Szent István University

MICROTOPOGRAPHIC CHARACTERISICS OF ENGINEERING PLASTICS' SURFACES TURNED

Thesis of the doctoral (Ph.D) dissertation

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1. INTRODUCTION AND AIMS OF THE DOCTORAL DISSERTATION

1.1. The significance of the research

The surface quality is influenced by numerous factors which can be approached from the manufacturing and from the utilization sides. The surface formed during machining has an effect on the operational characteristics of machine-parts, on their tribological behaviour. Roughness measuring numbers are used to characterize the surface quality in the technical practice which can be 2D, so called microgeometric parameters and 3D so called microtopographic characteristics. The surface microgeometric measuring and characterizing are mostly standardized so it is suitable to compare certain types of surfaces. Wide-ranging set of parameters is available to characterize the surface texture, the industrial practice uses still 2-3 measuring characteristics. The computing technique development made it possible to intake great number of data in comparatively short time, and so introducing the 3D-al surface evaluation, too. The favoured interest of scientific life to surface topography is caused by making possible the significantly more reliable characterizing of the surface. Stout and his fellows put down the foundation of the 3D-al evaluation technique when in their publication explained the 3D-al surface roughness and they defined the 3D-al measuring characteristics, too. Wide-ranging attention is in the field of technical sciences now days to develop various plastics. During the century old history of plastics such extensive developments happened those nowdays they already don't pass for substitute material but they pass for very important constructional material in the industry almost in every field. They often surpass the traditional materials in their properties, by changing their composition (for example: adding softening material, fibre reinforcement) they can be formed onto concrete application field. The lower density the high strength, the corrosion resistance the chemical stability, the electric resistance capability are advantages comparing to the metals but their disadvantageous properties as the low heat-resistance from time to time the high moisture absorption has also to be taken into consideration during their use. „The engineering plastics are such polymers which have got excellent mechanical properties in wide ranging temperature". These plastics are produced in more forms, which depend on basically their further processing methods. They can be powder or granule products, semi-finished products (bars, pipes, plates etc.) finished product respectively. One important group of engineering plastics in the general type engineering plastics, among them I have carried out cutting experiments with cast polyamide 6, with poly(oxymethylene) co-polymer and with poly(ethylene-terefthalate) materials. Among the high-performance engineering plastics I have selected the poly(etherether-ketone) plastic as high heat resistance, high-strength, good dimensional stability and rigidity characterizes it, its use is extremely widespread as example: aviation engineering, vehicle engineering, chemical and electric industry etc.

The cutting process, within this using turning at machining plastic for nowadays has got great importance and is mainly sole in repair technology. Despite this the technical literature gives the characteristic cutting parameters for certain plastics between very wide limits which first of all tend towards deformation caused by temperature to avoiding possible softening, serving respectively the economical production in the technical practice. The spreading of engineering plastics cut compelled the tool manufacturers to develop tools suitable machining plastics, too.

1.2. The aims of the research

During my research work the modelling of grinding process carried out in circulating ball grinder and the machining circumstances and data in the cutting process has to be selected such way that the work piece machined should be suitable to the accuracy to gage, to the geometrical trueness as well as to the surface quality given by the designer. Several researchers dealt with the machining of metals by cutting as well as with the examination of factors characterizing the given process (in case of turning for example: feeding, nose radius, cutting time, cutting speed, edge geometry etc.) having effect on the surface roughness.

The primary goal of my research work is to evaluate and to analyse the parameters of surface roughness of engineering plastics machined by turning. Further important task is to work out the requirements of suitable surface planning of expected operational behaviour of surfaces produced during machining plastic parts. The most important viewpoint was that the experiments' results should be useful for engineering practice, too. The connection between the surface microgeometry and the technological data at cutting of engineering plastics now days are not yet revealed properly. I have selected some thermoplastics types among the engineering plastics as test material which fulfil decisive role in engineering application.

- Examining the interaction between the tool-edge determined geometrically (various tip geometries, technological parameters) and the surface machined. The applied turning parameters during the first two test phases: cutting speed: v_c = 200; 250; 315; 400 m/min, the feeding during roughing phase: *f* = 0,2 ; 0,25; 0,315; 0,4 mm/rev., the feeding during finishing phase: *f* = 0,05 ; 0,08; 0,12; 0,16 mm/rev., the depth of cut: *a* = 0,5 mm (keeping on constant value). The cutting speed during the third phase of test: v_c = 400 m/min (keeping on constant value), the feeding: *f* = 0,08; 0,125; 0,2; 0,315 mm/rev., the depth of cut: *a* = 1,0 mm and *a* = 2,0 mm.
- Examining the characteristics of surface pictures got by electron microscope (SEM) and of information-content in case of PEEK engineering plastic.
- To discover function-relations with empirical relations taking into account the effect of must influencing factors, too. I examine the $R = C_R \cdot v_c^{x_1} \cdot f^{x_2}$ function-relation with experiment planning method, in which the parameters selected is *Ra* (average roughness) and the *Rz* (unevenness height), the set out factors are the cutting speed (v_c) and the feeding (*f*).

Ramifying technical literature belong to the theme mentioned above, because of this I limit the survey of technical literature to the most important literatures considering the theme and I review these is the next chapter.

