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# OPTIMAL TOOL SELECTION FOR ENVIRONMENTAL-FRIENDLY TURNING OPERATION OF ALUMINIUM

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In case of machining of automotive parts in large series it is necessary to change to machining operations, sparing the environment. The paper summarises the experiences of the authors, gathered in turning operation. With the help of experiments, planned, carried out and documented systematically, determine the conditions, considered to be the most favourable for the fine turning operations of high silicon-content aluminium cast parts in order to achieve the most advantageous surface roughness parameters. They deal with the topographic examination of surfaces, describing the working characteristics of the machined parts; furthermore, the topological maps of the surfaces, machined with diamond, will be introduced as well. The most favourable parameters were determined not only in the case of tool material and optimal edge construction in case of selection of cutting conditions.

**Keywords:** machinability, aluminium castings, finish turning, carbide inserts, polycrystalline diamond turning, environmental-friendly machining

## Introduction

In the case of production of automotive parts in a large series it is necessary to pay a special attention to all factors, improving the quality and effectiveness of production. At the same time, operations, sparing the environment, should not be ignored: there is an increasing demand to completely change to application of any environmental-friendly flushing-lubricating-cooling medium in order to avoid use of cooling method, carried out with flood-type application of emulsion. Although machining operations, carried out with emulsion, mean only a few ten Forints pro part [1], but in case of a component, produced in a few millions of items this amount causes not only increase of production costs, but unnecessary burdens to the environment as well. In case of machining high silicon-content aluminium cast parts, dry turning operation is one of the alternatives to avoid the difficulties. The following papers deal with this subject [1-3].

It is reasonable to select such items from the tools with different shapes and design, which are able to produce the most favourable surface roughness profile with the smallest possible expenditure of time. In the present lecture we are going to introduce some from the results, gained by us during fine turning operations, carried out with carbide and diamond inserts. In our article we are going to determine machining operations as well, recommended by us to be followed.

## Description of the goals and circumstances of the tests

The aim of the tests was to get a clear picture of how the tools of different materials and with different edge geometry can meet the extremely strict roughness standards, applied in the automobile industry. The test was designed to research the disturbing phenomena that arise during turning operations of difficult-to-machine base material. The difficulties have been increased further by the fact that we had to carry out the tests without the use of cooling-lubricating liquid.

Surface roughness values, made with different compositions polycrystalline diamond tools, were compared, where the dry turning operations were performed with tools with different point angles and nose radii; (the cutting speed was varied in a very wide range ($v_c$ = 630–2000 m/min)). The depth of cut – due to reason of saving materials – were kept on a constant value (a = 0.5 mm), other testing conditions can be seen in *Table 1*.

*Table 1: Machine and materials used in the test*

| | |
|---|---|
| **Machine tool** | Type: EuroTurn 12B (NCT Kft.)<br>Control: NCT2000 |
| **Workpiece** | Material: AS17 (Rencast Reyrieux)<br>Contents: Si 16.8%, Cu 4.1%, Zn 1%,<br>Fe 0.8%, Mg 0.5%, Mn 0.2%,<br>Other components: Pb, Sn, Ni, Ti (<0.08%) |
| **Applied carbide and diamond inserts** | Carbide inserts, made by WNT GmbH.:<br>DCGT 11T304-AL H210T (WNT)<br>DCGT 11T308-25Q H210T (WNT)<br>Polycrystalline diamond, made by<br>Hoffmann Group GmbH.:<br>DCGW 11T304 FN (without chipbreaker)<br>DCGT 11T304 FN TWF (chipbreaker)<br>DCGT 11T304 FN TWM (chipbreaker) |
| **Testing circum-stances** | a= 0.5 mm (constant)<br>$v_c$= 630 …2000 m/min (varied)<br>f= 0.05 – 0.063 – 0.08 – 0.1 mm |
| **Measuring devices** | Surftest SJ301 (Mitutoyo, Japan)<br>Perthometer Concept 3D<br>(Perthen-Mahr, Germany)<br>Electron microscope JSM-5310<br>(Jeol Co., Japan)<br>HandyCAM, DCR-SR290E (Sony, Japan) |

