MACHINABILITY OF ENGINEERING POLYMERS

R. Keresztes, G. Kalácska, L. Zsidai, Z. Dobrocsi

Institute for Mechanical Engineering Technology,
Faculty of Mechanical Engineering, Szent István University, Gödöllő, Hungary
www.geti.gek.szie.hu

Abstract Nowadays parts made of up-to-date engineering plastics are used more and more in mechanical engineering practice. These machine-elements are produced most frequently by injection molding or by one cutting process. The injection molding technology are used generally for great number of pieces, in case of serial production while cutting processes are preferred to piece (unit) or smaller number production.
We used lathe and measured the main- and feeding-directional cutting force at different engineering polymers (cast PA6, POM C and UHMW PE, HD 1000). We compared these results with the tensile properties of the materials. The analysis made can be well used in practice.

Keywords: turning force components, lathe, force measuring, main cutting force, tensile stress,

1   INTRODUCTION

Among cutting processes the turning takes place often. During turning engineering plastics many problems can arise. Among these one is the splint (continuous chip) forming which can cause accident and can cause failure maybe the total ruin, fracture of the cutting tool. Because of this it is important to set the proper cutting parameters by which it is possible forming elemental or transitional (easily fracture) chip, too.
It is also important to know during cutting the amount of the main cutting force. Knowing this the load of cutting tool can be made more constant as well as the remnant stress in the material chipped can be reduced to minimum in case of proper cutting parameters. The tensile properties of the materials is also important and we analysed the tensile stress – strain curves of the polymers. We plotted the quotient of the specific cutting resistance and the yield stress in the function of the chip cross section with the all machining parameter groups.

2   TESTING METHODS, INSTRUMENTS

The cutting is a machining method during which the required shape of the workpiece is formed by removing the surplus material layer in smaller – bigger particles (chip) with a suitable tool. Relative displacement is needed between the tool and workpiece for chip removal, for cutting movement. We measured the tensile properties of the materials.

2.1   Equipment used for tests

The CNC-lathe, type EMCO COMPACT 5, was used for tests. The equipment can be found in the laboratory of Institute for Mechanical Engineering Technology its programming takes place of G-codes. The photograph of the workpiece clamped as well as the shank with strain-gauges clamped into tool-box and the turning tool can be seen in Figure 1.
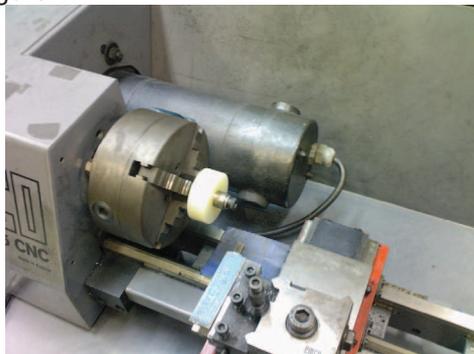

Figure 1. The lathe and the workpiece clamped

The tool clamping structure used for measuring the forces can be seen in Figure 2. The first section of the Figure shows the 3D-model.
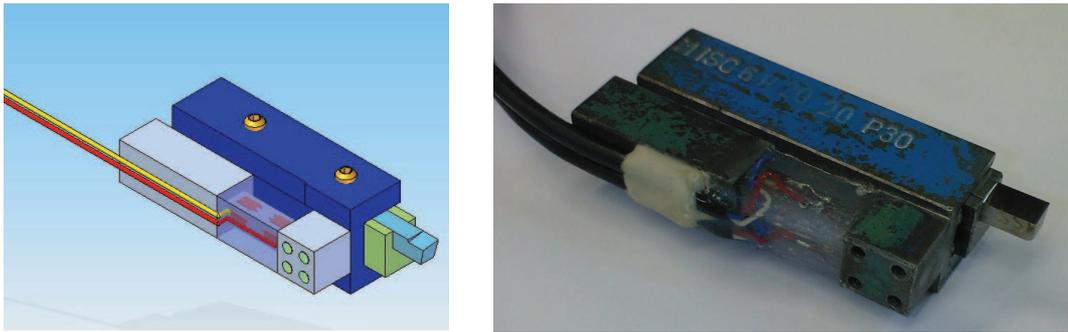

