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# Evaluation of Cutting Tool Parameters

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**Abstract**

Evaluation of the cutting tool is an important aspect when a machining process is monitored. At this time, microgeometry of the cutting edge is very frequently used term. It has a great influence on the cutting process and it is necessary to know how correctly to measure parameters of the cutting edge to ensure reliability and repeatability.
Nowadays, many devices exist on the market which can be used for measuring the cutting edge. They are based on tactile or optical principles. Parameters of the cutting edge have a great influence on tool life and therefore it is important to measure them correctly. Primarily the radius of the cutting edge and the K factor is usually monitored.
This paper deals with measuring parameters on the cutting edge such as radius of the cutting edge, K factor and roughness of the surface, chipping, and their evaluation when machining special alloy Inconel 718 which is used mainly in the aerospace industry. Other measuring methods for tool life will be presented.



*Keywords:* microgeometry; K factor; radius of the cutting edge; roughness; chipping; tool life

## 1. Introduction

Nowadays microgeometry of the cutting edge is a frequently discussed term. At academic institutions, the issue of cutting edge modifications has been researched for several years in the Czech Republic and abroad, see [1,2] In the last few years, this issue has become important in the industrial sector too. By modification of the micro-geometry tool life is often significantly extended. These benefits are on the basis of better adhesion of the layer to the substrate or achieving the defined parameters of the cutting edge. To achieve this condition it is necessary to ensure reliable measurement and evaluation of the parameters of the cutting edge. Today, a large range of measuring

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**Nomenclature**

| | |
|---|---|
| $\rho_r$ | edge radius between rake face and flank face |
| K | K factor - description of the cutting edge symmetry |
| $R_t$ | maximum height of the profile |
| $R_z$ | average distance between the highest peak and lowest valley in each sampling length |
| T | cutting tool life |
| $v_c$ | cutting speed |
| $v_f$ | feed rate |
| $a_e$ | depth of cut |
| $a_p$ | width of cut |
| ISO | International Organization for Standardization |

instruments and companies can be found which deal with this issue. These devices can be divided according to the principle of measuring into tactile and noncontact devices.

Tactile systems have a long tradition in surface measurement. They can be divided into two main categories. Among the first are contact stylus systems for the measurement of small-scale surface features such as surface roughness. These systems typically operate with a stylus tip, which is traced along a profile over the specimen surface.

Among the second category are (micro) coordinate measurement machines (CMMs) where a stylus tip, usually a synthetic ruby ball, is moved to (several) different positions on the specimen in order to measure large scale features such as different form parameters (e.g. sphere radius, cylinder diameter, etc.).[3] A good overview of surface metrology systems in general and tactile devices in particular can be found in [4].

In the last decade optical measurement devices have become increasingly popular. This is above all due to their ability to perform area based measurements which are a prerequisite for many powerful surface texture parameters [3]. These systems usually do not require as much maintenance because they measure runs in a noncontact way and therefore, do not damage the surface or the stylus. Many technologies have become increasingly popular recently in the field of optical measurement, for example methods based on interferometry, confocal microscopy, chromatic probe microscopy, and scanning electron microscopy. [3, 5]

Limitations of optical instruments are especially the maximum measurable flank angle in relation to the numerical aperture of the used objective, and the lateral resolution that is typically limited by the wavelength of visible light (> 400 nm).

This paper will deal with evaluation of the cutting edge with the device IFM G4 that exploits the small depth of focus of an optical system with vertical scanning to provide topographical and color information from the variation of focus.

## 2. Evaluation of selected parameters of the cutting edge

Microgeometry of the cutting edge influences tool life, stability of the cutting process, chip formation, surface quality and not least heat load and force load on the tool. Different size and radius shape can be achieved in many ways such as microblasting, brushing, magnet or drag-finishing or by laser. These technologies affect the cutting process not only with regard to the achieved shape and size of the radius but also stress in the tool surface, which is brought into the tool when the cutting edge is being modified.