## Test results

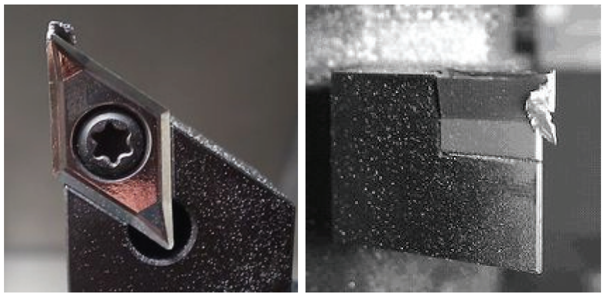
Description below contains the surface roughness values, measured along three different measuring lines, at setting every single of the test values.

### *Machinability of hypereutectic aluminum alloys*

One of the circumstances, making the machining difficult, is that aluminium is an easy-to-machine material, soft and ductile; but by increasing the Silicon-content, the abrasive effect of the alloys increases and the difficulties, arising during the machining. Because of the primary silicon crystalls, embedded in the aluminium matrix, the chips become easy-to-break; however, the presence of these hard particles lead to the quick wear of the insert, due to their strong adhesion and chemical reactions as well as low abrasive resistance with Al-Si alloys. When the primary Si-particles contact the tool edge in the cutting zone, they wear it intensive; furthermore, due to their hardness they hinder the formation of surface of good quality.

In our previous paper [1, 3-5] we have introduced the machinability of alloys with aluminium content of 16%. In our present research we have paid a special attention to two undesirable disturbing phenomena (built-up edge and deceptive chip formation), developing during chip formation.

Briefly about the well-known phenomenon of *built-up edge*: it develops on the rake face of the tool from the material of workpiece and in the majority of cases it deteriorates the roughness of the machined surface. There are less articles in the topic of phenomenon „*deceptive chip formation*", published in the specialised technical literature: its development and effects are less known; we can gather more information on it with research of slow-motion video records. Depending on the edge quality and wear conditions of the tool and as a result of intensive cutting conditions, in the chip formation zone increasing force and temperature can be observed. If the developed temperature reaches the melting point, as a result of the three-sided stress state a chip-like formation (a so-called deceptive chip, DCH or flank build-up, FBU), having only few μm thickness, will be extruded from the zone between the flank land of tool and the contacting surface of workpiece, being machined at the given moment. The material particles, having been extruded, adhere to the flank land of insert: the intensity of this process depends on the cutting conditions (mainly on $v_c$ and f values), settled by us. All the factors, like cooling the zone, variing of material and friction properties of the tool, appropriate shape and condition of the tool edge and application of less intensive cutting parameter, affect the development of deceptive chip formation. The phenomena, observed during our tests, can be seen in *Fig. 1.*



a) built up edge (observed only on the rake face) | b) deceptive chip formation (observed only on the flank land)

*Figure 1:* The disturbing phenomena of chip development, in case of turning of hypereutectic aluminum alloys with carbide inserts; Cutting conditions: carbide insert; $r_ε$=0.4 mm; $v_c$=1000 m/min; f=0.05 mm

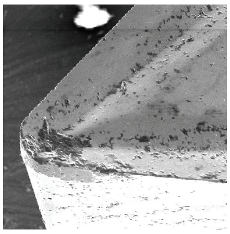
### *Application of carbide inserts at increased cutting speed values (quasi HSC machining)*

The basic goal of the tests was to find out in what kind of degree the carbide inserts, recommended expressly for this purpose, can be applied to environmentally-friendly cutting under HSC conditions. For these test we have selected tools, recommended by the manufacturer, expressly to application in factory due to their design. The characteristics of the tools are:

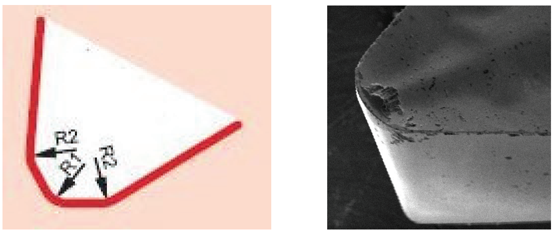
- optimal edge quality, its determinant properties are:
- very low surface roughness values on the rake face and flank land,
- resulting in very low edge roughness,
- minimum value of edge radii;
- the material quality of carbide meets the specification: it belongs to the K group, according to ISO,

- in order to support the optimal chip flow we have selected D insert shape,
- nose radius of different sizes have been selected,
- on one of the types, chipbreaker has been placed.

Due to the reasons, mentioned earlier, the tests were proved to be carried out in a significantly increased range of cutting speed values, compared to our previous tests [5]. The insert, coded DCGT11T304-AL, expressly suitable for cutting operations of aluminium: it had an average edge fillet off $r_n$=17 µm, the edge roughness is $Rz_{edge}$=10 µm, the other one type, coded DCGT11T308-25Q, with chipbreaker and wiper edge form, had an average edge rounding off $r_n$=10 µm, the edge roughness is $Rz_{edge}$=10 µm. Both types had a finely polished rake face and flank land ($Ra_\gamma \approx Ra_\alpha$=0.05–0.08 µm), it is a very important precondition to the cutting operation of aluminium. Due to space limitations it is not possible to introduce other data, concerning the tool edge, or any other diagrams. The design of carbide inserts, tested by us, can be seen in *Fig. 2*.



a) $r_\varepsilon$=0.4 mm (ISO shape)

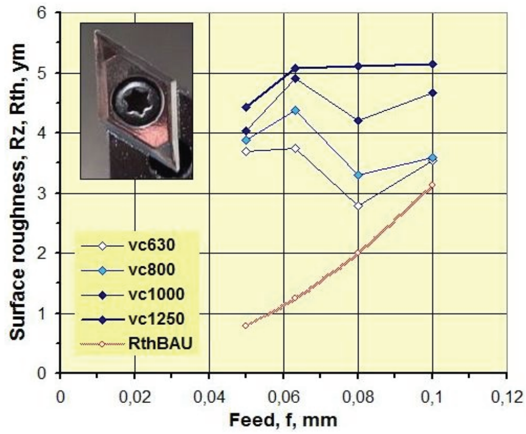



b) $r_\varepsilon$=0.8 mm (wiper edge form)

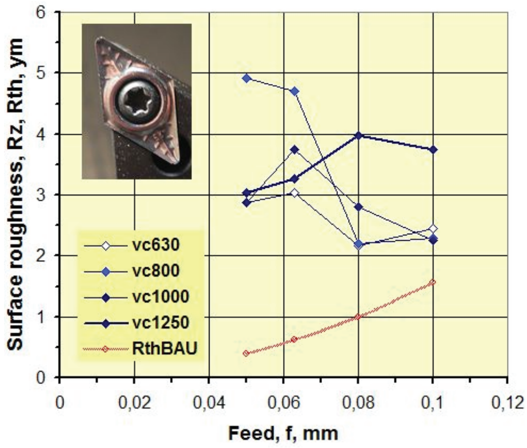
*Figure 2:* The most popular carbide inserts for aluminum turning applications
a) DCGT11T304-AL (left, magnification: 35x)
b) DCGT11T308-25Q (right, magnification: 35x)
Manufacturer: WNT Deutschland GmbH, Germany [6]

In *Fig. 3* the maximum height of profile roughness (Rz) and the well-known Bauer-formula (RthBAU) of theoretical surface roughness is introduced. The tests had really surprising results and they can be summarised as follows:

- the measured surface roughness values – due to the disturbing phenomena, mentioned earlier – had a constant or even a mildly decreasing tendency in case of increase of the feed rate. In case of inserts, having small nose radius it can be explained by the fact that as a result of a relatively great edge rounding off, the minimum detachable layer ($h_{min}$) is great, the built-up edge and deceptive chip formation have unfavourable effect on surface roughness of the machined surface. In case of insert with greater nose radius we have measured much lower edge rounding off value, and the occurrence frequency of disturbing phenomena was lower.




a) $r_\varepsilon$=0.4 mm (ISO); chipbreaker: AL




b) $r_\varepsilon$=0.8 mm (wiper); chipbreaker: 25Q

*Figure 3:* The development of maximum height of profile (Rz) and theoretical surface roughness (RthBAU) in case of carbide inserts

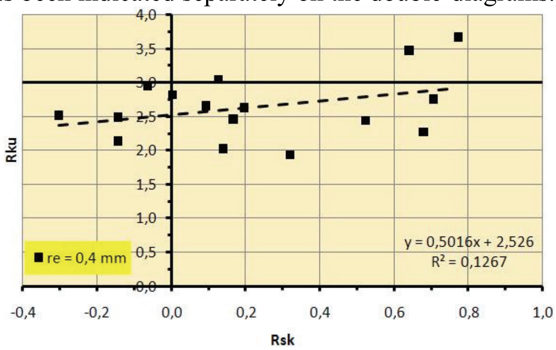
- The ISO shaped insert with nose radius of 0.4 mm (Fig. 2a) has produced just a bit worse surface roughness, compared to the surface, produced by insert with MasterFinish edge construction and wiper edge section, having nose radius of 0.8 mm. It can be explained by the fact that both carbide inserts have been applied at the same conditions (dry HSC cutting operation); therefore it was not possible to observe in full measure the development of the more favourable surface finish producing capability of the wiper edge form.
- in case of insert with small nose radius, the increase of the cutting speed has a clearly unfavourable effect from the point of view of surface roughness. The low cutting speed values, enabling favourable surface roughness, affects unfavourably the main times ($t_g$, min) and the reachable level of productivity (Q, pcs/h) in the tested range of cutting speed values. In case of insert with wiper edge form (Fig. 2b) we have succeeded to find out an optimal cutting data range, as regards surface roughness ($Rz_{opt}$=2–3 µm), it is as follows: $v_{copt}$=630–1000 m/min and

$f_{opt}$=0.08–0.1 mm. Furthermore, in this range of set values the productivity can be evaluated as excellent.

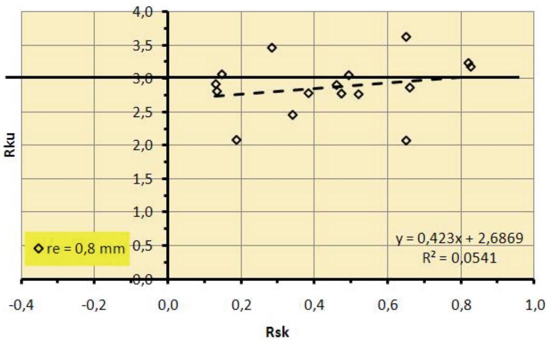
- during comparison of the performance of these two inserts, we have to consider, that the insert, having small nose radius – excepting one case – has worked with development of built-up edge or deceptive chip formation, while working with tool with MasterFinish geometry no disturbing phenomena could be noticed in the majority of cases (mainly at cutting speed value of $v_c$=1250 m/min and in case of feed rate of f=0.05–0.063 mm).

During our research – continuing our previous works – we have striven to determinate the topological map of surfaces, machined with fine turning and carbide inserts. The topological map contains the distribution of skewness (Rsk) and the kurtosis (Rku) of amplitude parameters. The first one is the measure of the symmetry of realised profile about the mean line, while the last one can detect if measure profile „spikes" or „bumps" are evenly distributed above and below the mean line. The surfaces, having reliable working properties, like Rsk<0 and Rku<3, mean that the surface roughness profile indicates a predominance of valleys, or bumpy surfaces have a low kurtosis values.

