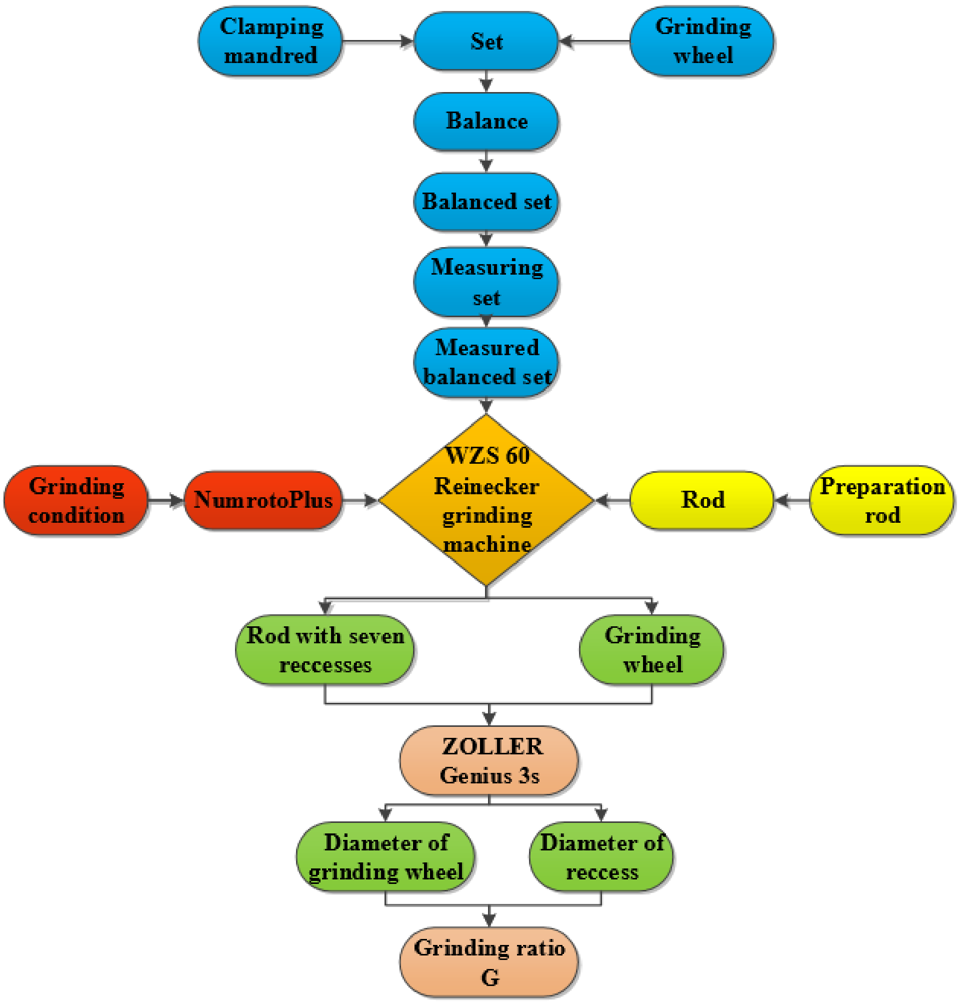

***Figure 1** Scheme of the experiment implementation*

The grinding strategy was designed in the NUMROTOplus software. The 2D and 3D simulations were an integral part of NUMROTOplus. The NUMROTOplus software by the Num Company is a comprehensive software for sharpening and producing cutting tools. The software is equipped with integrated collision control. The software is equipped with a perfect 3D machine simulation. After simulating the program, the software automatically creates an NC code that is exported from the software and imported into the grinding machine. Based on this program, we can produce the required tools. One of the results of the tool design is a list of grinding operations. Figure 2 shows the grinding of the first recess and seven recesses after 3D grinding simulation.