A double-edged milling cutter with diameter 8mm from sinter carbide was chosen for the evaluation of the above mentioned parameters. Tools were made in many variations of radius of the cutting edge, for example drag finishing, stream finishing, polishing, two different types of layers, polishing after deposition and competitive tools for machining Ni alloys. Results from machining can be found in the paper ‘Influence of the edge microgeometry when machining Inconel’ 718 [8].

Evaluation of all parameters was always done on the basis of cutting conditions (cutting speed 35m/min, feed per tooth 0.04mm, axial depth of cut 3mm, radial depth of cut 0.5mm) 2mm from the tool tip so that monitored values were predictive in evaluation of the effects of parameter changes on the cutting process.

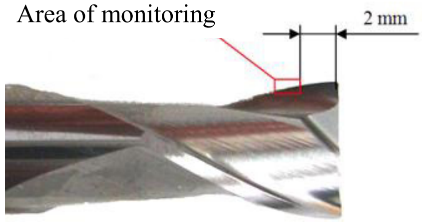


Fig. 1. Area of monitoring on the cutting edge.

### *2.1. Measuring the radius of the cutting edge and K factor*

Radius of the cutting edge and K factor are the most commonly monitored parameters for cutting edge modification. In general, it can not tell what is the best radius and shape. These values depend on many factors, such as machining technology, workpiece material, roughness of the functional surface on the tool, used layer, etc.

At this time, many types of equipment can measure the cutting edge radius. In the introduction the differences between optical and tactile measurement principles were outlined. The following figure shows the differences between results from a tactile device, confocal microscope and IFM G4. The first two devices can not measure the K factor. The tactile device is limited by changing the point between stylus tip (ball). The operator influences the confocal microscope because the radius is pasted manually.

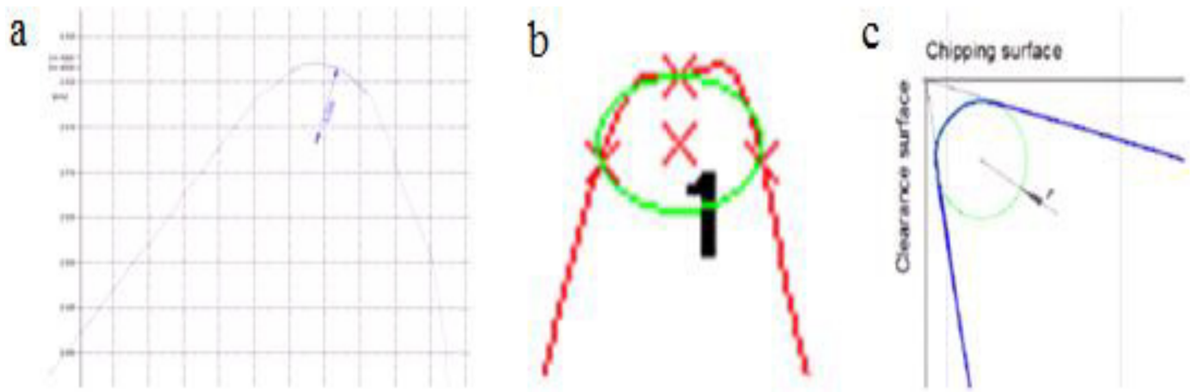


Fig. 2. Results of cutting edge radius from tactile device, confocal microscope, and IFM G4.

Fig. 2 shows that the accuracy of the interleaving is not very credible when measuring with the first two devices. It shows that not every device which is recommended for measuring cutting edge parameters is suitable for reliable measurement of its parameters with a guaranteed repeatability.

Even though measuring on the IFM G4 is completely automatic, correct setting is necessary for reliable and repeatable results. A thorough cleaning of samples is very important for every measurement because any dirt can distort measurements. Further, it is important to choose the lens, lateral and vertical resolution correctly. Table 1 shows the minimal measurable radius for each lens. For example, tools after grinding have a radius of about 5 μm therefore a 50x lens was used.