*Fig. 4* shows the average of skewness (Rsk) and kurtosis (Rku) values, determined by three individual measurements, under conditions of our examination. (The value of Rku=3, showing the Gauss-distribution, has been indicated separately on the double-diagrams.)




a) ISO shaped




b) MasterFinish edge

*Figure 4:* Topological maps of different carbide inserts with varied rake face designs
Cutting conditions: $v_c$=630–1250 m/min; f=0.05–0.1 mm; dry turning

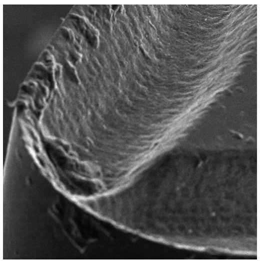
From the above diagram it can be noticed that

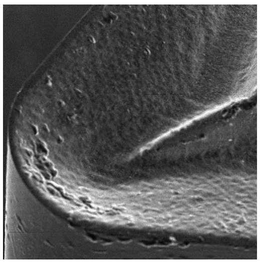
- in the range of values, settled during the examinations, the carbide inserts with different edge constructions, have produced a quite favourable surface roughness profile as regards working conditions: the Rku-values were mainly below 3.5, while Rsk values have reached a maximum value of approx. 0.8.
- the surface, machined with ISO-shaped insert, has shown negative Rsk-values in this case of certain data combination and it means – considering the low Rku-value, achieved by us – working surfaces of quite durable and long-lasting parts. It has been noticed in case of surfaces, machined with low feed rate.
- the results, gained by us, refer to the fact that 32 surface profiles, produced with both types of tools, contain details, reminding of valleys and blunt outstanding peaks. This type of surface textures means excellent load bearing capacity, appropriate wearing properties and contain cavities, being favourable for lubricating oil film.

*Application of polycrystalline diamond inserts at increased cutting speed values (quasi HSC machining)*

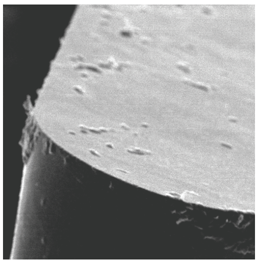
As we have already introduced in our previous studies [1-4], tools with plane rake face are absolutely appropriate to fine turning operations of high silicon-content aluminium: the Si-content guarantees the favourable break of the chip, occurred by itself. The versions with chipbreaker have come onto the market only in the past few years: these special constructions can be produced only by few companies, machining with laser operation [6].

We have already introduced some of the results, gained during fine turning operation tests with diamond inserts [2]. In this process our goal was to test different types of chipbreakers, produced by other company. On *Fig. 5* three edge types of polycrystalline diamond inserts, received from the producing company, can be observed and compared – the inserts have the same code (DCGT 11T304 FN). As it can be seen well on Fig. 5a, the type (FN), produced with plane rake face (and without of chipbreaker), has an edge rounding off value $r_n$=1.5 μm and edge roughness of $Rz_{edge}$=2.7 μm. The Fig. 5b shows the TWF coded insert: it has a chipbreaker. This type has the characteristic feature that the dividing ridge of the chipbreaker has a direct connection with the main and minor edges, therefore we can observe a narrow groove with small depth and width: it has been developed exclusively to use with low depth of cut and feed rate values. This type has an edge rounding off 2 μm and edge roughness value of 1.6 μm respectively. The TWM coded chipbreaker (it can be seen on Fig. 5c) can be characterised by relatively great width, the dividing ridge of the chipbreaker is relatively far from the edges, therefore it is customary to apply this type to chips with greater cross section. This version has been produced with the following parameters: $r_n$=2 μm and $Rz_{edge}$=1.9 μm. To sum up the results of the preliminary researches, it can be established that in case of all the three insert types the flank land and the rake face of the inserts have been finely polished $Ra_\gamma \approx Ra_\alpha$=0.04–0.05 µm; therefore we have measured unusually low values of edge rounding off. Due to space limitations we refrain from introducing further data and diagrams, concerning edges. We have taken photos on all the three insert types after machining operation, in this way the aluminium material particles, adhered to the tool and the wear marks, developed on the inserts, can be understood well.