2. MATERIAL AND METHOD

2.1. Engineering polymers

Plastics are such organogenous giant molecular materials to be produced and workable by technical processes which are produced by transforming synthetic or natural giant molecules. The plastics are total value structural materials since decades which are applied by the engineering practice in several areas. The technological processes connecting to produce and to work plastics – by continuous increase of their application – develop in a great extent from day to day. The plastics can be put basically into two groups concerning their behaviour against heat, they can be thermoplastics and non-softening plastics. The technical literature distinguishes further two groups too:

- General type engineering plastics the polyamides (PA), the poly-oxymethylenes (POM), the polyethyleneterefthaletes (PET) as well as the polyethylenes with ultra-high molecular weight (UHMW-PE) belong to here.
- High-performance engineering plastics among them belong the polyetheretherketone (PEEK) the polyphenylsulfide (PPS), polyvinyldenfluoride (PVDF), the polyimide (PI) etc.

I have selected from the wide-ranging assortment of engineering plastics four crystalline structure thermoplastic polymers for research work: cast polyamide 6 (PA6), poly(oxy-methylene) (POMC), poly (ethylene-terefthalate) (PET), poly(ether-ether-ketone) (PEEK).

In case of machine-parts produced from engineering plastic semi-product by cutting that interest can be observed that the quality and accuracy to gage of the surface quality got can significantly differ depending on the molecular structure in case of identical cutting parameters, too. Because of this it is reasonable by a means to examine and to research separately the polymers with significant different molecular structure it the interest optimizing cutting.

2.2. Engineering plastics machining by cutting

During developing up-to-data products it cannot be left those structural materials out of consideration which are evident from their strength and thermal physical properties as well as low density. Such materials are among others also the plastics, by which spreading the designers must reckon more and more. The plastics used in practice must satisfy several requirements:

- they must be workable without damage,
- to be capable preserving their characteristics for a long time during use,
- their mechanical, thermal and other characteristics should be formed according to demands given.

The primary forming of plastics is the hot-forming (injection-moulding, extruding, etc.) undoubtedly, however as a secondary process the cutting gets also important role, especially at such parts with accurate, complicated shape. Some reference to cutting circumstances of various plastics can be found in the technical literature. Studying the literatures referred it can be established that every company producing or selling plastic semi-finished product suggests cutting data in within very wide range for cutting certain plastics. The following conditions influence the cutting of plastics generally:

- The dimensional change of certain plastics caused by temperature is ten times higher than the metals.
- The plastic is a bad heat conductor comparing to metal, because of this it has to be protected from local heating up, in such case during machining cooling has to be applied.
- Its softening (meeting) temperature is by far lower comparing to metals. Although during cutting plastics cutting lubricants are not used generally but at adhering strict tolerance or to reach minimal roughness emulsion made of non aromatic oil is suitable. Fog-cooling or compressed airs are usually used at chip-tool contact. Universal cutting lubricant with

petroleum base can be used at several metals and also at plastics, inasmuch improves the chip formation (helps on certain plastics).
- The plastic is by far more elastic than generally the metals, because of this dimensional stability (and adhering the tolerance) is also more difficult.
- The built-up edge can be reduced and roughness of surface cut can be improved by using tools with fine grinded back and with face lapped by stoning.
- The most suitable is using fine-grain tip for turning with using accordingly great relief angle.
- The work piece supported accordingly restricts the tool inclination.

Optimum result can be expected only by collective and proper choosing of champing, tool material, edge geometry and of cutting data.

2.3. The cutting experiment

2.3.1. The machine-tool applied

I have carried out the cutting on NCT EUROTURN 12B CNC control HSH-lathe, which was bought by the Institute in 2004. The machine-tool was well conformed to my experiments, its condition can be still qualified excellent. I have far – reaching taken into account the experimental character at writing the CNC-program, so after running different data combinations there was always possibility to collect chips respectively to prevent sudden events (for example: chip stuck, tool barbing, etc.)

2.3.2. The parameters selected for turning

I have selected the cutting data combinations of certain experimental settings as well as the turning tools used taking into account the technical literature suggestions. I have applied four cutting speeds, and I have carried out the turning by splitting to roughing and to finishing phases. The experimental setups were the followings:

- cutting speed: v_c = 200; 250; 315; 400 m/min;
- feeding during finishing phase: f = 0,05; 0,08; 0,12; 0,16 mm/rev.;
- feeding during roughing phase: f = 0,2; 0,25; 0,315; 0,4 mm/rev.;
- depth of cut: a = 0,5 mm;
- the dimensions of work pieces: d_{md} = Ø 40 mm;
  l_{md} = 80 mm;
- during machining I have not used cutting lubricant.

2.3.3. The turning tools

At selecting the turning tools I have taken into account at the highest the technical literature suggestions. Based on this I have selected the tips applied to cutting experiments among the available tips from commerce suitable machining aluminium (Table 2.1.). I have used 4-4 pcs. from each type of tips this I have used new tip during cutting each types of engineering plastics.

Table 2.1. Geometric characteristics of cutting tools

Geometric characteristics of tip	**„A” tip**	**„B” tip**
nose angle: ε_r (˚)	35	55
relief angle: α_0 (˚)	5	7
nose radius: r_ε (mm)	0,4	0,4
tip thickness: s (mm)	2,4	3,9

Before starting the experiments I have submitted the tips to edge-condition check consisting of checking the nose radius and edge roughness. The edge radius measured at „A”-type tip showed surprisingly high standard deviation, in the roughness parameters of edge however nearly 50% difference was shown. The *Ra* value took shape around 1,29 μm, the *Rz* value however was 6,43 μm. The No.4 tip proved to be the best from viewpoint of edge geometry (*Ra* = 1,16 μm, *Rz* = 5,47 μm). During examining the previous edge radius and edge roughness of „B” tips I have experienced that very small radius and accurate edge characterized the tips – as a result of an expert edge stoning – they had minimal roughness standard deviation. The average roughness value was *Ra* = 0,58 μm, while the value of height unevenness was around *Rz* = 2,66 μm with low standard deviation, thus the tips with greater nose angle have got very good quality.

