UNIVERSITY OF PITESTI
FACULTY OF MECHANICS AND TECHNOLOGY

SCIENTIFIC BULLETIN
AUTOMOTIVE series, year XV, no.19, vol. A

STUDIES REGARDING MACHINABILITY DURING THE TURNING PROCESS OF PA 66 MoS_2 POLYAMIDE WITH AN CERAMICS INSERTS

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Abstract: *Polyamide PA 66 MoS_2 is a technical thermoplastic material which has excellent mechanical and physical properties and which is more and more often used in the automotive engineering industry. This is the reason why we need to know the machinability characteristics of this thermoplastic material during the turning process. In this paper we intend to study the influence of the cutting parameters on the power of cut, the main cutting force, the specific cutting pressure, the roughness of the surface and the international dimensional accuracy during the turning process of PA 66 MoS_2 polyamide. The planes of experiments were established based on the Taguchi Methodology. The works were done with a carbide tipped lathe tool.*

Keywords: Polyamide, Cutting Process, Roughness, Machinability, Taguchi Methodology, Turning, Cutting Tools.

INTRODUCTION PROCEDURE

As we know, the main cutting force is one of the factors which influence the workability of a material during the cutting process.
In this work we determine the influence of the cutting regime parameters on the power of cut, the main cutting force, the specific cutting pressure, the roughness of the surface and the international dimensional accuracy, during the lathing process of a polyamide PA 66 MoS_2.

EXPERIMENTAL

The influence of the cutting parameters on the power of cut and the main cutting force
Following the experimental researches regarding the dependence of the cutting force on the depth, feed and speed, we have established that the main cutting force by lathing can be expressed by a relation, such as:

$$F_z = a \cdot t^b \cdot s^c \cdot v^d \tag{1}$$

where a, b, c, d are constant and t, s and v represent the depth of cut, the cutting feed and the cutting speed.
This dependence may be linearized by logarithmation:

$$\lg F_z = \lg a + b \lg t + c \lg s + d \lg v \tag{2}$$

By substituting: $\lg(F_z) = Y$; $\lg(a)=A_o$; $b=A_1$; $\lg(t)=X_1$; $c=A_2$; $\lg(s)=X_2$, $d=A_3$; $\lg(v)=X_3$ we obtain the linear equation (3).
The values X_1, X_2, X_3 are known to be imposed values, and the value Y is measurable. In order to determine the equation one has to determine the A_0, A_1, A_2 and A_3 coefficients.
If the relation of dependence $Y = Y(X_1, X_2, X_3)$ can be expressed by such an equation:

$$Y = A_o + A_1X_1 + A_2X_2 + A_3X_3 \tag{3}$$

then Y depends linearly on the X_1, X_2, X_3 variables.
This equation represents the mathematical model chosen to characterize the process or the phenomenon. One can reach the linear dependence of a value with many variables through mathematical artifices.

Starting from the data presented in table 1, meaning the admission parameters of the process, we have established an experimental factorial and fractional plan of the type 2^3. This plan is presented in table 2.

Table 1. The values of the admission parameters of the process

The parameter		The real value	The normal value
The cutting speed, v [m/min]	v_{min}	117.75	-1
	v_{max}	235.5	1
The cutting feed, s_l, [rev/min]	s_{min}	0.1	-1
	s_{max}	0.225	1
The depth of cut, t [mm]	t_{min}	0.1	-1
	t_{max}	0.3	1

The conditions under which the researches took place are:

- the machine-tool used: a parallel screw-cutting lathe MSZ 5022;
- a lathe tool having the geometry presented in table 4;
- with cooling;
- the force was measured with a digital clamp meter, DIGITAL CLAMP METER 202B, having a 0.01 degree of precision.

Table 2. The experimental plan [2, 7]

Exp.	The standardized values of the independent variables		
	t	s	v
1	-1	-1	-1
2	1	-1	-1
3	-1	1	-1
4	1	1	-1
5	-1	-1	1
6	1	-1	1
7	-1	1	1
8	1	1	1
9	0	0	0
10	0	0	0
11	0	0	0
12	0	0	0

The force F_z is indirectly determined by measuring the amperage and by calculating the power consumed during unloaded and loaded running.

The material on which the experimental researches were done is the polyamide PA 66 MoS_2, its properties are presented in table 3.