Table 1. Overview of limit values for each lens.

| Objectives | | 2.5x | 5x | 10x | 20x | 50x | 100x |
|---|---|---|---|---|---|---|---|
| Min. measurable height | nm | 2300 | 410 | 100 | 50 | 20 | 10 |
| Max. measurable height (approx.) | mm | 8 | 22 | 16 | 12 | 9 | 3.2 |
| Step height accuracy (1mm height step) | % | - | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Max. measurable area | $mm^2$ | 10000 | 10000 | 10000 | 4500 | 700 | 150 |
| Max. measurable profile length | mm | 100 | 100 | 100 | 100 | 100 | 100 |
| Min. repeatability | nm | 800 | 120 | 30 | 15 | 8 | 3 |
| Min. measurable roughness (Ra) | nm | 7000 | 1200 | 300 | 150 | 60 | 30 |
| Min. measurable roughness (Sa) | nm | 3500 | 600 | 150 | 75 | 30 | 15 |
| Min. measurable radius | µm | 20 | 10 | 8 | 5 | 2 | 1 |
| Min. measurable vertical angle | ° | 20 | 20 | 20 | 20 | 20 | 20 |

Of course, it is not always known what radius will be measured on the cutting edge and it is necessary to make approximate measurements. It shows the approximate values of the radius and on this basis, the right lens can be chosen.

The radius is not the only way to modify the cutting edge. Other shapes, such as an ellipse, can be used. They are known as "waterfall" and "trumpet" and they can function on the flank face like a wiper facet and on the rake face like a firming facet. These shapes are shown in Fig. 3.

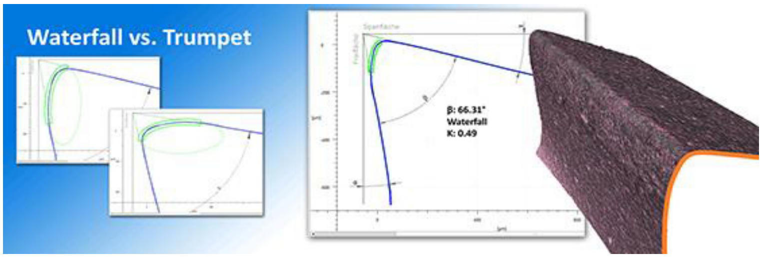


Fig. 3. Elliptical shapes of the cutting edge.

The influence of the size of the radius on tool life was tested in this experiment. The radius should be modified to values 5, 10, 15, 20 and 25 µm. Each value was made by drag finishing. During the process was measured if the size is already finished. In the first experiment the tool life was very close for 15 and 20 µm. After repeated measuring of the radius it was found that those radiuses are not 15 and 20 µm but both of them were close to 17 µm.

Differences in tool life were obvious after the new modification to correct values (see Fig. 4).

These results show that a difference of 5 µm has a great influence on tool life (about 25%). The cause of the mistake was the incorrect setting of the device by a qualified machine operator. This shows how important correct measurement is. Correct measurement can often help when detecting the reason why the tool does not work. For example, the first production charge of tools can prolong tool life and the next may not work. Then it is simplest to make repeated measurements and find out if the micro-geometry is the same. This simple operation can save a lot of time.

Currently the K factor has a great weight when evaluating the micro-geometry. It is an indicator of the symmetry of the cutting edge.

K is defined as:

$$K = S\gamma / S\alpha \tag{1}$$

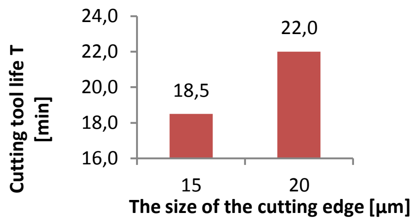


Fig. 4. Comparison of correct and incorrect measurement.

A symmetrical cutting edge microgeometry is defined by the form factor K = 1, while K > 1 indicates the slope towards the rake face and K < 1 describes the slope towards the flank face. The size of the asymmetrical honed cutting edges is described by the parameters Sγ, Sα and K.

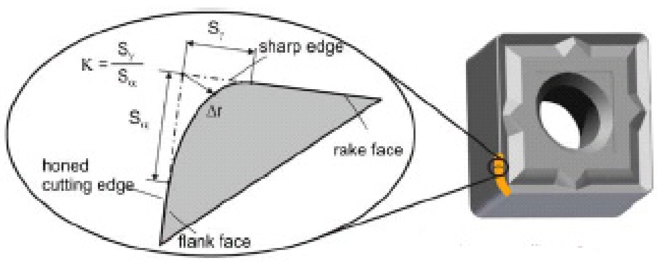


Fig. 5. Definition of K factor [6].

