Surface Quality Analysis of Cutting Tool Microgeometry to Achieve Higher Durability

Ondřej Hronek, Miroslav Zetek, Tomáš Baksa, Pavel Adámek
Laboratory of Experimental Machining, Regional Technological Institute, Univerzitni 8, 306 14 Pilsen, Czech Republic, E-mail: hroneko@rti.zcu.cz, mzetek@rti.zcu.cz, baksa@rti.zcu.cz, adamek@rti.zcu.cz

Mapping surface quality changes during modification of the cutting tool microgeometry and reflecting on overall quality is the main purpose of this article. A complex view of microgeometry brings together the effects of indvidual stages in the processes which increase the cutting tool properties. The main objective is to increase the durability of the cutting tool. Grinding, microgeometry modification and deposition of a thin resistant layer on the cutting tool are the basic stages during the experiment. These stages have a significant effect on microgeometry parameters. Cutting edge radius, cutting edge symmetry (K factor), roughness of chipping and clearance surfaces are parameters affected by modification processes. Changing individual microgeometry parameters determines not only the surface quality of the cutting tool, but also affects the durability and stability of the cuting process. Appropriate microgeometry modification can make the cutting process more efficient. The combination of process stages and their influence on the quality of the microgeometry of the cutting tool is the primary objective in this article.

Keywords: Cutting Edge Modification, Cutting Edge Microgeometry, Surface Quality, Cutting Tool Surface

1 Introduction

1.1 Motivation

Chips are formed during the cutting process, which leads to wear on the cutting tool. Elastic and plastic deformations, thermal and force load at the cutting area are the main reasons for cutting tool wear. The cutting tool geometry affects the size and direction of the mechanical and thermal loads. [1, 2, 3, 4] The cutting tool microgeometry is one of the two subgroups into which the geometry is divided. Currently, the behaviour of the cutting process can be affected by modifying the cutting edge. This is essentially extends the lifetime by achieving lower cutting tool wear and thus machining a higher number of workpieces.

1.2 Modification of cutting tool microgeometry

Cutting tool geometry is divided into macro and microgeometry. Macrogeometry is characterized by the size of the chip and flank angle, the width and shape of the facet and the type of die. Overall, these are shapes and dimensions that are mostly achieved by grinding. However, in 1897 it was found that the cutting edge of a cutting tool is not ideally sharp. During the 20th century, the effect of cutting tool microgeometry on the cutting process was investigated. [5] Cutting tool microgeometry is characterized by the cutting edge radius. This is the radius at the critical point on the cutting tool and is the connection between the chipping and flank surface. Cutting edge radius, labelled r_n, is also created by grinding. The value of the cutting edge radius is about 2 – 3 microns after grinding.

A cutting edge with a radius of about 2 µm can be characterized as a stress concentrator. A cutting edge with a small radius has a higher tendency to create fatigue cracks. In combination with the properties of sintered carbides, which include higher hardness but lower toughness (compared to high speed steel tools), creation of fatigue cracks requires less energy. [6, 7] Modification of the microgeometry – to make the cutting edge more rounded, reduces the high stress concentration on the tip of the cutting edge. Increasing the adhesion for thin layer deposition on the cutting tool is another reason for cutting edge modification. By using the appropriate process parameters for the modification, the surface quality of the cutting tool chipping and flank faces can be also improved. The behaviour and shape of the cutting tool wear is also influenced by proper cutting tool modifications. Furthermore, the cutting edge radius influences the plastic deformation in the area of chip formation, thus affecting the size of the cutting forces and formation of BUE. [8]

Currently, there are many technologies that are used for cutting edge modification. Firstly, it is necessary to select the appropriate technology for the cutting tool. For example, turning inserts are modified by brushing. Reason for brushing is process efficiency of modification. The economic advantages of the technologies are another important factor for appropriate selection. Last but not least, accuracy and repeatability of the cutting edge radius on the cutting tool are also important factors. For drilling and milling monolithic tools the appropriate technology for cutting edge modification is drag finishing. This technology is based on the combination of three rotary movements inside of the process container. Parameters such as cutting edge radius, cutting edge symmetry and surface quality are achieved in a short period of time by selecting the most suitable process medium. An alternative technology for cutting edge modification of drilling and milling tools is wet abrasive jet micromachining. It was proved [9] that during wet abrasive jet micromachining there is an increase in cutting edge toughness and reliability.