2.4. Conditions of surface roughness measurement

I have submitted the work pieces cut to preliminary examination. I measured the surfaces with C3A shop surface roughness tester. The instrument is capable to indicate numerically the *Ra, Rz, Rt* characteristics and is capable producing profile-graph. Its analogous output signal through A/D converter is directly capable processing data by computer too. I have carried out the 2D-la and 3D-al roughness examinations of surfaces machined with Mahr Perthometer-Concept feeler type instrument in the measuring technique laboratory of the institute. The setup used at evaluation of surfaces according to ISO 4288:1996 standard:
- evaluation length, l_m = 4 mm;
- the prescribed filter, l_c = 0,8 mm.

The profiles and parameters taking up during measuring:
- raw (*P*) profile;
- filtered roughness (*R*) profile;
- 9 roughness parameters: *Ra, Rmax, Rz, Rq, Rp, Rt, RSm, RSk, RKu*;
- 5 waviness parameters: *Wt, Wa, WSm, WS, Wdq*;
- 6 raw parameters: *Pt, Pa, PSm, PSk, PKu, Pdq*.

I have carried out the measurements with the Mahr RHT 3/50e and with the Mahr BFRW 750 – type feeler perpendicular to the machining direction. The feelers chosen were suitable to measure the surface texture of the plastics applied in research work, they did not cause scratch or other defect. The 3D-al parameters were made from the 2x2 mm section of the surface examined. The making of topographical pictures during measuring - during scanning of the sampling surface - takes place by producing profile sections (in present case 501) to be determined distances from each other, on the measuring length and with using prescribed filter) to be appropriate to the standard. I have made the electron microscopically exposures with the JEOL JSM 5310 – type scanning electron microscope from the surfaces turned of the PEEK engineering plastic in the laboratory of the Institute of Material Science and Manufacturing Engineering.

3. RESULTS

3.1. Examining the theoretical roughness at engineering plastics turned

The optimal cutting parameters are not yet determined exactly concerning the surface roughness at certain types of plastics. My aim was with the examinations to establish the effect of machining parameters to the most characteristic parameters of the surface profile (*Ra, Rz*) that is I was seeking connection at $Ra = Ra(v_c;f)$ and at $Rz = Rz(v_c;f)$. The diagram (Fig. 3.1.) presented show the differences in % of the expected theoretical roughnesses - the Bauer-kind connection (*Re*) and the Brammertz-kind formula (Re_{Br}) - from the real, measured (*Rz*).

In case of cast, polyamide 6 so determine the theoretical roughness the Brammetrz-formula can be better applied. I have experienced 12 % or less than this difference from the surface measured at machining with „A" tip having smaller nose angle with the results got at this formula, in the f = 0,12-0,4 mm/rev. feeding range and in the whole experimental speed range. It can be stated that at evaluating the surface cut with „B" tip the Bauer-kind theoretical roughness shows significantly greater difference than the values got with the Brammertz-kind formula. Re_{Br} values in the f = 0,16-0,2 mm/rev. feeding range approximate the real *Rz* value with great safety altogether around 5-12 % difference.

In case of PET turning with „A" tip at the f = 0,12-0,4 mm/rev. feeding the Bauer-formula can be well applied, while at f = 0,05 mm/rev. as well as f = 0,315-0,4 mm/rev. feedings the theoretical roughness calculated with Brammertz-formula still better approximated the *Rz* value measured. It can be said at evaluating the surface cut with „B" tip, that at f = 0,12-0,25 mm/rev. feedings the theoretical roughnesses calculated with the Brammertz-formula approximate with great safety the real *Rz* value.

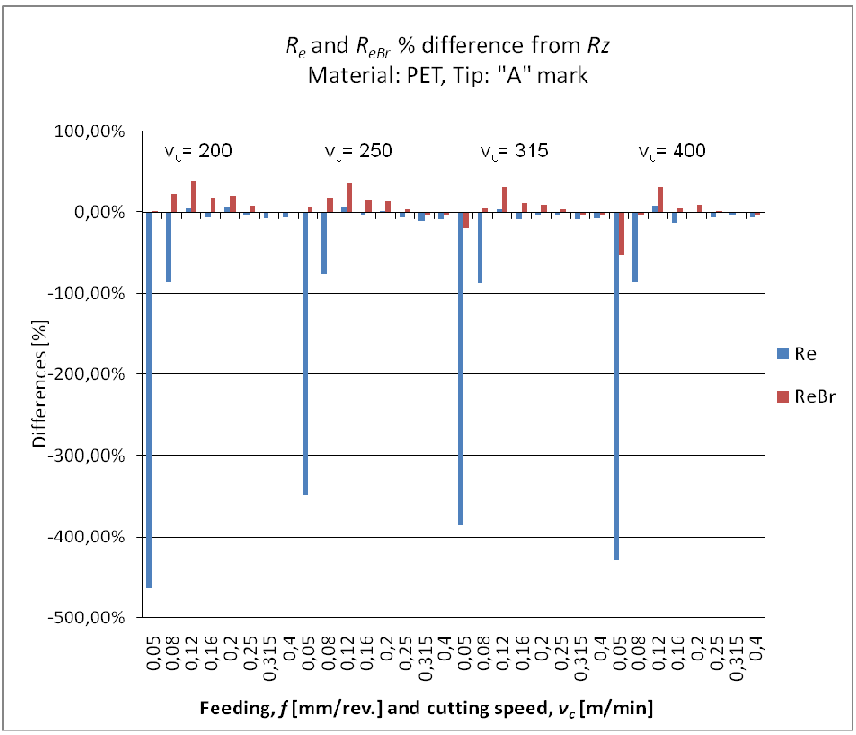


Figure 3.1. The difference of theoretical roughness (*Re*, Re_{Br}) compared in % to the measured *Rz* at feedings and cutting speeds examined in case of PET

