HUNGARIAN JOURNAL
OF INDUSTRIAL CHEMISTRY
VESZPRÉM
Vol. 38(2). pp. 99-105 (2010)

ENVIRONMENTAL-FRIENDLY CUTTING OF AUTOMOTIVE PARTS MADE OF ALUMINIUM CASTINGS

R. HORVÁTH, B. PALÁSTI-KOVÁCS, S. SIPOS

Bánki Donát Faculty of Mech. Eng., University Obuda, HUNGARY
E-mail: horvath.richard@bgk.uni-obuda.hu, palasti@uni-obuda.hu, sipos.sandor@bgk.uni-obuda.hu

Through an example of an automotive component, the lecture introduces difficulties, arising during the turning operations of high silicon content aluminium castings. It evaluates the production, running currently with cutting fluid flood-type application; introduces the preliminary tests, carried out before change-over to the green manufacturing; furthermore, the circumstances of the tests, carried out with the method of DoE at High Speed Machining. The results of measurements, carried out with different tool materials and edge constructions, will be evaluated from the point of view of surface roughness minimisation. The results of topographic (3D) measurements of the machined surface will be compared with the results, gained with the electron-microscope; the disturbing phenomena, arising during the turning operation with diamond tool, will be analysed. Finally, the production circumstances will be determined in order to ensure the prescribed surface roughness - despite the increased productivity and the environmentally friendly cutting.

Keywords: machinability, green machining, aluminium castings, polycrystalline diamond turning, CVD coated thick diamond layer

Introduction

One of the determinant characteristics of modern production is that the quality of the products is improving continuously: on of its cause can be the development of the machine tools, the other important reson is the development of new geometries and tool materials. This progress is accompanied by an ever-increasing productivity (reduced productive time, shorter non-productive times and production period) as well. This process can also be noticed especially in the case of high level technologies, characteristical for the modern automotive industry, defense industry, aircraft industry and aerospace industry.

Another determinant factor, to be considered during the production, is the increased consideration of the effects, carried out on the environment: we must abstain from processes, harmful to the environment; and the safe treatment, storage and desposal of waste materials are also our tasks to be solved. The manufacturing intermediates (cooling liquids, emulsions of different concentrations, lubricants) can cause huge danger to the environment. The fact is that there are always more and more strict regulations in favour of the environmental-friendly production.

In this article we are going to present the difficulties, arising during the turning operations of the fixture of a large-scale produced compressor. The paper will also present possible solutions and determines the circumstances, meeting all the three segments of the concepts of “quality-environment-productivity”.

Machinability of high silicon content aluminium alloys

The industries, mentioned earlier, use preferred aluminium cast alloys, especially versions, alloyed with silicon, copper, magnesium. In these alloys excellent mechanical features (hardness, strength) and appropriate technological advances (excellent castability, machinability, corrosion resistance, weldability) are combined. Parts, made in the 80’ and made of aluminium with high silicium content, have spread in the automobile industry (for example, fixtures of engines, compressors, steering devices) and their unfavourable machinability causes several problems.

The aluminium alloys, having a silicon content of higher than 11.8% are called hypereutectic, and almost all of them have good strength characteristics, higher fatigue limits and excellent wear resistance. One of the circumstances, making the machining difficult, is that aluminium is an easy-to-machine material, soft and ductile; but with increasing the Si-content, the abrasive effect of the alloys increases and the difficulties, arising during the machining, are on the increase. Because of the primary silicon crystals, embedded in the aluminium matrix, the chips breaks off easily; however, the presence of these hard particles leads 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. In case if the primary Si-particles contact the tool edge in the cutting zone, then they wear it; furthermore, due to their hardness they hinder the formation of good quality surfaces. Therefore, the precondition of the favourable surface roughness is the even dispersion, small grain size and favourable shape of the primary Si-particles, otherwise the particles, adhered to the edge on the “adhesion way”, can “plough” the surface completely, to be machined.