2 Description of experiment

The most important factor affecting the final quality of the cutting tool is the selection of the cutting tool material. The relationship between the cutting tool material and the workpiece material needs to be fully understood. Material choice and chemical composition, combined with mechanical properties, affects the cutting tool resistance to wear. For example, a cutting tool for machining difficult to machining Ni alloys (e.g. Inconel 718) requires: high hardness, abrasion resistance, heat resistance, etc. Another important attribute is toughness. It is also necessary to choose the material of the cutting tool, which can be used for finish cuts and also for roughening operations. Sintered carbide is the most used cutting tools, because it meets the above requirements.

***Tab. 1** Composition and properties*

Structure	Grain size	Portion Co ±0.5 %	Hardness HV30	Hardness HRA	Density [g/cm^3]	TRS [N/mm^2]
Submicron	0.7	10.0	1580	91.8	14.35	3600

Twelve cutting tools were ground for the main experiment. The properties of the cutting materials are listed in Tab. 1. All twelve end mill tools with a diameter of 8 mm were ground under the same girnding condition. It was necessary to use the same grinding conditions to avoid the influence of grinding. [10] This makes same input quality and condition of the cutting tools. After grinding, the cutting tool microgeometry was measured on an IFM G4 microscope. The cutting edge radius (r_n) was between 2 – 3 μm after grinding (Fig. 1). The cutting tools were measured at the same location on the cutting edge to allow comparison of the measured values. The cutting edge measurement was always at 2 mm from the tip of the cutting tool. No defects on the cutting edge were recorded during the analysis. At the same time, it is possible to notice the marks on the chipping and flank surface after grinding. These marks primarily affect the roughness parameter Rz.