Figure 2. The force measuring shank model and its real picture

2-2 pcs. strain gauges are fixed at every side. Coupling the strain gauges into total (full) – bridge those is a possibility measuring the forces arising in two directions. To measure the main cutting force F_v (tangential) arising from the movement in vertical plane of the tool and F_f feeding (axial) force arising from the movement in horizontal plane. A second tool-box is fixed to 4 pcs. threaded holes on the measuring-shank into which the real cutting tool is fixed. The strain gauges measure the tangential (lower – upper) and the feeding (right side – left side) forces connect to a Spider-8 type measuring amplifier though wires, which amplifier convert the analogous signals into digital than transmits to the computer. With the help of Catman 3.1 program data measured can be seen. The frequency of measuring and data collecting is 25 Hz.

We measured the tensile properties of the materials according to MSZ EN ISO 527 standard with a type of INSTRON 5581 tensile machine and we prepared the tensile stress – deformation curves of the polymers. From these diagrams we determined the yield stresses of the materials.

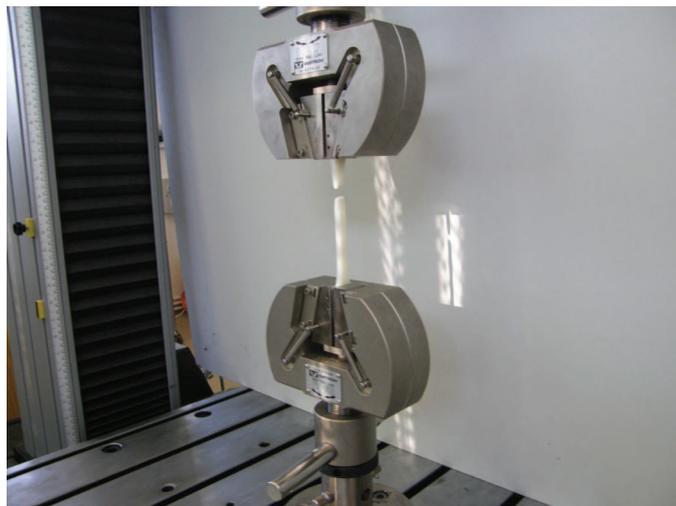The figure (Fig. 3) shows the tensile machine.

Figure 3. The tensile machine and the workpiece clamped

2.2   Materials tested

The materials tested are those polymer basic types that are often used in engineering practice to manufacture machine-elements. Table 1 shows the name of product, the whole name and the marks accruing on lather diagrams. The specimens prepared for cutting are shown the first part of Figure 4 and the tensile specimens are shown the second part.

Table 1. Name and mark of plastics

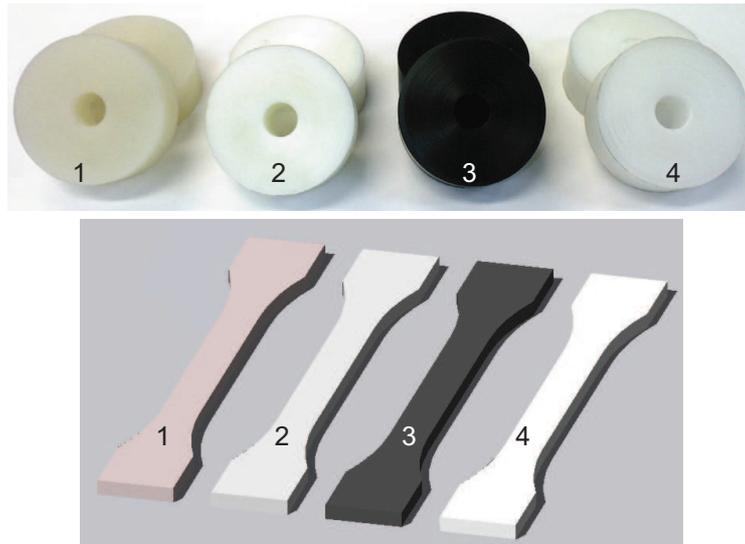| Serial number	Product name [6]	Whole name	Own mark
1.	DOCAMID 6G H	Cast polyamide 6, (Magnesium)	PA 6G Mg
2.	DOCAMID 6G	Cast polyamide 6, (Natrium)	PA 6G Na
3.	DOCACETAL C	Polyoximethylene / Polyacetal	POM C
4.	DOCALENE	UHMW – Polyethylene	HD 1000

Figure 4. Specimens prepared for machinig and for tensile tests

In the Table 2. the more important properties of polymers tested can be seen summarized.

