MEASUREMENT OF THE GEOMETRY OF MANUFACTURED DRILLS USING OPTICAL SCANNING

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This article deals with the control of the geometry of manufactured tools. The geometry of the cutting tool has a great influence on the machining process. One of the processes of manufacturing cutting tools is grinding. Grinding cutting tools is a complex process after which it is necessary to check the geometry of the tools. Five solid drilling tools were manufactured for the experiment. The measured parameters were tool diameter, helix angle, point angle, rake angle, relief angle and core diameter of the cutting tools. The geometry of the cutting tools was measured on a non-contact structured 3D scanner ATOS Triple Scan light. The measurement results were evaluated using GOM software. The scanning results were compared with the geometry measurement on an optical measuring device Zoller Genius 3s. It has been found that the use of a non-contact structured 3D scanner is suitable for checking the geometry of cutting tools. Furthermore, the article deals with the roughness arising when grinding a sintered carbide flute.

KEYWORDS

tool geometry, 3D scanner, drilling tool, non-contact scanning, grinding, roughness surface

1 INTRODUCTION

Optical or laser measurement systems (3D scanners) are increasingly used today with the quality control of parts. The advantages of using an optical 3D scanner include fast measurements of complex components. Using a 3D scanner, the part to be inspected is first digitized and a real inspection is performed on the obtained virtual model. Scanning accuracy depends on calibration of the device, exposure time, measurement volume, number of scans, angle of scanner, heat up process of the scanner, camera shutter and quality of reference points. Scanning is used in the medical industry, in the design of prototypes, biomedicine, measurement and inspection of manufactured parts, art, automotive, etc.

[Sandak 2011] in their research focused on novel optical instruments such as laser micrometer and triangulation scanner in scrutinizing of tool wear and scanning of the cutting tool geometry. Basing on the results presented in the research authors can say, that the most reliable method of all presented here seems to be shadow triangulation. However, laser micrometer might be the most suitable for inline application.

[Peterka 2013a] concentrated on 3D scanning process of chosen individual tool objects. The problems that occurred during 3D digitizing of individual parts are step by step discussed and solved. This research deals with 3D scanning of ball nose end mills and screw drill. The article gives a procedure for digitizing and comparing the results of the scanned digital models of the two ball nose end mills and screw drill.

[Hawryluk 2020] investigated problems related to the use of optical 3D scanning techniques and their support by means of replication methods for the analysis of the geometrical changes in deep tool impressions used for the forward extrusion of valve-type elements assigned for motor truck engines. Authors investigated, that for the analyzed tool, the maximum angle during direct scanning was 40 degrees, which unfortunately does not enable an analysis of the entire pattern, while for larger angles, it is necessary to make the measurement by indirect scanning, i.e., by replicating the cavity imprint of the tool. Therefore, for a given geometry, the reflection angle should be determined individually.

[Li 2020] focused on proposes of rapid prediction method for the tool point FRF based on RCSA. The method divides the spindle-holder-tool system into two parts: the spindle-holder-partial shank and the remaining tool. In this basis, this study proposes a method of accurately establishing the model of the remaining tool with a 3D scanner and improves the calculation method of the rotational FRF of the spindle-holder-partial shank assembly through the reverse RCSA and finite difference method directly through the modal impact testing on the cutting tool. Authors provides the experiments on a vertical machining center and compares the predicted FRF and the measured FRF on the tool point. The result indicates that the predicted FRF curve is consistent with the measured FRF curve with the relative error of natural frequency within 4.0%.

[Thakre 2019] present in their research a development of machine vision system for the direct measurement of flank wear of carbide cutting tool inserts. This system consists of a digital camera to capture the tool wear image, a good light source to illuminate the tool, and a computer for image processing. The vision system extracts tool wear parameters such as average tool wear area, wear width and tool wear perimeter. The results of the average tool wear width obtained from the vision system are experimentally validated with those obtained from the digital microscope. An average error of 3% was found for measurements of all 12 carbide inserts.