In case of poly(oxy-methylene) at evaluating the surface cut with „B” tip the Bauer-kind theoretical roughness shows a little greater difference than the values got with Brammertz-kind formula. Because of we got here the best surface cut, therefore the differences with smaller amount were also here with the Bauer-formula. I have experienced 10 % or smaller than this difference at the roughness measured at machining with „A” tip in the f = 0,12-0,4 mm/rev. feeding range in case v_c = 200 m/min and v_c = 400 m/min with the Brammertz-kind formula.

In case of PEEK at using both the „A” and the „B” tips the theoretical roughness values calculated with the Brammertz-formula approximate with great safety the real *Rz* values.

3.2. Factorial experimental-plan concerning the effect of cutting parameters on the direction of height characteristics of the surface roughness

I have planned and carried out the examination with the experiment-planning method which is often used to examine the effects of cutting parameters. I have modelled with two factorial power functions the values measured of the direction height characteristics (*Ra, Rz*) of roughness profile at the surfaces machined. Thus in the factorial experimental-plan:

- the parameters:
  - profile average difference: *Ra* [µm],
  - the height of profile unevenness: *Rz* [µm],
- the factors:
  - cutting speed, v_c [m/min],
  - feeding, f [mm/rev.].

The two characteristics (parameters) of surface roughness and the cutting data (factors) set can be described with the following function:

$$R = C_R \cdot v_c^{x_1} \cdot f^{x_2} \text{ [µm]} \qquad (3.1)$$

I have completed the regression function examinations and the evaluating the results with the Minitab14 statistical software. I have determined the coefficient of invidual models and exponents (C_R, x_1, x_2), the standard deviation (s) and the value of determinant coefficient showing the correlation (R^2) with the help of program.

The regression functions (Table 3.1.) got to *Ra* and *Rz* parameters describe the measuring results with small standard deviation (s = 0,093-0,111) and with relatively high correlation (R^2 = 0,921-0,971).

During machining with „A” tip the cutting speed set had smaller effect (-0,292 ≤ x_1 ≤ -0,316) to the surface roughness at only PA 6 material, while this can be said as minimal in all other cases. The feeding exponents took shape between 1,2 ≤ x_2 ≤ 1,46 , thus it has got smaller effect onto the measuring results as the Bauer-formula shows that. In case of „B” tip the speed effect can be neglected, while the feeding shows 1,58 ≤ x_2 ≤ 1,8 exponent-value, this suits better to the theoretical formula applied at turning with regular edge geometry.

According to the 3.1. Table onto the poly(ethylene-terefthalate) plastic is altogether true that the effect of speed in the range examined is very small (-0,008 ≤ x_1 ≤ -0,105) (Figure 4.10.) to the direction of height characteristics of surface. The feeding effect to the values *Ra* and *Rz* at „A” tip resulted an exponent that is greater than one (1,37 ≤ x_2 ≤ 1,6), while at „B” tip x_2 value approximate better the two.

It cutting poly(oxy-methylene) – at both tips – the effect of speed in the range examined is very small (-0,002 ≤ x_1 ≤ -0,062), it does not influence significant effect onto the surface characteristics examined. The effect of feeding however has got greater validity, it is following comparatively regularly Bauer-kind formula determining expected roughness, the *Ra*, *Rz* value increases nearly quadratic (1,54 ≤ x_2 ≤ 2,1) with f value, to be noted that the function of „B” tip here also gives higher exponent (Fig. 3.2.).

Table 3.1. Results of regression function examination

Cast polyamide 6					
„A" tip			„B" tip		
Function relation	*s*	R^2	Function relation	*s*	R^2
$Ra = 191 \cdot v_c^{-0,292} \cdot f^{1,46}$	0,111	0,94	$Ra = 93 \cdot v_c^{-0,036} \cdot f^{1,8}$	0,093	0,971
$Rz = 631 \cdot v_c^{-0,316} \cdot f^{1,2}$	0,106	0,921	$Rz = 240 \cdot v_c^{-0,017} \cdot f^{1,58}$	0,105	0,953
Poly(ethylene-terefthalate)					
„A" tip			„B" tip		
Function relation	*s*	R^2	Function relation	*s*	R^2
$Ra = 46 \cdot v_c^{-0,008} \cdot f^{1,6}$	0,1606	0,899	$Ra = 120 \cdot v_c^{-0,067} \cdot f^{1,88}$	0,052	0,992
$Rz = 117 \cdot v_c^{-0,026} \cdot f^{1,37}$	0,154	0,877	$Rz = 490 \cdot v_c^{-0,105} \cdot f^{1,75}$	0,074	0,98
Poly(oxy-methylene)					
„A" tip			„B" tip		
Function relation	*s*	R^2	Function relation	*s*	R^2
$Ra = 50 \cdot v_c^{0,003} \cdot f^{1,68}$	0,077	0,977	$Ra = 110 \cdot v_c^{-0,002} \cdot f^{2,1}$	0,035	0,997
$Rz = 234 \cdot v_c^{-0,062} \cdot f^{1,54}$	0,076	0,974	$Rz = 288 \cdot v_c^{0,0319} \cdot f^{1,95}$	0,060	0,99
Poly(ether-etherketone)					
„A" tip			„B" tip		
Function relation	*s*	R^2	Function relation	*s*	R^2
$Ra = 63 \cdot v_c^{-0,048} \cdot f^{1,48}$	0,067	0,978	$Ra = 42 \cdot v_c^{0,04} \cdot f^{1,6}$	0,110	0,95
$Rz = 275 \cdot v_c^{-0,089} \cdot f^{1,36}$	0,054	0,983	$Rz = 135 \cdot v_c^{0,062} \cdot f^{1,47}$	0,128	0,923

