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Influence of the Cutting Edge Radius and the Cutting Edge Preparation on Tool Life and Cutting Forces at Inserts with Wiper Geometry

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Abstract

This article deals with the influence of cutting edge preparation and cutting edge radius on tool life, cutting forces and the roughness of machined surface. The cutting edge preparation was done on the inserts with wiper geometry which are used during machining of dividing plane at a steam turbine casing. This cutting inserts were prepared by the technology of grinding, drag finishing and laser technology. The edge radius for drag finished tools was 5, 10 and 15µm and for laser treated tool 5µm. The workpiece material was ferrite – martensite steel with the content of 9%Mo and 1%Cr and the material of cutting inserts was submicron sintered carbide. There was used only one cutting insert in the milling cutter.

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Keywords: cutting edge preparation; wiper geometry; cutting edge radius; milling

1. Introduction

During machining there are high local pressures between the tool and the workpiece, high temperatures, cutting forces, etc. The cutting temperature, which is generated during cutting process, exposes the cutting tool to extreme thermal conditions. Heat, which is also generated by chip formation and by the friction on the rake face during high speed cutting, is adverse effect. This adverse effect can influence the tool life. At both discontinuous and continuous cut the cutting forces act unstable that is caused by small and very hard elements in the workpiece microstructure. That is why there are very strict requirements on the cutting material. The example of requirements is following:

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high hardness at elevated temperature, high fracture toughness, resistivity to tool wear and high strength. The user expects from the tool productive machining and very low tool wear. These requirements are possible to realize by better design of the cutting tool, new substrates, new deposited thin layers, etc [1]. The design of cutting tool is possible to improve in the area of either macro-geometry (tool profile, reshaping, angles, etc.) or micro-geometry. Micro-geometry of cutting tool is influenced to a certain extent by the cutting material and the deposited thin layer, which influences the roughness of machined surface and also the edge radius. For the cutting edge preparation there are used different methods, for example: brushing, drag finishing, mirco-blasting dry, micro-blasting wet, magnet finishing, honing by hand, laser, etc. Most of these methods are based on the principle of abrasive elements effect. The effect is transmitted by suitable process media. The process media can be: air, paste, a fibre, a magnet, etc [2].

The required edge radius is created by the combination of speed and the duration of abrasive movement or the workpiece. The aim of cutting edge preparation is: increasing the strength of the cutting edge, increasing the tool life, to reduce the internal stress of the coating, to reduce the risk of edge chipping, the preparation of the tool for deposition (smoother surface) and to create the defined shape and size of the cutting edge. Why is it necessary to prepare cutting edges? In the Fig.1 there is shown the difference between a sharp tool and a tool with prepared edge. On the left side there is the sharp cutting edge which was created by grinding the rake face and the flank of the tool. The cutting edge has defined edge radius because we are not able to produce perfectly sharp tool. The roughness on the tool edge is higher and the surface of this tool may have defects. The defects can be: micro – defects (they arise during grinding process and they are also caused by manipulation among each step of production process. These defects can be seen both before and after coating), burrs (they are caused by the grinding process. Burrs can roll up over the cutting edge during the cutting process and they can destroy it. Definitely necessity for coating is the tool without burrs) [3, 4].