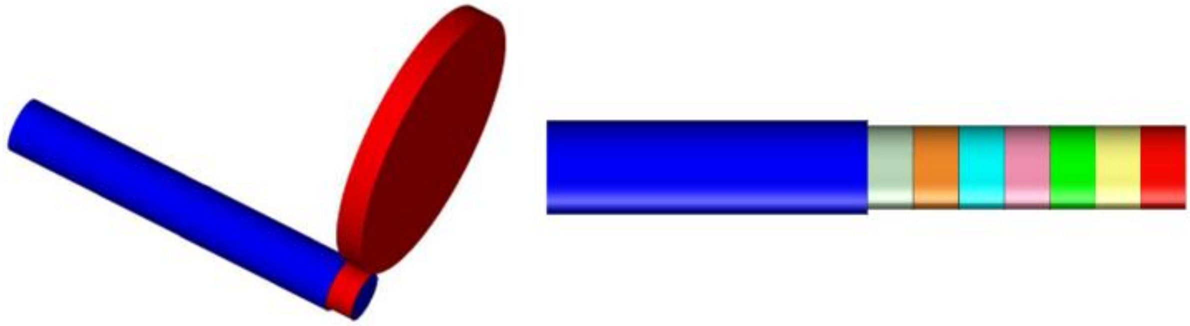

Figure 2 *a) The grinding of the first recess b) seven recesses after 3D grinding simulation*

ZOLLER Genius 3s measuring machine was used to measure the diameter of grinding wheels. ZOLLER Genius 3s is a measuring machine for checking and measuring all kinds of cutting tools. The measuring machine is equipped with CNC-driven, adjustable 3D CCD camera, and LED lighting. It is designed for fast measurement from individual parameters to fully automatic control of tools. All measurements are documented and can be exported in a printed or electronic form. The measurement results can be documented in detail and can be transferred to the grinding machines at the push of a button. It is controlled by Pilot 3.0 optical measuring software. The values were measured to 2 decimal places. The maximum weight of the tool is 50 kg. Peterka [16] used ZOLLER Genius 3s measuring machine for checking and measuring the manufactured tools. Figure 3 shows the result of machining and measuring the diameter of the grinding wheel.

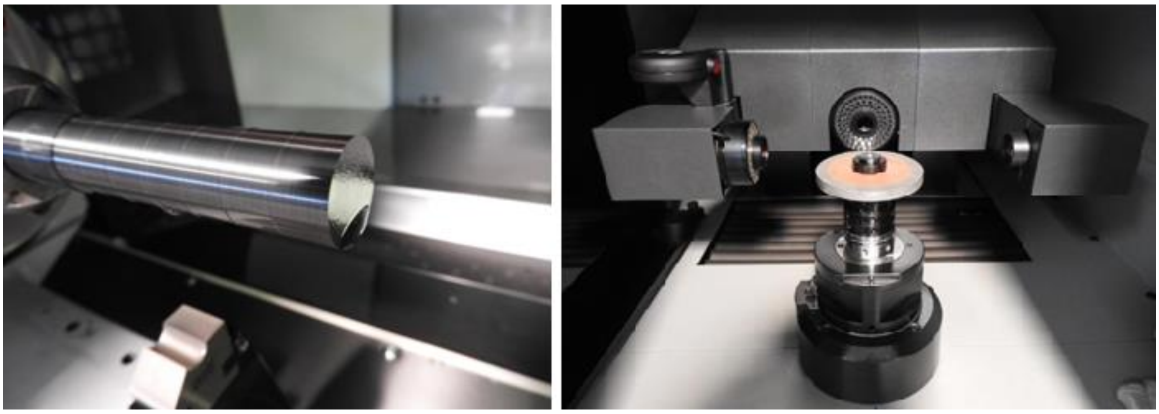

Figure 3 *a) Machining result - seven recesses b) Measuring diameter of grinding wheel*

ATTAINED RESULTS

Measurement of a grinding wheel ability to remove material is given by the grinding ratio. An efficient hard-wearing grinding wheel will grind an easy-to-grind material for a long time with only a small amount of wheel wear. In the evaluation of the experiment, the values obtained by grinding with a cubic boron nitride wheel as well as the values obtained by grinding with a diamond wheel were observed. For both grinding wheels, we chose the same values of feeds, spindle rotation frequencies, and the thickness of the removed layer. Four sintered carbide rods were ground. Seven recesses were made on each rod along the entire width of the wheel. The thickness of the removed layer was set to 1 mm from the diameter of the rod.

