Research of machining forces and technological features of cast PA6, POM C and UHMW-PE HD 1000.

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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). The analysis made can be well used in practice.

Keywords turning force components, lathe, force measuring, main cutting force

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.

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. The following (Fig. 1) figure shows the relations of arising forces during turning.

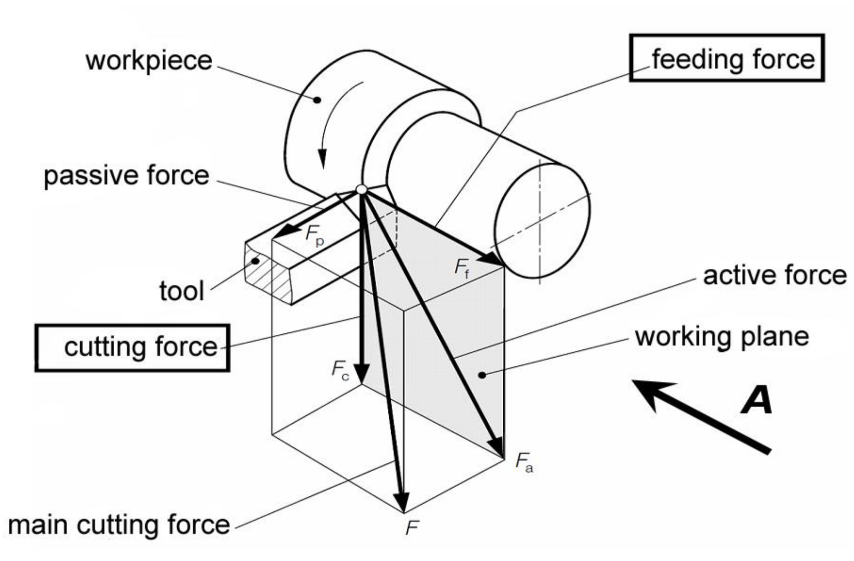


Figure 1. Turning force components (ISO 3002/4, DIN 6584)

<u>Equipment used for tests.</u>

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 2.