[Alabdullah 2016] investigated tool wear and geometry response when machinability tests were applied under milling operations on the Super Austenitic Stainless Steel alloy AL-6XN. Authors used in the experiment two cutting speeds, two feed rates, and two depths of cuts. Cutting edge profile measurements were performed to reveal response of cutting-edge geometry to the cutting parameters and wear. For inspection of the cutting edges authors used a scanning electron microscope (SEM). Results showed the presence of various types of wear such as adhesion wear and abrasion wear on the tool rake and flank faces.

[Vagovsky 2015] concentrated on deals with the possibility of measuring a small object, namely hard metal rod which is a semi product for cutting tool, e.g. end mill. The research was the evaluation of the measuring capability of the GOM ATOS Triple Scan II optical 3D scanner when measuring the dimensions, i.e. tool diameter, with using of different measuring volumes. Measuring of a small object is often difficult due to ensuring the measuring repeatability and low bias. Capability evaluation was performed using statistical methods, namely indices which define the measuring device capability. The work contributed to the practical knowledge about abilities of ATOS optical 3D scanner in reverse engineering and measuring processes, and to the determination of its measuring capability.

[Morovic 2013] deals with utilization of active triangulation method for shape investigation of cutting inserts after wear.

For measuring of cutting insert shape a method using the structured light (fringe projection/strips of light) was used. As a measuring device the optical 3D scanner GOM ATOS II Triple Scan SO was used. Cutting inserts with different shapes was measured. From the 3D model moreover, it is possible to measure the geometrical properties as well as tool wear, plastic deformation, build-up-edge, corner damage and chipping of cutting insert.

[Mendricky 2011] discussed the design of a device for automated scanning of people and large objects. The result was a device that allows automated digitization of objects up to a height of two meters. [Mendricky 2018] conducted research finding how may the surrounding conditions and parameters of digitization process affect the dimensional and shape accuracy of optical 3D measurement. Calibration, exposure, number of images, quality used, scanning angle and reference points were assessed. The measurement was performed on an ATOS optical 3D scanner using GOM software.

Cemented carbide is a very tough composite material, which is used as a wear resistant material for manufacturing cutting tools. Cemented carbides are used in the cutting tool industry due to their excellent mechanical properties at high temperature, such as high stability, high strength, corrosion resistance and hardness. Cutting tools are typically created using grinding. The grinding of cemented carbide is very problematic due to the high level of hardening carbide components within. Grinding of cemented carbide tools using diamond grinding wheels is well known as the primary process used to achieve a specific tool geometry with the small tolerances prescribed by its design [Yang 2014].

The quality of the cutting edge depends mainly on the process of grinding the flute and subsequent grinding on the sides using shaped grinding wheels. The tool grinding process has a significant impact on tool performance, and therefore a balance needs to be struck between the target tool life and tool grinding productivity [Uhlmann 2011].

[Abdullah 2007] dealt with wear of the grinding wheel and surface roughness of the workpiece when grinding tungsten carbide with a 20% cobalt binder using a diamond wheel with a nickel-plated resin coating. Attempts to show that wheel wear increase and surface roughness decrease thus increase feed rate, on the other hand wheel wear and surface roughness decrease thus increase wheel speed.

[Biermann 2009] investigated the grinding of silicon nitride and cemented carbide materials with diamond grinding wheels. In the experiments, four different types of diamond grinding wheels were used in face grinding processes. Diagonal grinding wheels vary according to grain size, grain concentration and bonding material. During grinding, the components of grinding forces and the surface quality of ground workpieces were monitored. It has been observed that the resulting surface roughness and the cutting force component are significantly affected by the coolant. The use of a non-water based coolant has a positive effect on achieving a lower value of abrasive forces, especially in connection with a lower value of surface roughness.