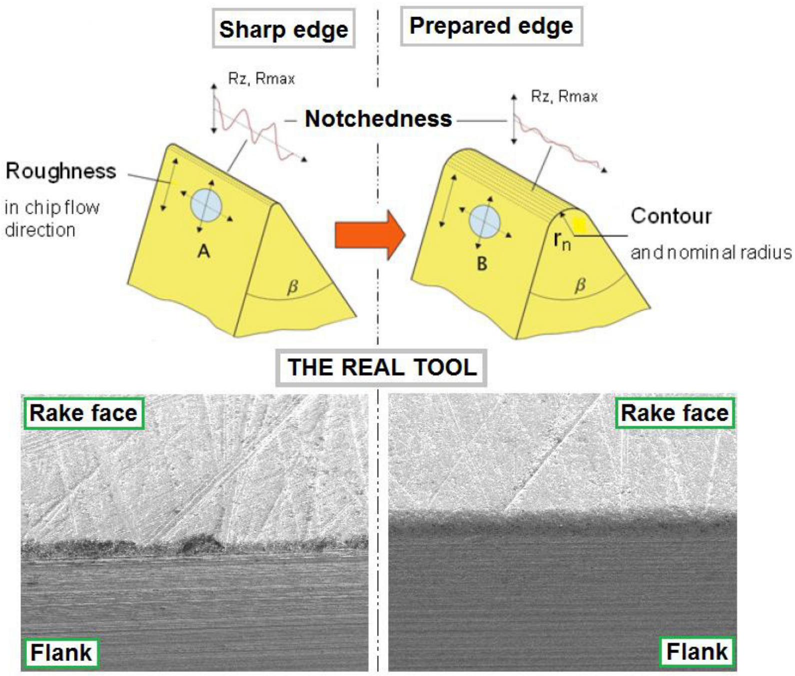

Fig. 1. Characterization of cutting edge preparation [5].

The cutting edge preparation can influence: cutting forces/gyroscopic moment, cutting forces, tool wear – tool life, chip formation, quality of machined surface, accuracy of machining, adhesion of deposited thin layer, etc. At a production process of a cutting tool it is necessary to follow the influence of inter-process preparation and also the influence of tool process technologies because right these factors have essential influence on the success of coated thin layer and the tool life. The production process of a tool can be seen in the Fig.2 [6].

Fig. 2. Manufacturing process for precision tools [7].

For the evaluation of the cutting edge micro-geometry it is necessary to use consistent specifications. The cutting edge is defined by: cutting edge radius r_β, parameters: Δr, φ, Sα, Sγ and K= Sγ/Sα. These parameters can be seen in the Fig. 3. K is defined to describe the symmetry of the contour generated by the cutting edge rounding process. If K=1, the micro-geometry is symmetrical. While K > 1 indicates a slope towards the rake face and K < 1 describes a slope towards the flank [8, 9].

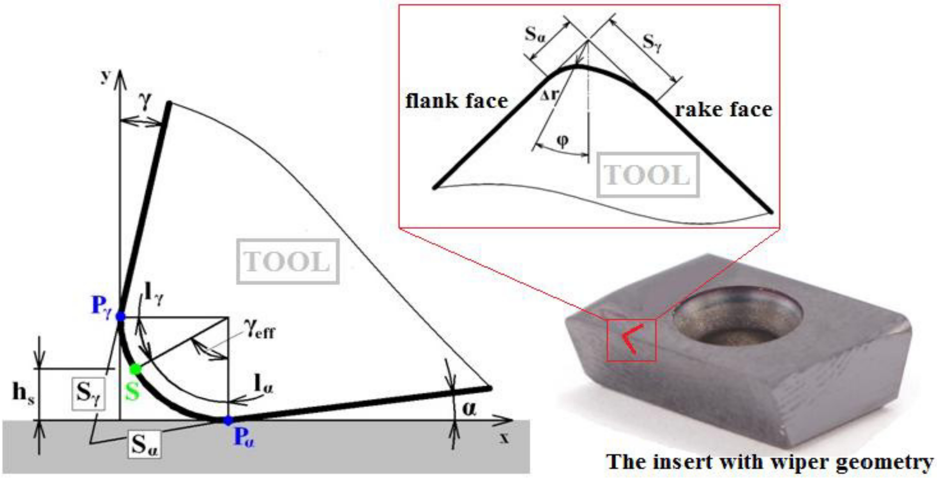

Fig. 3. Characterization of the cutting edge micro-geometry [10].

Nomenclature

a_e	radial depth of cut
a_p	axial depth of cut
B	volume of removed material
F	total force load
F_x, F_y, F_z	components of cutting force in the x,y and z-axis
f_z	feed per tooth
h_s	undeformed chip thickness
KB	tool wear on the rake face
l_α	contact length on flank face
l_γ	contact length on rake face
P_α	contact point on flank face
P_γ	separation point on rake face
Ra	arithmetic mean profile deviation
r_β	cutting edge radius

S	stagnation point
S_α	cutting edge segment on flank face
S_γ	cutting edge segment on rake face
VB_n	average tool wear on the flank face
v_c	cutting speed
α	flank face
γ	rake face
γ_{eff}	effective rake angle
Δr	cutting edge flattening
φ	inclination angle of the hone

2. Experimental setup

A set of experimental tests was carried out in order to investigate the effects of the cutting edge preparation and the cutting edge radius on tool life and cutting forces during finishing milling of ferrite-martensite steel EN ISO X12CrMoVNbN9-1. The material of workpiece is used for cast of a body steam casing in the power industry. There is machined a dividing plane with a milling cutter which is fitted by only one insert with the wiper geometry. So this work is based on the real machining process and that is why there are set up the following experimental criteria:

- machining which just one insert
- maximal tool wear VB_n/KB = 0.15mm
- roughness of machined surface Ra < 0.8μm
- volume of removed material B ≥ $60cm^3$

All the milling tests were performed on the three-axial vertical machining center MCV 750A. Workpiece, which was fixed on the work-table of the machining center, was machined by a milling cutter with diameter 80mm. External cooling was running. The milling cutter was fitted with the sub-micron sintered carbide tangential insert without chip breaker (YDA323L101). During machining there was measured: tool wear, cutting forces and roughness of machined surface. The cutting conditions and technical data are shown in the Tab.1. There is also the photo of the milling cutter, the insert and the machining centre in the Fig. 4.

Table 1. Technical and cutting conditions.

Parameter	Value or description
Milling type	Down milling, outer cooling
Axial depth of cut ap [mm]	0.02
Radial width of cut ae [mm]	50
Cutting speed vc [m/min]	200
Feed rate fz [mm/tooth]	4.5
Measurement system	Three-component piezoelectric dynamometer KISTLER 9255 A Alicona InfiniteFocus – optical measurement system, surface metrology and form measurement Device for measuring roughness Marsurf M300 Microscope MULTICHECK PC 500 (zoom 10x, 30x, 75x a 150x)

2.1. Cutting edge preparation and the cutting edge radius

The inserts were prepared by grinding, drag finishing and laser technology. The grinding inserts were directly bought from the tool producer. The inserts which were prepared by drag finishing had edge radius 5, 10 and 15µm and by laser beam had the edge radius 5µm. The Fig. 5 shows cutting edges and the Tab. 2 summarizes the geometric characteristics of the tools used in the cutting tests.

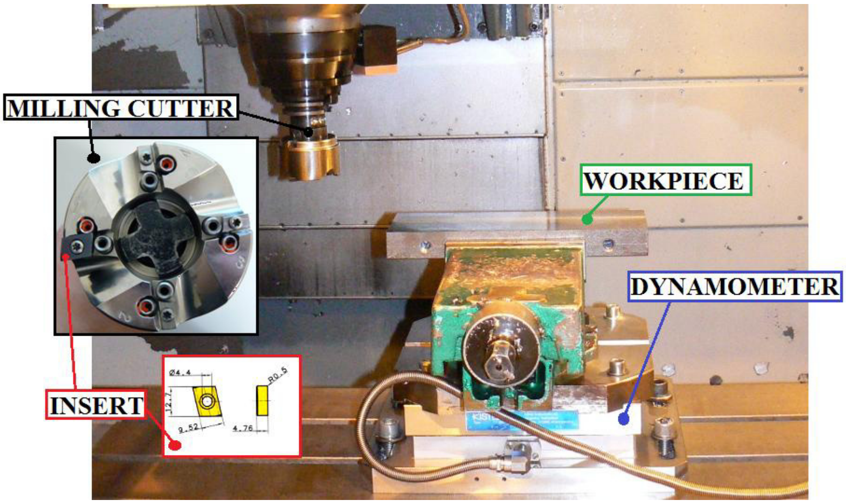

Fig. 4. Description of the workspace.

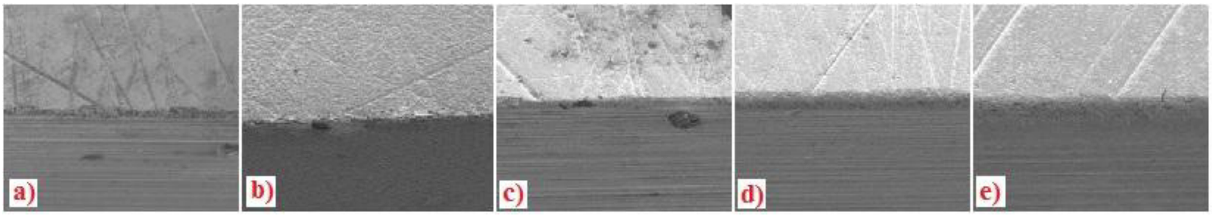

Fig. 5. Cutting edge prepared by: a) grinding, b) laser technology to edge radius 5µm and drag finishing to edge radius c) 5µm, d) 10µm and e) 15µm (500x zoom).

Table 2. Tools for cutting tests.