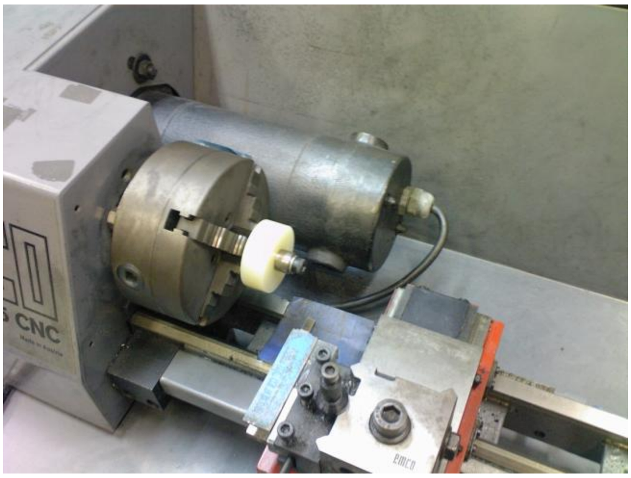


Figure 2. The lathe and the workpiece clamped

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

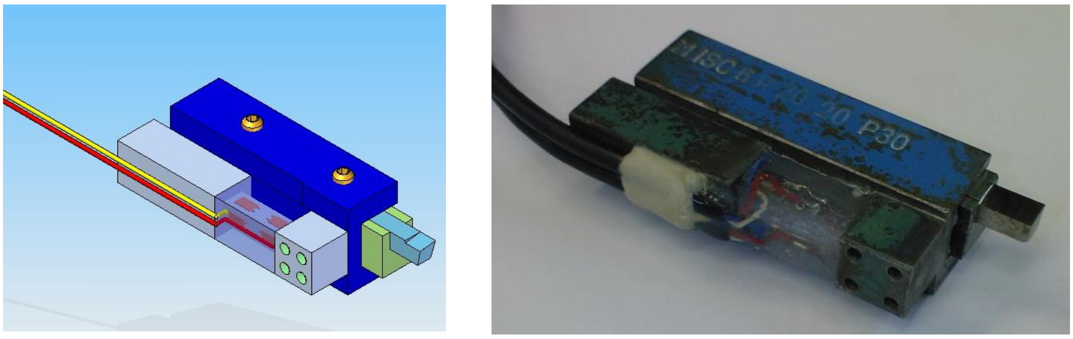


Figure 3. The force measuring shank model and its real picture

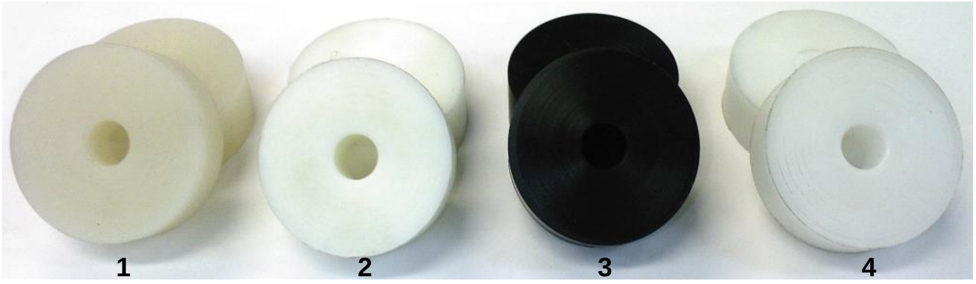
2-2 pcs. strain gauges are fixed at every side. Coupling the strain gauges into total (full) – bridge those is a possibility measuring the forces arising in two directions. To measure the main cutting force F_v (tangential) arising from the movement in vertical plane of the tool and F_f feeding (axial) 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.

<u>Materials tested.</u>

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 in Figure 4.

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



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

Table 3. contains the parameters summarized used at tets. Each cutting speed data registered means test carried out by one-one material to which belong one feeding and one depth of cut. This gives 60 measuring by each material.

Table 3. Cutting speeds in the function of feeding and depth of cut

a \ f	0,025 mm/rev.			0,05 mm/rev.			0,1 mm/rev.			0,2 mm/rev.		
0,1 mm	50 m/min	100 m/min	200 m/min	50 m/min	100 m/min	200 m/min	50 m/min	100 m/min	200 m/min	50 m/min	100 m/min	200 m/min
0,25 mm	50 m/min	100 m/min	200 m/min	50 m/min	100 m/min	200 m/min	50 m/min	100 m/min	200 m/min	50 m/min	100 m/min	200 m/min
0,5 mm	50 m/min	100 m/min	200 m/min	50 m/min	100 m/min	200 m/min	50 m/min	100 m/min	200 m/min	50 m/min	100 m/min	200 m/min
1 mm	50 m/min	100 m/min	200 m/min	50 m/min	100 m/min	200 m/min	50 m/min	100 m/min	200 m/min	50 m/min	100 m/min	200 m/min
2 mm	50 m/min	100 m/min	200 m/min	50 m/min	100 m/min	200 m/min	50 m/min	100 m/min	200 m/min	50 m/min	100 m/min	200 m/min

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: $\alpha_0 = 10^\circ$, the rake angle: $\gamma_0 = 5^\circ$. 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.

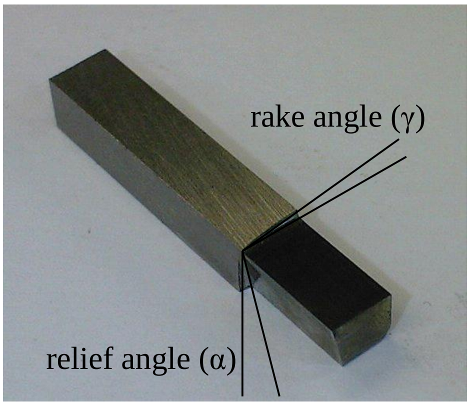


Figure 5. The bit of turning tool used.

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.

