THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE V MACHINE BUILDING TECHNOLOGY. ISSN 1221-4566
2004

Technological Particularities of the Turning Process for Thermo Reactive Materials

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ABSTRACT

Between different plastic materials machining procedures, turning is the most used, although it leads to a great quantity of waste. Among all machining methods, turning has a share of 60 %.

The paper presents some technological particularities of the thermorigide materials turning procedure. It shows aspects concerning the mechanics of the cutting process and the geometry of the tools.

Keywords: *plastic materials, cutting process, tools.*

1. Introduction

Between different plastic materials machining procedures, turning is the most used, although it leads to a great quantity of waste. Among all machining methods, turning has a share of 60%.

By turning, it is possible to process cylindrical, cone shaped, plane, helicoidally or profiled, interior or exterior surfaces. This procedure uses different types of cutting tools, drills, reamers, taps and screw plates.

Plastic materials machining is done both in normal lathes and in face lathes, for small scale production or for prototypes, as well in turret lathes, semi-automatic and automatic lathes, for large scale or mass production.

Blanks to be turned are fastened in elastic clamping bush, to avoid deformation.

When turning plastic materials, a large variety of types and shapes of cutting tools can be used.

The one-piece tools, made of high – speed steel, are used mainly in thermoplastic materials machining, and less in the machining of thermo reactive materials – pertinax, bakelite, textolite, in which case, the abrasive wear causes decreases the durability of the cutting tools.

In large scale and mass production, using thermo reactive materials, are used cutting tools with metal carbide plates.

These are tough, have a good resistance to wear and great thermal stability, properties that make them superior to high-speed steel tools.

In case the machined surface needs a quality corresponding to a roughness $2\mu m \leq R_a \leq 10\mu m$, the turning is done with mineral ceramic plated cutting tools. Their wear, according to VB criterion, does not go beyond $(0.05 \div 0.08)$mm.

In special cases, when the goal is achieving a superior quality of the machined surface, within a tight tolerance zone, it is recommended to use diamond plated cutting tools. In 80% of plastic materials machining cases, there is an elastic tempering of the machined surface, phenomenon that requires a special attention to the calculation of the tool cutting end geometry.

The parameters of the cutting conditions are calculated according to the properties of the material, the quality requirements for the product and the cutting tool material.

2. Turning thermo reactive materials

The process of turning thermo reactive materials is done similar to the turning of thermoplastic materials. There are, though, some particularities, generated by the physic, chemical and mechanical properties of the materials involved.

The productivity of the machining process is affected by the cutting conditions: cutting speed, cutting feed and cutting depth.

An increase of the cutting speed causes an increase in tool wear and a decrease in quality of the machined surface.

Depending of the type of material used, the cutting speed may vary within a large interval, from 20m/min, when machining glass fiber reinforced thermo reactive materials, to 800 m/min, when machining textolite.

High cutting speeds amplify the friction in the cutting region, favorizing deformations, and the temperature in the cutting region rises, leading to an intensifying wear of the cutting edges and the thermal destruction of the polymer.

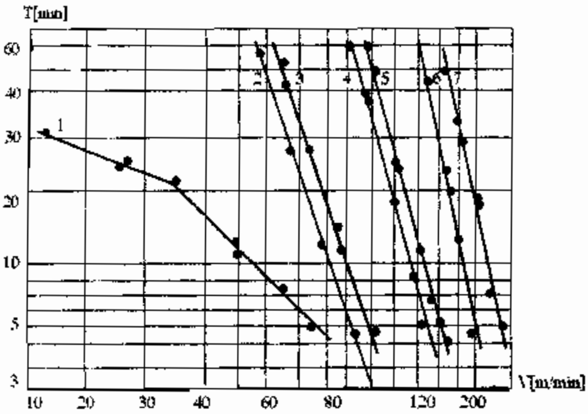


Fig. 1. Variation of the cutting tools durability. as a function of cutting speed. for s = 0.21mm/rot. t = 1.5mm, when machining: 1 - pertinax: 2 - capron: 3 - phenoplast: 4 - bakelite: 5 - textolite: 6 - aminoplast.