The aim of this article is to use optical scanning to measure and control the geometry of manufactured tools. The geometry of the cutting tools was measured on a non-contact structured 3D scanner ATOS Triple Scan light. The measured values were compared with the values obtained with a Zoller Genius 3s measuring device.

2 MATERIALS AND METHODS

2.1 *Machining of cutting tools*

The required geometry of a cutting tool is obtained using grinding process. CNC grinders are used to produce solid cutting tools. CNC machining centers using a rotary grinding wheel, which achieves the required material removal on the workpiece. The shape of the material removed from the blank corresponds to the shape of the surface of the package, which is the result of the relative movement between the grinding wheel and the workpiece [Karpuschewski 2011]. Grinding machine WZS 60 Reinecker by company ULMER WERKZEUGSCHLEIFTECHNIK was used for manufacturing solid cemented carbide drills. Peripheral grinding wheel from synthetic diamond by the producer URDIAMANT Slovakia s.r.o. was used to manufacture the tools. Grain size of grinding wheel was D64 by ISO 6106. The geometric shape and dimensions of the grinding wheel are standardized. Each grinding wheel contains data about the given wheel. The production of the tool consists of four grinding operations. One grinding wheel marked 1A1 was used to produce all tools. Tab. 1 shows basic properties grinding wheel.

Grain size	D 64
Application	For medium grinding, cutting tools sharpening
Surface roughness Ra [µm]	0.4
Type of bond	Resinoid
Abrasive concentration	K 100
Amount of abrasive [g.cm^{-3}]	0.88
Cooling	Yes

Table 1. Basic properties grinding wheel [Urdiamant 2007]

Software NUMROTOplus by company NUM was used to create NC code for grinding machine. All grinding operations can be simulated on the PC using the 2D and 3D simulation. The tool can be cut in a desired position so that the subsequent cross-section can be measured and evaluated. Software NUMROTOplus allows to export a cutting tool model in STL format. This model was used as a nominal model in the evaluation of manufactured tools in GOM software. Fig. 1 shows geometry drilling tool in software NUMROTOplus (Peterka 2020). Tab. 2 shows setting basic geometric of the cutting tools in software NUMROTOplus.

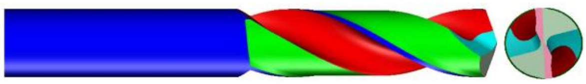

Figure 1 geometry drilling tool in software NUMROTOplus

Table 2 The setting basic geometric of the cutting tools in software NUMROTOplus

	Nominal tool
Tool diameter [mm]	10
Core diameter [mm]	3
Rake angle [°]	9
Relief angle [°]	6
Point angle [°]	140
Helix angle [°]	30

Sintered carbide bars with grade of CTS20D by the Ceratizit Company (K20-K40 by ISO) were used to produce cutting tools. This cemented carbide material with content of Co of 10% The round bar had dimensions Ø10h6 x 73 mm. The properties of cemented carbide are shown in Tab. 3. This material is used to produce high-performance tools for machining hard-to-machine materials.

Table 3 Basic properties cutting material [Ceratizit 2019]

Density [g.cm^{-3}]	14.1
Binder [m %]	12
Hardness HRA	91.7
Transverse rupture strength [MPa]	4000

2.2 *Scanning the geometry of cutting tools*

The measurement of geometric parameters of the drills was performed by the 3D scanning process using the ATOS Triple Scan II optical scanner. The measuring systems work non-contact by using structured blue light. 3D scanner is a device serving for the conversion of a real object into digital form. During the process of sensing, the scanner collects information about the dimensions and shape of the scanned object [Toth 2014]. The information obtained can be used to create a digital three-dimensional model of the scanned object, most often into *.STL due to the universality of its use. This involves a surface triangle mesh. The ATOS Triple Scan II is equipped with several different projector and camera lenses setups that enable scanning to be performed inside different measuring volumes. Scanning accuracy decreases with increasing measurement volume. However, a larger measurement volume speeds up the scanning of large objects by reducing the number of subsequent scans required [Brajlih 2011]. The scanning of the drills took place at a measuring volume of MV100 (100 x 75 x 70) [Vagovsky 2015]. The tool models were measured in software GOM Inspect.