Test	Rake angle γ [°]	Flank angle α [°]	Edge treatment	Edge radius[µm]
1			Grinded	5
2			Laser	5
3	6	8		5
4			Drag finished	10
5				15

3. Results and discussions

3.1 Cutting edge radius

At this first part here will be introduced the influence of the cutting edge preparation on the tool life and the force load. There is shown the influence of the edge radius on the tool life in the Fig. 6. During experimental machining tool wear on the rake face and on the flank was measured. When the tools wear either rake face or flank reached/crossed the criterial value the experiment was stopped. The experiment was also stopped when the volume of removed material reached 60cm^3. The Fig. 6 shows very important information, that the tool life is increasing with increasing edge radius. The information in the scientific articles speaks about the most suitable edge radius which is about 20 ÷ 25µm. We could not prepare the edge radius higher than 20µm, because the depth of cut is equal 20µm! So here can be confirmed hypothesis: increasing edge radius (in the interval 5 ÷ 15µm) means increasing tool life. It is done by compact and smooth surface of the cutting edge; the cutting edge has higher strength and it is without defects (see in the Fig.6). The tool wear was in the form of chipping cutting edge parts for the edge radius r_β = 5 and 10µm and in the form of uniform tool wear for the edge radius r_β =15µm. The tool wear was measured on the rake face and on the flank face, but in the Fig. 6 is analysed the tool wear on the flank face. It is done because the tool wear on the flank influences the roughness of machined surface more than the tool wear on the rake face.

The roughness of machined surface is also very important because it must not be higher than Ra = 0.8µm; this value is written in the design documentation. The next parameter is difference of machined surface roughness at the beginning and at the end of machining. It is not so suitable if the difference of machined surface roughness is high because it means problems with accuracy of machined surface, assembly problems and possibility of accidental cutting edge damage which can influence integrity of machined surface. The influence of the edge radius on the roughness of machined surface can be seen in the Fig.6. The lowest roughness of machined surface is reached with the edge radius r_β = 15µm, because this tool is the most stable during machining. This tool has the lowest tool wear, no defect on the cutting edge and the roughness of machined surface is the same both the beginning and the end of machining. Roughness of machined surface for the edge radius r_β = 5 and 10µm is decreasing and from the volume of removed material 30cm^3 is the same. It can be explained as an incising (there is forming a cutting edge on the new tool).

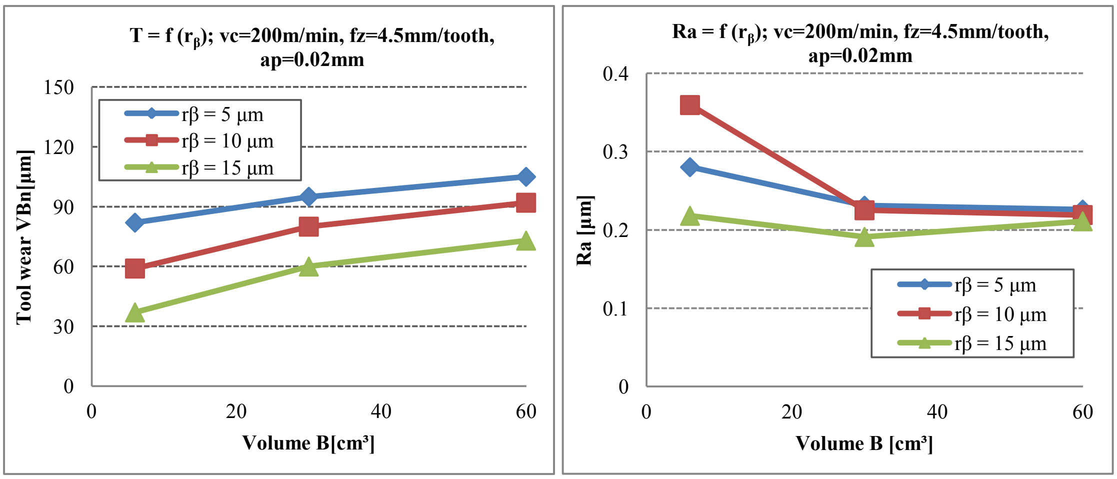

Fig. 6. Influence of the edge radius on the tool life and the roughness of machined surface.