Table 2. More important properties of plastics

Polymer	Strength [MPa]	Toughness (Charpy) [kJ/m^2]	Sliding characteristic (μ)	Thermo-duricity [°C]	Hardness	Density [kg/dm^3]
PA 6G Na	77 - 110	112	0,15 - 0,5	-40 - 140	Rockwell 85 – 98 HRC	1,15 – 1,6
PA 6G Mg	77 - 110	112	0,15 - 0,5	-40 - 140	Rockwell 85 – 98 HRC	1,15 – 1,6
POM C	70 – 80	8	0,25 – 0,45	5 – 120	Rockwell 86 – 90 HRC	1,4
HD 1000	20 – 24	no fracture	0,2 – 0,3	-80 – 110	Shore 60 – 65 D	0,96

Cutting parameters
    Feeding/rev.:   f = 0.025, 0.05, 0.1, 0.2 mm/rev.
    Depth of cut: a = 0.1, 0.25, 0.5, 1, 2   mm
    Cutting speed: v = 50, 100, 200   m/min

Tensiling parameters
    Speed: v = 50 mm/min
    Humidity: RH = 50 %
    Temperature: T = 23 °C

2.3   Forming of the cutting tool

The cutting angles of high-speed steel (HSS Co5) turning tool have been determined on the basis of technical tables. The relief angle: $\alpha_0 = 10°$, the rake angle: $\gamma_0 = 5°$. The grinding of turning tool was carried out on profile-grinding machine using diamond grinding wheel. The ready made turning tool can be seen in Figure 5.
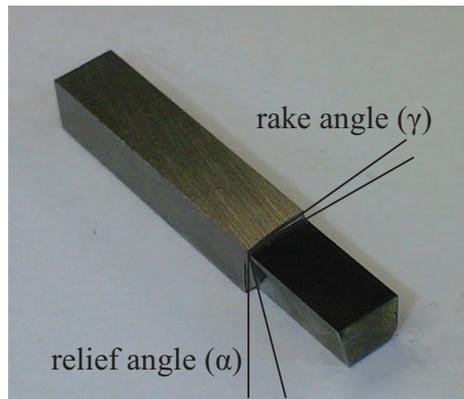
Figure 5. The bit of turning tool used.

3   TEST RESULTS AND THEIR EVALUATIONS

We have measured two-way forces during tests. The tangential-directional main cutting force and the axial feeding-directional force. We have grouped the materials by depth of cut, by feeding within on these by cutting speed. Unite these in one file we have got four series main cutting force and the same series feeding-directional cutting force diagrams. We have made one-one diagram by parameter from these. Figure 6. and 7. show one-one sample diagram. The cutting force given (main or feeding directional) as well as the feeding (f[mm/rev.]), depth of cut (a[mm]) and the cutting speed (v[m/min.]) appear in the diagram title. The force values [N] given appear on the vertical axis, the cutting time [s] appears on the horizontal axis. We have presented all four materials in one diagram, so it can be well comparing that at same cutting parameters how great force befalls onto the cutting tool at various materials. Each colour marks one material according to mark explanation under the diagram. Continuous line shows the test results. The dotted line shows the average during measuring time given. Its value can be seen beside the line.
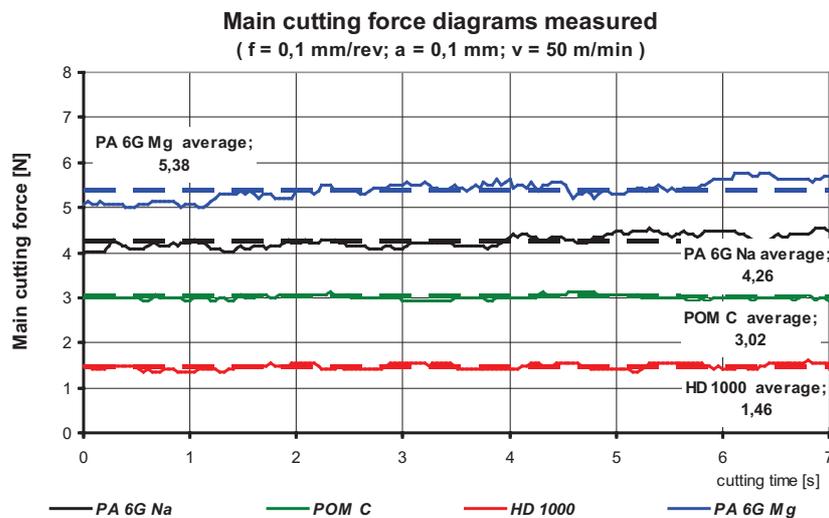