Reaching the temperature that destroys the polymer in the superficial layer, leads, in the case of glass fiber reinforced thermo reactive materials. to an increase of the wear probability, by chipping, of the cutting tool. This happens because the destruction the binding material of the blank leads to an increase of the abrasive properties of the bulking agent [5], [8].

Figure 1 shows the variation of the durability of the metal carbide plated tool K 01. as a function of cutting speed, when machining different types of materials. for s = 0.21mm/rot and t = 1.5mm.

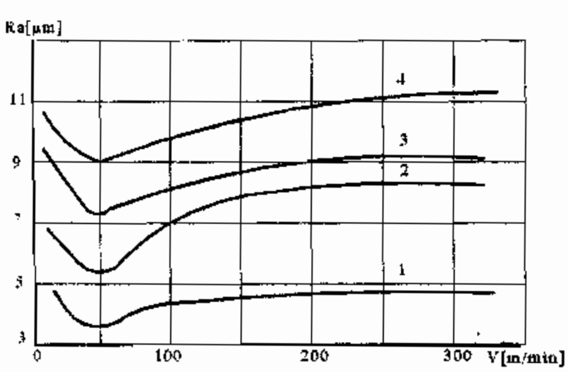


Fig. 2. Variation of the machined surface roughness, R_a, as a function of cutting speed, for: 1 - glassplast; 2 - pertinax; 3 - capron; 4 - textolite.

Figure 2 shows the variations of the roughness of the machined surface, the R_a criterion, as a function of cutting speed, for different materials [2].

It can be noticed that the roughness of the surface decreases with the increase in cutting speed. Within the interval v = (45 ÷ 50)m/min, the roughness reaches a minimum. and after that, with a further increase in cutting speed. the roughness slowly increases too.

Related to the durability of the cutting tools. an increase in the cutting feed (fig 3.a) leads to a decrease of the wear (VB criterion) (fig. 3.b).

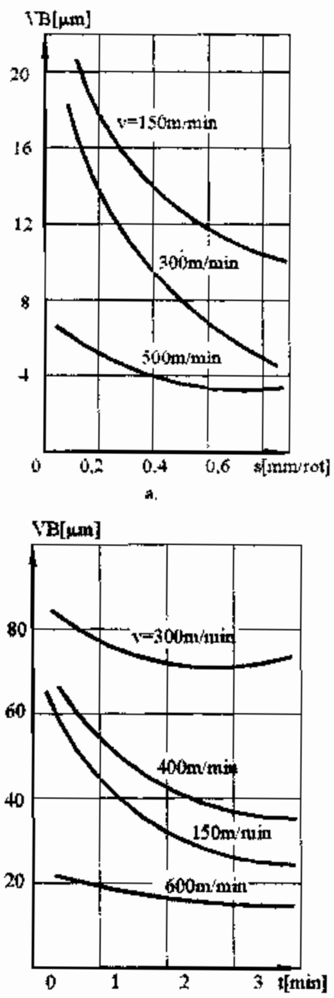


Fig. 3. Variation of the wear, h_{α}, as a function of the cutting feed *s* and the cutting depth *t* (turning with metal carbide plated cutting tool. K 30) for: 1 - capron: 2 - pertinax; 3 -glassplast; 4 - textolite; 5 -phenoplast.

For a cutting feed within (0.1÷0.3)mm/rot, the variation of the wear on the side flank, VB, is considerable. Within the (0.41÷0.92)mm/rot interval, the wear is practically constant and even slowly decreases.

To achieve an increase in productivity and in the same time, to maintain the wear within acceptable limits, in rough cutting and in semi-finishing cutting, it is recommended a cutting feed greater than 0.11mm/rot.

In the finishing cutting, it is recommended a cutting feed within (0.2÷0.3)mm/rot.

No matter the material, the increase of the cutting feed leads to an increase in the roughness of the surface. The value of cutting depth influences the active length of the cutting edge, the contact surface between the cutting tool and the machined piece, the friction surface and the cutting forces.