The diameter of the grinding wheel was measured after each formed recess. After the experiments were performed, the obtained values were substituted into the following equation:

$$G = \frac{V_w}{V_s} \text{ [-]} \tag{1}$$

Here G is the Grinding ratio, V_w is the volume of material removed and V_s is the volume of grinding wheel wear. The values of volume of material removed and the volume of grinding wheel wear were calculated according to the following equations:

$$V_w = \left(\frac{\pi * D_{p0}{}^2}{4} - \frac{\pi * D_x{}^2}{4}\right) * \text{ h; x = 1} \div 7 \quad [\text{mm}^3] \tag{2}$$

$$V_s = \left(\frac{\pi * D_0{}^2}{4} - \frac{\pi * D_x{}^2}{4}\right) * \text{ h; x = 1} \div 7 \quad [\text{mm}^3] \tag{3}$$

$$D_p = \left(\frac{D_{p1} + D_{p2} + D_{p3}}{3}\right) \quad [\text{mm}] \tag{4}$$

Here, h is the width of the grinding wheel and D_x is the diameter of the grinding wheel. These values were measured after each recess. D_{p1}, D_{p2}, and D_{p3} are diameters of recess. The diameter of each recess was measured at three points. D_p is the average value of measured diameters. D_{p0} is the diameter of the cemented carbide rods measured before the start of the experiments, which was 19.996 mm. Figure 5 shows the measuring points of the diameter of the recesses.

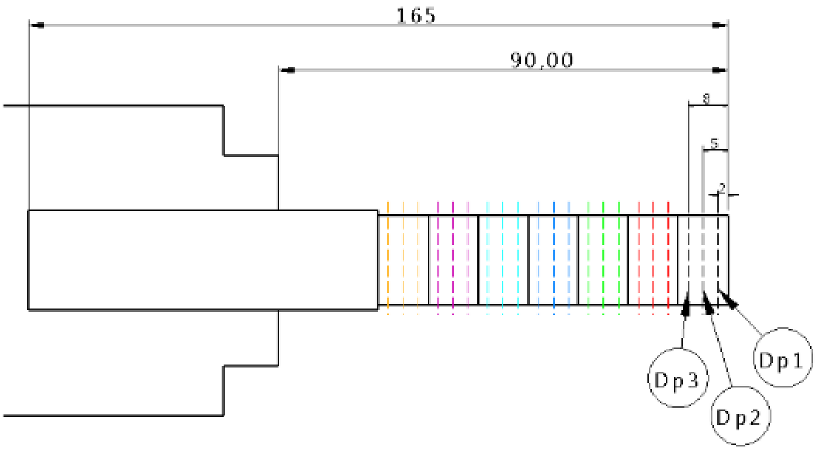

Figure 4 *Diameter measurement points*

DISCUSSION

Figure 6 suggests that as the number of operations increases, the grinding ratio decreases. Fig. 6 shows the dependence of the grinding ratio and the number of operations on both rods, from a starting value of G = 18.464 after 14 operations to a value of G = 2.343. When grinding rods using a CBN grinding wheel, the grinding ratio decreases, which is consistent with the theory. According to the theory, the grinding ratio should decrease with increasing number of grinding operations [12]. However, this does not apply to the diamond grinding wheel. In the case of using a diamond grinding wheel, we can see that the grinding ratio decreases and also increases, which is a non-standard phenomenon. The increase in the grinding ratio results in the re-sharpening of abrasive grains, which means that it can cut more material with less wheel wear. From a starting value of G = 20.297 after 14 operations to a value of G = 7.51.