Table 3: Mechanical properties of the materials used [1]

Properties	Unit	PA 66 MoS_2
Density	g/cm^3	1.16
Breaking strength	MPa	78
Breaking elongation	%	25
Resistance to shock	KJ/m^2	3.5
Ball test hardness	N/mm^2	160

The cutting feed s, the depth of cut t and the cutting speed v are independent variables and have imposed values on two levels. The main cutting depth during the lathing process F_z is a dependent variable.

The main cutting force during the lathing process is indirectly determined by measuring the electric current intensity of operating of the machine-tool during the unloaded running of the machine $I_{unloaded}$ and the electric current intensity during the loaded running I_{loaded}.

The power developed during the unloaded running of the machine-tool $P_{unloaded}$ and the power developed during the loaded running by the electric engine of the machine-tool P_{loaded} are expressed by the relations:

$$P_{unloaded} = \sqrt{3} \cdot U \cdot I_{unloaded} \cdot \cos\varphi \cdot 10^{-3} \ \text{[KW]} \tag{4}$$

$$P_{loaded} = \sqrt{3} \cdot U \cdot I_{loaded} \cdot \cos\varphi \cdot 10^{-3} \ \text{[KW]} \tag{5}$$

where: - U is the power-supply voltage (U = 380 V);

- cosφ, the power factor (cosφ = 0,88).

The power consumed during the cutting process will be:

$$P_{cutting} = P_{loaded} - P_{unloaded} \ \text{[KW]} \tag{6}$$

Between the main cutting force F_z and the cutting power we may write the relation:

$$F_z = \frac{6000 \cdot P_{cut} \cdot \eta}{v} = \frac{6000\left(P_{loaded} - P_{unloaded}\right)}{v}\eta \ , \tag{7}$$

where: η is the efficiency of the machine-tool (η = 0,8); v, the cutting speed expressed in m/min.

The cutting speed is determined with the relation:

$$v = \frac{\pi \cdot D \cdot n}{1000} \quad \text{[m/min]} \tag{8}$$

Where: D is the diameter of the piece to be lathed expressed in mm; n, the rotative speed of the piece expressed in rot/min.

In the relation, in order to calculate the force, we will use the real speed function of D and n.

Table 4. The geometrical elements of the turning tool used, [4], [5]

The clearance angle, α, [°]	The rake angle, γ, [°]	The main entering angle, χ, [°]	The secondary entering angle, χ_1, [°]
8	30	75	15

Table 5. The values of the independent variables and those obtained for the dependent variable

Exp	The values of independent and dependent variable				
	v, [m/min]	s, [rev/min]	t, [mm]	$I_{unloaded}$, [A]	I_{loaded}, [A]
1	117.75	0.1	0.1	6.28	6.39
2	117.75	0.1	0.3	6.28	6.38
3	117.75	0.225	0.1	6.3	6.44
4	117.75	0.225	0.3	6.3	6.41
5	235.5	0.1	0.1	6.65	6.87
6	235.5	0.1	0.3	6.65	7.05
7	235.5	0.225	0.1	6.76	6.88
8	235.5	0.225	0.3	6.76	6.99
9	166.42	0.15	0.18	6.37	6.54
10	166.42	0.15	0.18	6.37	6.53
11	166.42	0.15	0.18	6.37	6.55
12	166.42	0.15	0.18	6.37	6.57