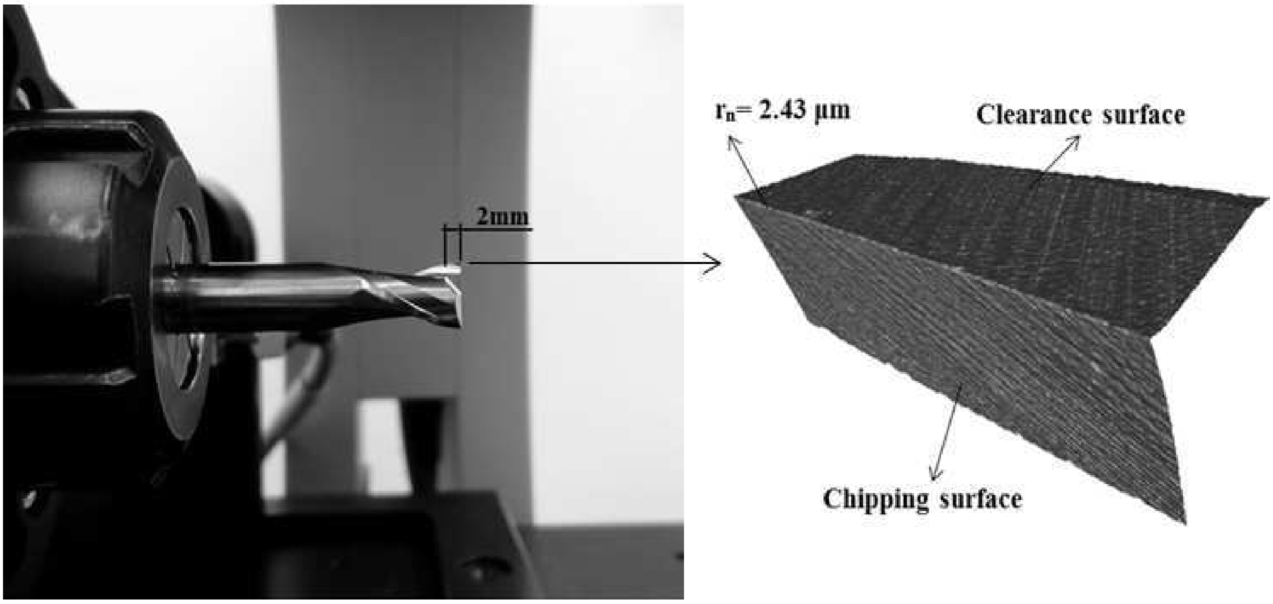

***Fig. 1** Cutting edge microgeometry before modification*

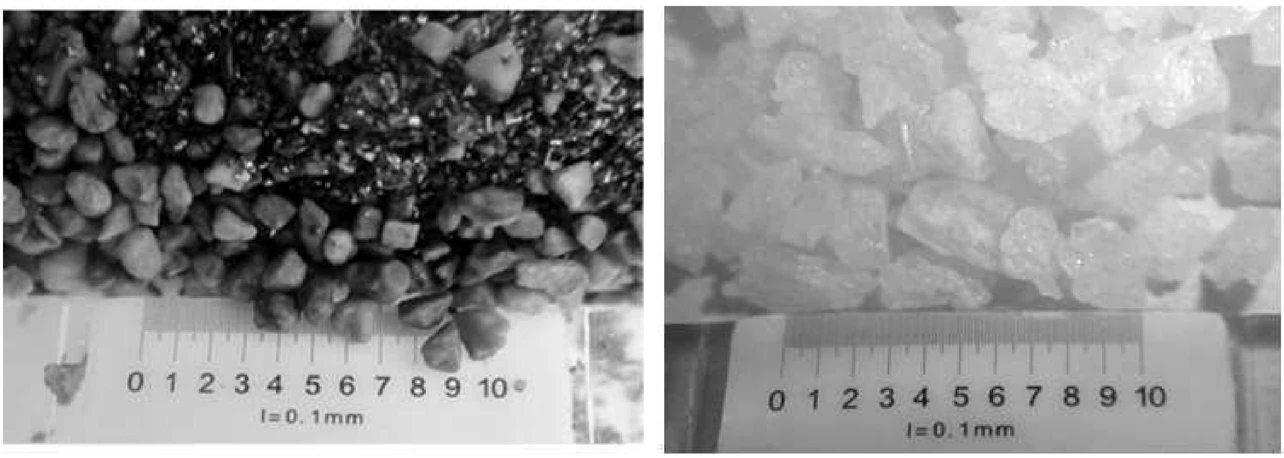

***Fig. 2** HSC 1/300 (a), QZ 1-3W (b)*

Wet abrasive jet machining and drag finishing are used to modify cutting tool microgeometry. As already mentioned, drag finishing is a conventional technology for cutting edge modification of drilling and milling tools.

The process medium has the biggest impact on the final quality and accuracy of the cutting tool microgeometry. The process intensity and duration is affected by the process medium. Currently, there are many types of abrasives, but only some are suitable for modifying cutting tool microgeometry. The grain size and chemical composition influence the choice of the process media. The media used for modifying the microgeometry of sintered carbide tools are walnut shell granulate, white corundum, corn granulate and plastic polishing chips. Two types of media are used in this experiment; walnut shells with SiC (HSC 1/300), and white corundum (QZ 1 – 3W). Fig. 2 shows the grain size of each medium. The biggest difference is in the chemical composition, so a different efficiency of drag finishing is expected.

The process parameters are related to the desired cutting edge radius. The values of the cutting edge radius for the experiment were 15 µm; 20 µm and 25 µm. The choice of process technology for microgeometry modification and the process media had the biggest impact on the process conditions. The following table shows the process conditions. There is a significant time saving between wet abrasive jet micromachining and drag finishing in HSC. However, during water abrasive jet micromachining only one cutting edge is modified. For identical modification of the other cutting edge it is necessary to observe the process parameters. During drag finishing, it is much more time consuming to modify the microgeometry by HSC 1/300, especially if the cutting edge radius > 20 µm. The efficiency of this process medium is reduced above this value. But another medium can be used for r_n > 20 µm, for example QZ 1 – 3W (white corundum).

***Tab. 2** Process parameters for modification*

Wet abrasive jet micromachining					
Tool number	Process time [min]	Jet pressure [MPa]	Jet nozzle distance [mm]	Jet inclination angle [°]	/
1 – r_n= 15 µm	0:30	170	5	0	
2 – r_n= 20 µm	0:50	170	5	0	
3 – r_n= 25 µm	1:20	170	5	0	
4 – r_n= 25 µm	1:20	170	5	0	
Drag finishing – HSC 1/300					
Tool number	Process time [min]	CW [min]	CCW [min]	Rotor speed [rpm]	Holder speed [rpm]
5 – r_n= 15 µm	6:00	3:00	3:00	40/-40	65/-65
6 – r_n= 15 µm	6:00	3:00	3:00	40/-40	65/-65
7 – r_n= 20 µm	15:00	11:00	4:00	40/-40	65/-65
8 – r_n= 25 µm	23:00	17:00	6:00	40/-40	65/-65
Drag finishing – QZ 1-3W					
9 – r_n= 15 µm	0:12	0:09	0:03	35/-35	35/-35
10 – r_n= 15 µm	0:12	0:09	0:03	35/-35	35/-35
11 – r_n= 20 µm	1:00	0:45	0:15	35/-35	35/-35
12 – r_n= 25 µm	1:40	0:60	0:40	35/-35	35/-35

The modified and measured cutting tools were prepared for the next stage, which was increasing the quality of the cutting tool by deposition of a thin layer. TripleCoating Cr was selected . This thin layer is applied to the cutting tool by PVD technology and is very tough as it contains Al, Si, Ti and Cr. [11] Other advantages are high hardness and fire resistance. [12] Therefore it is suitable for hard to machine material such as ISO M, S, H. PVD deposition technology means there is no significant increase in the cutting edge radius, compared to CVD deposition technology. Coated cutting edges were measured after deposition to study the influence on cutting edge microgeometry changes.