The K-factor should be set to a range of 0.5 to 2. These values are just theoretical because there is no machine on the market which can do that. During these experiments there was no K factor which was close to the values 0.5 or was over 1. In this experiment the K factor was in the range from 0.83 to 0.96.

The radius could not be greater than 1 in all cases, as shown in Fig.6.

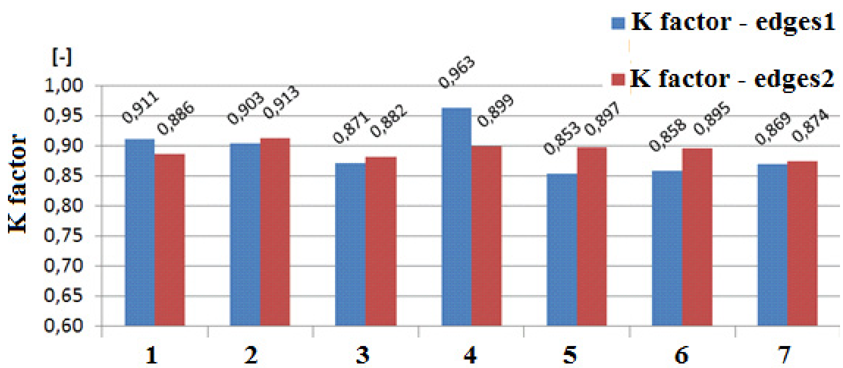


Fig. 6. Values of K factor for different modified tools.

Values of radius and K factor were measured on both edges. Results show that the values were very close. Difference analysis for the comparison of both of edges was done (see Fig. 7). The picture shows deviations in the range of about 6μm. It will be monitored to see if this manufacturing inaccuracy influences cutting process.

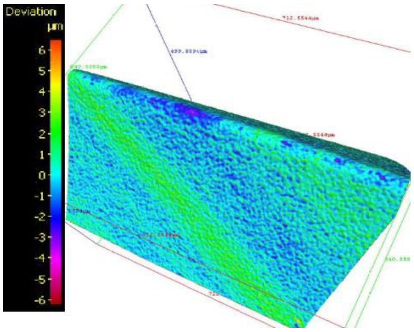


Fig. 7. Differences analysis for both edges.

The article [6] shows that not only values of K factor but also size of Sγ and Sα influence tool wear, heat load and force load significantly.

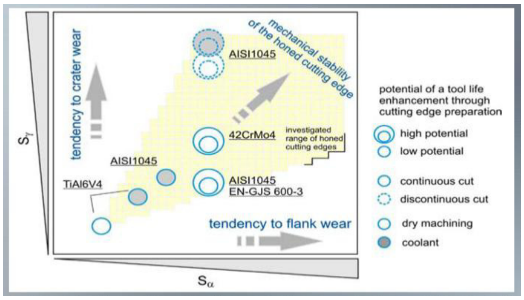


Fig. 8. Influence of the size Sγ and $S_\alpha$ on tool wear [2].

The value of K factor is very often measured incorrectly. The cause can be choice of the lens, changing of the rake face and flank face – many devices have their own specific set conditions such as the position of the tool towards the lens that must be followed. Another very common mistake is the incorrect interleaving of tangents to the measured radius – see Fig. 9.

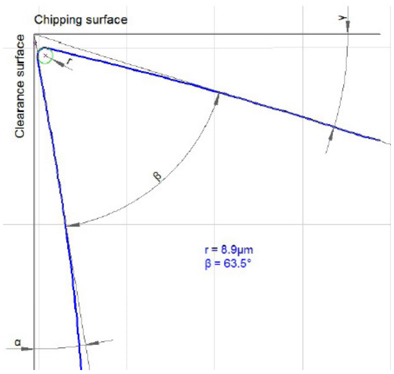


Fig. 9. Incorrect interleaving of tangents to the measured radius.

The error is exaggerated so as to be readily visible.