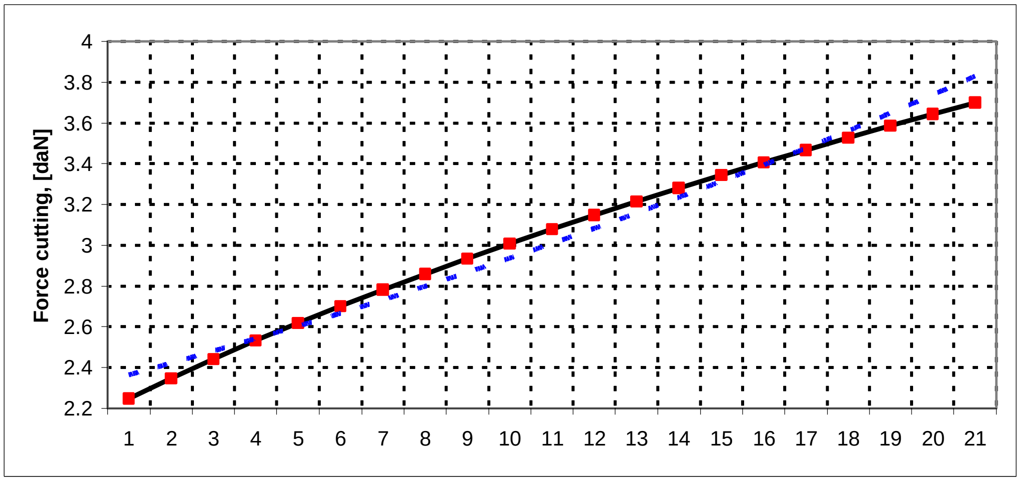

Fig. 1. The influence of the cutting depth on the cutting force, F_z

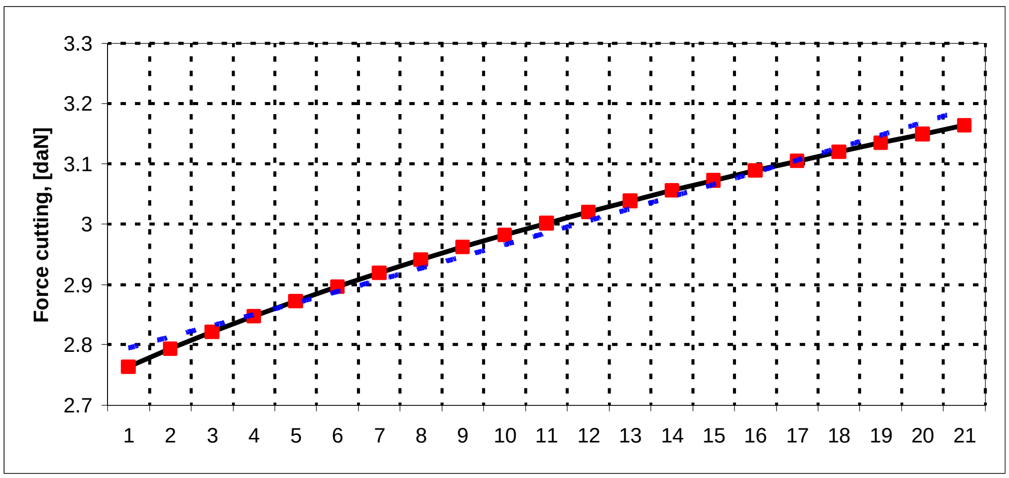

Fig. 2. The influence of the working feed on the cutting force, F_z

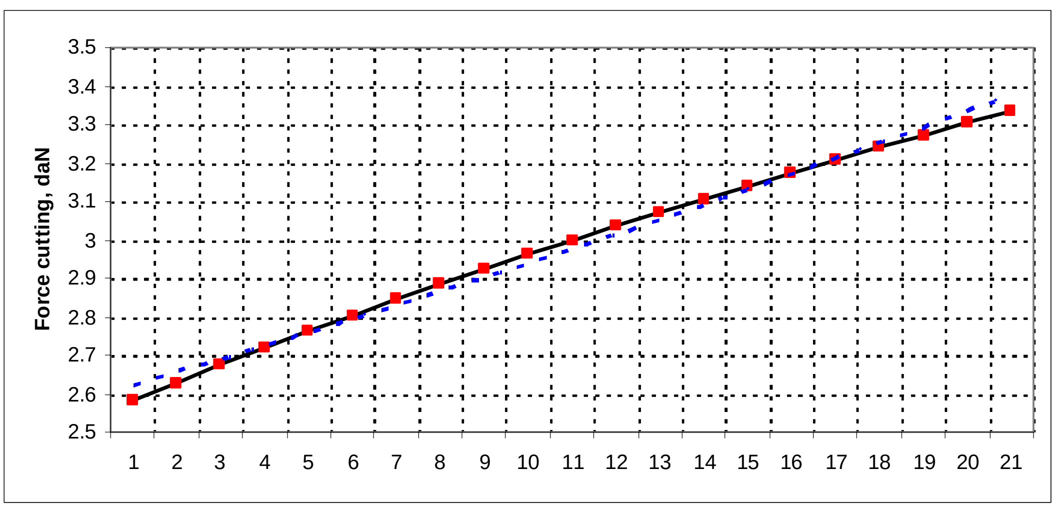

Fig. 3. The influence of the cutting speed on the cutting force, F_z

Based on the measurements and on the relations (4), (5), (6) and (7) we have calculated the power during unloaded running, $P_{unloaded}$, the power during the loaded running, P_{loaded}, the cutting power, $P_{cutting}$, and the main cutting force, F_z.
The calculated values are presented in table 6.