The following table shows the values of cutting edge radius modified by water abrasive jet and drag finishing. After deposition all twelve cutting tools had a bigger cutting edge radius. This is caused by deposition of the thin layer. It is reported that the thin layer TripleCoating Cr has a thickness between 2 – 3 µm. The measured differences of cutting edges before and after coating were 1.7 – 3.4 µm.

For obtaining credible values of the cutting edge radius it is necessary to follow several principles. Firstly, it is necessary to perform the measurements on the same cutting edge which is modified. Also it is important to measure at the same distance from the tip of the cutting tool. In this experiment, the cutting edge microgeometry was measured at 2 mm from the cutting tool tip. Last but not least, the correct measurement and evaluation of the cutting edge radius is also necessary. The cutting edge radius is measured in accordance with DIN 6581, DIN 6582, ISO 3002. There are fifty values measured on the cutting edge. The arithmetic average is generated from the values (Tab. 3). Some dependencies can be seen for the cutting edge microgeometry. As the distance decreases from the tip of the cutting tool, the cutting edge radius increases. Increasing immersion depth causes higher pressure between the cutting tool and the process media. By a combination of rotation movements and greater immersion depth, the intensity of drag finishing increases. This effect is evident in the order of tens microns, as shown in the following figure. There is a gradual increase of the cutting edge radius. As has been said, this is caused by higher intensity of the process closer to the cutting tool tip (deeper immersion).

***Tab. 3** Influences of coating on cutting edge radius*

Sample number	Modification technology	r_n before coating[μm]	r_n after coating [μm]	Δr_n [μm]
1	Water jet	15.0	18.0	3.0
2	Water jet	20.8	22.5	1.7
3	Water jet	23.7	26.7	3.0
4	Water jet	24.5	27.9	3.4
5	Drag finishing HSC	14.6	17.6	3.0
6	Drag finishing HSC	14.5	17.4	2.9
7	Drag finishing HSC	19.3	22.4	2.1
8	Drag finishing HSC	24.9	26.9	2.0
9	Drag finishing QZ	15.6	17.9	2.3
10	Drag finishing QZ	15.4	17.7	2.3
11	Drag finishing QZ	21.3	23.4	2.1
12	Drag finishing QZ	24.9	28.3	3.4