The individual cutting tools were sprayed with titanium powder using a pneumatic pump. By using titanium powder, the cutting tools get a matte surface. It is necessary to use a small layer of titanium powder. The application of titanium powder did not affect the measurement results. The average thickness of the titanium powder is 5 µm [Palousek 2015]. The drilling tool was clamped in a three-jaw chuck. A fixture was attached to the chuck to which reference points were applied. The reference points are used to connect the individual measurement images and at the same time increase their accuracy. The application of titanium powder did not affect the measurement results.

ATOS scanner runs with GOM ATOS Professional V7.5 software. The normal exposition time, the resolution as well as high quality of the scan, were adjusted. Scanning was performed on a rotary table. Position, angle, and number of rotations of chuck with clamped tool were set. The tool was scanned in three positions due to the complex shape of the tool. Fig. 2 shown two scanning positions. The number of recorded images per table rotation was set to 36. Subsequently, digitizing was performed. Scanning obtains a cloud of points that represent the surface of the scanned object. Polygonization of a point cloud creates a surface that consists of polygons. The next step was to remove redundant scanned elements and objects such as chuck and fixture. As a result, from these steps the digital model of drilling tool in the *.STL format was exported. The measurement was performed with the measuring software GOM Inspect.

Figure 2 Cutting tool scanning position

3 RESULTS AND DISCUSSION

3.1 Measuring the geometry of scanned cutting tools using GOM software

The results of the geometric measurement of the object and the subsequent comparison with the nominal model (STL model from software NUMROTOplus) were evaluated using the program GOM Inspect. Software is designed for the analysis of 3D measured data of l aser scanners, coordinate measuring machines, and other measuring systems. Scans of cutting tools was used as the actual model. At first, both models must be aligned to the same position using the "Prealignment" function. Using the colour deviation map, it is possible to compare the nominal model with the actual model. Fig. 3 shows a colour map of deviations. The largest deviations were observed in body clearance. Maximum deviation values were observed around 0.15 mm.

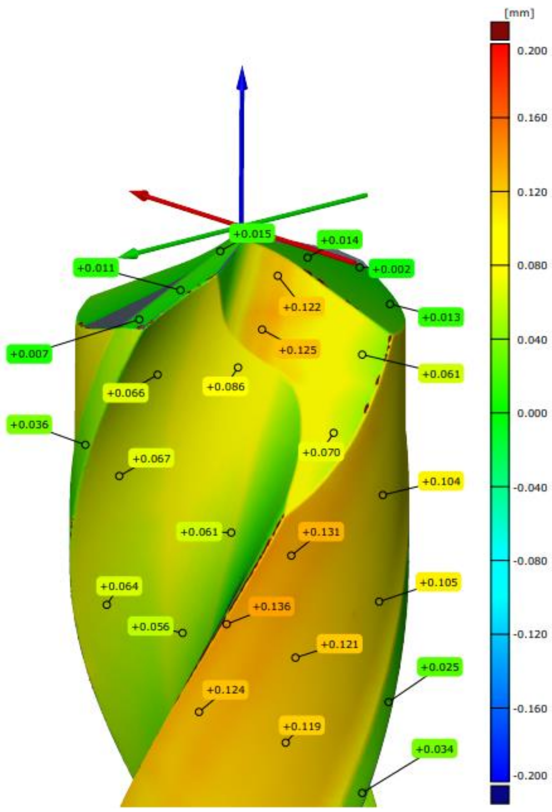

Figure 3 The colour map of deviations

The tool diameter, rake angle, and core diameter were measured on the circumference of the cutting tool. First, it was necessary to create a cross section of the cutting tool. The core diameter and the diameter of the tool were measured using circles created by the "3-point circle" function. The diameters were created individually on the nominal and actual model to compare the measured values. Using the "Link to Actual Element" function, the individual entities on the nominal and actual model were linked. Fig. 4 shows measurement core diameter and tool diameter. Each measurement shows the nominal and actual values of the measured parameters and the deviation between the parameters.