The situation can be even more complicated if the interdendritic region contains a high number of resistant intermetallic precipitates and inclusions. The cause-effect diagram (the so called Ishikawa diagram) of the unfavourable machinability of these cast alloys can be seen in *Fig. 1* [1, 2].

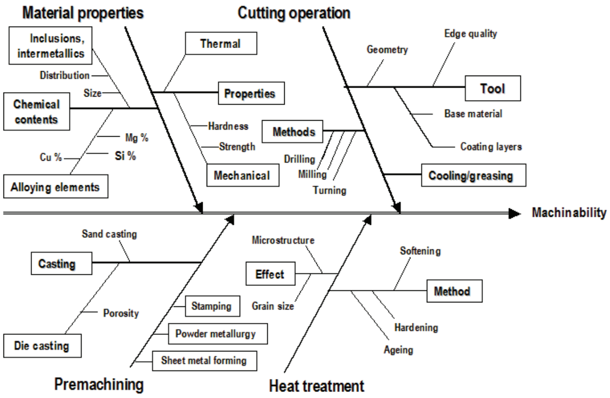


Figure 1: Machinability of high silicon content aluminium casts

Only tool materials with the highest performance can overcome the difficulties, as illustrated in Fig. 1. As already presented in [3, 4, 5], the polished types of ISO cemented carbide, belonging to K-group, are convenient for it only in limited degree. The most appropriate solution is to use monocrystallic, natural and artificial, polycrystalline diamonds and diamond layers, deposited with CVD. These tools appeared in the market recently.

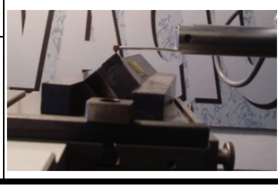
In the production of the manufacturer, flood type application of cutting fluid has been applied untill now. These were water soluble mineral oil, free from amine, sometimes cooling-lubricating liquid, containing EP additives. Although this medium enables the most convenient occupational health and safety conditions (its pH-value is 7.5–8.8), there is a huge consumption of it, nearly 30 l, calculated to one piece in case of turning with a diamond edge tool; furthermore, the cooling-lubricating liquid costs 5 HUF per each part. Therefore the company has made a decision about technology change to the environmental-friendly cutting: the casts, produced till now in millions of items, will be machined by dry turning.

Description of the goals and circumstances of the tests

The main goal of the tests was to get clear picture how the tools of different materials and with different construction can meet the extremely rigorous roughness standards, applied in the automobile industry. The difficulties have been increased further by the fact that we had to carry out the trial tests without cooling-lubricating liquid.

Measured surface roughnesses, made with poly-crystalline diamond of different compositions, have been compared, where the dry turning operations have been performed with tools with different point angles and nose radiuses; the cutting speed has been varied in a very wide range (v_c = 500…2000 m/min). The depth of cut – due to reason of saving materials – has been kept on a constant value (a = 0.5 mm), other testing conditions can be seen in *Table 1*.

Table 1

Machine tool	Type: EuroTurn 12B (NCT Kft.) Control: NCT2000	
Workpiece	Material: AS17 (Rencast Reyrieux) Contents: Si 16.8%, Cu 4.1%, Zn 1%, Fe 0.8%, Mg 0.5%, Mn 0.2%, Other components: Pb, Sn, Ni, Ti (<0.08%)	
Applied turning inserts made of diamond	CCGW09T304FST KD1425 (Kennametal) CCGW09T308FST KD1400 (Kennametal) CCGW09T308FST KD1425 (Kennametal) CPGW09T308FWSTKD1425 (Kennametal) CPGW09T304FST KD1425 (Kennametal) CCGT 09T304 CB1 PDC (WNT Deutschland GmbH) CCGT 09T304-W CB1 PDC (WNT) CCGT 09T304 CB1 CVD (WNT) CCMW09T304 MD220 (Mitsubishi) DCMT11T304 ID5 (Iscar) DCMW11T304FP CD10 (Sandvik) DCMW09T304 MD220 (Mitsubishi)	
Testing circumstance	a = 0.5 mm (constant) v_c = 1000 … 2000 m/min (varied) f= 0.05-0.063-0.08-0.1 mm (ISO) f=0.1-0.125-0.16-0.2-0.25 (wiper)	
Measuring devices	Surftest SJ301 (Mitutoyo, Japan) Perthometer Concept 3D (Perthen-Mahr, Germany) Electron microscope JSM-5310 (Jeol Co., Japan)	