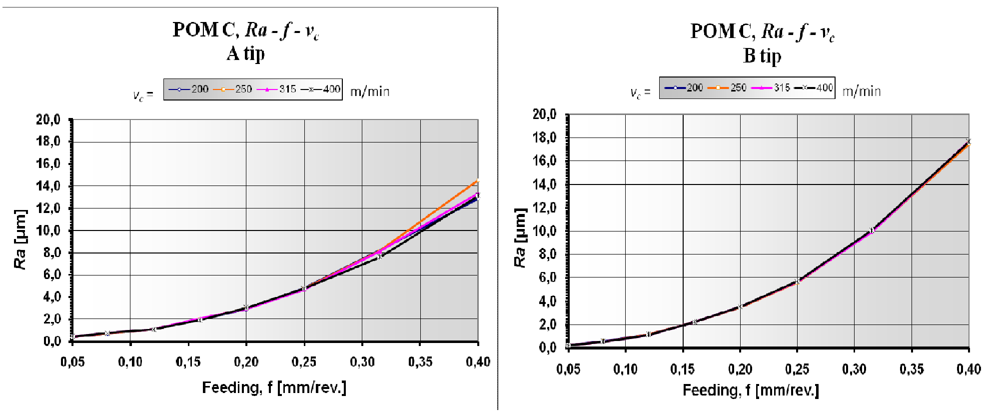


Figure 3.2. The *Ra* formation at machining with „A" and „B" tips in case of POM C

The measuring results in case of poly(ether-etherketone) were similarly formed as at the other engineering plastics examined. The regression functions got shows that these take up well form of the measuring results: I have experienced comparatively small standard deviation (s = 0,054-0,128) and very high correlation (R^2 = 0,923-0,983).
Summing up it can be observed that the cutting speed has got small effect onto roughness characteristics at the engineering plastics examined. This experience is inconsistent with those measuring results, which we have experienced at cutting steels in over experiments.

3.3. The results of cutting experiment carried out by tool with increased nose radius

I have carried out cutting experiments with tool having increased nose radius (r_ε = 0,8 mm) in the third phase of experiments. The cutting data-combinations of individual experimental set were the followings:

- cutting speed: v_c = 400 m/min (constant value);
- feeding: f = 0,08; 0,125; 0,2; 0,315 mm/rev.;
- depth of cut: a = 1,0 mm;
- depth of cut: a = 2,0 mm;
- work piece dimensions: d_{md} = Ø 40 mm; l_{md} = 80 mm;
- I did not apply cooling during machining.

By increasing the feeding such changes happened in the PEEK material structures which have caused drastic deterioration of the surface quality. The electron microscope exposures prove unambiguously that surface defects and tears in machining tracks happened which influenced the surface quality in great extent (Fig. 3.3.). The chip did not came off continuously from the surface, but it was crumpling for some time, then was torn, resulting broken chip, but leaving on the surface shell-like craters.

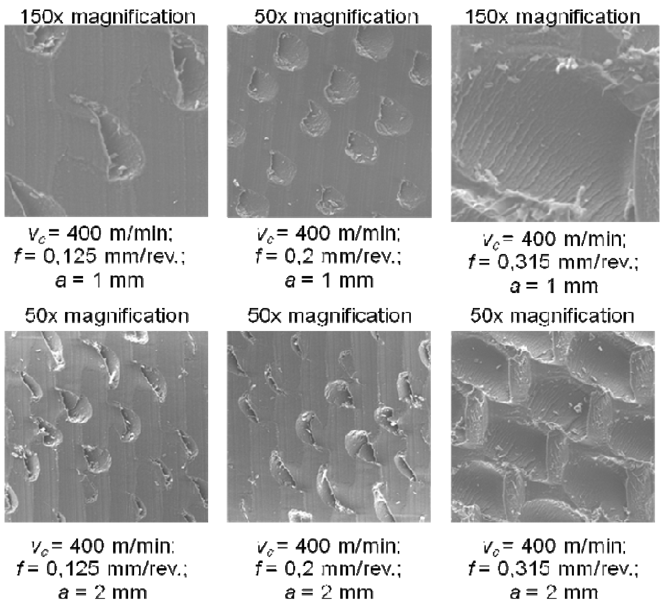


Figure 3.3. SEM pictures of the PEEK plastic surface turned

It can be established from comparing the 2D-al and 3D-al measuring numbers that among the amplitude parameters the *Ra* and the *Sa* correspond comparatively well in the range of small feeding (*f* = 0,05-0,125 mm/rev.). The difference between the two parameters is significant in the roughing phase where rough defects already characterize the surface. In case of *Rq* and the *Sq* parameters the results are similar (Fig. 3.4.). The sharpness of the height distribution (*Rku* and *Sku*) characterizes well the unevennesses form and by this means they also refer to the operational characteristics of surfaces, the 2D-al and 3D-al parameters show good agreement. Significant difference can be experienced in case of *Rsk* and *Ssk* measuring numbers. The 3D-al parameter refer to surfaces wear resistance and with good carrying characteristic, while the 2D-al characteristic shows in consequence of the individual, „planar" measuring that more cusps can be found on the surface.