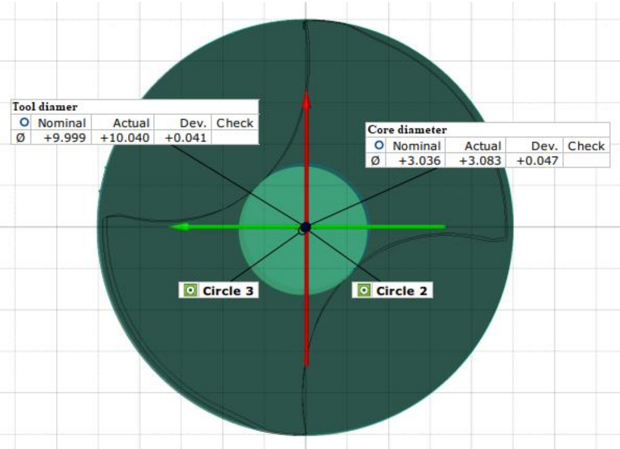

Figure 4 Measurement core diameter and tool diameter

Furthermore, the rake angle and the margin width were measured on the circumference of the tool. The measurement of geometric parameters was done individually on the nominal (blue) and actual model (green). Subsequently, these values were compared. Fig. 5 shows measurement rake angle and margin width on the circumference of the cutting tool. To measure the rake angle, a line was created that had a direction in the - X axis. Another line was created at the rake angle. Using the "2-Direction Angle" function, the created lines were selected and then the angle between them was measured.

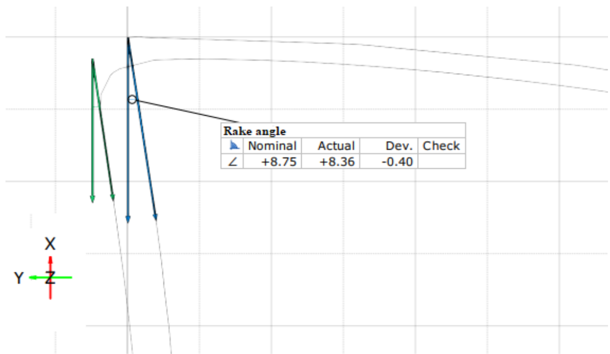

Figure 5 Measurement rake angle on the circumference of the cutting tool

The relief angle was measured at the face of the tool. As in previous case, auxiliary lines were created between which the angle was measured. An auxiliary line has been created in the direction of the + X axis. Fig. 6 shows measurement relief angle on the face of tool.

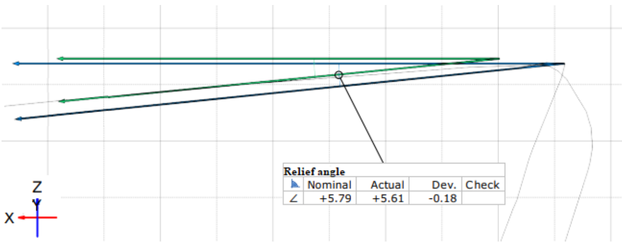

Figure 6 Measurement relief angle on the face of tool

To measure the point angle, a cross section was created in the YZ plane. However, it was not necessary to create an auxiliary line. The largest deviations were observed in the point angle. Fig. 7 shows measurement point angle.