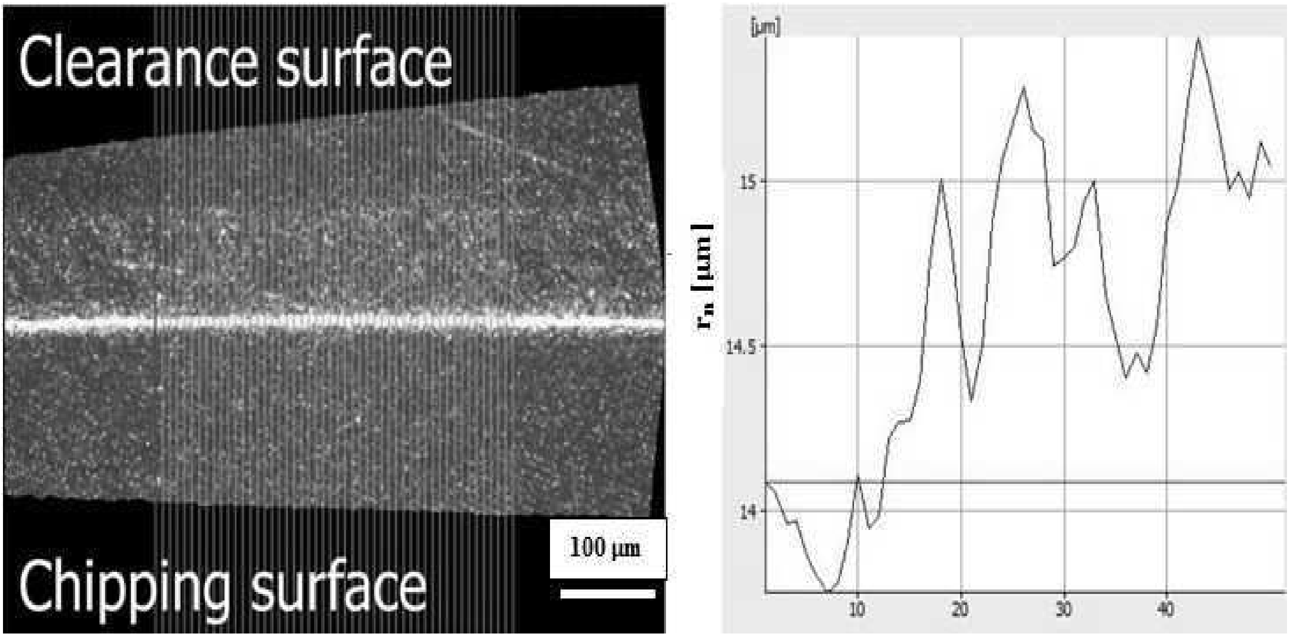

***Fig. 3** Intensity of drag finishing on cutting edge radius – cutting tool 5, r_n= 14.6 μm*

3 Experiment results

The proposed process parameters are primarily intended to achieve a defined cutting edge radius. However, the modification of cutting tool microgeometry should be regarded as a complex modification. The technology and the process parameters influence other factors, including the cutting edge symmetry, roughness on the flank and chipping surfaces etc. In this article, the roughness of the clearance surface and the cutting edge symmetry are investigated for detailed mapping of the cutting tool quality.

3.1 Influences of modification technology on cutting tool microgeometry

The cutting edge symmetry is characterized by factor K. First of all, K factor was investigated after cutting edge modification. K factor ranged from 0.75 to 1.03. Tools 5 and 6 had more unbalanced symmetry (K= 0.75 and 0.77). The direction of the rotation during drag finishing causes a more unbalanced symmetry on cutting tools 5 and 6. Cutting tools which were modified by a longer clockwise time period had a K factor closer to 1 than cutting tools 5 and 6. The deposition process causes an increase of the K factor on 9 cutting tools. Only tool number 4 had a higher K factor than 1. A detailed analysis of this tool is given below.

Cutting tool number 4 was the only tool with a K factor > 1(K= 1.03), therefore a more detailed analysis of the cutting edge condition followed. Measurement of the cutting edge showed that there were two areas with a K factor higher than 1.15. These higher K factors create a higher final arithmetical value (Fig. 4). Defects on the cutting edge are shown in Fig. 5. There are two areas with protrusions. These protrusions affect the cutting edge symmetry and are the reason for the higher K factor.