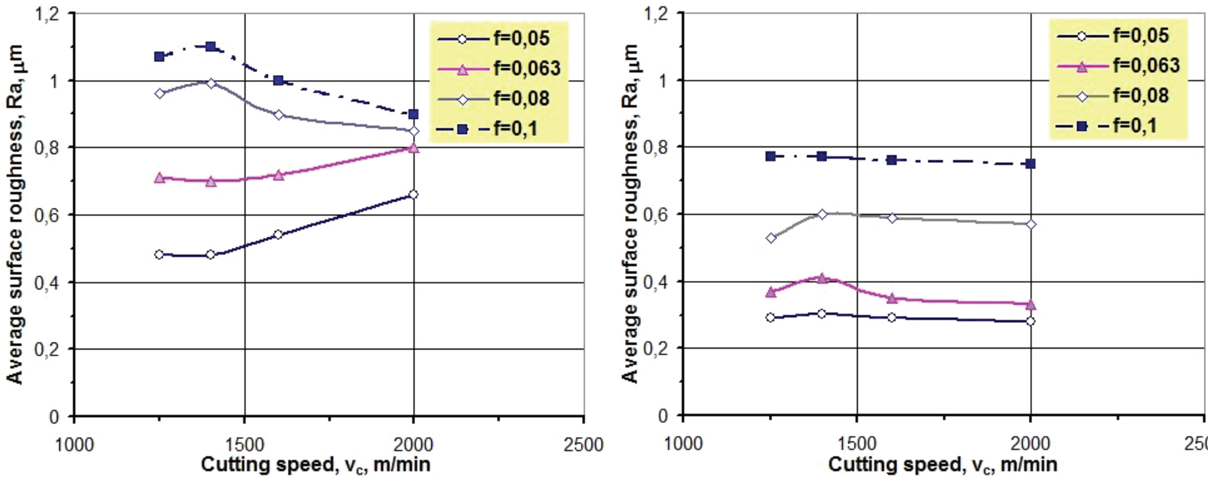
Test results

Due to space limitations it is not possible to present the complete results of our systematically performed tests; the research experiences of our far-reaching examinations will be summarised later. The description below contains the surface roughness values, measured along 3 different measuring lines, by setting every single test values.

Effects of the tool geometry

The most important features of the tool edge geometry are the point angle, rake face angle and design (with and without chipbreaker), flank face angle, nose radius of the insert and the tool edge quality. The selection of the insert with optimal design influences significantly the expectations, concerning the quality and efficiency during the cutting machining process [6].

In case of light metal alloys it is a general accepted principle to apply the point angle as small as possible: during the turning operation the surface roughness is considerably better if the chip has enough free space to leave the process, with other words: the chip space is wide (is not limited) [3]. This value of angle is in case of CCMW insert 80°, while in case of DCMW it is only 55°. The tests, carried out with the inserts of famous tool manufacturers, have confirmed that the average surface roughness values (Ra) can be significantly affected not only by the feed rate, but by the point angle of the insert as well. As it can be seen on *Fig. 2*, the value of Ra (average surface roughness) is by 20–40% smaller in case of application of sharper point angles. Furthermore, the Ra value of <0.4 μm can be achieved without any difficulties under reasonable defined machining conditions, even in case of inserts with small nose radius applied by us. What is surprising in this fact is the rate and this phenomenon can be noticed so significantly even in case of hypereutectic Al-Si alloys, This type of material has been also tested by us.



