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Research on the Turning of Technical Polymers

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Abstract: *Nowadays, the role of plastics has grown tremendously both in our daily lives and in the industry. Virtually everywhere we look, we see plastics. It is sufficient to make plastic parts or other products by injection molding or extrusion in many cases. Today, however, the field of application of plastics has become highly diverse. Often, high-precision fitting may also require for plastics. In such cases, machining may be necessary in many cases, with milling and turning being prominent here. In the case of rotating bodies, turning is most likely the appropriate method of cutting. Even in the turning of steels, it plays a significant role in avoiding flowing chips, but this is a more difficult task for plastics due to the nature of the material. For this purpose, lathes, inserts, and other tools specially developed for cutting plastics are already present in the industry. Of course, here, as in any production process, productivity and economy play a significant role, so it is essential to define and adjust the cutting parameters on machine tools properly. The price of special plastic processing tools is very high. With a low number, they may not be worth buying, in which case machining tools recommended for other materials, such as softer metals such as aluminum, may be considered. Therefore, we used a lathe insert for cutting aluminum in the research.*

Keywords: *turning, polymers, plastics, insert*

1 INTRODUCTION

Today, the role of plastics has grown tremendously in both our daily lives and in industry. Virtually everywhere we look we see plastics. Many machine parts are made of plastic. It is also common to use as a load-bearing or drive element, such as plastic plain bearings, gears, pulleys. In many cases, the material of the sliding guides in contact with the plant parts is also plastic. In such cases, high-precision fitting may also be required for plastics, in which case machining may be required in many cases. Of course, here, as in any production process, productivity and economy play a major role, so it is essential to properly define and adjust the cutting parameters on machine tools. The issue of tooling also arises in connection with this, as the price of special plastic machining tools is quite high. With low numbers, it may not be worth buying, which is when machining tools recommended for other materials, such as softer metals such as aluminum, are considered.

2 LITERATURE REVIEW

Plastics are substances made up of macromolecules, ie giant molecules. Their main constituents are carbon and hydrogen, which in some cases also contain nitrogen, oxygen, fluorine and sulfur. Plastics do not occur in nature, but can also be made from natural materials. We also differentiate plastics according to their origin, depending on where the monomer comes from and how it is polymerized.

- conventional plastics
- biodegradable or biodegradable polymers

The importance of the latter is growing due to the rising prices of fossil fuels and environmental and climate change considerations. Their advantages over biodegradable polymers are the need for recyclability, easy degradation ,and better waste management. Biodegradable plastics can be synthetic or natural based. The latter are produced from renewable raw materials, while the former is made from petroleum derivatives.

Based on the degradation mechanism, plastics can be:

- biodegradable
- compostable
- hydro-biodegradable
- bio-erodible

Polymers currently used in technical practice belong to the group of conventional plastics (Kalácska et al 2007).

2.1 Production of plastics:

Long-chain substances formed by chemical bonding between monomeric chemical units are called plastics. Low molecular weight monomers are able to bind to each other when they have double bonds or other active groups. Monomers require at least two functionally active moieties to form macromolecules.

Three types of plastics can be formed as a result of the reaction between monomers:

- thermoplastics
partly crystalline in structure
amorphous structure
- non-thermoplastic (duroplastics)
- elastomers

Advantages of plastics over metals:

- low density and high specific strength
- corrosion resistance, chemical resistance
- excellent heat and electricity insulation
- high design flexibility
- shaped finished products are easy to manufacture
- Unlimited coloring options
- energy costs can be reduced

(Kalácska et al 2007)

2.2 Engineering plastics:

Engineering plastics are polymers with excellent mechanical properties over a wide temperature range. Therefore, they can be used as structural materials in many constructions, often being more preferred than metals. In addition to their excellent mechanical properties, they have good chemical resistance, especially electrical insulators.

These plastics are available in the following forms:

- powder, granules
- semi-finished products (rods, tubes, boards, foils, etc.)
- finished products

Engineering plastics can be used to advantage in the production of new products as well as in maintenance and repair.

In terms of heat resistance, mechanical properties and chemical stability, they are distinguished by:

- mass-produced plastics, in some cases for technical purposes
- general purpose
- high performance materials (HPM) with outstanding properties (Kalácska et al 2007)

2.3 About turning

Turning is one of the most common machining operations in the industry, used in both custom manufacturing and mass production in both automated forms. Turning is a cutting operation with a single-edged tool with continuous separation of chips with a constant cross-section. (Kári-Horváth et al 2016)

Movements during turning:

During turning, movements in different directions occur, which are performed by the tool and the workpiece. The workpiece performs the main cutting movement, which in the case of turning is the rotating movement. The auxiliary movements are performed by the tool, which is the feed direction and the grip direction.