Fig. 4 *Symmetry of cutting edge*

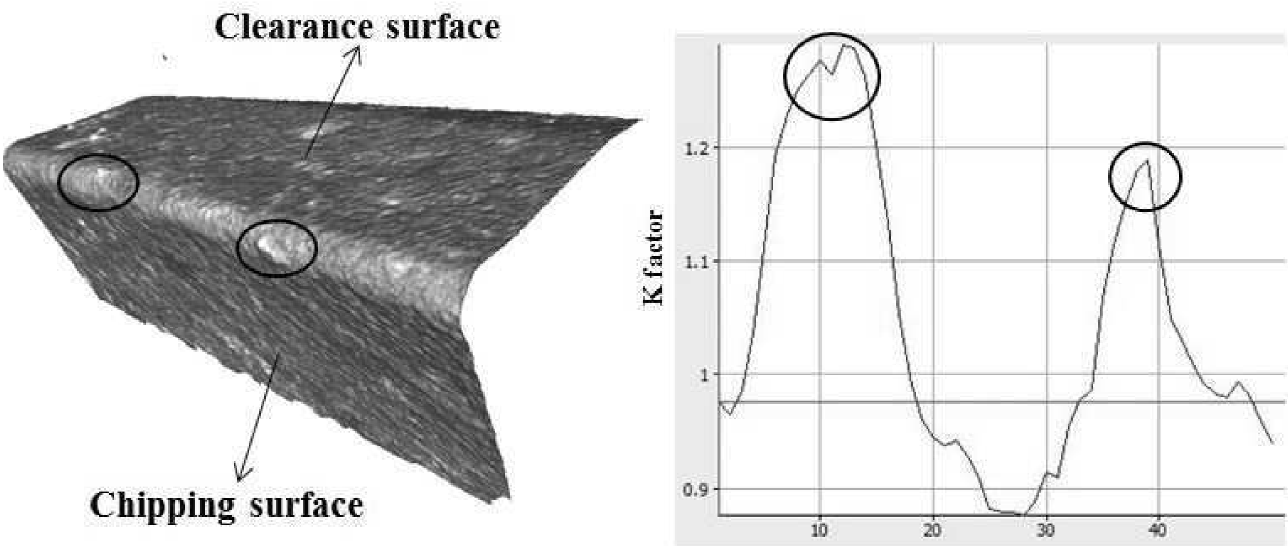

Fig. 5 *Influence of cutting edge defects on K factor evaluation*

3.2 Surface roughness on chipping surface of cutting tools

Cutting tool microgeometry cannot be viewed only as cutting edge radius or the symmetry of the cutting edge. The cutting edge modification involves not just shape change on the cutting edge but also changes to the surface topology. Above all, surface roughness is often investigated to increase the efficiency of the deposition process. The aim is to increase the adhesion between the substrate and the thin layer. Surface roughness on the chipping surface is investigated in this article. Surface roughness was measured before and after coating. This makes it possible to evaluate the effect of microgeometry modification, coating and compare the impact of these processes. Surface roughness was measured in an area of 0.8 x 0.75 mm. Roughness measurements were always amde perpendicular to the marks made by the grinding wheel. The evaluation was carried out over length Lc= 250 μm.

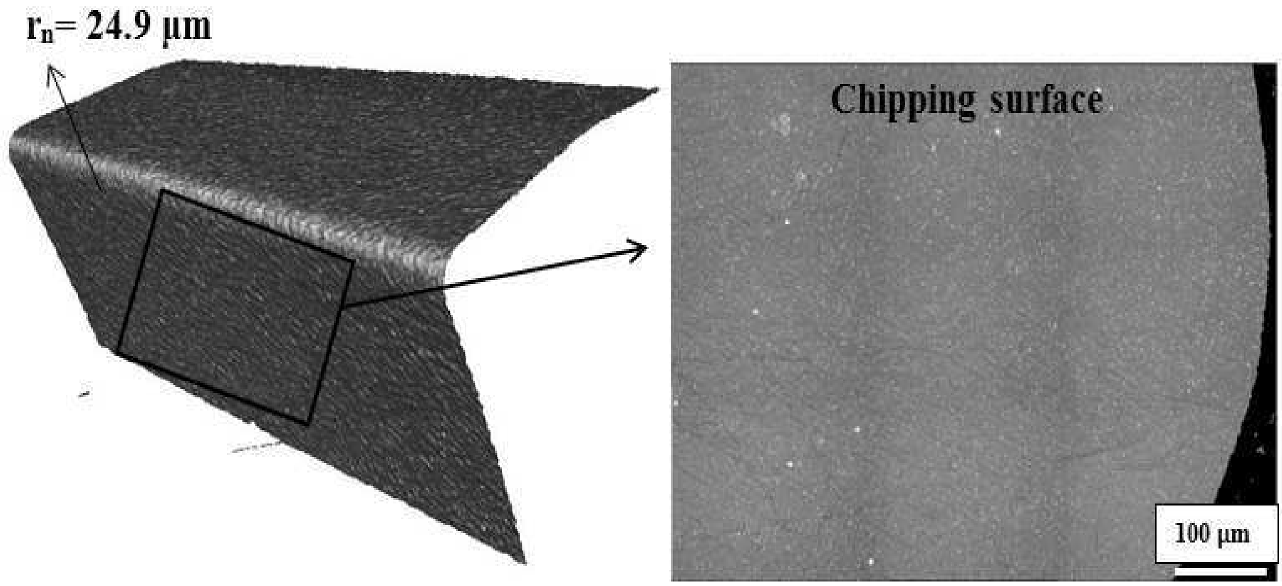

Fig. 6 *Chipping surface area for measuring roughness*

The following chart shows the roughness parameter Ra which was measured on the chipping surface. The abrasive water jet process causes cutting tools to have a higher Ra roughness parameter. As the process time increases, the selected abrasive water jet process parameters negatively affect the surface roughness. However, during drag finishing a longer process time lowers the value of the roughness parameter Ra. In comparison with HSC (tools 5 – 8) and QZ (tools 9 – 12) it is clear that HSC is more effective at making a better surface. But when making cutting tool modifications to cutting edge radius of 15 µm, QZ is more effective. Roughness after coating was measured at the same area on the chipping surface (black column). The coating process affects the surface roughness. The coating process causes the increase of surface roughness, characterized by the Ra parameter. The highest roughness value for Ra was measured on cutting tool 4 (Ra= 0.380 µm).