For smaller cutting depths, the wear increases. For increased cutting depths, t=(1.5÷4) mm, the specific wear becomes constant.

When calculating the cutting depth, it has to be taken into account that its value influences the quality of the machined surface.

The cutting speed, corresponding to a maximum in durability, is called "economic cutting speed", and is calculated using a relation as follows [6]:

$$v = \frac{C_v}{T^x \cdot t^y \cdot s^z} \cdot K_{T_v} \cdot K_{C_v} \text{ [m/min]}, \qquad (1)$$

where:

T is the durability, in [min];

t - cutting depth, in [mm];

s - cutting feed, in [mm/rot];

C_v, x, y, z - are constants, depending of the properties of the machined material, the type of cutting tool and its durability.

C_{Tv}, C_{Cv} - correction coefficients, that are needed because the difference between real and experimental working conditions.

Tables 1 and 2 contain the values of the coefficients from relation (1), for different materials.

When machining thermo reactive materials, the temperature of the cutting end of the tool may reach significant values, as high as 600°C.

Altering the cutting parameters does not has a significant influence over the cutting tool temperature, which can be calculated with the following relation:

$$\theta = 105 \cdot v^{0,29} \cdot s^{0,23} \cdot t^{0,24} \text{ [°C]}. \qquad (2)$$

In machining rolled bedded plastic material, pertinax, textolite, there are used rapid-steel cutting tools, reinforced with carbide metal plates. When machining plastic materials mixed with graphite or having asbestos or glass filling, there are used tools reinforced with carbide metal plates and tools with diamond edge.

When turning pertinax, a decrease in the tool durability can be noticed.

Decreasing the rake angle causes an increase in durability for the cutting tool, as a result of the decrease of the friction area, between the tool and the machined surface.

High values of the rake angle, γ=(25°÷30°), lead to an intense wear of the tool cutting edges.

Table 1.

The values of the correction coefficients C_{Tv} and C_{Cv}, as function of the tool durability and cutting conditions.

Machined material	C_{Tv}				
	Type of the plate				
	K 40	**K 10**	**K 01**		
	T, [min]				
	30	45	60	90	120
Pertinax	1.77	1.27	1	0.71	0.57
Textolite	1.47	1.17	1	0.80	0.68
Phenoplast	1.23	1.09	1	0.89	0.81
Glass fiber	1.36	1.14	1	0.84	0.73

C_{Cv} of the cutting tools for:				
Exterior turning		**Plane turning**	**Parting**	**Interior turning**
χ = 45°	χ = 60°	χ = 90°		
1.0	0.9	0.8	0.7	0.9

The optimum for the rake angle, when machining pertinax, for which we get the greatest durability and the finest roughness of the machined surface, is γ=(10°÷15°) for high-speed steel tools, Rp3 and γ=10°, for plated tools K30, K40 and K20.

Machining with cutting tools having big clearance angles, α=(30 ÷40°), assures a proper quality for the machined surface, as well as machining with small clearance angles, α = (8°÷15°).

These values are explained by the decrease of the contact area between the tool and the machined piece and, as a result, by a reduction of the friction between the tool and the material.

Increasing the angle of clearance, within the α = (10°÷30°) limits, leads to an increase of the durability up to two times. A further increase of the clearance angle, α=40°, leads to a decrease of the durability. The greatest durability is obtained:

- when machining with rapid-steel tools Rp3, having $\alpha = (20° \div 30°)$;
- when machining with carbide metal plated tools, having cu $\alpha = 20°$.

The durability of the rapid-steel cutting tools, Rp3, (even having optimal geometrical parameters) relatively small, = (10÷18) min, in comparison with the durability of the carbide metal plated tools, K40 and K30, which is 13 times greater [7].

Table 2.