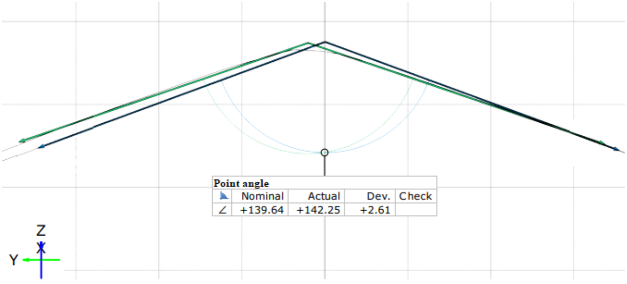

Figure 7 Measuring point angle

To measure the angle of the helix, another cross section of the tool was created, which was 30 millimeters apart. An auxiliary line was created and was oriented in the + Z direction. Fig. 8 shows measurement helix angle.

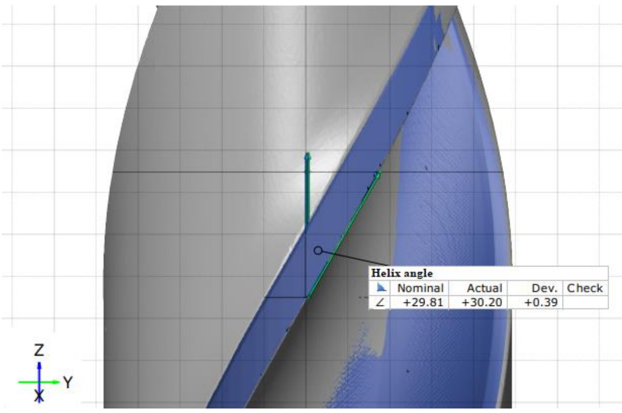

Figure 8 Measurement of helix angle

Such a procedure for measuring geometric parameters was performed on each cutting tool. The nominal model was the same for all measurements.

3.2 *Measuring the geometry of cutting tools by* ZOLLER Genius 3s measuring device

Another approach to checking the geometry of the cutting tool was to use a ZOLLER Genius 3s measuring device. ZOLLER Genius 3s measuring machine was used to measure macro geometry of tool. It is controlled by optical measuring software Pilot 3.0. The measuring was carried out at the Centre of Excellence of Five-Axis Machining at the Faculty of Materials Science and Technology in Trnava, Slovak University of Technology in Bratislava. ZOLLER Genius 3s® is measuring machine for checking and measuring all kinds of cutting tools. Measuring machine is equipped with CNC-driven, adjustable 3D CCD camera and LED lighting. Fig. 9 shown ZOLLER Genius 3s measuring machine. Such a procedure for measuring geometric parameters was performed on each cutting tool. The nominal model was the same for all measurements. Pätoprsty *et al.*, 2019 used ZOLLER Genius 3s measuring machine for measurement of macro geometry of grinded solid cemented carbide mills.

Figure 9 Measurement of cutting geometry on Device Zoller Genius 3s

3.3 Comparison of measured geometric parameters

In this experiment, the macro geometry of the drills was observed. The results of the two measurement methods were compared. The first measurement was performed using a non-contact structured 3D scanner ATOS Triple Scan light. The second measurement was performed on a ZOLLER Genius 3s measuring device. From Fig. 10, 11 and 12 can be seen the comparison of measured parameters.

Fig. 10 shows a comparison of the measured diameter and the tool core. The table shows that the differences in the measured parameters ranged from 5 hundredths of a millimeter. It follows that the application of titanium powder did not have a significant effect on the measurement of these parameters.