Table 6. The values of the power during unloaded running, the power during the loaded running, the cutting power and the main cutting force

Exp	$P_{unloaded}$ [kW]	P_{loaded} [kW]	$P_{cutting}$ [kW]	F_z [daN]
1	4.133	4.205	0.072	2.935
2	4.133	4.199	0.066	2.69
3	4.146	4.238	0.092	3.75
4	4.146	4.218	0.072	2.935
5	4.462	4.521	0.059	1.203
6	4.462	4.639	0.177	3.608
7	4.495	4.528	0.033	0.673
8	4.495	4.6	0.105	2.14
9	4.258	4.304	0.046	1.327
10	4.258	4.297	0.039	1.125
11	4.258	4.31	0.052	1.5
12	4.258	4.324	0.066	1.904

The relation obtained after working on the data in table no. 6 is:

$$F_z = 1,28 \cdot t^{0,454} \cdot s^{0,148} \cdot v^{0,369} \quad [daN] \tag{9}$$

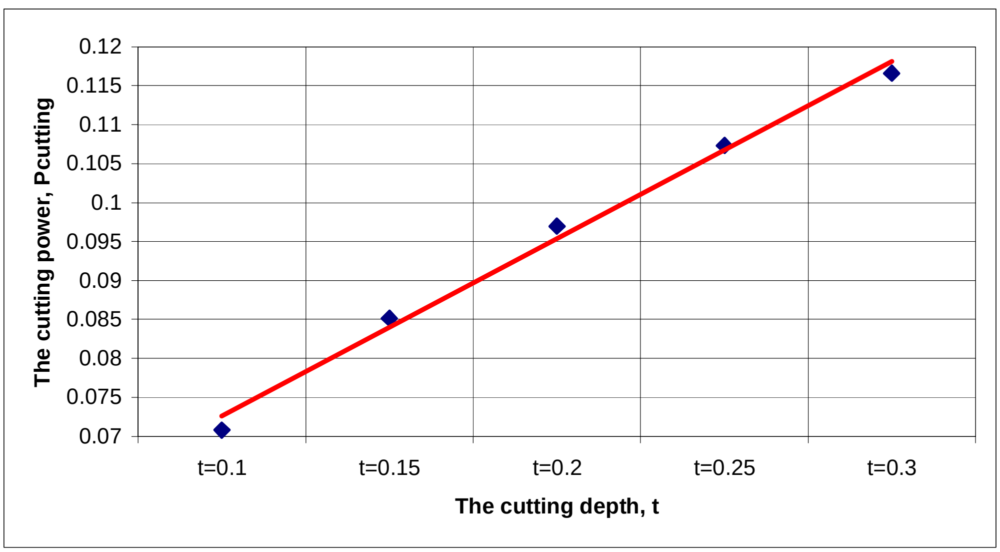

Fig. 4. The influence of the cutting depth on the cutting power, $P_{cutting}$

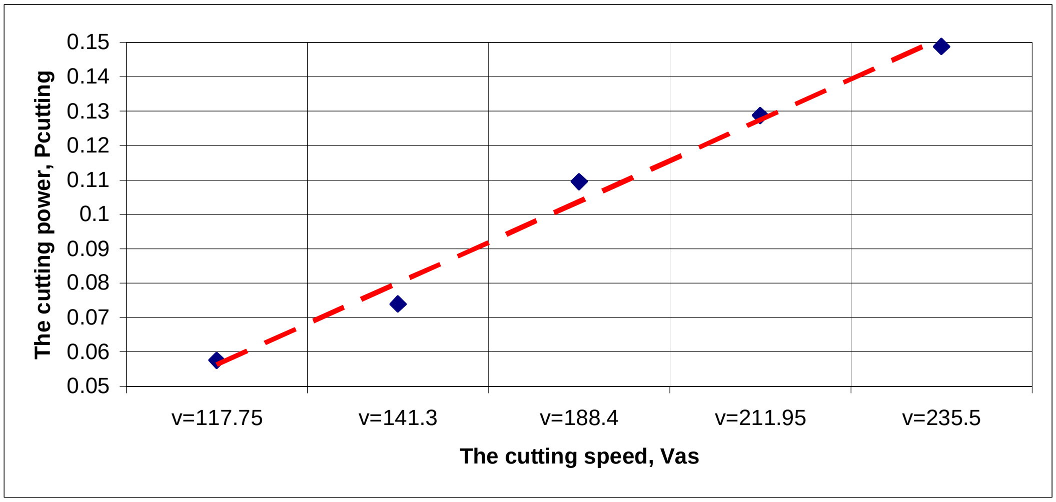

Fig. 5. The influence of the working feed on the cutting power, $P_{cutting}$

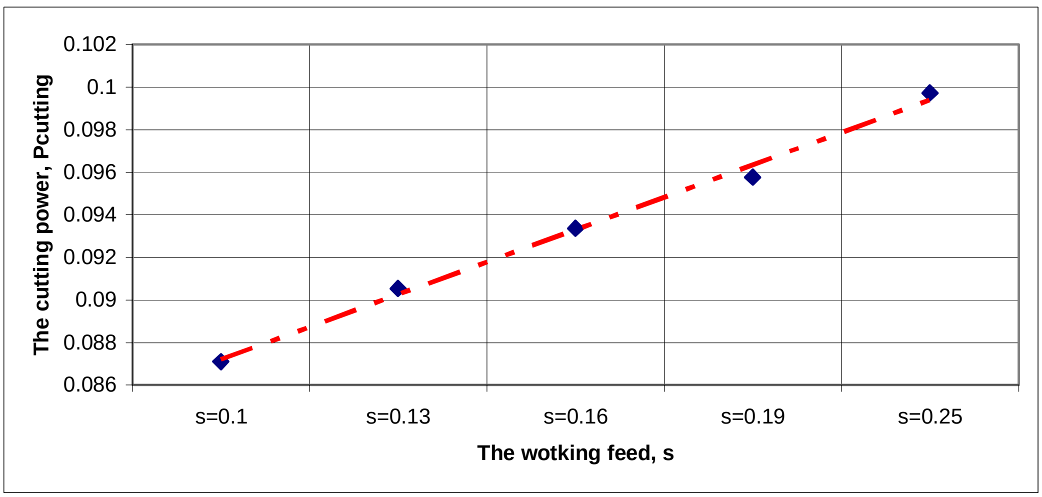

Fig. 6. The influence of the cutting speed on the cutting power, $P_{cutting}$

The relation obtained after working on the data in table no. 6 is:

$$P_{cutting} = 0{,}027 \cdot t^{0{,}555} \cdot s^{-0{,}595} \cdot v^{0{,}16} \quad [kW] \tag{10}$$

The influence of the cutting parameters on the international dimensional precision

The value of the international dimensional precision (IT) can be obtained by using the following empiric relation [7]:

$$IT \cong 30 \cdot R_a \ [\mu m] \tag{11}$$

where IT is the international dimensional precision expressed in µm and Ra is the roughness expressed in µm.

Figure 7 presents the evolution of the international dimensional precision function of the working feed at different values of the cutting speed.

Figure 8 presents the evolution of the international dimensional precision function of the cutting depth at different values of the cutting speed.

From figure 8 we can observe that IT increases with the growth of the working feed. Knowing that IT6 = 20 µm and IT7 = 48 µm we can notice that the working precision is situated between the two IT levels.