Figure 6. Main cutting force value at materials tested at cutting parameters given.

Feeding-directional cutting force diagrams measured
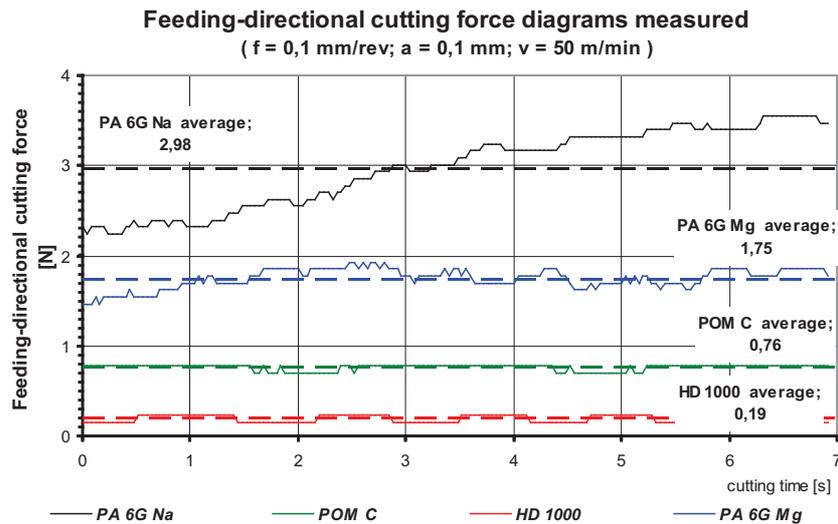(f = 0,1 mm/rev; a = 0,1 mm; v = 50 m/min)

Figure 7. Feeding-directional cutting force at materials tested at parameters given.

As each workpiece tested had the same directions the measuring time period was continuously changing because of various feeding and cutting speed values. Therefore we have 7 s –time taken into account at most measuring. In case of certain cutting parameters this value could not be reached, therefore at these parameters the cutting time was reduced to 4 at one case 2 s respectively. The next diagram we have presented the main –and feeding- directional cutting forces in the function of depth of cut and of feeding from average values belonging to parameters given according to the following sample (Figure 8). Similar evaluations were done for each material types.
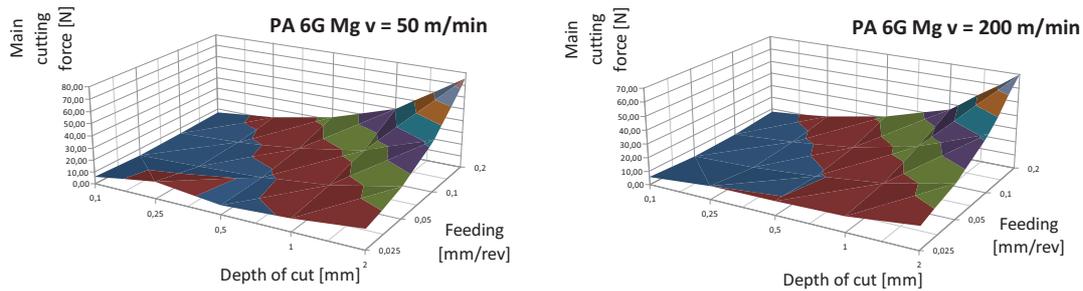

Figure 8. The value of main cutting force in the function of depth of cut and of feeding, PA 6G Mg