Values of the constants C_v, x, y, z

Machined material	Cutting tool material	C_V	x
Textolite	Rp 3	1000	0.46
	K 30	2516	0.56
	K 40	2130	0.56
	K 01	3050	0.56
Pertinax	K 40	4400	0.56
	K 30	5713	0.56
	K 01	6300	0.56
Phenoplast	K 40	382	0.30
	K 30	496	0.30
	K 01	545	0.30
Glass fiber	K 40	283	0.44
	K 30	368	0.44
	K 01	405	0.44

Machined material	Cutting tool material	y	z
Textolite	Rp 3	0.64	0.10
	K 30	0.70	0.10
	K 40	0.70	0.10
	K 01	0.70	0.10
Pertinax	K 40	0.70	0.10
	K 30	0.70	0.10
	K 01	0.70	0.10
Phenoplast	K 40	0.26	0.38
	K 30	0.26	0.38
	K 01	0.26	0.38
Glass fiber	K 40	0.20	0.45
	K 30	0.20	0.45
	K 01	0.20	0.45

The use of rapid-steel tools is recommended only when manufacturing samples/prototypes.

The cutting speed has a special influence over the durability of the carbide metal plated tools, used in machining thermo reactive materials. For speeds within the (70÷150) m/min interval, the increase of the wear is slow, whilst for speeds v=(50÷500)m/min, the wear raises quick. The feed value does not affect much the durability. Its calculation is made according to the desired quality of the machined surface. The feed which assures the best quality of the machined surface and in the same time the greatest durability, when machining pertinax for example, is s=0.2mm/rot.

The cutting depth is comprised within values of de t=(0.5÷3)mm. With the increase of the wear of the cutting tool, the quality of the machined surface gets coarse and, at a value of the side flank wear criterion VB = 0.4 mm, the colour of the machined surface changes and raisin begin to stick to the cutting edge.

When machining textolite, the cutting tools plated with K20, K30 and K40 plates have a greater durability than high-speed steel tools, Rp3. The recommended cutting speeds, when turning with carbide metal plated tools, are v=(100÷800)m/min, and the recommended feeds are s = (0.08 ÷ 0.2) mm/rot. For instance, the durability of the rapid-steel tool, Rp3, is (9÷10) times smaller than the durability of a carbide metal plated tool K30, working in the same conditions.

Use of the rapid-steel cutting tools, Rp3, is recommended when machining prototypes, having the following geometry: $\gamma = (10° \div 12°)$, $\alpha = 20°$, $\chi = 45°$, $\lambda = 0°$, $r_\varepsilon = (3 \div 4)$mm.

To obtain a surface roughness, corresponding to the (5÷6) steps of precision, turning of the textolite parts must be made only with carbide metal plated tools, sharpened accordingly [2].

It needs to be emphasized that the radius of the tool point r_ε has also a special influence over the quality of the machined surface. The radius of the tool point must not be greater than (3÷5)mm. The contraction effect has a large influence over the quality of the machined surface and over the final dimension of the machined textolite parts.

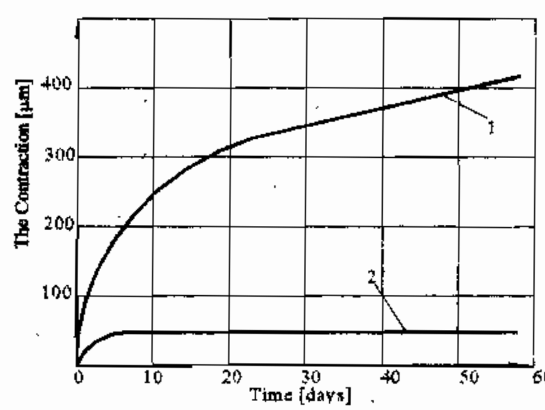


Fig. 4. Contraction variation in time, for:
1 - rough cutting; 2 - finishing cutting.

As a result of this effect, the machined parts dimensions get smaller in time, with (0.1÷0.5)mm, depending of the diameter of the part (fig. 4).

That is why, when a certain tolerance is imposed, it is recommended to split the machining process into two stages:

- in the first stage, is done a rough cutting, after which a contraction takes place c=(0.6÷0.8)% from the nominal dimension.
- in the second stage, after the part was kept in a store for (1.5÷2) months, the part is machined to its final dimensions.