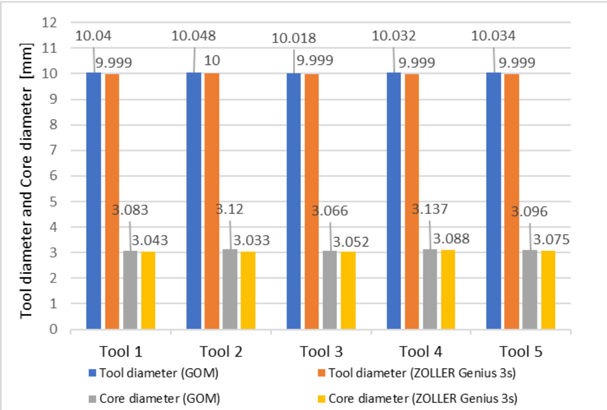

Figure 10 Comparison of parameters tool diameter and core diameter

Fig. 11 shows a comparison of parameters rake angle and relief angle. It was found that the values of the measured rake angles obtained by scanning are lower. The deviation in the measurement of the forehead angle could be caused by the application of titanium powder. When measuring such small areas, it is necessary to use the smallest possible measuring volume (MV). The MV100 measurement volume was used in this experiment, but the ATOS Triple Scan light scanner is able to scan with a smaller measurement volume. The use of a smaller measuring volume would result in sharper edges of the cutting tool. The deviation between the measured angles was in the range of six tenths of a millimeter. The largest difference in values when measuring relief angle was observed on tool 4.

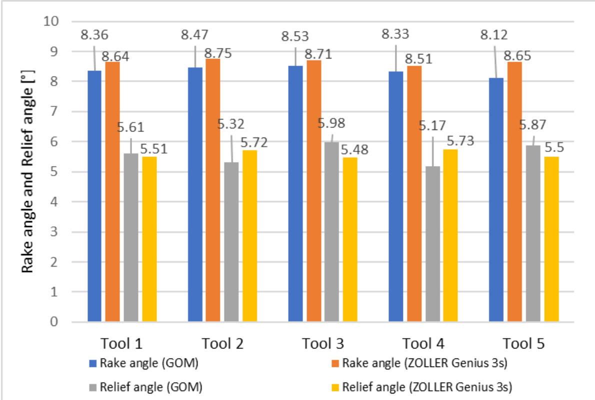

Figure 11 Comparison of parameters rake angle and relief angle

Fig. 11 shows a comparison of measured parameters point angle and helix angle. When measuring the point angle, the largest deviation was observed between the individual measurement methods. This can be caused by the alignment of individual models. By using the "Local Best Fit" function, it would be possible to align the tool, which would mainly depend on the selected part of the actual model. However, the use of this function could affect other measured parameters. When measuring the helix angle, the smallest deviations between the measurement methods.

The most significant differences were observed for point angle. It can be caused by the alignment of individual models. When comparing the rake angle and the relief angle, small deviations were observed, but not greater than 1 °.

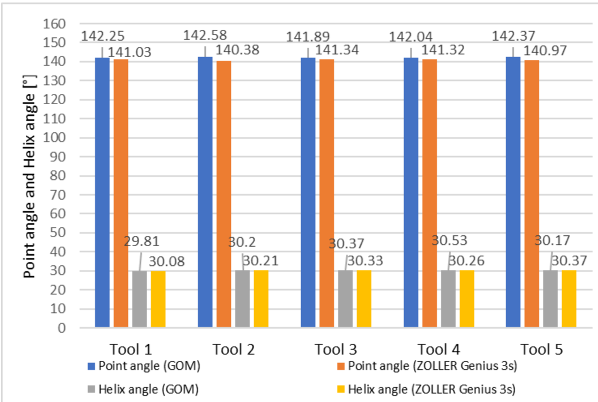

Figure 2 Comparison of parameters point angle and helix angle

3.4 Roughness of machined flutes

Cutting tools are one element of the MTWC (Machine-Tool-Workpiece-Clamp) technological system. Different machining technologies such as turning, milling, drilling, broaching [Kolesnyk 2020, Sentyakov 2020, Peterka 2013b, Vopat 2014] place different requirements on the quality of the cutting tool. Geometric properties (dimensions, angles, radius after rectification etc.) are usually considered. From the point of view of cutting theory, the surface roughness of the cutting tools itself is also important.