b) TWF-type, with breaker c) TWM-type, with breaker

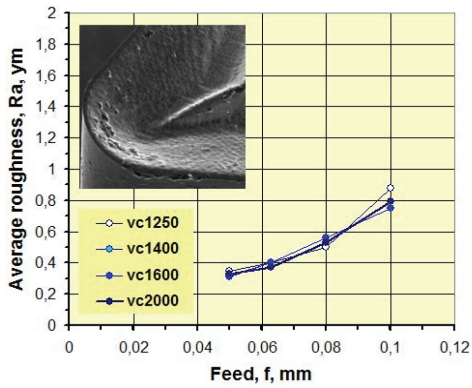


a) FN-type, without breaker

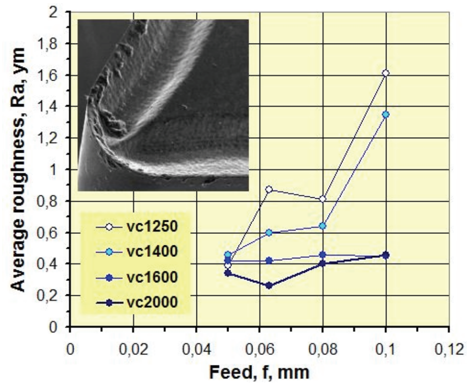
*Figure 5:* The tested polycrystalline diamond inserts with various rake face constructions (SEM photograph, magnification: 150x)

*Fig. 6* shows average results of three measurements: the tests have been carried out with the same depth of cut value (a=0.5 mm) and similar feed rate values (f=0.05–0.1 mm) and in the range of cutting speed values ($v_c$=1250–2000 m/min), settled for diamond tools. Based on the measured average surface roughness values the followings conclusions can be drawn:

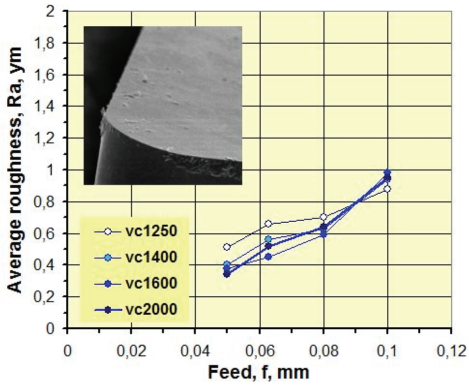
- in that case of machining with insert, produced without chipbreaker, the settled feed rate powerfully influences the measured surface roughness values, while the applied cutting speed value has a lower influencing affect on it; therefore the surface finish producing capability of this insert can be evaluated as moderate.
- the insert with TWF chipbreaker reacts to the settled cutting data really sensible: at low cutting speed values the settled feed rate causes really great deterioration in the surface roughness, while in case of cutting speed values of $v_c \geq 1600$ m/min the feed rate almost does not influence (!) the roughness of the machined surface.
- the TWM chipbreaker has excelled in its surface finish producing capability: it was the best, the cutting speed values have not influenced the surface roughness, the feed rate had only small influence on it.
- during the evaluation of the results we have to consider the fact that the final profile of the machined surface is mainly determined by the feed rate values, settled by us (this is the so-called kinematic or theoretical roughness), but the undesirable phenomena, like undetachable chiplayer ($h_{min}$), built-up edge (BUE), formed on the rake face or deceptive chip formation (DCH), developed on the flank land, have a great effect on it. The last-mentioned phenomena have played a significant role on the surface roughness, determined with measurements, and in case of FN geometry we have observed the development of these phenomena in 12 cases from 16 data combinations. In this case of inserts with chipbreaker the disturbing phenomena, stated earlier, have played smaller role: in case of tests, carried out with TWF, we have observed the development of BUE and/or DCH in 9 cases, while in case of TWM-type only in 3 cases.