When machining phenoplast and aminoplast materials, the greatest durability is obtained for tools with K20 plates, with the following geometry of the cutting end: $\gamma=10°$, $\alpha=20°$, $\chi=45°$, $r_\varepsilon=(1.5÷2)$mm. Machining materials with textile insertions, is done with cutting tools with K20 and P10 plates, with a geometry: $\gamma=15°$, $\alpha=20°$ and a cutting speed of (700÷800)m/min Machining materials with textile insertions, phenoplast and aminoplast materials can also be done successfully using cutting tools with ceramic mineral plates. In table 3 are shown geometrical parameters of the cutting tools with ceramic mineral plates. The ceramic plates are mechanical fastened or soldered on the cutting tool's body [1], [9].

The elements of the cutting regime - cutting speed, cutting feed s, cutting depth t - are calculated depending on the material to be machined, on the dimensional precision conditions and on the imposed quality for the machined surface.

Table 3.
Geometrical parameters of the cutting tools with mineral ceramic plates

Machined material	γ [°]	α [°]	χ [°]	χ_1 [°]
Aminoplast	-5 ÷ 0	12	30 ÷ 90	45
Phenoplast	-5 ÷ 0	12	30 ÷ 90	45
Materials with textile insertions	0	12	30 ÷ 90	45

Machined material	λ [°]	r_ε [mm]	V [m/min]
Aminoplast	0	1	100 ÷ 30
Phenoplast	0	1	20 ÷ 50
Materials with textile insertions	0	1	200 ÷ 500

Depending on the machined material, in table 3 is shown different geometrical parameters for the cutting tools, when turning thermo rigid materials using tools with ceramic plates [8], [15].

In fig. 5 are presented the constructive shape and the geometry of two types of cutting tools with mineral ceramic plates. The cutting feed, when turning with tools with ceramic mineral plates, is chosen according to the imposed roughness of the machined surface.

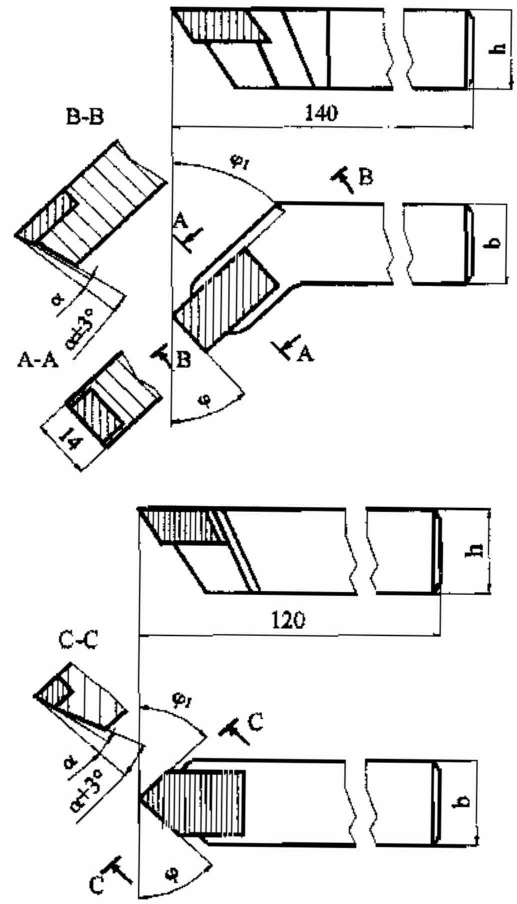


Fig. 5. Constructive shape and geometry of the mineral ceramic plated tools

The value of the cutting feed, correlated with the plate radius of the tool point, has a decisive influence over the roughness of the surface. The following values are recommended for the cutting feed:

-(0.05÷0.2)mm/rot, for finishing cutting;
-(0.25÷0.5)mm/rot, for semi-finishing cutting;
-(0.5÷2)mm/rot, for rough cutting.

The cutting feed is calculated depending on the machining allowance of the machined part.