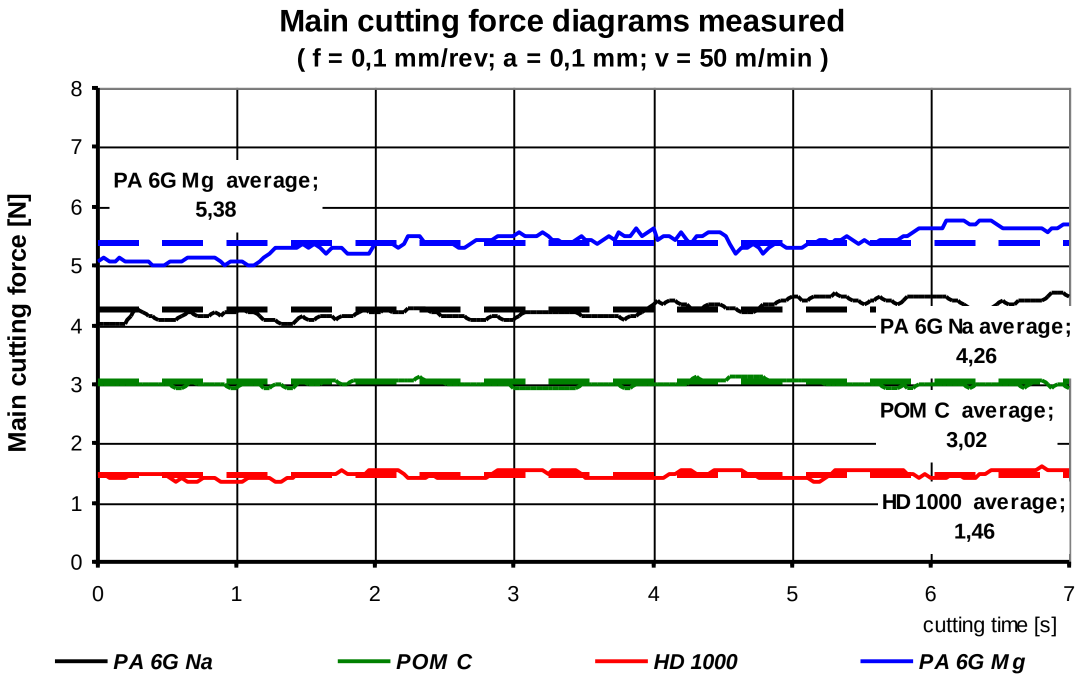


Figure 6. Main cutting force value at materials tested at cutting parameters given.