3.1 Specific cutting resistance

Cutting materials the specific cutting resistance (k_s) is an important factor. The following sample shows its change in the function of depth of cut and of feeding (Figure 9).
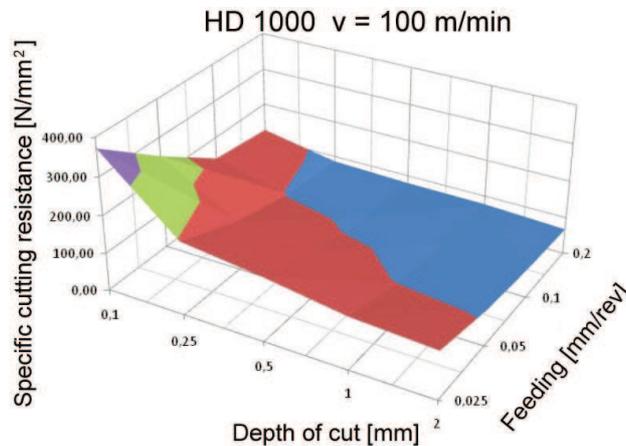

Figure 9. The value of specific cutting resistance in the function of depth of cut and of feeding, HD PE 1000

According to the relation to be found in the literature the main cutting force is the function of the specific cutting force (or resistance) and of the chip area. As during measuring we have also measured the main cutting force, the chip area was given because of parameters set, so the value of the specific cutting force can be got by transposing the original relation.

$$F_v = k_s \cdot A = k_s \cdot a \cdot s \Rightarrow k_s = \frac{F_v}{a \cdot s} \rightarrow \left[\frac{N}{mm^2} \right] \tag{1}$$

The material tested and the cutting speed used occur in the title of sample diagram. Beside the depth of cut and feeding the specific cutting resistance (y-axis) in N/mm^2 unit can be found on the datum lines.

3.2 Chip pictures (photographs)

The chip removed during machining have been collected and photographs have been made. Based on these the types of chips formed can be examined. Figure 10. shows the chip pictures (splint, continuous chip, transitional platelike, elemental) in the function of feeding and depth of cut at 50 m/min cutting speed at POM C material. It can be established those parameters at materials in case of which chip type meets well the practical requirements.
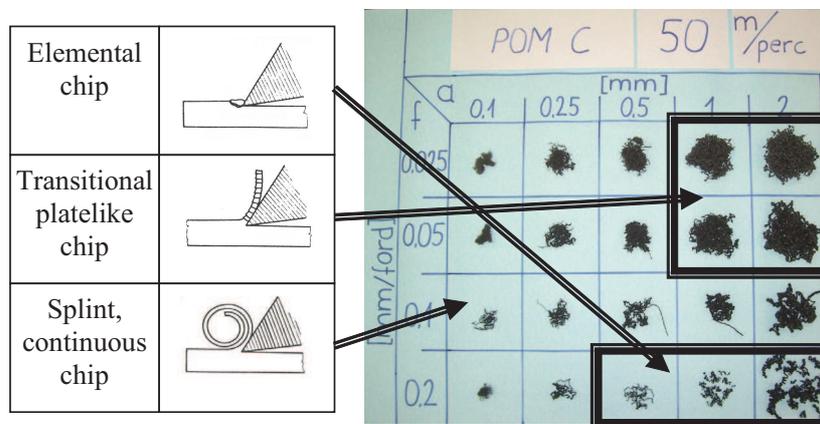

Figure 10. The forming of chip picture in the function of depth of cut and of feeding, POM C

3.3   Tensile strength and specific strain

During the test the pulling force (F) and strain (ΔL) is registered. From these data we have determined the tensile strength values and specific strain.