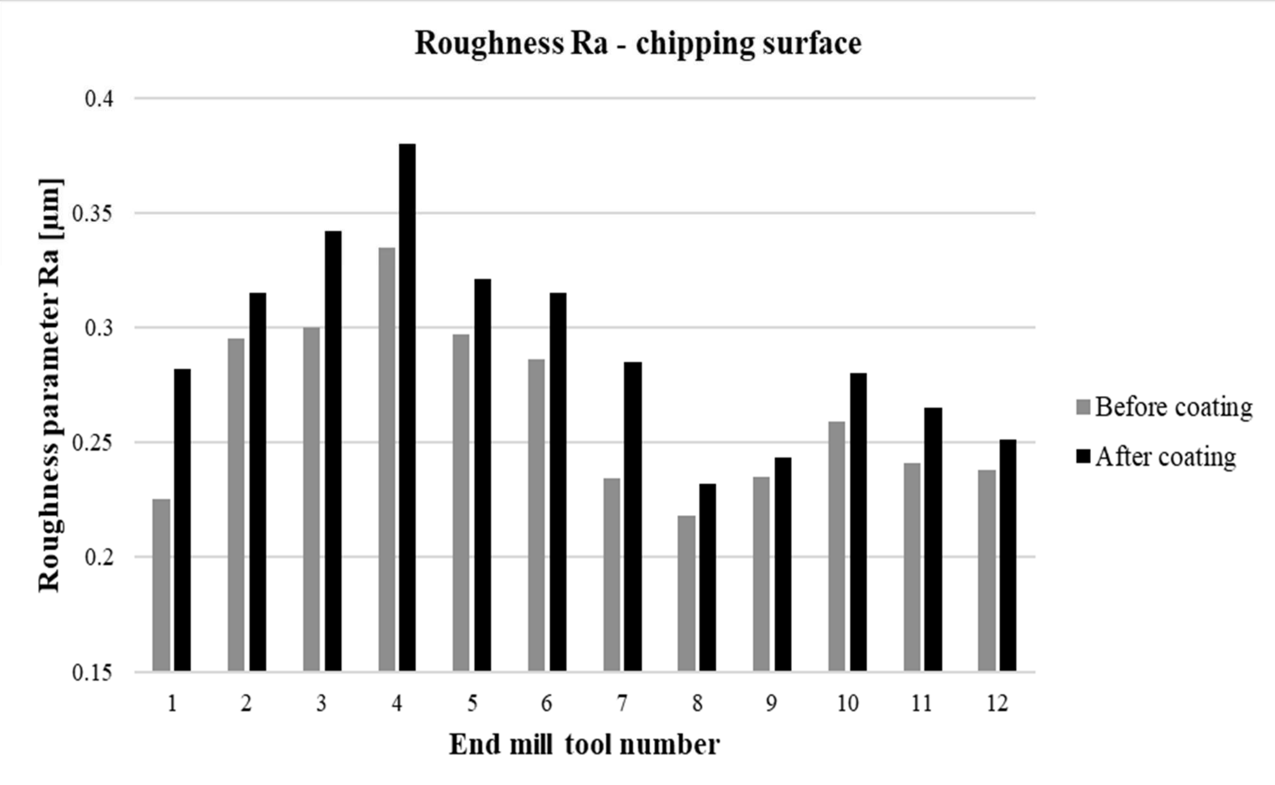

Fig. 7 *Arithmetical mean roughness measurement results*

It is not appropriate to evaluate the surface roughness with only one parameter, even though the Ra parameter is largely used. Furthermore, a major disadvantage of the Ra parameter is the lower reporting ability. Therefore it is necessary to use other parameters of surface roughness. One of them is the Rz parameter. This parameter is suitable for evaluating cutting tools, because it describes the grinding process, modification and the coating process. Rz parameter also describes the marks left after the grindstone and the efficiency of the modification process at reducing these marks.

When measuring tools which were modified by the abrasive water jet process (tools 1 – 4) roughness Rz did not confirm the same dependence that was investigated by parameter Ra. On the other hand, with a longer process time the Rz parameter is lower on the cutting tools modified by drag finishing. The only Rz value under 1 µm was measured on the chipping surface of cutting tool 8. Nine of the twelve tools have lower Rz parameters after coating. A thin layer follows the defects on the substrate surface and in some areas it causes decreased roughness and also waviness.