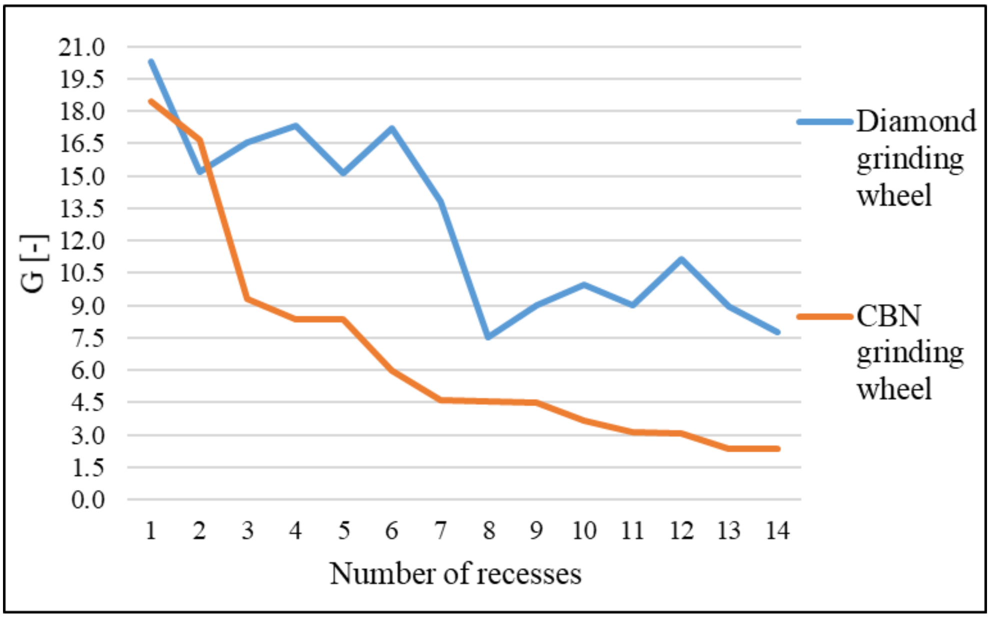

Figure 5 *Grinding ratio of diamond wheel and CBN wheel*

Figure 7 shows the dependence of the diameter of the recesses after machining and the number of operations on one bar. Rods 1 and 2 were ground using a CBN grinding wheel. Rods 3 and 4 were ground using a diamond grinding wheel. The theory is that the diameter of the bar should increase owing to the reduction in the diameter of the grinding wheel. In all cases, it is clear that the diameter of the blank varies according to the assumptions of the theory. That means that the diameter gradually increases by a few thousandths of a millimeter between the individual recesses with an increasing number of grinding operations. The grain size of the grinding wheel also has a significant effect on the diameter of the bars, since larger grain size produces higher roughness on the machined surface. Grain size has a significant effect on the material removal rate. The grain size also has a significant effect on the material removal process for CNB grinding wheels [13].

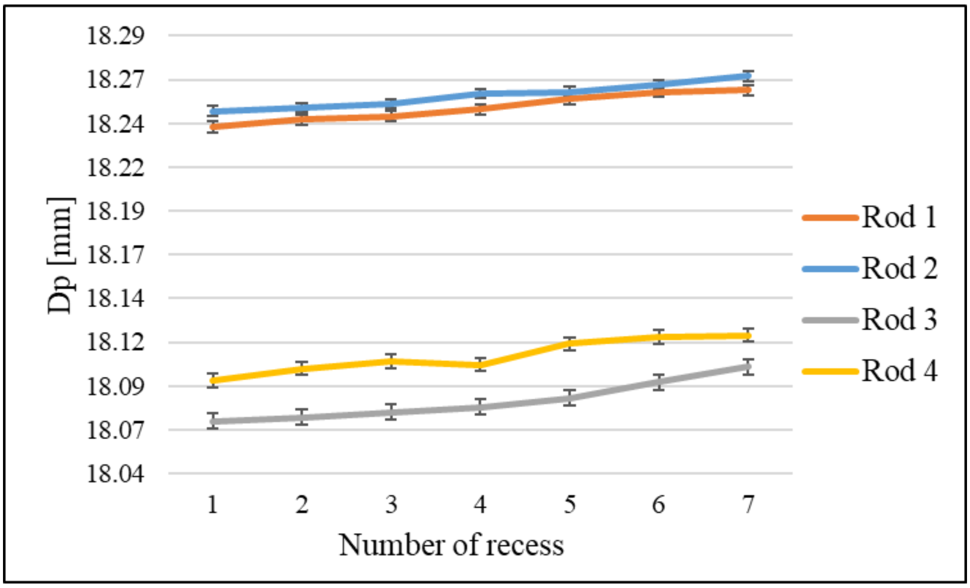

Figure 6 *Diameter of recesses after machining*

Figure 8 shows the change in the diameter of the grinding wheel. The diameter of the grinding wheel was measured after each recess. It is clear from the graph that the diameter of the CBN grinding wheel decreases as expected. It can be said that the diameter of the wheel decreases almost evenly during the grinding process. From a material removal viewpoint, the most important characteristics of the wheel surface topography are the cutting edge distribution and their parameters, such as size, concentration, and type of binder [17, 18]. The wear of the grinding wheel does not change in a certain interval and remains unchanged between two grindings; then the diameter drops sharply. The diameter of the diamond grinding wheel varies by only a few thousandths of millimetres between individual grinding operations. It is interesting that the diameter of the disk not only decreased, but also increased during the measurements. This anomaly can be due to the measurement inaccuracy or clogging of the wheel. The change in diameter is then also reflected in the calculation of the grinding ratio.