$$\sigma = \frac{F}{A} \rightarrow \left[\frac{N}{mm^2} \right] \tag{2}$$

$$\varepsilon(\%) = 100 \cdot \frac{\Delta L_0}{L_0} \rightarrow [\%] \tag{3}$$

As an example Figure 11 shows the tensile diagram of POM C, where tensile strength is plotted against specific strain. While the different colors belong to different test samples the black dashed line expresses the average of six measured samples. Later the averaged curves were taken into account for further evaluations.
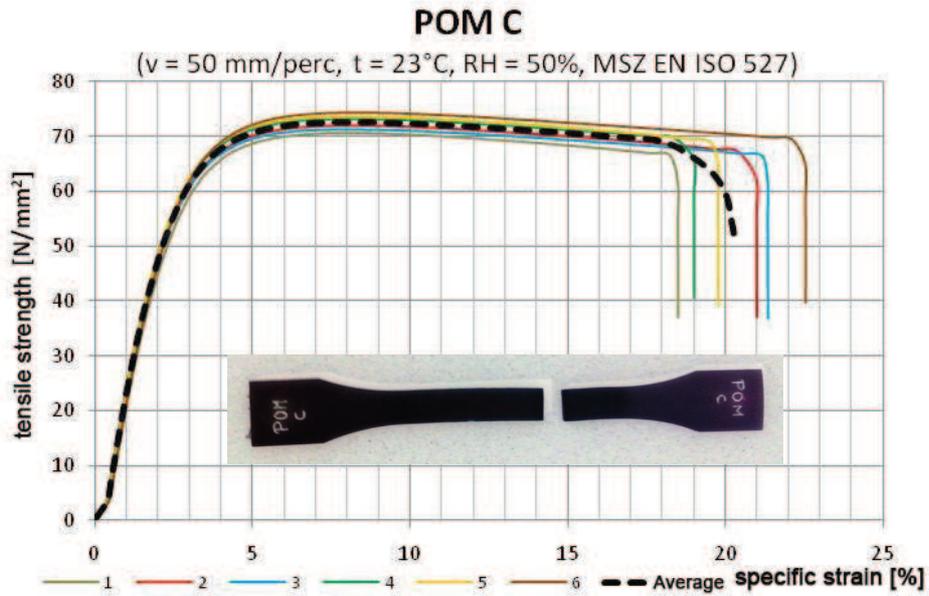
Figure 11. Tensile curves of POM C

Figure 12. shows the yield stress values determined from tensile tests. We found that PA 6G Mg material had the highest yield strength.
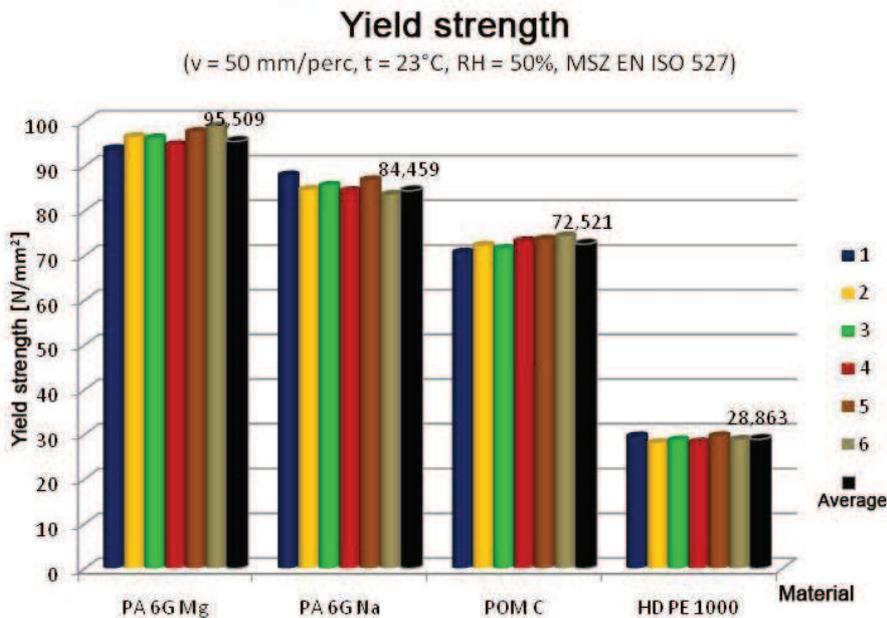

Figure 12. Yield strength of the different samples

3.4   Quotient of specific cutting resistance and yield strength

We devided the specific cutting resistance (N/mm^2) (according to the set parameters - *a, f, v -*) with the yield tress values:

$$\frac{k_s}{\sigma} \rightarrow [-]$$

(4)