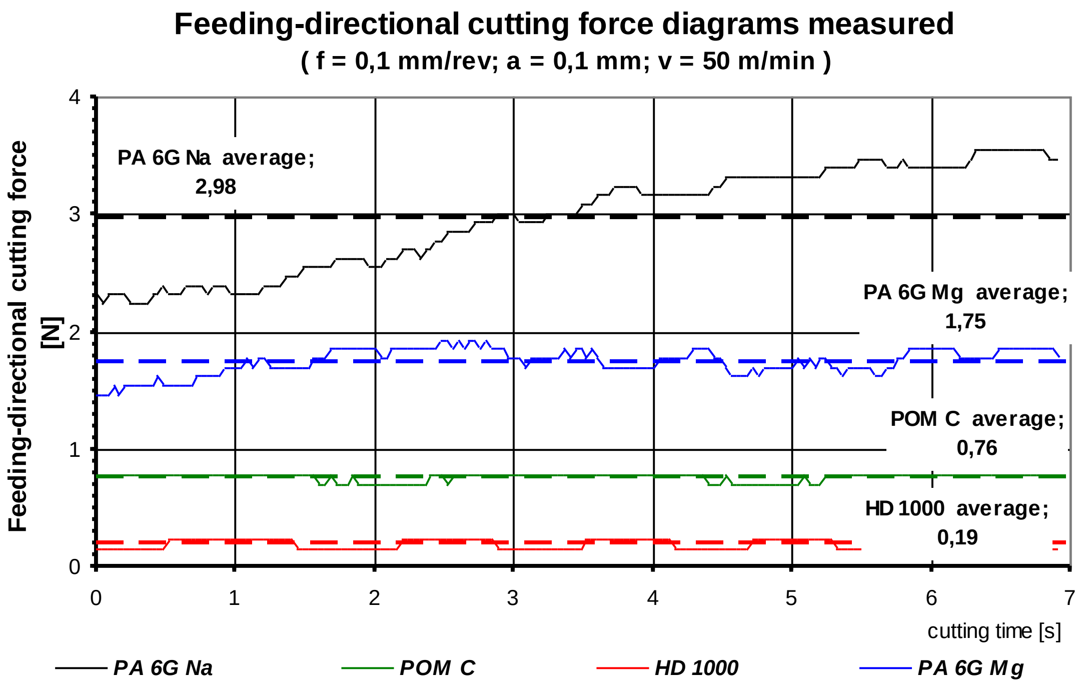


Figure 7. Feeding-directional cutting force at materials tested at parameters given.

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. After putting down into each 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 samples (Figure 8 – 11).

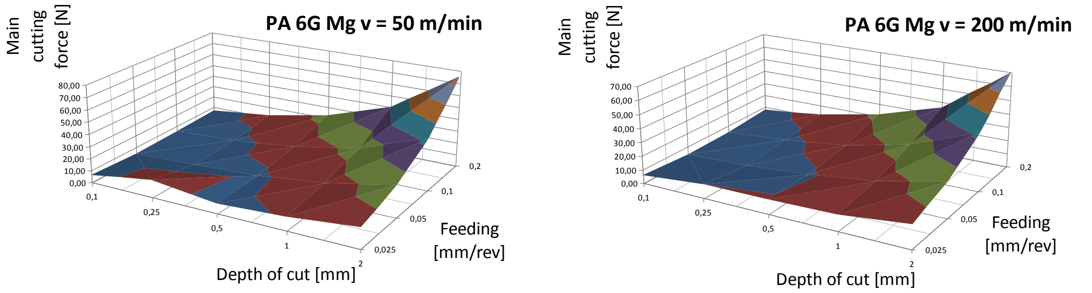


Figure 8. The value of main cutting force in the function of depth of cut and of feeding, PA 6G Mg

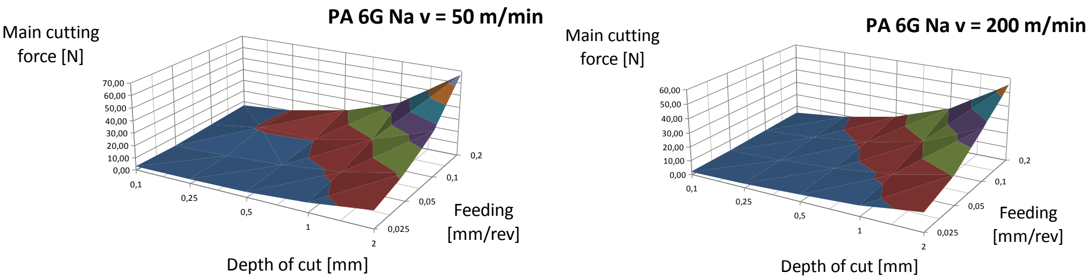


Figure 9. The value of main cutting force in the function of depth of cut and of feeding, PA 6G Na

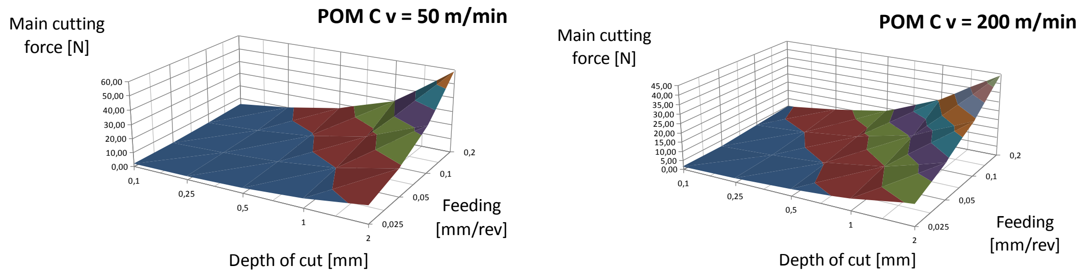


Figure 10. The value of main cutting force in the function of depth of cut and of feeding, POM C