a) Insert code: CCMW (ε_r = 80°) b) Insert code: DCMW (ε_r = 55°)

Figure 2: Surface roughness under high speed cutting conditions
Cutting conditions: v_c = 1000–2000 m/min; r_ε = 0.4 mm

An important factor, to be considered during the design of the insert, is the nose radius, its increase affects favourably the surface roughness. In *Fig. 3a* the different (measured and calculated) surface roughness values can be seen: the R_{theor} value means the surface roughness data, calculated with the well-known Bauer-formula:

$$R_{theor} \approx R_z \approx 125 \cdot \frac{f^2}{r_s}[\mu m] \tag{1}$$

Another known and used formula (see (2)) has been created by Brammertz:

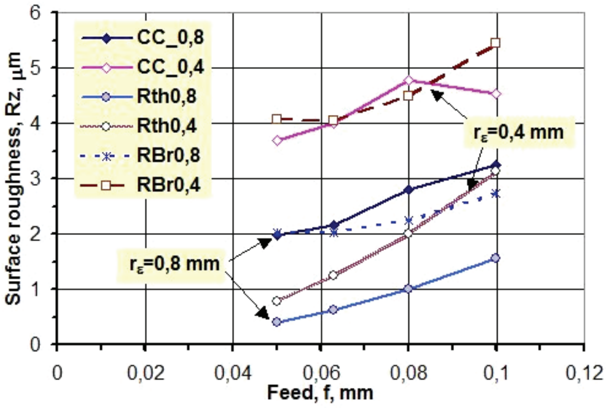
$$R_{thBr} = 125 \cdot \frac{f^2}{r_s} + \frac{h_{\min}}{2} \cdot \left(1 + \frac{h_{\min} \cdot r_s}{f^2}\right)[\mu m] \tag{2}$$

This (2) relationship can be convenient to provide a basis for the determination of a reasonable feed rate during the technological design process, provided that we use the formula, applied by us, as the method of continual approaches. The aim is to define the value of the minimum undetachable chip thickness ($h_{\min}$) [1] with a computer program. Other tests, carried out by us, have confirmed that in case of change in cutting speed values, very diverse average surface roughness values have been measured by applying inserts with relatively small (e.g. r_ε = 0.4 mm) nose radius. In case of inserts with bigger nose radius (e.g. r_ε = 0.8 mm) much more regular, better predictable surfaces have been produced.

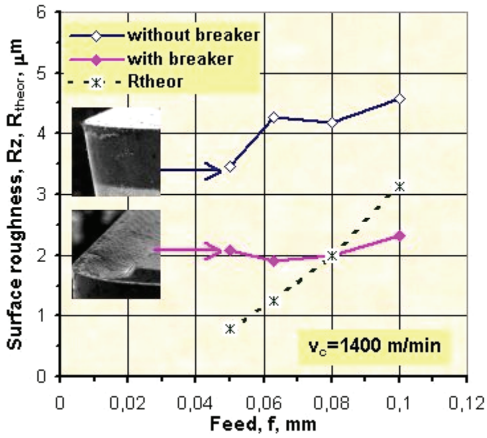
Beside the tests, carried out on traditional designed rake face, we have had the possibility to test the version with chip-breaker as well [7]. As it can be seen in *Fig. 3b*, the chip-breaker, produced with laser, is extremely efficient and it reduces the value of R_z (so called maximum height of profile) almost by 100%. It can be seen as well that the so called Bauer-formula can describe the real surface roughness only in limited degree.