In function of the quality conditions imposed for the final surfaces, the machining allowance can be removed in one pass or in a certain number of passes. To improve productivity, it is recommended that the removal of the machining allowance to be done in a small number of passes, whilst the cutting depth must not be greater than 6mm.

For mineral ceramic plated tools, the wear criterion is the criterion of the destruction of the side flank, VB.

If the wear on the side flank exceeds 0.8mm, the plate strongly heats up and the roughness of the surface becomes coarse.

To increase productivity, it is recommended that, with the increase of the wear of the tool, without removing the tool from the cutter holder, to sharpen it with an abrasive strap made of silicon carbide, with a grain size of (100÷160) and Mohr hardness of 9.5. After sharpening, the finishing is done with a grey cast iron strap, mixed with boron carbide or silicon carbide paste, with a granularity of (160÷200) [7].

When machining thermo rigid materials, using cutting tools with K30 plates, the main component of the cutting force F_z can be calculated with the following relations:

- for materials with textile insertions:

$$F_z = 9,6 \cdot t^{0,77} \cdot s^{0,43} \text{ [daN]}; \qquad (3)$$

- for aminoplast:

$$F_z = 9,63 \cdot t^{0,62} \cdot s^{0,20} \text{ [daN]}; \qquad (4)$$

- for phenoplast:

$$F_z = 8,45 \cdot t \cdot s^{0,34} \text{ [daN]} \qquad (5)$$

The influence of the cutting speed over the value of the F_Z cutting force component is done in the direction of increasing the cutting force, within the (15÷45) m/min interval (see fig. 6), [3], [17].

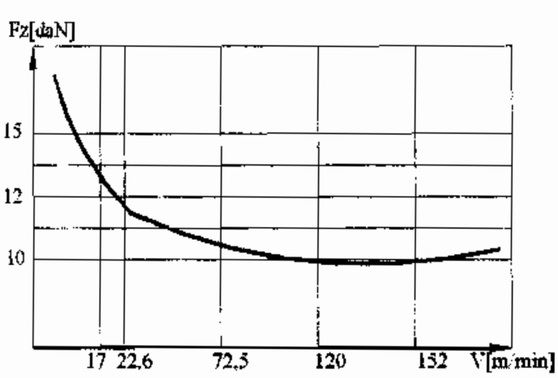


Fig. 6. The dependence of the component F_z on the cutting speed, when turning pertinax

The diagram if fig. 6 has been drawn for turning a blank part made of pertinax, with D=70mm, with a K30 plated tool, having a clearance angle of $\gamma=10°$, the clearance angle $\alpha=20°$, radius of the tool point r_z=1.5mm, the cutting feed s=0.5mm/rot and a cutting depth t=2mm.

The diagram shows out that the cutting speed, after exceeding the critical interval of (15÷45)m/min, leads to an important decrease of the component F_z of the cutting force.

Tables 4 show values of the geometrical parameters of the cutting tools, in function of the machined material and the cutting tool material, parameters that assure optimal durability of the tool [12].

When machining thermo reactive materials, as wear criterion can be used the wear on the chip bearing surface, KM. Acceptable values for this criterion are: KM=(0.4÷0.7)mm.

When a special quality of the machined surface is required, the wear on the chip bearing surface has to be limited to KM=(0.2÷0.3)mm

Table 4.

Cutting tools geometry when turning thermo reactive materials

Machined material	Cutting tool material	γ [°]	α [°]	χ [°]
Pertinax	Rp 3	10 ÷ 15	20 ÷ 30	45
	K 30 K 01 K 40	10	20	45
Textolite	Rp 3	10÷12	20	45
	K 30 K 01 K 40	8 ÷ 10	16 ÷ 20	45
Aminoplast	K 30 K 01 K 40	10 ÷ 20	20	45
Phenoplast	K 30 K 30 K 01	10	20 ÷ 24	45

Machined material	Cutting tool material	χ_1 [°]	λ [°]	r_ε [mm]
Pertinax	Rp 3	45	0	4 ÷ 6
	K 30 K 01 K 40	12	0	1 ÷ 2
Textolite	Rp 3	45	0	3 ÷ 4
	K 30 K 01 K 40	45	0	2 ÷ 3
Aminoplast	K 30 K 01 K 40	45	0	1.5 ÷ 3
Phenoplast	K 30 K 30 K 01	45	0	1.5 ÷ 3