The roughness of the treated surface depends on the grinding conditions, the type of binder, the grain size of the sintered carbide and the grinding wheel [Habrat 2016]. Two voids were used for the experiment and six flutes were created for each. NUMROTOplus software was used to create the NC code. Fig. 13 shows the geometry of glutes in NUMROTOplus.

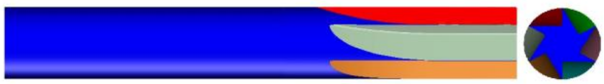

Figure 3 Geometry of flutes in software NUMROTOplus

The blanks with the same properties as in the production of drills were used. The experiment was performed on a WZS 60 Reinecker tool grinder using said 1A1 grinding wheel with spindle rotation speed 3634 min^{-1}. During the production of the flutes, the feed of the grinding wheel was changed. One grinding wheel was used to produce all the flutes. Tab. 1 shows measured value of roughness. The surface structure is responsible for the mechanical function of the component as well as the fatigue strength. With increasing surface roughness, the influence of micro geometric notches on fatigue strength is becoming increasingly important.

After grinding, surface roughness analysis was performed. The surface profilometer used to measure surface roughness after the grinding process was a Mitutoyo Surftest SJ-210. For each sample, the measured length was maintained at 3 mm. Tab. 4 shows the measured roughness values on the produced flutes. Three measurements were performed on each flute produced.

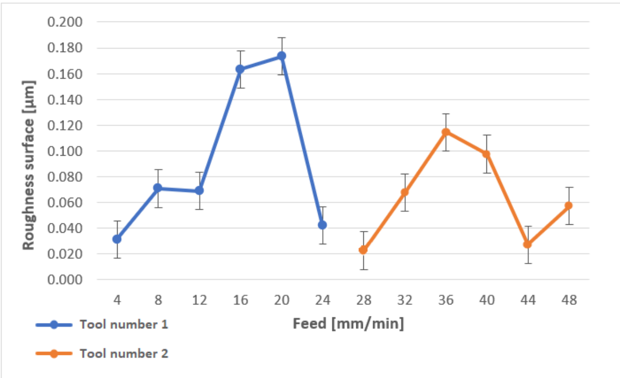

Figure 14 The measured value of roughness

Fig. 14 shows the course of the dependence of the roughness (Ra), of the new ground surface, on the feed rate vf. For tool number 1, the dependence for the feedrate is from 4 mm/min to 24 mm/min. For tool number 2 from a feed rate of 28 mm/min to 48 mm/min.

From the graph in Fig. 14 it can be stated that at the higher feed rates vf used in the production of tool number 2, a better roughness of the machined surface of the produced grooves was achieved. As the speed of the vf shift increased, the surface roughness also increased.

4 CONCLUSIONS

The aim of the paper was to check the geometry of manufactured tools using a non-contact structured 3D scanner ATOS Triple Scan light. The tools were made using a CNC grinding machine. Five drills were produced for the experiment. GOM software was used to measure the geometry of the scanned tools. The cutting tool model designed in the NUMROTOplus software was used as the nominal model. NUMROTOplus software was also used to generate NC code to produce cutting tools. The measured parameters were tool diameter, helix angle, point angle, rake angle, relief angle and core diameter of the cutting tools. The monitored geometric parameters were also measured using a ZOLLER Genius 3s measuring device. The following facts were found:

- A good correlation was found between the values measured using the GOM software and the ZOLLER Genius 3s measuring device. The most significant differences were observed for point angle. It can be caused by the alignment of individual models.
- When comparing the rake angle and the relief angle, small deviations were observed, but not greater than 1°.
- When comparing the tool diameter and the core diameter, the deviations were the smallest.
- During the production of grooves, it was found, that with increasing feed rate vf and with each additional groove produced, the surface roughness of these grooves deteriorated.

It can be said that scanning tools are a suitable method for measuring their geometry. Future work will focus on the use of optical geometry for measuring under different grinding conditions depending on the geometry achieved.

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