The insert selection determines the value of relief angle, to be applied during the cutting process and it significantly influences all characteristics of surface roughness. Based on our tests, we can observe that bigger relief angle produces much more regular surface roughness profile as the edge of the diamond tool creates much more characteristic mark on the workpiece, preventing the development of adhesion layer (deceptive chip formation) on the flank land. Analysing the *Fig. 4a*, we can notice that all values of maximum height of profile (R_z) are significantly lower in case of each test setting. Beside this fact, the components, turned with CPGW coded insert, have much more favourable behaviour (smaller wear, longer life time) than in case of workpieces, machined with CCGW coded insert (relief angle: 7°). From the surface roughness parameters, the kurtosis of profile informs us about it: the kurtosis of profile (Rku) is the quotient of mean quadric of the ordinate values, within the sampling length. *Fig. 4b* shows that the texture of surface profile has much more favourable distribution (so called full surface profile), if the machining is carried out with great relief angle, at increased feed rate. For example, if Rku-value is higher than 3, then the machined surface has a many outstanding peaks, so the working surfaces, sliding away on each other, can be characterised by really intensive wear [7].

Due to space limitations it is not possible to analyse the tool edge quality (surface roughness values on the rake face and flank land of the inserts, roughness of main cutting edge, edge sharpness, edge radius etc.)

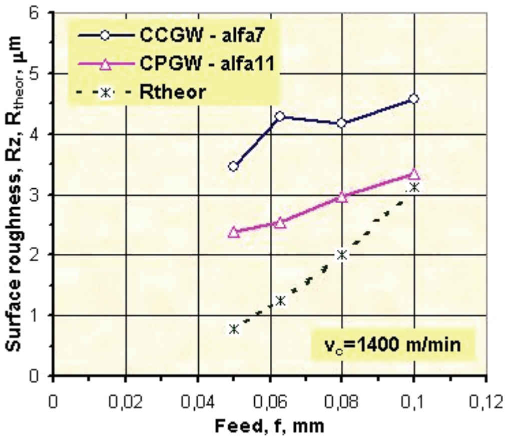


a) different nose radii (r_ε = 0.4 and 0.8 mm)

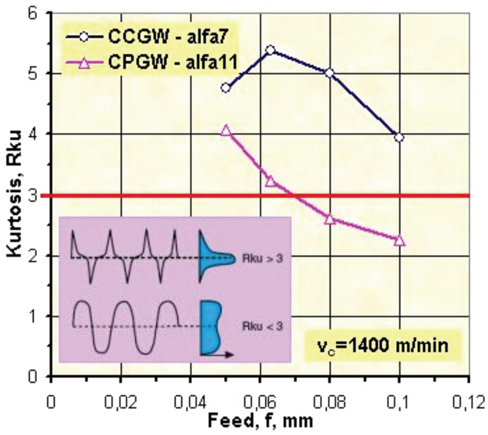


b) different versions of rake face

Figure 3: Surface roughness vs. insert geometry
Cutting conditions: v_c = 1400 m/min



a) maximum heights of profile



b) profile kurtosis

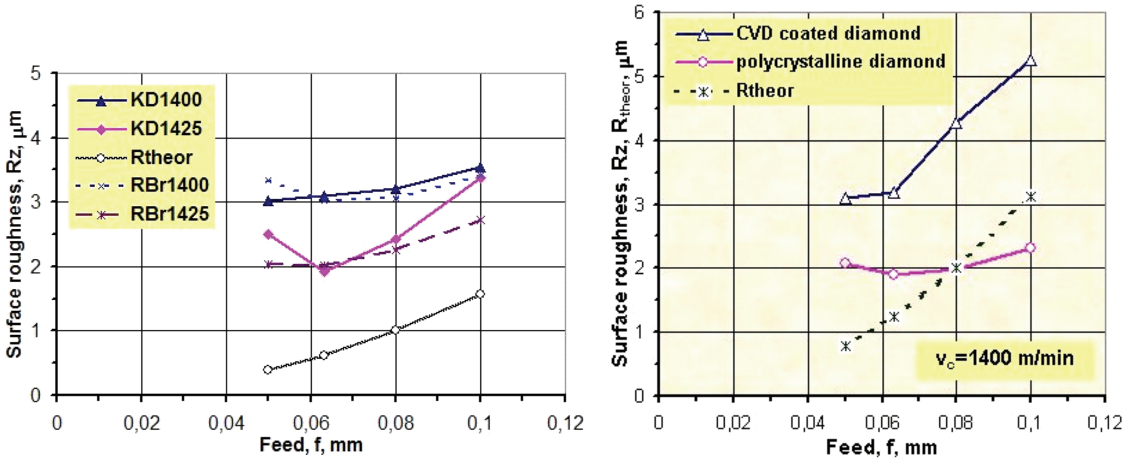
Figure 4: Surface roughness versus relief angle