During machining process there were also measured components of cutting forces Fx, Fy and Fz. In the Fig.8 there is influence of the edge radius on the total force load (a diagram on the left side) and component of cutting force Fz (a diagram on the right side). The total force load was calculated from:

$$F = \sqrt{F_x^2 + F_y^2 + F_z^2} \tag{1}$$

Cutting forces are increasing with the volume of removed material (with increasing tool wear). The lower edge radius, the higher total force load and the component of cutting force Fz. This result is very interesting, because it should be to the contrary (the lower edge radius, the lower cutting forces). The tool with edge radius 5μm is sharper than the tool with edge radius 15μm. Sharper tool should generate lower cutting forces because this tool easier enters to the material, but when we look in the Fig. 6 there can be seen the answer to this matter. After removing the volume 6cm^3 the tool wear of the tool with edge radius 5μm is almost 0.085mm and the tool wear on the tool with edge radius 15μm is around 0.035mm so the tool wear is responsible for higher cutting forces for the tool with lower edge radius.

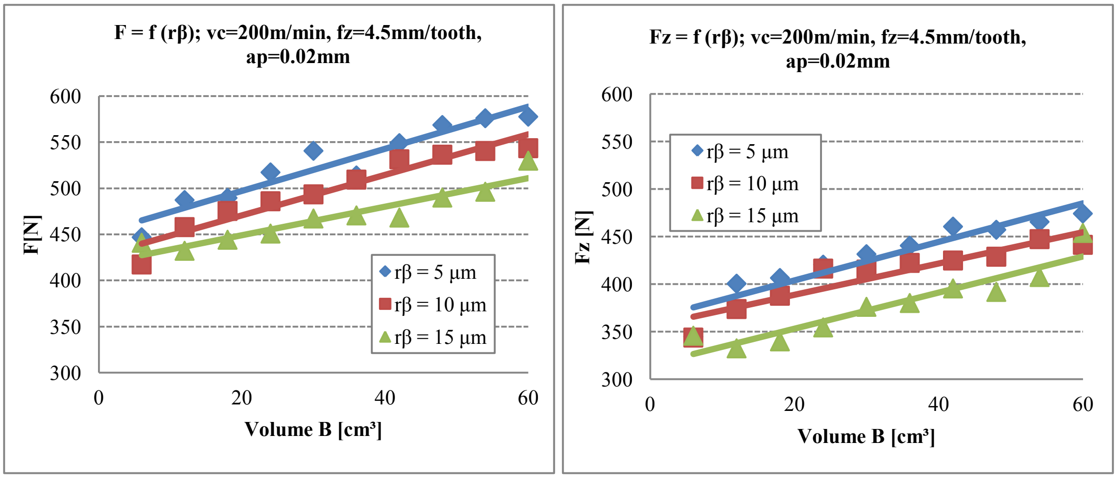

Fig. 7. Influence of the edge radius on the total force load (left) and and on the component of cutting force Fz (right).

3.2 Cutting edge preparation

As in the previous case, there is shown the influence of the edge treatment on the tool life. All tool had the same edge radius, only the notchedness was different and it was dependent on the edge treatment. The highest tool life was reached with the drag finished tool and the worst results had the laser treated tool. It was caused by wrongly set conditions for laser. Generally, it is very difficult to treat the tool by laser, because each element of the sintered carbide substrate has different melting temperature. When there are set up wrong conditions of the laser beam the cutting edge become brittle. At the first contact of this tool with the workpiece the cutting edge was destroyed (breakage of the cutting edge). Better results had the grinded tool, compared to laser treated tool, in spite of the cutting edge of grinded tool was micro-chipped. The best results reached drag finished tool because the cutting edge was compact and the notchedness (expressed by Rs) was very low. This tool did not reach the criterial value of tool wear, but reached the required volume of removal material. The tool which was treated by drag finishing has almost 60% better tool life than grinded tool.

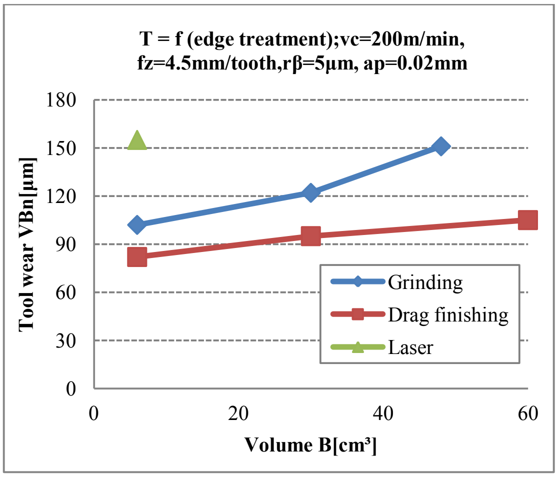

Fig. 8. Influence of the edge treatment on the tool life.