c) chipbreaker type: TWM




b) chipbreaker type: TWF




a) without chipbreaker

*Figure 6:* The development of average surface roughness parameters in function of examination data, at finish turning with polycrystalline diamond inserts Cutting conditions: $v_c$ = 1250–2000 m/min; f=0.05–0.1 mm; dry turning

Summing up the results of the researches, carried out by us, we can establish that in case of dry machining the disturbing phenomena are surely limiting factors from the point of view of the minimum produceable surface roughness. If these phenomena do not develop too often, then – considering the point of view of process security – the same surface roughness values as in case of use of flushing-cooling-lubricating liquids can be reached even in case of working surfaces of parts, produced under conditions of environmental-friendly machining [1, 2].

The Rsk-Rku diagrams (i.e. the topological map) of the polycrystalline diamond inserts have shown an interesting result *(Fig. 7)* – the diagrams have been made based on average values from three measurements. In case of FN-type insert with plane rake face (and without chipbreaker), the Rsk-Rku values, measured at the same time and in case of machining with different data combinations, have been depicted in diagrams: the values are distributed in a very wide range, as regards skewness and kurtosis values, and their tendency has shown a surprising great correlation. The Rku and Rsk-values of the insert with TWM chipbreaker, having achieved a better performance, have distributed in a much narrower range, but it is much more difficult to determine any trend.

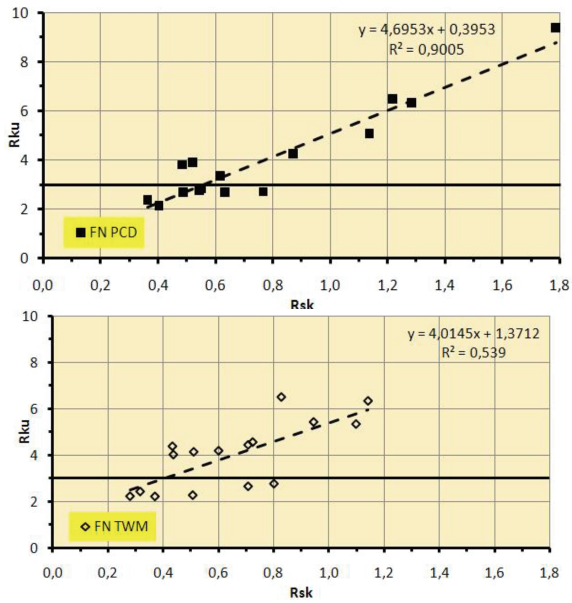



*Figure 7:* Topological maps of different PCD inserts with various rake face constructions
Cutting conditions: $v_c$=1250–2000 m/min;
f=0.05–0.1 mm; dry turning

*The correlation of the surface roughness and the cutting data*

From the tests, carried out by us, it become clear that the arithmetical height roughness parameters (like Rz, Ra etc.) significantly depend on the cutting conditions. In the previous parts of the present study we have separately analysed the effect of feed rates and cutting speed values on the surface profile, developed during machining. The results of several surface roughness measurements, carried out by us, show promise for us to use the formula, developed by us, to the calculation of theoretical surface roughness values in the following form:

$$R_{elm} = c_1 \cdot h_{min} + c_2 \cdot f^{c_3} + c_4 \cdot h_{min} \cdot f^{c_5} \qquad (1)$$

where
$h_{min}$ – minimum detachable layer thickness, µm,
$f$ – settled feed, mm,
$c_1$, $c_2$, $c_4$ – constants, determined with regression,
$c_3$, $c_5$ – exponents, determined with regression.