Forming forces:

During turning, the knife is subjected to three forces. (Fig. 1) The knife is perpendicular to the main cutting force (Fc), the force in the direction of gripping (Fm) is parallel to the blade shank, and the force in the feed direction (Ft) is perpendicular to the blade shank in the horizontal direction. The largest of these is the main cutting force.

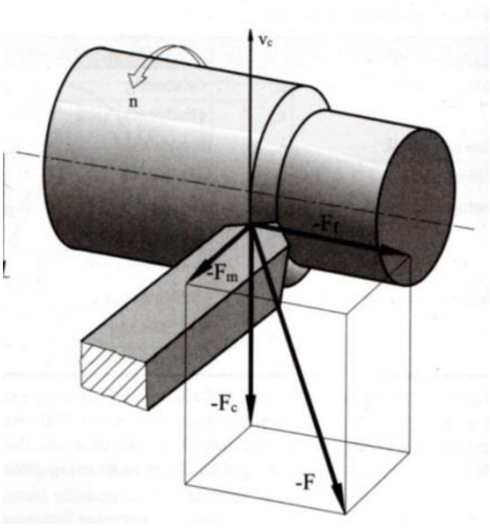

Figure 1. Turning force conditions (Fenyvessy et al 2010)

2.4 Types of chips generated:

During cutting processes, 3 types of chips are usually formed: elementary, temporary and flowing chips. Elemental chips, small chips are formed during the cutting of hard materials, which is advantageous because the chipping of the chips on the workpiece or tool is not a problem. (Figure 2) The temporary chip when small chips are welded together into larger pieces after detachment. The last type is formed in flowing, soft materials, which is why it plays a significant role in plastics. As its name suggests, it is a chip that can come off in continuous pieces up to several meters long during machining, which is unfavorable from the point of view of work safety and cutting technology, as it can wind up on the workpiece and the tool, and this causes surface roughness. degrades, increases cutting force, degrades dimensional accuracy. (Kalácska 2005)

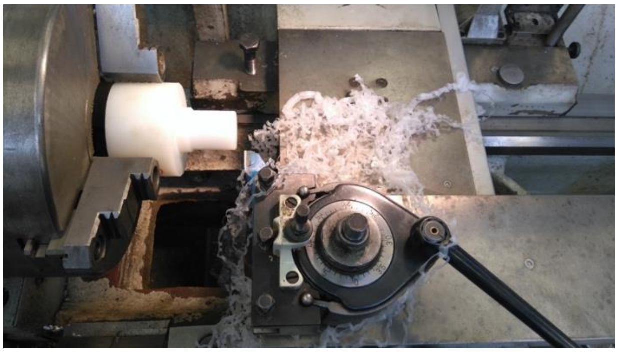

Figure 2. Formation of river chips

3 MATERIAL AND METHOD

In the research, we used a turning knife insert for cutting aluminum. (Figure 3) During the measurements, the machined materials were PA6, POM C ,and UHMW PE HD 1000. During the turning process, we investigated the problems encountered, such as the avoidance of chip formation, the main and feed cutting forces acting on the knife, at different feeds, depths of cut and different cutting speeds, between which the possible correlations were examined. The machining was performed on an NCT Euroturn-12B type CNC controlled lathe. The cutting and feed force were measured using an indexable insert shank equipped with strain gauge stamps. (Figure 3) The stamp mark goes to a Spider 8 type electrical metering system that is connected to a computer through a parallel port.

Figure 3
A knife with strain gauges placed in the knife holder

The data were collected using Catman software, which collects the data and also graphically depicts the forces acting as a function of time. After saving, the measurement results can be opened with a spreadsheet program. Chips formed with different cutting parameters for different materials were examined. For environmental and other reasons, all turning was performed without emulsion and any other coolant. We have determined the specific cutting force, which is important for determining the good utilization of the tool and can also be used to design the economics of machining.
Applied lathe insert: (Fig. 4)
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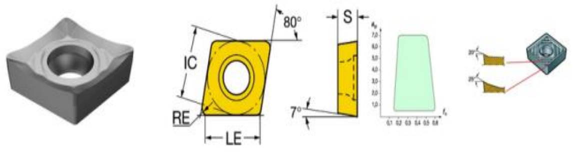

Figure 4
Tile geometry (www.sandvik.coromant.hu)

4 RESULTS AND CONCLUSIONS

The diagram shows the values of the main cutting force as a function of the feed and the depth of cut. (Fig. 5) During the measurement, it can be noted that at the highest cutting parameters indicated in the diagram, the turning was already accompanied by a strong sound effect, which may have been caused by the vibrations.