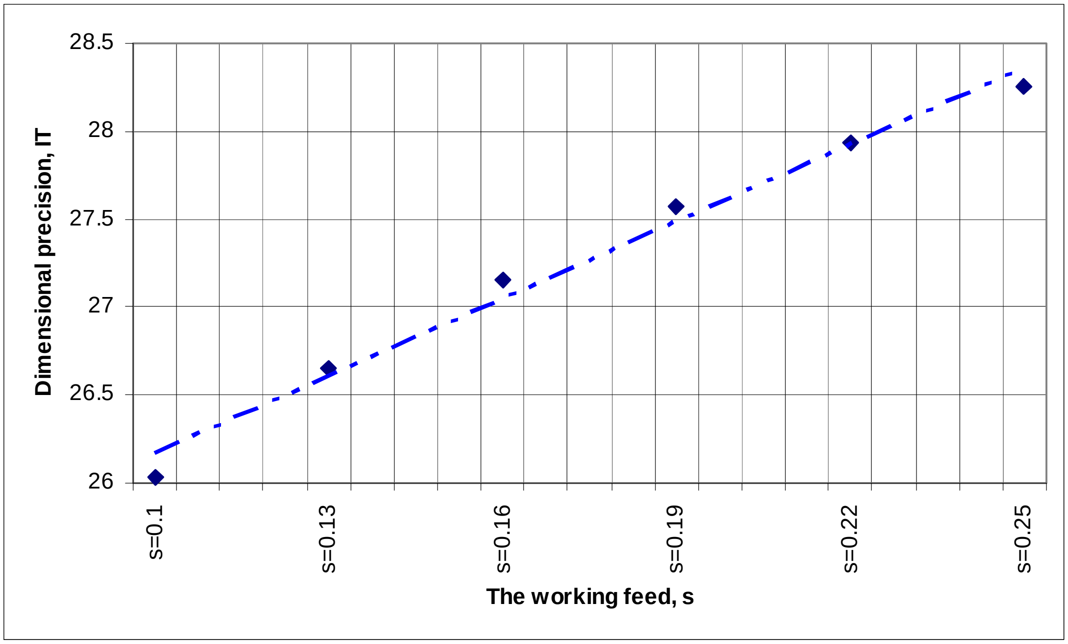

Fig. 7. Dimensional precision IT function of the working feed, s (v = 166,4 m/min and t = 0,18 mm)

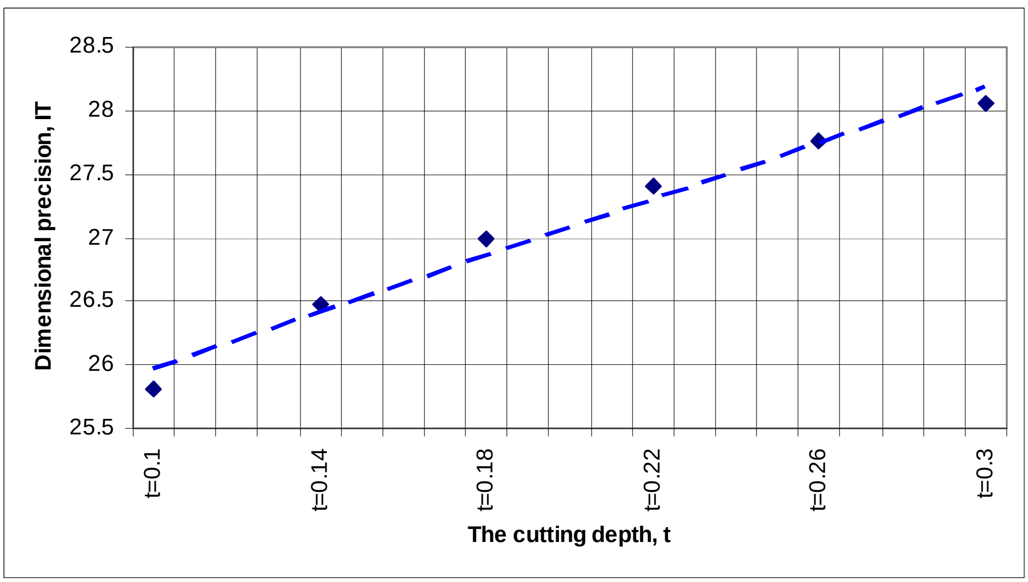

Fig. 8. Dimensional precision IT function of the cutting depth, t (v = 166,4 m/min and s = 0,15 mm/rot)

The influence of the cutting parameters on the specific cutting pressure

It is known that the specific cutting pressure is given by the relationship:

$$K_c = \frac{F_z}{S} = \frac{F_z}{a \cdot b} \tag{12}$$

where:

FZ - main cutting force;

a - thick chips;

b - width chips

$$a = s \cdot \sin\chi;$$
$$b = \frac{t}{\sin\chi} \qquad (13)$$

where:
t - cutting depth;
s - advance work
From [1] it is known that the main force for the cutting of the form:

$$F_z = a \cdot t^b \cdot s^c \cdot v^d \qquad (14)$$

Based on previous relationships can write that:

$$K_c = \frac{a \cdot t^b \cdot s^c \cdot v^d}{s \cdot t} = a \cdot t^{b-1} \cdot s^{c-1} \cdot v^d = a \cdot t^{b_1} \cdot s^{c_1} \cdot v^d$$
$$K_c = a \cdot t^{b_1} \cdot s^{c_1} \cdot v^d \qquad (15)$$

Based on measurements and previous relationships have led to specific cutting pressure.