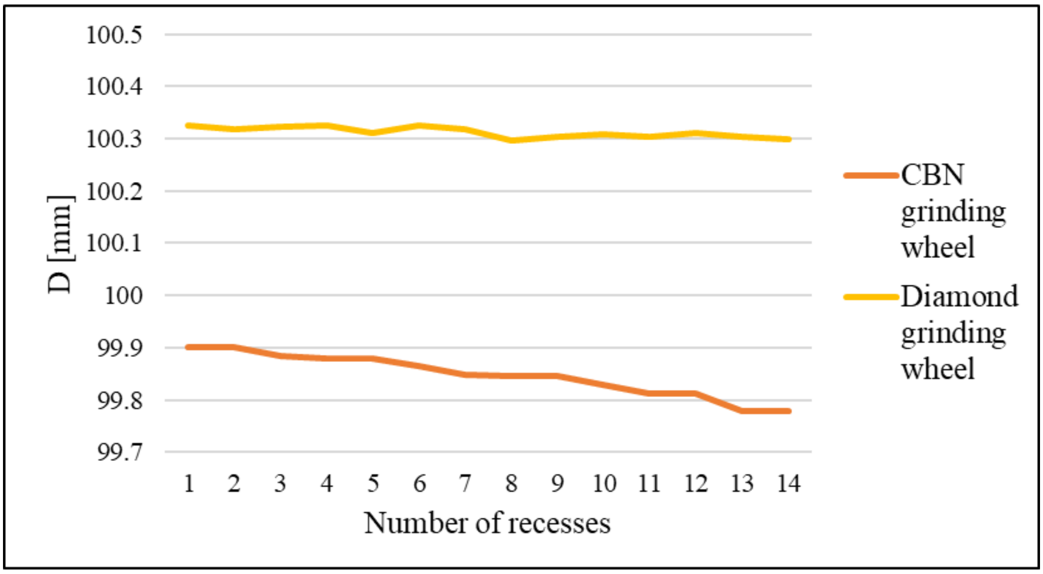

Figure 7 *The diameter of grinding wheels as a function of the number of recesses*

CONCLUSION

The article presents the use of grinding wheels made of various materials in the machining of cemented carbide materials. The grinding ratio, the diameter of the grinding wheel, and the diameter of the recess were observed during the experiment. Grinding operations were performed on the WZS 60 Reinecker grinding machine. NUMROTOplus software was used to design the NC code for the grinding machine. The diameter of the grinding wheel and diameter of recesses were checked on the ZOLLER Genius 3s optical measuring machine. The diameter of recesses was measured at three measurement points. It was found that the grinding ratio decreases with both grinding wheels. The grinding ratio decreased faster when using a CBN grinding wheel. That means that the grinding wheel can remove more material, depending on the type of abrasive. It was confirmed that, with an increasing number of grinding operations and with decreasing diameter of the grinding wheel, the diameter of the recesses after machining increases. The diameter of a cubic boron nitride grinding wheel decreases several times faster than the diameter of a diamond wheel. So, it can be stated that a diamond grinding wheel is more suitable for machining the sintered carbide, since it achieved better values than a CBN grinding wheel for all monitored parameters. The grain size of the grinding wheel also has a significant effect on the amount of the material removed and the surface roughness [13, 14]. Figure 7 for bars 1 and 2 shows grinding inaccuracy. The rods were ground using a CNB grinding wheel. The recesses produced should have a diameter of 18 mm. The deviation of the measured diameters was more than 0.2 mm. Since the Zoller Genius measuring instrument can measure with an accuracy of up to 0.001 mm, it is assumed that the grinding wheel in the

Reinecker WZS 60 tool grinder was measured incorrectly. In this way, an inaccuracy was introduced into the experiment. However, the course of the grinding ratio decreases as expected. In the future, a weighting method will be used to determine the grinding ratio. Using this method, it would be possible to determine whether the increase in diameters of the diamond grinding wheel was due to the subsequent expansion or clogging of the wheel.

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