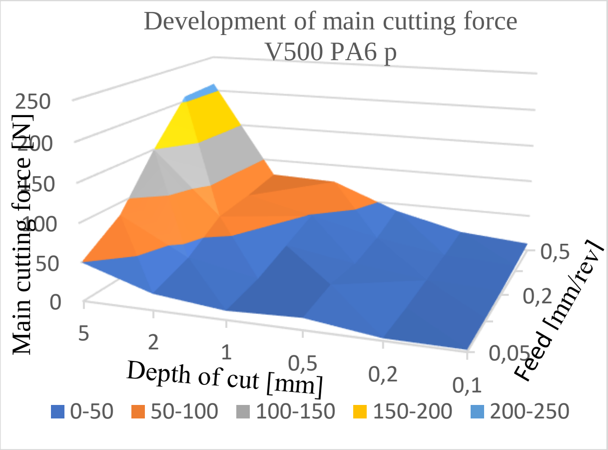

Figure 5
Development of the main cutting force PA6.

It is clear that the feed force takes on largely negative values, which shows that the lathe blade should not be pushed but pulled, so it should be held back because the workpiece is so to pull on the blade. (Fig. 6) This phenomenon may be important because the longitudinal slide of CNC-controlled machines has no backlash, unlike most conventional lathes, which have backlash, and thus this phenomenon is extremely disadvantageous. In this case, the amount of backlash pulls the knife on itself and a sudden high dynamic load is created which can damage the knife, suddenly increase the forces acting and degrade the surface quality. So on conventional machines, it is worth considering these parameters.

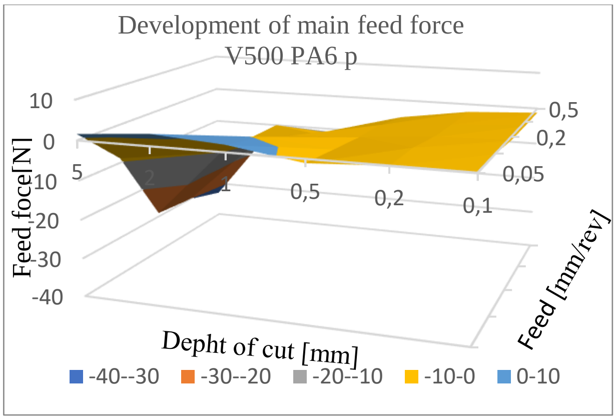

Figure 6
Evolution of feed force PA6

Measurements were made with the feed and depth values shown in the diagrams above for the PA6 at cutting speeds of 300m / min and 100m / min, respectively. (Fig. 6) At a cutting speed of 300 m / min, the cutting force showed higher values than at a cutting speed of 500 m / min. Here, too, it was observed that the main cutting force decreased almost abruptly between 0.3 and 0.2 mm / revolution. As before, only the highest feed and depth of cut values showed a significant change in the main cutting force. The feed force was similar to that measured at the previous cutting speed, so it was observed that the feed force changed to a negative value for certain cutting parameters.

At a cutting speed of 100m / min, the main cutting force showed a more even change, and the feed force also behaved similarly to previous measurements. The same series of measurements were performed for UHMW PE HD1000 and POM C, with the same parameters. The UHMW PE HD1000 has less force than the PA6 and varies much more evenly as a function of feed and depth of cut. In the case of the feed forces, the forces developed similarly to the previously studied PA6, much smaller forces were generated.

During the cutting of the POM C, it can be observed that the main cutting force varies uniformly as a function of the feed and the depth of cut. It shows no major bounces anywhere. Smaller positive forces appeared in the feed force than in the case of the polymers previously studied.

4.1 Development of specific cutting force:

The specific cutting force shows how much force is required to separate 1mm2 of material. It is clear that it shows higher values at low feed rates and shallow depths than at higher values for the same parameters. It is important to test it, because it makes it easier to determine the utilization of the tool and also optimizes the economy of cutting.