Table 7. The values of the independent variables and those obtained for the dependent variable

Exp	Valorile variabilelor independente si dependenta				
	t	s	v	Fz	Kc
1	0.1	0.1	117.75	2.935	240.8
2	0.3	0.1	117.75	2.69	145.5
3	0.1	0.225	117.75	3.75	71.3
4	0.3	0.225	117.75	2.935	21.6
5	0.1	0.1	235.5	1.203	611.4
6	0.3	0.1	235.5	3.608	255.2
7	0.1	0.225	235.5	0.673	125.0222
8	0.3	0.225	235.5	2.14	71.6
9	0.18	0.15	166.42	1.327	127.6
10	0.18	0.15	166.42	1.125	127
11	0.18	0.15	166.42	1.5	127.5
12	0.18	0.15	166.42	1.904	128.4

The relation obtained after working on the data in table 7 is:

$$K_c = 1,27114 \cdot t^{-0,546} \cdot s^{-0,8523} \cdot v^{0,369} \quad [N/mm^2] \qquad (16)$$

Based on the relationship (16) have high dependency graphs for each parameter entry, presented in figures 9, 10 and 11.

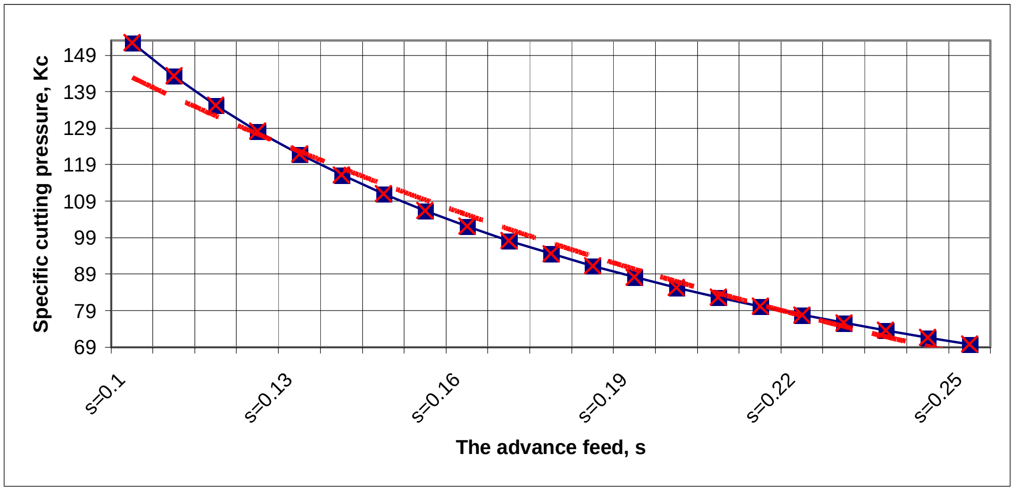

Fig. 9. The influence of the advance work on the specific cutting presure, K_c

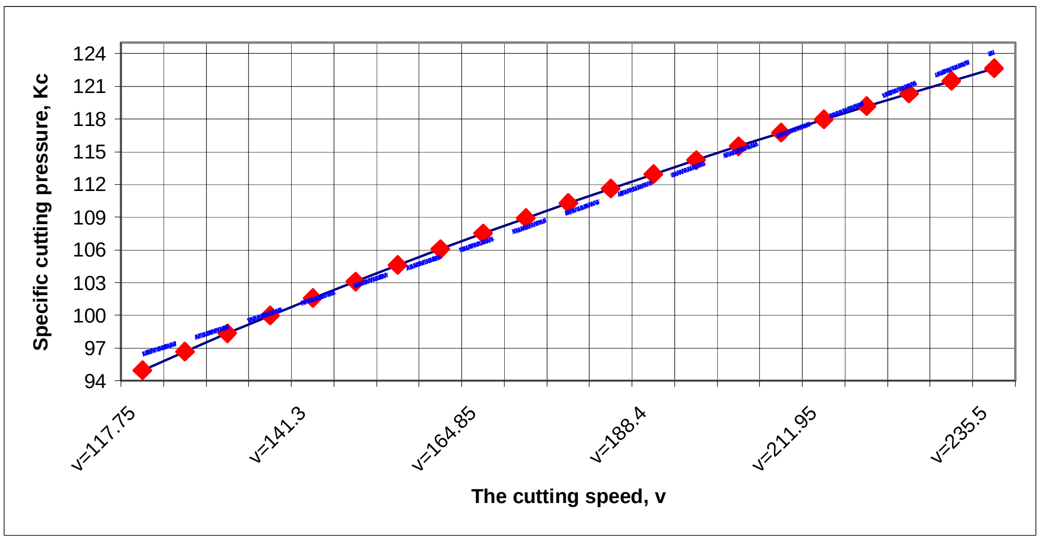

Fig. 10. The influence of the cutting speed on the specific cutting presure, K_c

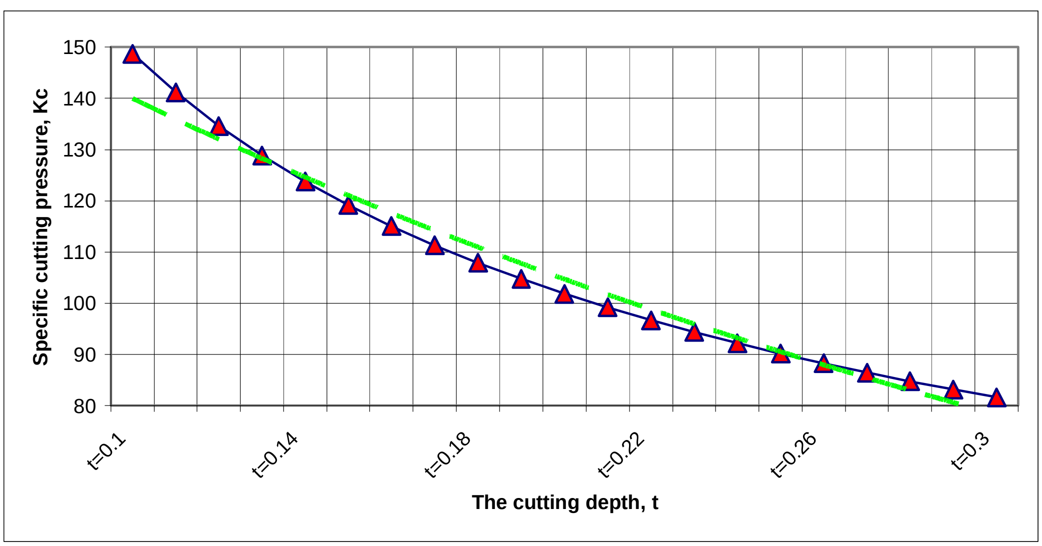

Fig. 11. The influence of the cutting depth on the specific cutting presure, K_c

CONCLUSIONS

By analysing the figures 1, 2 and 3 above we observe that the work feed and the cutting speed have a smaller influence on the main cutting force than the cutting depth. Another observation is that the influence of the feed and of the cutting speed is approximately equal.
By comparison to the forces which occur when lathing a metallic material, we observe that in the case of the lathing process of the polyamide PA 66 MoS_2 these forces are very small.
In figures 4, 5 and 6 we notice that the cutting speed has a great influence on the power of cut and that it is closely followed by the cutting depth. The working feed has an almost insignificant influence on the power of cut.
Thus, we notice that the cutting depth has the greatest power on both the force of cut and the power of cut.
So, in order to have a force and power of cut with values as low as possible we have to work with smaller cutting depths.
Based on the experimental results presented we can draw the following conclusions:

- the roughness of the lathed surface is mostly influenced by the working feed;
- the roughness of the surface (Ra) and the international dimensional precision (IT) increase with the growth of the working feed and decrease with the growth of the cutting speed (fig.7);
- the roughness of the surface (Ra) and the international dimensional precision (IT) increase with the growth of the cutting depth (fig. 8).

We can obtain precision values in conditions similar to those in which the experiments took place, between IT6 and IT7.

In the figures 9, 10 and 11 is observed as:
- to increase the advance of cutting and the cutting depth is observed that the specific cutting pressure decreases;
- increasing the speed of specific cutting pressure increases.

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