The effect of the tool material

The first material, coming into question, is the polycrystalline diamond (PCD): it has anti-adhesion characteristics, chemical inertness, compared to cemented carbide better abrasive wear resistance and low friction coefficient. These technological characteristics make it possible, and, the expensive tool materials requires to use PCD inserts at increased cutting speed values, especially if the component is produced in large scale, with high quality expectations, in environmental-friendly way.

The size and structure of the grains of PCD significantly affect the Rz value of the machined surface. As it can be seen on *Fig. 5a* the KD1400 grade is fine-grained (~2 µm), the wear resistance of the KD1425 grade, having a grain size of 2…30 µm, is greater as it has a multi-modal structure. The measured Rz values inform us that the use of diamond inserts is not effective enough at low cutting speed values. This last version can withstand moderate interruptions, appearing – in the case of machining aluminium alloys – in the form of microporosity, caused by the hydrogen gas. At low cutting speed values and feed rates it is recommended to use the grade with higher wear resistance, in case of higher cutting speed values the recommendation "for high speed finishing", given for the KD1400, can prevail.

Other tool material, coming into question is an approximately 1 mm thick diamond layer, deposited with CVD: compared to the polycrystal it has different behaviour. This layer, deposited at very low pressure, can be characterised by a really low friction coefficient, (built-up edge, deceptive chip formation), connected with the adhesion of the machined material, will not even develop. Based on *Fig. 5b*, summing up the results of the tests, it can be noticed that (to our surprise) the PCD insert has permanently achieved Rz value of approx. 2 µm, while diamond layer, deposited with CVD, has "produced" greater surface roughness by 50–130%.

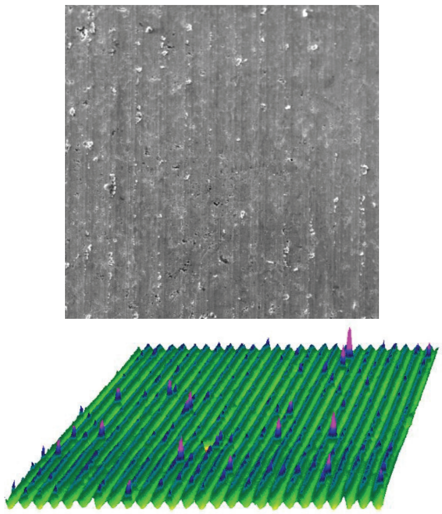


a) various types of polycrystalline diamonds (r_ε = 0,8 mm; v_c = 500 m/min)

b) various origin of diamonds (r_ε = 0.4 mm)