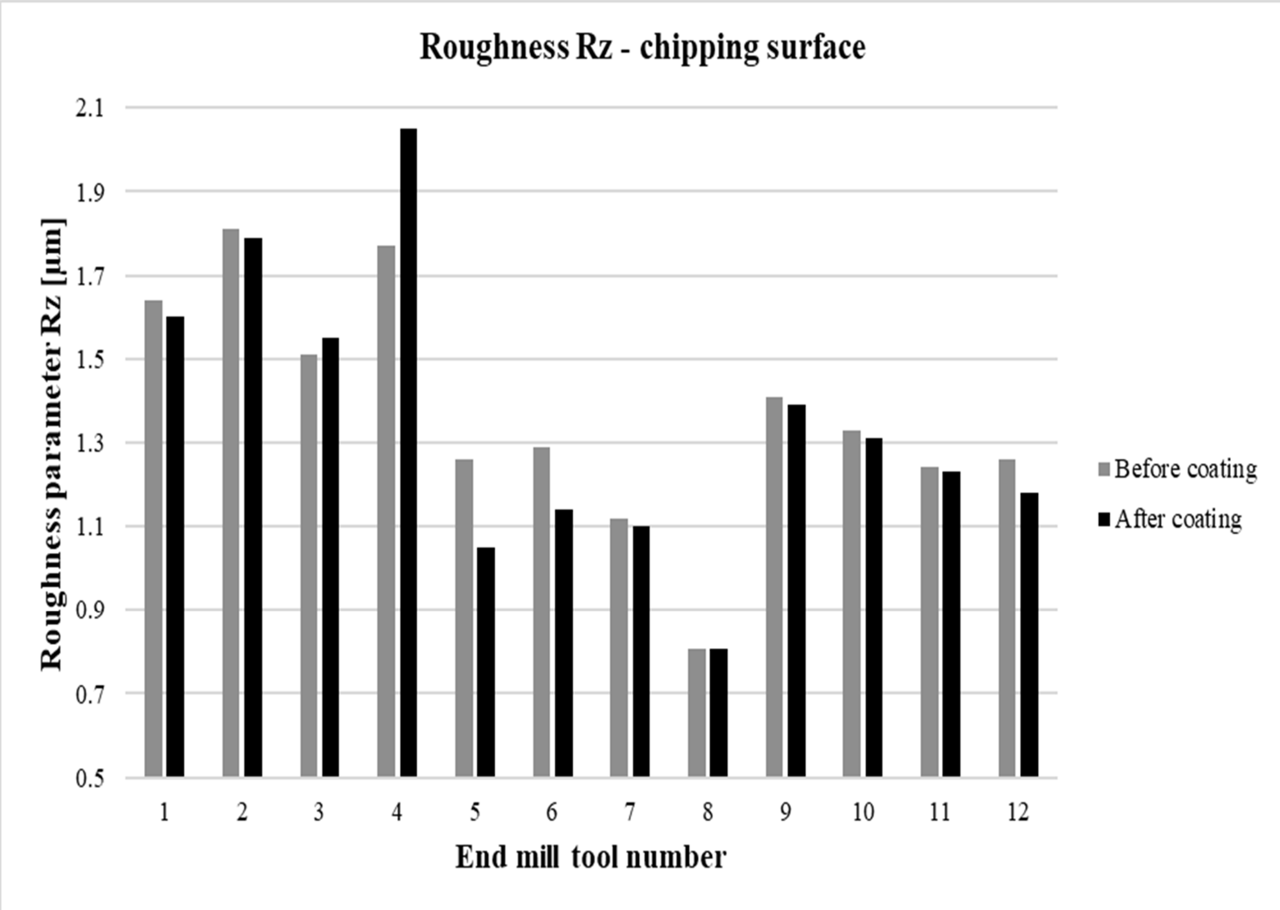

Fig. 8 *Mean roughness depth measurement results*

4 Conclusion

The experiment compares the influence of different microgeometry modification technologies. Cutting edge radius (r_n) was selected as the main microgeometry parameter with values 15 µm; 20 µm and 25 µm. Abrasive water jet technology and drag finishing were used for microgeometry modification. Walnut shells (HSC 1/300) and white corundum (QZ 1 – 3W) were used for drag finishing.

Drag finishing in HSC 1/300 was the most accurate in terms of the cutting edge radius. The proposed process parameters combined with HSC 1/300 modified the microgeometry to the desired r_n. A higher value of the cutting edge radius means a longer process time. The longest process time was recorded during the modification of cutting tool number 8. The process time was 23 minutes. The long modification time for $r_n > 20$ µm is a disadvantage of the HSC medium. On the other hand, it has been confirmed that short modification times are an advantage of the abrasive water jet modification. However, the process parameters have to be optimised. The evaluation of surface roughness was also a part of the experiment. Surface roughness was investigated on the chipping surface of the cutting tools. During modification by the abrasive water jet process, the increased process time causes an increase of roughness. However, longer process times create better surface roughness during drag finishing. HSC medium was more efficient than QZ. The lowest values of roughness were Ra= 0.218 µm and Rz 0.815 µm. After modification and measurement, the deposition of a thin layer followed. After deposition, cutting tool microgeometry was also measured. After deposition, cutting edge radius was measured and r_n values increase, so the expectation was confirmed. This increase was in the range 1.7 – 3.4 μm. The primary effect of deposition was on the chipping surface. Roughness was measured before and after coating. The Ra roughness parameter was always higher on tools with thin layer. On the other hand, nine cutting tools had lower Rz parameters.

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