Calculation: $k_c = \frac{F_f}{f \cdot a}\ [\frac{N}{mm^2}]$

where: F_f – main cutting force [N], f – feed [mm/fordulat], a – depth of cut [mm]

4.1.1 PA6:

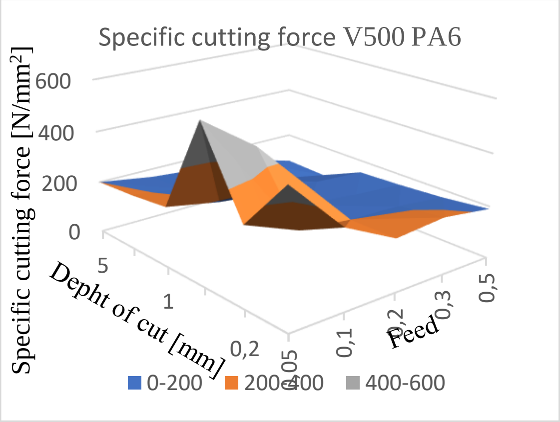

Figure 7
Specific cutting force PA6

In the case of PA6, the change is not completely uniform, but it is clear that the value of the specific cutting force decreases with increasing depth of cut and feed and hardly changes after a certain value. (Figure 7)

4.1.2 UHMW PE HD 1000

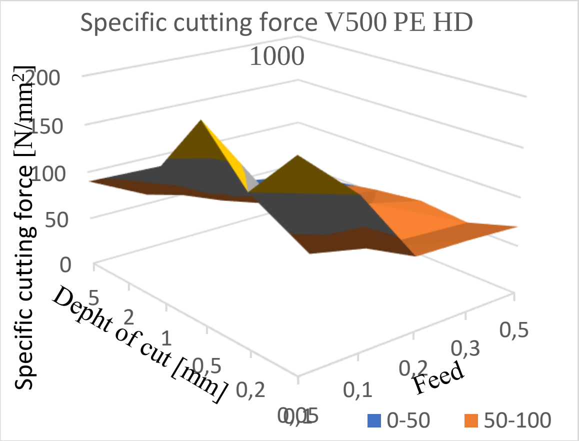

Figure 8
Specific cutting force UHMW PE HD1000

In the case of the UHMW PE HD 1000, the value of the specific cutting force is already lower, but the diagram shows much different values for the different depth of cut and feed settings. (Figure 8) Here again, it can be observed that the value of the specific cutting force is almost constant in a certain area.

4.1.3 POM C

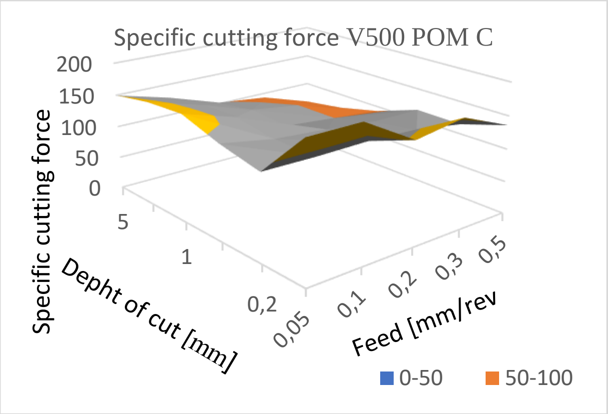

Figure 9
Specific cutting force POM C

In the case of POM C, the values of the specific cutting forces are between the values found for PA6 and PE HD 1000 tested previously. (Figure 9) The almost constant value area observed above is omitted here, but here the values move within narrower limits in the whole examined range.

4.2 *The ratio of the specific cutting force to the tensile strength*

In the course of the tests, we tried to find some correlation between the strength and the forces occurring during cutting, on the basis of which the magnitude of the main cutting force can be estimated in advance.

The relationship used is: $\frac{k_c}{\sigma_B}\ [-]$

Where: k_c – specific cutting force $[\frac{N}{mm^2}]$, σ_B – the tensile strength of the polymer $[\frac{N}{mm^2}]$

The result is a dimensionless ratio, the change of which is shown below.