*2.2. Measuring of the roughness and chipping*

In general, roughness influences adhesion of the thin layer to the substrate and the adhesion coefficient. It was found that the longer the time of the drag finishing process, the better the roughness of parameter Rt (see Fig. 10).

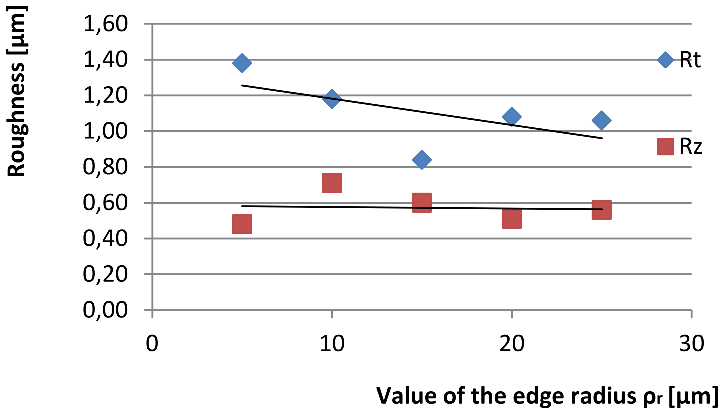


Fig. 10. Roughness in relation to radius of the cutting edge.

Roughness parameters were measured on the rake face and flank face two millimeters from the tool tip. The surface after drag finishing is without grinding marks (see Fig 11).

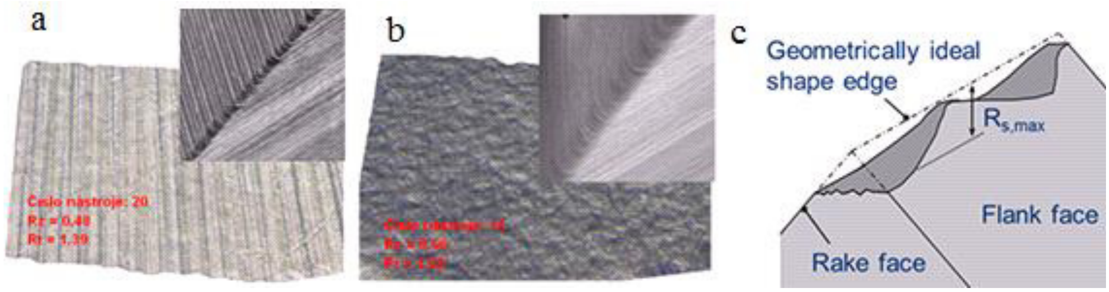


Fig. 11. (a) Surface after grinding (on the left) (b) after drag finishing (in the middle); (c) Chipping – roughness of the cutting edge.

Chipping is the parameter for evaluating the quality of the cutting edge. It influences the size and orientation of the marks after grinding.

Modification of the cutting edge increases radius size but decreases roughness of the cutting edge. This is positive for deposition of a thin layer. The cutting edge is the most problematic place for the deposition layer because it includes many defects and it is the place where stress is concentrated.

*2.3. Evaluation of tool wear*

The tool wear was monitored during experiments. Firstly, it was measured normally according to standard IS0 3685:1993 on the optical microscope Multicheck PC 500.