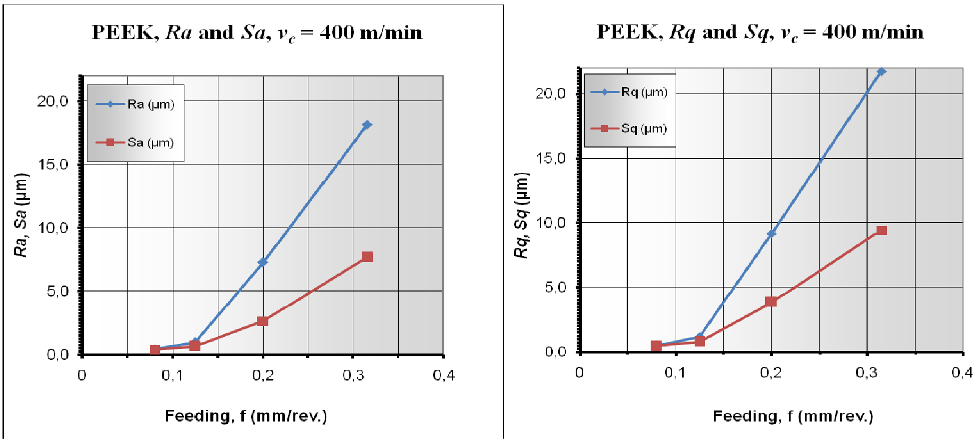


Figure 3.4. Comparing the 2D-al and 3D-al parameters at PEEK plastic

3.4. Connection between the average roughness and mechanical properties of engineering plastics

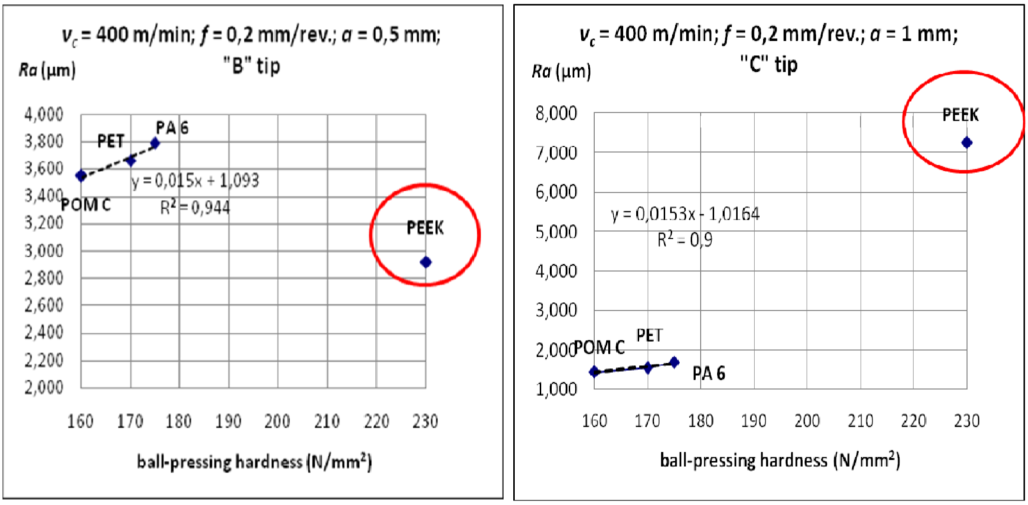
The goal of the tests were to determine that mechanical properties (Yield point, elongation at rupture, Young's modulus), specific impact energy (Charpy) as well as hardness (ball-pressing, Shore D) of engineering plastics applied in the experiment how influence the average roughness (*Ra*).

The **Yield point** values do not have significant effect onto the values of measured *Ra* in case of „A" and „B" edge-forming at constant v_c value. The changing the cutting edge-forming to „C" – type already changes the independence: over 85 MPa Yield point increasing *Ra* was experienced. The phenomenon can be considered exception as in case of the PEEK material – it is a member of the high-performance material group – ensued.

The *Ra* values examined in the function of **elongation at rupture** and the **Young's modulus** show basically independence in case of „A" and „B" tip edge-forming in case of small, medium and great feeding too (in same cases the PEEK is exception). During using „C" –type tip the PEEK material represents definitely exception in the result range. Its shows high *Ra* values with increasing feeding.

It can be stated of the *Ra* values analyzed in the function of **Charpy specific impact energy** that the PEEK belonging among the high-performance engineering plastics here can be also separated from the general purpose engineering plastics. In case of „A" and „B" tip forming the difference is small, while in case of „C" tip increasing the feeding value to *f* = 0,315 mm/rev. unexpectedly great difference happens to *Ra*, which can not be taken into account with linear regression.