4.2.1 PA6

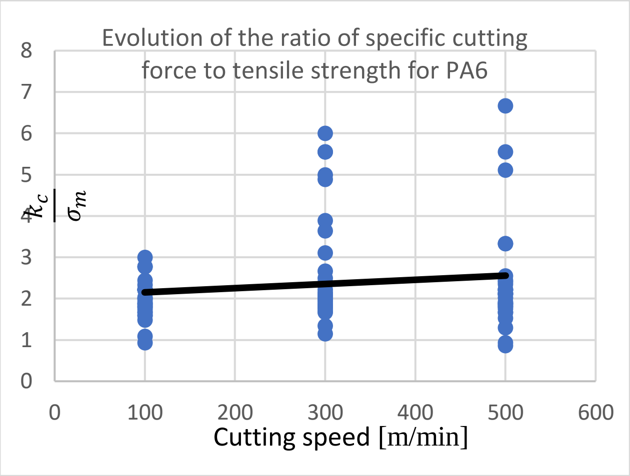

Figure 10.
Development of the quotient of the specific cutting force and tensile strength in the case of PA6

The diagram shows well that the ratios are around 2 mainly. (Figure 10) The line shows the change in their average by changing the cutting speed.

4.2.2 UHMW PE HD 1000

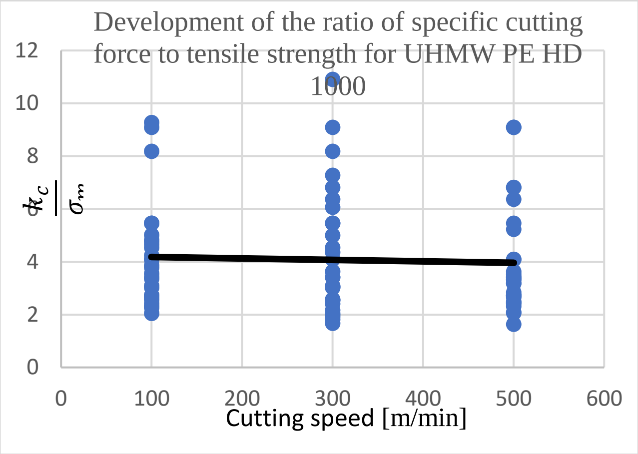

Figure 11.
Development of the quotient of the specific cutting force and tensile strength in the case of UHMW PE HD 1000

The opposite is true for UHMW PE HD 1000 as for PA6 (Figure 11). Here the ratio is around 4.

4.2.3 POM C

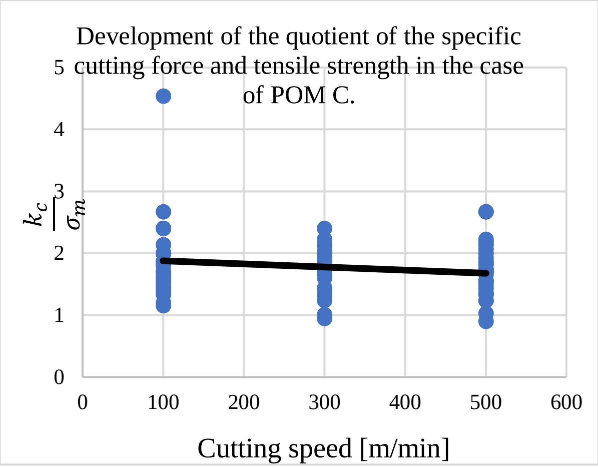

Figure 12.
Development of the quotient of the specific cutting force and the tensile strength in the case of POM C

In the case of POMC, the ratio changes similarly to that of the UHMW PE HD 1000. (Figure 12) It is also clear that the values show a similar distribution. The ratio is between 1.5 and 2 on average.

5 CONCLUSION

Overall, the specific cutting forces shown in the diagrams showed high values at low depths and low feed rates, while the opposite was observed at high feed rates and high depths, so low cutting forces were observed. The latter is more favorable from an economic point of view. In the case of POM C, the specified specific cutting force and tensile strength ratios can be used very well in practice to estimate the specific cutting force based on the tensile strength and from this the expected main cutting force can be determined for a given depth and feed. From a practical point of view, this can be extremely advantageous in terms of quick calculations, tool selection and many more. In the case of PA 6, the ratio already showed a larger standard deviation, and here the value increased with increasing cutting speed. Despite the larger standard deviation, this can also be used to estimate the specific cutting force that occurs, but it should be noted that a more uncertain result is obtained. For UHMW PE HD 1000, the ratio showed a similar standard deviation as for PA 6. However, here the value of this ratio decreases as the cutting force increases. Despite the greater variance mentioned, this can also be used to estimate cutting data, albeit to a lesser extent than in the case of PA 6. Which is less important for this material as less forces are encountered during cutting. The quotients of the specified specific cutting force and the tensile strength of the material can be used advantageously and give fast, good approximation results, which is an important aspect in practice.

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