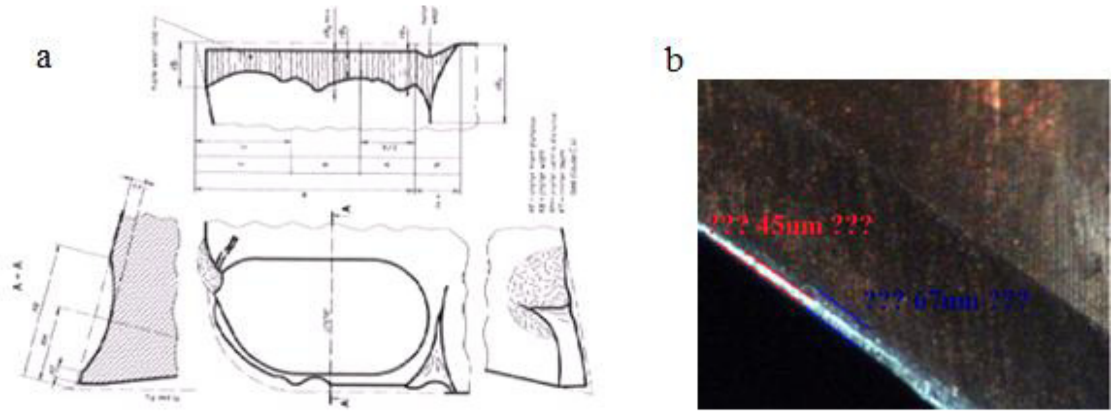


Fig. 12. (a) Evaluation of the tool wear according to the standard; (b) Conventional method of measuring tool wear [7].

Exotic materials like Inconel 718 significantly influence the process of tool wear due to their specific properties. Sometimes it is difficult to measure the tool wear by using standard methods like common optical microscopy. In this experiment the operator of the microscope after a few measurements was not sure what had been measured. It was not clear if the right VBB value is between the blue lines in Fig. 13 or if it is between the red lines shown in Fig. 12b.

This was the reason for finding other possibilities for evaluating tool wear. Device IFM G4 was used. First, the new tool was scanned. Then machining tests continue to the next measurement and after this the worn tool was scanned. A cut was made in the scan. The following figure shows that the value of the wear was clear. On the basis of this knowledge it was obvious which value from the optical microscope is correct.

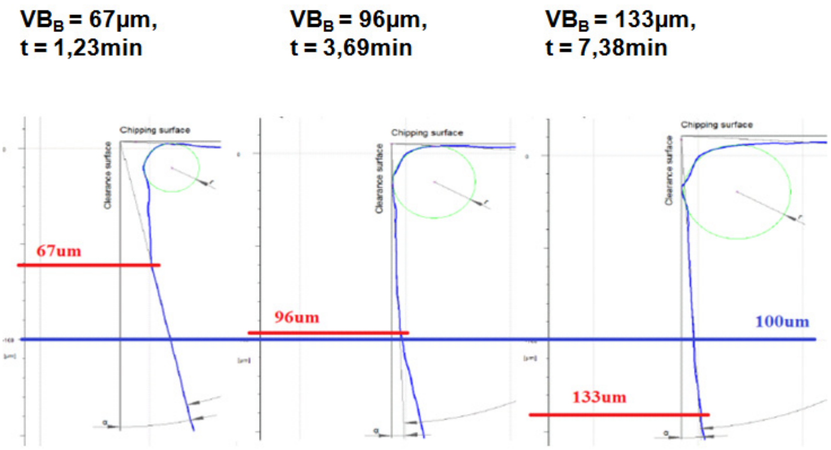


Fig. 13. Measuring tool wear on IFM G4.

Cuts which were made on the scan of the worn tool are very useful for measuring depth dimensions such as parameter KT. Common methods for measuring tool wear are not very useful for this, as their reliability and repeatability is not high.

The device IFM G4 allows further possibilities for evaluating tool wear. The first of them is measuring through difference analysis. A new and worn tool are scanned and then these scans are put together. The result is a spectrum of colours, as seen in Fig. 14.

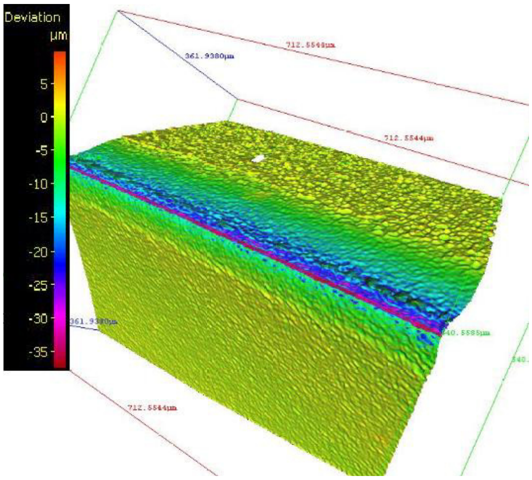


Fig. 14. Evaluation of tool wear though difference analysis.