In case of „A" tip at the **ball-pressing hardness** with increasing feeding it can not be drawn up unambiguous connection or trend between *Ra* and hardness. In case of „B" tip – the PEEK separates favourably – at the general engineering plastics tested the increasing ball-pressing hardness resulted increased *Ra* values. In case of „C” tip the PEEK unexpectedly differs from the other materials at which *Ra* slightly increases with the increase of ball-pressing hardness (Fig. 3.5.).



a) b)

Figure 3.5. a) *Ra* values in case of „B” tip in the function of ball-pressing hardness at medium feeding b) *Ra* values in case of „C” tip in the function of ball-pressing hardness at medium feeding

Examining the *Ra* in the function of Shore D-hardness in case of „A” and „C” tip it can be established that at the smallest feeding (f = 0,08 mm/rev.) independence can be established between the Shore D values and *Ra*. Increasing the feeding the *Ra* also increases with Shore-D increase. At surfaces cut with „B” tip, in case of increasing feeding the increase of hardness causes *Ra* decrease.

3.5. New scientific results

1. Thesis: I have proved from the turning experiments carried out with single-point toll having regular edge geometry that the height directional microgeometric characteristics (*Ra*, *Rz*) of the surface machined the $200 \le v_c \le 400$ m/min cutting speed influences only in minimum way in the experimental range applied by me. This is contradictory with experiences at cutting steels. The conclusion is valid for the four engineering thermoplastics (PA 6, PET, POM C, PEEK) used in the experiment.

2. Thesis: I have established with cutting experiment series that at the engineering plastics examined with the applied types of tip („A”, „B” tip) with f = 0,05-0,16 mm/rev. feedings with keeping the cutting speed between v_c = 200-400 m/min the average roughness $Ra < 2$ µm.

3. Thesis: I have established that the theoretical connection applied to indicate in advance the probable surface roughness at cutting steels (Bauer, Brammertz-formula) can be used to qualify the surfaces turned of engineering plastics in different data – range depending on the properties of the engineering plastic.

4. Thesis: I have proved that the expected surface roughness (*Ra*, *Rz*) at turning engineering plastics can be well modelled with fraction-exponential power functions ($Ra = C_{Ra} \cdot v_c^{x_1} \cdot f^{x_2}$; $42 \le C_{Ra} \le 191$; $-0{,}002 \le x_1 \le 0{,}04$; $1{,}46 \le x_2 \le 2{,}1$; $0{,}035 \le s \le$

0,16; ; $0{,}95 \le R^2 \le 0{,}997$, and $Rz = C_{Rz} \cdot v_c^{x_1} \cdot f^{x_2}$; $117 \le C_{Rz} \le 631$; $-0{,}017 \le x_1 \le 0{,}062$; $1{,}2 \le x_2 \le 1{,}95$; $0{,}054 \le s \le 0{,}154$; ; $0{,}87 \le R^2 \le 0{,}99$).

5 Thesis: I have established that the values of profile unevenness' height (*Rz*) measured on the surface turned with „A"-type and „B"-type tips in the cutting range examined significantly exceeded the calculated values of the theoretical roughness (*Re*). The Bauer-formula determining the theoretical roughness describes with great error the expected roughness in this data-range because of this its application is unsuited for engineering plastics examined.

6. Thesis: The Brammertz-formula by far better approximated the values of the profile – unevenness' height (*Rz*) measured on the surfaces turned with „A" type and „B" type tips at PA 6, PET, POM C, PEEK plastics than the Bauer-formula because of this it can be well used to determine the expect roughness in the data-range examined.

7. Thesis: I have established that the tool with increased nose radius („C" tip) produced similar roughness at the PA 6, PET, POM C general function engineering plastics with the turning parameters used (v_c = 400 m/min; f = 0,08-0,315 mm/rev.; a = 1-2 mm). At turning the PEEK high performance plastic with r_ε = 0,8 mm nose radius tool occurs a phenomenon damaging the surface quality. During chip removal takes place a tough and brittle shear crack propagation alternating with pulsing character in the cutting system. The visible result of this is the cut surface with scaled character. This phenomenon causes the deterioration of the surface quality.

8. Thesis: Evaluating the measuring results of average roughness (*Ra*) in the function of mechanical properties of changing feeding and different edge-forming („A", „B", „C"-type tip) I have established that:

a) There is such a cutting system when the measured *Ra* values on case of PEEK belonging to the high performance material category can be separated from the trends experienced in case of general engineering plastics (PA 6, POM C, PET) examined. The *Ra* trends estimated in the function of ball-pressing hardness, Yield point, Young's modulus in case of increasing feeding different edge-forming („A", „B" and „C" tips) can not be commonly evaluated in case of the two materials group.

b) Analysing the *Ra* values in the function of Shore D hardness it can be established that the PEEK does not constitute exception among the general engineering plastics. In case of all three edge-formings independence can be established – at the smallest feeding (f = 0,08 mm/rev.) – between the Shore D values and *Ra*. By increasing the feeding the *Ra* also increases with the Shore-D increase in case of „A" and „C" edge-forming. At surfaces cut with „B" tip in case of increasing feeding the increase of hardness caused *Ra* decrease.

c) In case of general engineering plastics examined – without PEEK – I have established the following regularities:

- the *Ra* in the function of elongation at rupture of Young's modulus as well as of Yield point of individual materials can be considered independent – in case of increasing feeding too – the incline of straight line of regression is zero.

- the *Ra* trends established at different feedings in the function of ball-pressing hardness belonging to individual material depend on forming of the cutting tool. In case of „A" „B" and „C" tip different trends can be established.