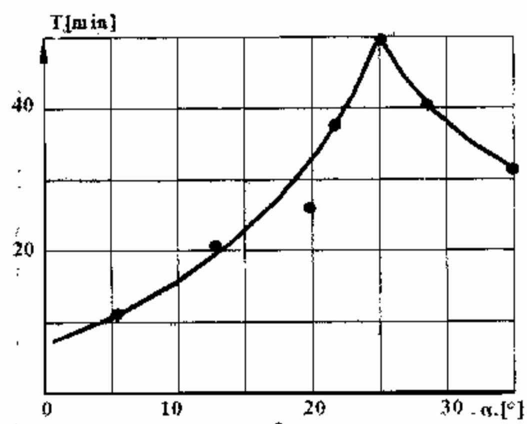
Machining rolled materials, reinforced with glass fiber and asbestos filling, generates the biggest problems. When machining this kind of materials, due to abrasive properties and tough components, the temperature in the cutting area is significantly higher, leading to an increased wear of the tool.

Machined surfaces, in this way, have unsuitable precision and low quality.

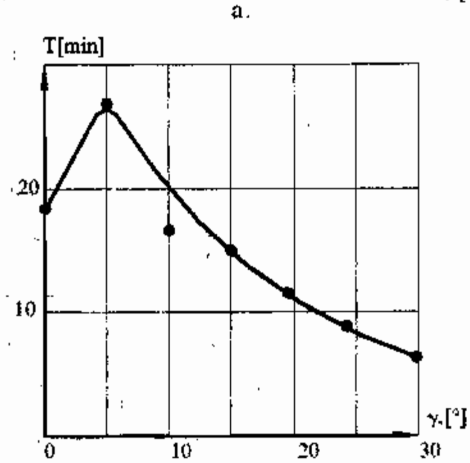
When turning this type of materials, high-speed steel cutting tools cannot be used, and the tools with P10 and P30 plates have low efficiency.

Tools plated with K01 plates are recommended for finishing and semi-finishing cutting. Rough cutting needs to be done using K10 plated tools.

Turning glassplast materials. using mineral ceramic plated tools. proves to be economically unsuited. due. to low durability T=(4÷ 4.5)min.



a.



b.

Fig. 7. The dependence of durability of the lathe cutting tools on the value of the clearance angle, α, and on the value of the rake angle γ, when machining a textolite part, with D=60mm, v=300m/min, s=0.2mm/rot. t=1mm.

The factors which lead to a faster wear of the mineral ceramic plates, compared to metal carbide plates, are: high friction coefficient, low thermal conductivity - which leads to a concentration of high temperature in the cutting zone and to thermal destruction of the material, lower resistance to abrasive wear.

Tools with small clearance angles and high rake angles have an increased durability, when turning glassplast materials.

In fig. 7 it is presented the dependence of the durability of the lathe cutting tools on the value of the clearance angle, α (fig. 7,a) and on the value of the rake angle (fig. 7,b), when turning a part made of textolite. which has a diameter D=6mm.

High durability of the tools is obtained for clearance angles γ=(0÷10)°, and the maximum durability is obtained for γ=5°.

The recommended roughness. for the machined surface. R_a=(10÷30)μm, and the optimal value of the cutting force. are obtained for the following parameters: r_s=(0.5÷2)mm, λ=45° and λ_1=15. The use of the above mentioned types of tough plates and the recommended geometrical paramaters for the cutting end of the tool, leads to an increase of durability of 1.5 times. while there is a risk of getting a lower quality of the machined surface.

When turning glassplast materials, it is recommended to use cooling/lubricating fluids, to increase the durability of the tool and to lower the temperature in the cutting area.

To avoid the risk of rust. due to using water as coolant. when turning thermo reactive materials it is recommended to use compressed air. which has a double effect: it reduces the temperature in the cutting area and also, it removes the splinters. To collect the gas and dust formed during the cutting process. it is recommended to use collector installations.