The cutting forces reflect the tool wear. The worst results are reached by the laser treated tool and the best results are with drag finished tool. The cutting forces are increasing with the volume of removed material (with increasing tool wear).

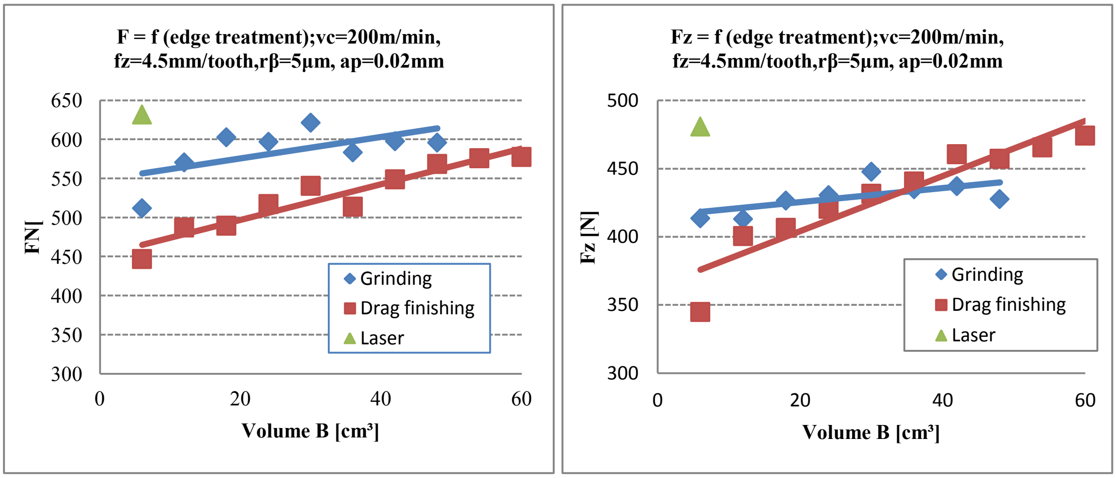

Fig. 9. Influence of the edge treatment on the total force load (left) and on the component of cutting force Fz (right).

4. Conclusion

This article was focused on the influence of the cutting edge preparation and the edge geometry on the tool life, roughness of machined surface and the cutting forces during finishing machining of ferrite-martensite stainless steel which is used for cast of body steam casing. The described technology is used for machining dividing plane where the depth of cut is 0.02mm, so it means that the edge radius cannot be higher than 20µm. Sub-micron sintered carbide insert, which was only grinded on the functional surfaces, was prepared by the technology of drag finishing to the edge radius 5, 10 and 15µm, laser technology to the edge radius 5µm and only grinded. The cutting conditions was experimental determined (the extensive experiment went before this experiment) on the $v_c = 200$m/min, $f_z = 4.5$mm/tooth, climb milling and external cooling. The results were clear and they were with theoretical hypotheses that the best edge radius is 15μm (from the tested interval 5 ÷15μm). The tool with the edge radius 15μm reached the highest tool life, the lowest roughness of machined surface and the lowest force load in comparison to the tools with edge radius 5 and 10μm. The roughness of machined surface and the force load is in connection with the tool wear. The tool wear on this tool was uniform. The other tools were worn by chipping of cutting edge. The best results were also reached with the drag finished tool in comparison with grinded and laser treated tools. So the recommendation for using inserts with wiper geometry on this specific machining process is following: v_c = 200m/min, f_z = 4.5mm/tooth, a_p = 0.02mm, r_β = 15μm, drag finished treatment, down milling and external cooling.

The following research will be focused to cutting edge preparation by technology wet and dry blasting and brushing. The cutting edge will be prepared on the cutting edge radius 15μm (because this edge radius is the best for the cutting conditions which are mentioned before). After that we will know what the best treatment is for that kind of submicron sintered carbide with the edge radius 15μm. The next step of my research will be change of K factor. I am going to prepare cutting edge radius 15μm by the best treatment technology with K>1 and K<1. At the end of this research I will have complete information about the most suitable edge treatment, edge radius and K factor for this insert with wiper geometry. This "new" insert will be compared with the original one from the tool producer to find out pros and cons of each treatment and there will be also quantified costs.

Acknowledgements

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