These quotient values were plotted against the product of "a"- cutting depth and "f"- feed, namely the chip's cross section (A$_c$, mm^2). Figure 13. shows as an example the UHMW-PE HD 1000 material. The quotient is dimensionless number. All of those graphs were constructed for each materials.
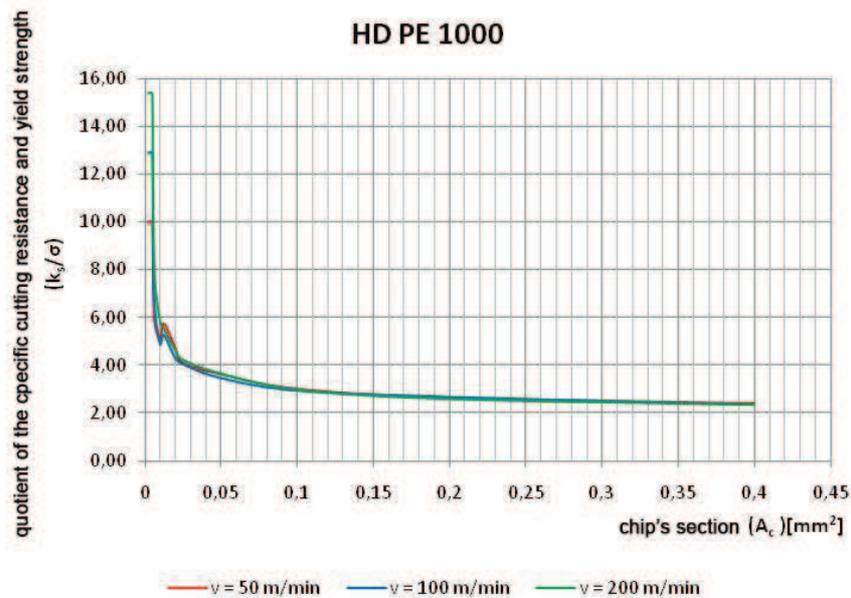
Figure 13. The quotient of the cpecific cutting resistance and yield strength against the chip's section for HD PE 1000

4   CONCLUSIONS

- It can be established from the test results that PA 6G Mg –material proved to be the toughest from both the cutting force and the specific cutting resistance point of view. The specific cutting force decreases substantially by increasing the cutting parameters (feeding, depth of cut). Taking into account the chip type formed it can be said that it is a hardly machineable material. Using the lower feeding (0.025 mm/rev) is suggested.
- The PA 6G Na polymer shows a little lower toughness from the cutting force point of view, on the other hand in case of the specific cutting force it shows already more important change, approximately it reduces into third. Its value with the increasing of feed and depth of cut does not decrease such amount as in case of Mg-containing material. At cutting the small feeding (0.025 mm/rev) and the greater depth of cut (1-2 mm) is suggested.
- At POM C –material could be observed the further decrease of cutting – and specific cutting force. Both decreased into half approximately, but in case of latter, similarly finding PA 6G Na –material, neither here decreased such amount with increasing the feeding and depth of cut as at Mg – containing material. From the standpoint POM C had got the most favourable chip picture among the engineering plastics taking part in tests. Comparing to PA 6G –materials here is suggested the use of greater feeding with increasing depth of cut which results more favourable chip type forming, too.
- The smallest cutting forces can be measured at HD 1000 –polymer. It can be well observed at the value of the specific cutting resistance that this material has got the lowest toughness. From the standpoint of turning this is not a favourable material as regarding the chip type formed is split (continuous chip) in great part of cases tested. The analysis made can be well used in practice. The favourable values of feeding, of depth of cut and of cutting speed, within the ranges tested, can be set for cutting materials tested and for the favourable chip picture.
- We measured the tensile properties of the materials according to MSZ EN ISO 527 standard with a type of INSTRON 5581 tensile machine and we prepared the tensile stress – deformation curves of the polymers. From these diagrams we determined the yield stresses of the materials. We plotted the quotient of the specific cutting resistance and the yield stress in the function of the chip cross section with the all machining parameter groups.
- The specific cutting resistance values of the engineering polymers practically are not available. Only the mechanical properties are highlighted in producers' data sheets. Based on my research work knowing the tensile values of the material the specific cutting resistance can be estimated in case of a given machining settings. These can ease significantly the cutting calculations and the proper technological setup and determine the type of chip produced with a given setup. In the engineering practice the obtained new information formerly were not available, but now the commonly used engineering polymers have special machining database connecting the cutting forces, tensile values, chip formations and removal into one technological datasheet.

5 REFERENCES

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