In figure 8. there is shown a lathe-cutting tool provided with an installation for collecting dust and splinters [4]. [10]. [14].

The metal carbide plate is fastened to its holder. represented as (2). holder which is. in the same time. the collector for dust and splinters. with the screw (3). The dimensions of the aspiration section for dust and splinters are (20x20)mm. The distance between the entrance section and the cutting edge must not exceed 8mm.

When turning glassplast materials. using metal carbide plated tools. the roughness of the machined surface. given by the Ra criterion. has a value within the Ra=(5÷10)μm interval. The cutting workability. of the glassplast materials. is influenced by the composition of the filling material. as well as by the manufacturing method [1], [5]. [11].

As an example. the cutting workability of the glassplast materials reinforced with dioxide silicon glass fiber is 8 times lower than the one of the material reinforced with alumn-boron-silicate glass fiber [2]. [6].

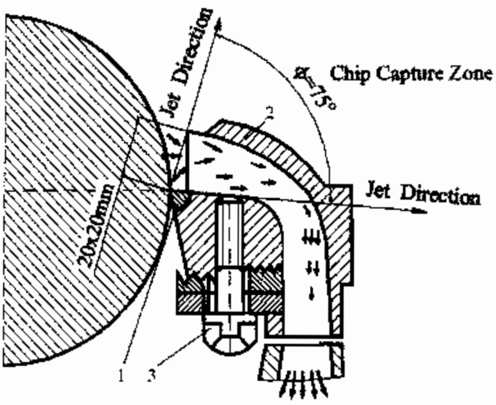


Fig. 8. Lathe cutting tool with splinters and dust collecting system

When machining glasplast materials, as a result of the intense wear of the cutting tool, on the chip bearing surface, the dimensions of the machined part are varying with up to 0.05 mm, depending on the length of the machined surface and the machining method.

3. Conclusions

When machining plastic materials, the durability of the metal carbide plated cutting tools is (10÷12) times greater than the one of the rapid-steel tools.

When soldering the carbide metal plates, it has to be taken into account that the tough alloy and the tool body have different dilatation coefficients. This is the reason why, if the soldering isn't done properly, significant internal tensions may appear within the plate, and it might crack.

Due to the fact that, in the process of machining plastic materials, the temperature of the cutting area is (60÷80)°C, the probability of appearance of internal tensions within the soldered plates is low.

In the case when the machined surface has to reach a quality corresponding to a roughness of $2\mu m \leq R_a \leq 10$ μm, the turning has to be done with mineral ceramic plated tools. Their wear, the VB criterion, does not exceed (0.05÷0.08) mm.

In special cases, when a superior quality of the machined surface is required, within a tight tolerance zone, it is recommended to use diamond tools [13], [16], [18].

When turning plastic materials, in 80% of the cases. there is an elastic tempering of the machined surface that is why s special attention is required when calculating the geometry of the cutting end of the tools.

In function of the scale of the production. and of the metal-cutting machine tool utilized. the durability of the cutting tools is:

-(30÷90) min, for machining on normal lathes:

-(60÷180)min, for machining on semiautomatic lathes:

-(120÷480)min, for machining on automatic lathes.

The parameters of the cutting regime are chosen in function of the properties of the material. in function of the requirements imposed for the final product and of the cutting tool material.

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Aspecte tehnologice la prelucrarea maselor plastice termoreactive prin strunjire

Rezumat

Strunjirea este cel mai mult utilizat procedeu de prelucrare prin aşchiere a maselor plastice, deşi este procedeul care conduce la formarea unei cantităţi însemnate de aşchii. Ponderea strunjirii, faţă de celelalte procedee de prelucrare prin aşchiere, este de 60%.

În lucrare se prezintă unele particularităţi tehnologice la prelucrarea materialelor termorigide prin strunjire. Sunt prezentate aspecte legate atât de mecanica procesului de aşchiere cât şi de geometria cuţitelor pentru strunjire.