Figure 5: Surface roughness versus insert material

The micromechanisms of cutting operations have been confirmed by the photos, taken with electron microscope (type JEOL JSM-5310). With the help of 3D surface roughness (i.e. microtopographical) measurements we can get even more detailed picture about the textures of surfaces, machined with polycrystalline diamond tool. *Fig. 6* shows a photo with 1000 magnification, taken of a surface, turned with a PCD tool. It shows the photosimulation visualisation of the machined surface, filtered from the waviness and cylindricity, the most important parameters of the P-topography. Some 3D roughness parameters can be seen in this figure (for example arithmetical mean deviation, sPa; total height of profile, sPt; the profile peak heights, sPp; the profile valley depths, SPv etc.). The profile peak heights, machined with PCD tool, are significant lower (sPp), the profile valley depths are much higher (sPv). It means that diamond tool produces much more even surfaces and it "machines" the surface in its real meaning. It is confirmed by the kurtosis value of profile (sPKu < 3), characterising the topography height distribution of the 3D surface roughness values as well. On the examined section of surface, machined with PCD tool, whole "series" of primary Si-crystalls can be observed in the feed grooves.



2 mm × 2 mm (1000 × 1000 points)

T: sPa	2.54	µm
T: sPv	16.30	µm
T: sPp	10.54	µm
T: sPt	26.83	µm
T: sPq	3.02	µm
T: sP Sk	1.47	
T: sP Ku	2.54	

Results of 3D surface representation

Figure 6: Microtopography of surface, machined with polycrystalline diamond
Cutting conditions:
v_c = 1000 m/min; f = 0.05 mm; r_ε = 0.4 mm

Tests of up to date constructions diamond inserts

We have managed to purchase diamond inserts with different materials and different edge constructions *(Fig. 7)* from the same company. The common characteristic of the tested inserts is the chip-breaker, produced with laser: its design can be seen well on the photo, taken with an electron microscope with 150 magnification.

The material and design of the tool edges, differing from the traditional ones, have had undoubtly positive effect on the results, gained with the presented inserts. All results, introduced till now, refer to ISO shaped inserts (where nose radius is surrounded by two straight edge sections). If the main and minor cutting edges have been made with great radius (it means the insert has wiper edge form), then the surface is machined mostly by nose radius and by minor cutting edge. The amplitude parameters of the surface texture (for example, average surface roughness (Ra), maximum heigth of profile (Rz) etc.), machined this way, are significantly lower, with the same test settings. As it can be seen in *Fig. 8*, it is also possible to set data, enabling two and a half times greater productivity – the surface roughness values are the same. In case of inserts with wiper edge form, the expectable results can be influenced by deceptive chip formation, developed as a result of increased cutting speed values: it contacts the machined surface as well.