4. CONCLUSIONS AND SUGGESTIONS

Based on my research work presented in my dissertation. I sum up those connections in the followings which can further widen our knowledge and can help in case of practical application. The roughness examinations of surfaces of engineering plastics cut allow to conclude the followings:

- I have drawn up a complex cutting plan applying to four-type engineering plastics which gave a possibility to examine the behaviour of the individual materials during turning with peculiar consideration to the microgeometry of surface texture and to chip formation. I have proved this that the cutting speed has a slight effect onto the surface roughness examined in the experimental range determined by me. This differs basically from the experiences at cutting steel.
- The experimental results show into that direction that the cutting data-combinations cab be still made more exact relating to the surface roughness at the semi-finished products of engineering plastics examined.
- I have established at comparing the 2D-al and 3D-al roughness characteristics that the microgeometric parameters react more sensitively to the rough unevennesses of the surface because of this applying the microtopographic measuring numbers would be indispensable in the engineering practice to determine the surface quality, but the high price of measuring instruments and the long measuring process still put a stop to spreading in the practice.

My suggestions are the followings concerning the further experimental fields raised by the theme:

- The real roughness value (*Rz*) got based on turning experiments can be well compared with the Brammertz-formula. The limit of error maximum appears here disregarding from the outstanding value does not exceed neither at the smallest feeding 50-60 %. All this cannot say about the Bauer-formula. Based on this it would be expedient and desirable with experiments to adapt the $h_{min} = f(v_c, r_n)$ connection occurring in the Brammertz-formula onto engineering plastics which could probable make possible still more exact application of the formula.
- I have stipulated as a boundary condition at the surface roughness examination that I take into account the parameters in the height direction of the roughness characteristics, as is the most widespread in the engineering practice. It would be worth to examine further 2D-al and 3D-al parameters as a future task.
- The cutting experimental plan drawn up by me refers to turning with single-point tool having regular edge-geometry. It is suggested an experimental plan worked out for other cutting process as a future task by which knowing the behaviour of engineering plastics would be possible.
- I haven’t taken into account the time factor at cutting experiments therefore it is justified by all means to make the duration experiment during appear among the future tasks.

5. SUMMARY

The demands against the surface quality of machine-parts are going to be amore and more severe. The characterization of surface roughness is realized in the engineering practice decisively with 2D-al microgeometrical measuring numbers but several researchers already deal with examining the applicability of 3D-al micritopographic parameters. The appearance of engineering plastics among constructional materials offers new possibilities both in the field of product development and in production technology. I have dealt in my research work with examination of surfaces cut and with turning such engineering plastics, which can be useful for the engineering practice.

During surveying the technical literature I have read hundred domestic and international scientific articles. I have summed up the factors determining the surface quality furthermore the 2D-al microgeometric and teh 3D-al microtopographic parameters used to characterize the surface texture. Ihave presents those typical measuring process, which are widespread in the surface roughness theme, and the measuring process with feeler as well as I have displayed the electron microscopy in detail because I have applied them during my research work.

I have presented the engineering plastics with particular consideration to four types pf plastic used in the research work: PA 6, PET, POM C, PEEK. After this I have summed up the literature concerning the cutting of plastic semi-finished products. I referred with critical character to the shortcomings of the given domain then the tasks to be solved in the end of chapter.

I have drawn up a complex cutting experimental plan in which I selected the turning parameters (v_c, f, a) as well as the turning tools applied based on the suggestions of technical literature. Valuable experiences were got from the cutting experiments in the behaviour of plastics during turning. Certain plastics – as an example the POM C and the PEEK – can be explicitly well cut chip, the chip form developed is favourable which cause can be the small heat sensibility and the cristal structure. During cutting the PA 6 and the PET the splint caused often trouble which during machining wound to the material and influenced unfavourably the process. It can be established from the results got during examining the surface roughness of plastics that the cutting speed does not considerably effect to the formation of roughness – in the range examined – which differ from the experiences at steels. During cutting plastics the feeding influenced decisively the *Ra* value determining the surface finish.

Based on my experiments I have drawn up my new scientific results which I have summed up in a separate thesis paper too.

Finally I gave suggestions for practical exploiting of the results achieved and for setting further experimental tasks.

6. PUBLICATIONS IN CONNECTION WITH THE THEME OF DOCTORAL DISSERTATION

Referred article in English with impact factor:

Kalacska, G., Farkas, G.: The effect of the different cutting tools on the micro-geometrical surface of engineering plastic, *Sustainable Construction & Design*, 2010 Vol. 1, pp. 102-107

Referred articles in Hungarian:

Farkas, G.,Czifra, Á., Palásti, K. B., Horváth, S.: Műszaki felületek mikrogeometriai vizsgálatában alkalmazott 2D-s és 3D-s paraméterek összevetése, információtartalmuk elemzése, *Gép*, LVI. évf., 2005/2-3. szám, 51-59 o.

Farkas, G., Palásti, K. B.: Forgácsolt műszaki műanyagok felületi simasága, *Gépgyártás*, XLVI évfolyam, 2006/5. szám, 6-10 o.

Farkas, G.: A megmunkálási körülmények hatása a felületi mikrogeometriára műszaki műanyagok esztergálásakor, *Gyártóeszközök, szerszámok, szerszámgépek*, 2007/1. szám, 9-12 o.

Farkas, G., Kalácska G.: Felületi mikrogeometria vizsgálata forgácsolással megmunkált műanyagok esetén. *Gép*, LVIII. évfolyam, 2007/4. szám, 7-12 o.

Kalácska G., Farkas G.: Forgácsolt műszaki műanyagok felületi érdességének vizsgálata, *Műanyag és Gumi*, 2007/44. évfolyam, 10. szám, 419-423 o.

International conference proceedings:

Palásti K., B.; Farkas, G.: Relationship between the cutting surface-microgeometry and it's evaluation. The 5th International Scientific Conference, Development of metal cutting DMC, Kosice, 2005. pp. H 15.

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