The feed rate ($v_f = f \cdot n$, mm/min) is a complex, characteristic mark of the turning operation, combing two cutting data, (feed rate, $f$ and cutting speed, $v_c$) and through the main machining times it significantly influences the important objective functions of the process – and in this way the optimal conditions of the machining as well. Based on the results of our tests, the Rsk and Rku values, describing the statistical distribution of the outstanding peaks of the machined profile, have a provable correlation with the feed rate. According to our experiences, in all cases, examined by us, the Rku parameter, compared to the Rsk, show a tighter correlation with the settled $v_f$ values. *Fig. 8* shows the comparison of two polycrystalline diamond inserts, having different rake face constructions.

Analysing the diagrams, the conclusion can be drawn that Rku values have shown a clearly decreasing tendency in case of increase of the feed rate. The insert with a plane rake face construction has shown correlation of relatively greater tightness, while in case of the insert with TWM chipbreaker correlation with smaller tightness can be observed. From the examinations it has become clear that the most favourable Rku values have been observed above the cutting speed value of $v_f \geq 360$.

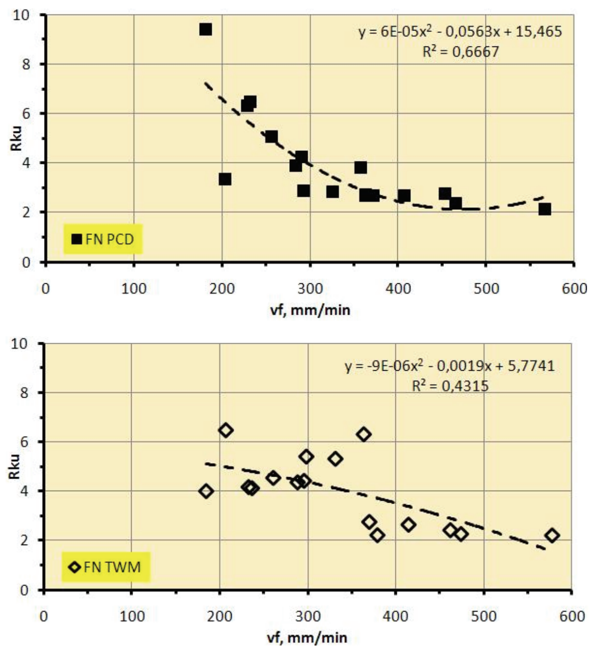



*Figure 8:* Kurtosis vs feed rate of polycrystalline diamond inserts with varied rake face constructions
Cutting conditions: $v_c$=1250–2000 m/min;
f=0.05–0.1 mm; dry turning

In both cases the number of the optimal settlements amounts to 6, they belong to the following values: $f_{opt}$=0.08–0.1 and $v_{copt}$=1600–2000 m/min. We would like to remark that the correlation between Rsk and $v_f$, published in our previous articles [1-5], has shown a similar characteristic mark, and it was possible to determine it either with function, locating minimum extreme value or with monotonous decreasing function.

**Summary**

During our short term tests, carried out to examine the cutting performance of applied inserts, we can get a picture about the roughness parameters of surfaces, machined with tools, having different materials, shapes, constructions and produced by different manufacturers. The most important conclusions are the following:

1. One of the important conclusion of our researches is that in case of diamond insert, with appropriate tool material design and edge geometry, it is possible to meet the requirement of the average surface roughness Ra≈0.3 μm, even under conditions of environmental-friendly machining.

2. The carbide as tool material may be used in case of dry machining only in case if the insert has a shape, being similar to the one, published in the present article (point angle $\varepsilon_r$=55°), has a wiper-like edge construction (so-called MasterFinish) and the operation is carried out with similar conditions, as mentioned in our present study.

3. We have shown a clear correlation between the surface finish producing capability of the inserts, and the topological map. The Rsk and Rku diagrams can play an important role during the selection of the optimal insert and generating data as well. For the last one there was a demonstrative example: the data search, carried out based on Fig. 8. It is recommended to carry out preliminary tests in case of preparation works, prior to production in large series.

We are going to conduct further research on other environmentally-friendly methods of cutting operations and in our next paper we are going to introduce the results of the process, carried out with compressed, cold air and with minimum quantity of lubrication (MQL/MMKS).

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