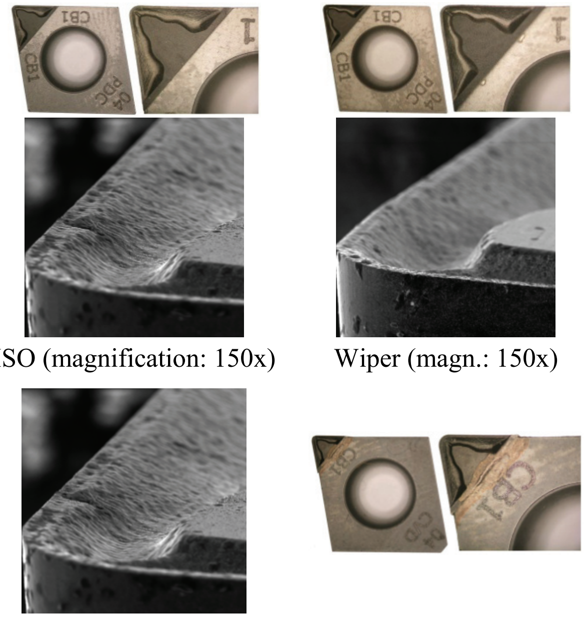


Figure 7: Several diamond inserts with up-to-date constructions

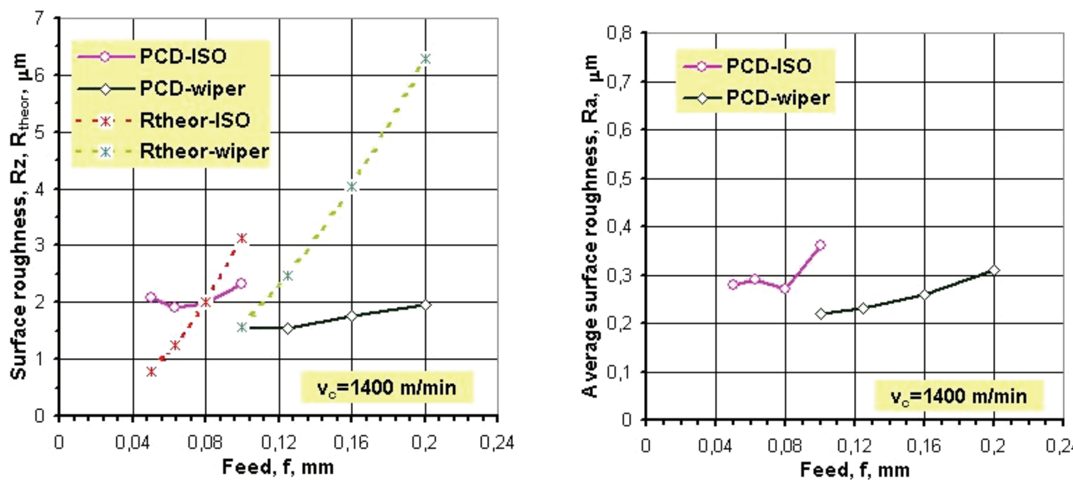


Figure 8: Development of surface roughness in case of ISO shaped and wiper insert

Summary

During our short term tests, carried out to examine the machinability of the grade, mentioned earlier, we can get picture about the roughness parameters of surfaces, machined with tools, having different materials, shapes, constructions and produced by different manufacturers. We have carried out 2D and 3D measurements; and also, our tests have been extended by electron-microscopic analyse as well. Not having the approval from the manufacturers, we do not wish to publish the results of our research in details.

The most important conclusion of our investigations 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 $\leq$ 0.2 µm, even under conditions of environmental-friendly machining. The circumstances of the application can be seen in the diagrams, presented earlier. In case of insert with wiper edge form, the productivity can be increased by twofold or more. The strategy and exact steps how to avoid disturbing phenomena (built-up edge, deceptive chip formation), developing during the cutting process of aluminium parts, will be presented in our next paper.

ACKNOWLEDGMENTS

Authors wish to thank Mr. Tornyi, Mr. Nagy and Mr. Benkó, working at Delphi Thermal Hungary Kft. in Balassagyarmat, for their valuable comments and for the company as well, having provided us with the casting components.

REFERENCES

1. www.forgacsolaskutatas.hu/Elmélet/Forgácsolhatóság
2. H. YE: An Overview of the Developement of Al Si-Alloy Based Material for Engine Applications JMEPEG (2003) 12:288-297.
3. R. HORVATH, S. SIPOS: Machinability of High Silicon Content Aluminum Alloys, microCAD 2010 International Scientific Conference, Miskolc, 18-20 March 2010. Section N: Production Engineering and Manufacturing Systems, 75–82, ISBN 978-963-661-918-3.
4. R. HORVÁTH, S. SIPOS: Nagy szilíciumtartalmú alumíniumötvözetek forgácsolhatósága, XV. Fiatal Műszakiak Tudományos Ülésszaka, Kolozsvár, 2010. március 25-26., 135–138. ISSN 2067-6808
5. R. HORVÁTH, S. SIPOS: Nagy szilíciumtartalmú alumíniumötvözetek forgácsolhatósága Gyártóeszközök, szerszámgépek, szerszámok, 15, 2010. 44–48.
6. www.fogacsolaskutatas.hu/Szerszámválasztás
7. B. PALÁSTI KOVÁCS, Á. CZIFRA, S. HORVÁTH, S. SIPOS: Műszaki felületek mikro-geometriájának, mikrotopográfiájának vizsgálata és értékelése, Gép, 2010.