Difference analysis shows the deviation between the new and worn tool. Specific values of the missing material and a lot of other values can be found in the table of results. Volume parameters could be added to the current standard for measuring tool wear because they could have an important interpretive value. For example, the same value of VBB for two same worn tools can have a different relief of tool wear or a different volume of the missing material.

Table 2. Results from difference analysis.

| Name | Value | [u] | Description |
|---|---|---|---|
| Dth | 2.4474 | µm | Set tolerance for defect detection |
| Dneg | 37.4569 | µm | Max. deviation below reference surface |
| Dpos | 9.6252 | µm | Max. deviation above reference surface |
| Dmean | -2.8955 | µm | Mean deviation |
| Vp | 29629.3991 | $µm^3$ | Volume of peaks above reference surface |
| Vv | 1455024.2202 | $µm^3$ | Volume of valley below reference surface |
| Vdp | 29629.3991 | $µm^3$ | Volume of peaks defects extending above tolerance |
| Vdv | 1455025.2221 | $µm^3$ | Volume of valley defects extending below tolerance |
| Aproj | 8356.3922 | $µm^2$ | Projected area specimen |
| Adp | 8356.3922 | $µm^2$ | Projected area of peaks above tolerance |
| Adv | 96728.8520 | $µm^2$ | Projected area of valley below tolerance |
| Pc | 679769 | % | Coverage Percentage (Area within tolerance) |
| SIMcd | 37.4569 | µm | Greatest depth of defects (ISO 8785) |
| SIMch | 9.6252 | µm | Greatest height of defects (ISO 8785) |
| SIMt | 105085.2442 | $µm^2$ | Whole area of defects (ISO 8785) |

IFM G4 has at least one more solution for evaluation of the tool wear. Scans of new and worn edges must be done as in the previous method. They must be put together and then the cut made through the final scan. Fig. 15 shows the contours of the new and worn tool. Here it is possible to measure the required parameters. This method is used for evaluation of the tool wear in [3].

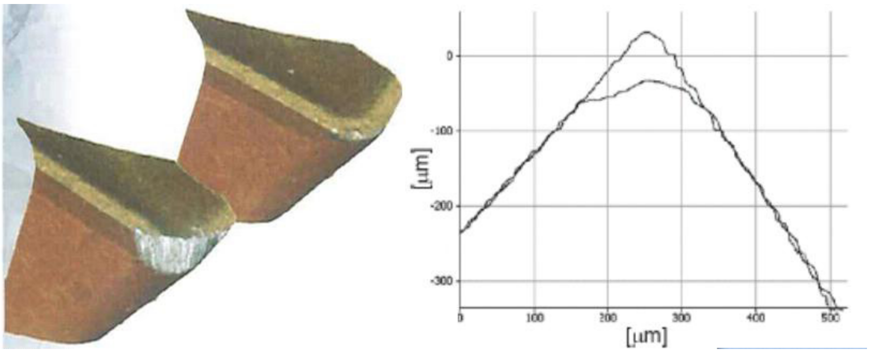


Fig. 15. Evaluation of tool wear through contours of the new and worn tools [3].

## 3. Conclusion

This article shows the importance of correct measurement of the cutting edge because it has a great influence on the cutting process - mainly tool life, forces and temperature load.

Development of tools is a very active process, so norms and evaluation methods of tool wear must evolve along with it, so that the description is complex and informative. Some researchers, for example [3], are using methods of evaluation which will be acceptable for their needs.

In this paper three methods were suggested as a support or extension of the current standard for measuring tool wear: IS0 3685:1993. According to this standard the 2D parameters are observed. The most common method is measurement using optical microscopy. The problem is that it is not always clear if the correct value has been measured. Here the measuring can be supported by 3D scanning. Another way is that the norm will be supplemented by 3D parameters for example the volume of the missing material. Finally, extension of the current standard could be by difference analysis of the new and worn material. From this it is clear where and how much material is missing. These are just ideas, which it will be necessary to investigate further and find out if they might be usable for practical measurement.

On the basis of these experiments we would like to find a more complete and more informative method for evaluation of the cutting edge and tool wear which will be usable for a wider spectrum of users.

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