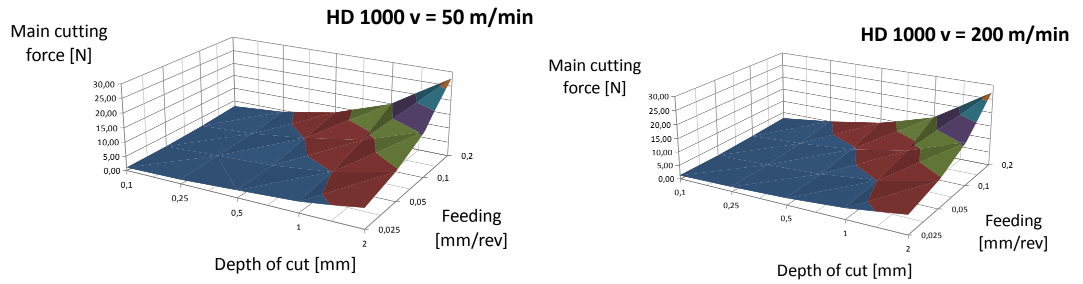


Figure 11. The value of main cutting force in the function of depth of cut and of feeding, HD 1000

<u>Specific cutting resistance.</u>

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 12).

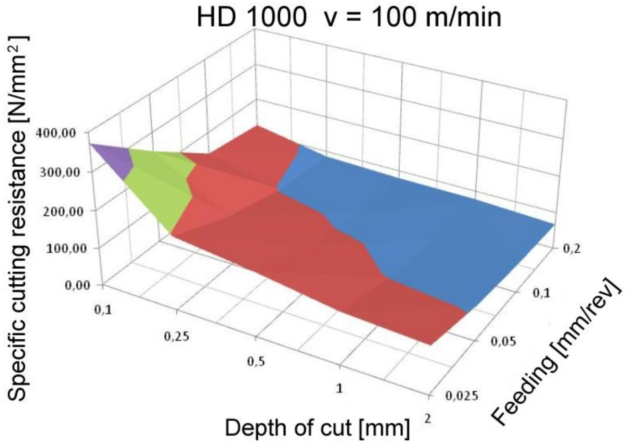


Figure 12. The value of specific cutting resistance in the function of depth of cut and of feeding, HD PE 1000

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.

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

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.

<u>Chip pictures (photographs)</u>

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 13. 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.

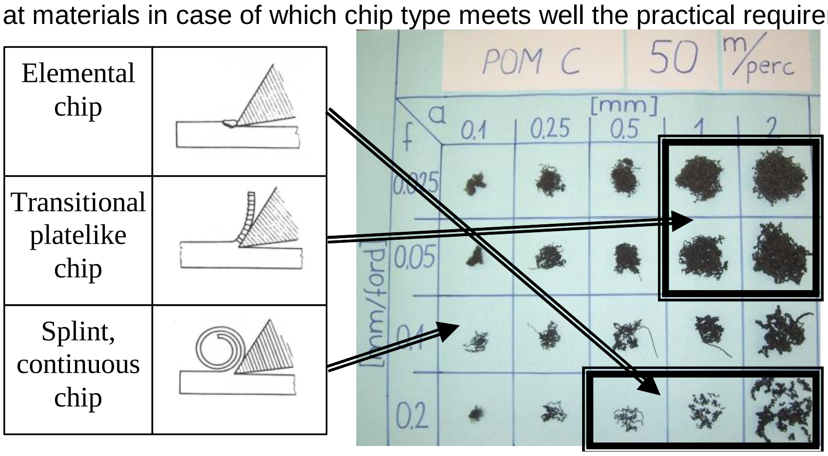


Figure 13. The forming of chip picture in the function of depth of cut and of feeding, POM C

4. SUMMARY

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.

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