Systemic Approach of Ultrasonically Assisted Cutting of Glass Fiber Reinforced Polymeric Materials

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This paper presents a method to improve the performance of glass fiber processing by cutting of the fiber reinforced polymeric materials based on the application of ultrasonic vibrations on the cutting tool. General conditions of the process are established and, based on the analysis of the processing mechanism, the authors provided the fundamental condition for the selection of the cutting speed values in the case of ultrasonically assisted cutting of glass fiber reinforced polymeric materials. The paper also presents the theoretical foundations of rising the macrogeometric accuracy of ultrasonically assisted cutting in the case example of the universal grip turning.

Keywords: polymeric materials, ultrasonic cutting, glass fiber

Although it is recommended that items of plastics or fiber reinforced polymeric materials are obtained through specific mold forming processes in final shape, without the need for additional machining processes, there are situations where cutting is required for processing of these materials. The most important processes for the machining of polymeric materials reinforced with fiber of glass, carbon, graphite, etc. are cutting, drilling, turning and milling [9].

Machining of polymeric composite materials faces a number of difficulties mainly due to thermal stresses on the processed material, the negative action exerted by the reinforcing fibers on the cutting tool and also due to other issues related to the arrangement of reinforcing fibers and their quality [9]. The heat generated during the cutting process leads to softening in the case of thermoplastic matrix materials, to oxidation in the case of thermosetting matrix materials, as well as the effect of delamination due to the difference between the thermal expansion coefficient of the base material and the fiber reinforcement. Depending on the angle of inclination relative to the direction of cutting and their quality, the reinforcing fibers have a strong effect on the wear of the cutting tool. In most cases the result is poor quality of machined surfaces due to breakage, pull-out or fluffing of the reinforcement fibers.

Accordingly, one improvement tendency of the cutting performance in the case of polymer composite materials, very little addressed in specialized literature [2, 4, 5] is the ultrasonically assisted cutting.

General conditions regarding ultrasonically assisted cutting of fiber reinforced polymeric materials

The developed research conducted by the authors on the ultrasonic vibration assisted cutting of composite polymeric materials is based on two main standpoints. The first is that, in many applications, the introduction of pulse energy is much more effective than placing the same energy continuously; this efficiency is better with the increasing of frequency. This general principle, which we also find among the 40 inventive principles formulated by Altshuler [1] leads to the idea of using high frequency vibrations, ultrasonic vibrations, respectively. The second important standpoint of the research development presented in this paper focuses on the results obtained by the authors in the processing of several metallic materials when the application of ultrasonic vibrations for turning, drilling and boring have led to a sharp reduction in cutting forces, lower roughness of machined parts and signifficant reduction of the macrogeometric deviations of machined parts.

Choosing the type of vibration

Depending on the relationship between the direction of oscillation of the material points and the direction of propagation of the wavefront, three main types of vibration shall be considered: longitudinal – that is the oscillation is performed linearly in the direction of the wavefront propagation; transversal, when linear oscillation is achieved in a plane perpendicular to the direction of wavefront propagation and torsional – the oscillation is performed circumferentially in a plane perpendicular to the direction of the wavefront propagation.

Choosing the direction of oscillation

If working with ultrasonically assisted cutting we will consider two directions for the application of ultrasonic vibrations: along the tangent component direction of the cutting force and along the direction of the normal component of the cutting force. Based on preliminary experimental determinations it was found that the application of ultrasonic vibrations along the third direction - the direction of the normal component of the cutting force leads to lower quality of the machined surface quality as compared to the classic cutting.

Mechanism of ultrasonically assisted cutting of glass fiber reinforced polymeric materials

Studies and research performed by several authors [2, 4-8, 10, 11] show that applying ultrasonic vibrations on the cutting tool for processing purpose influence the size and direction of real cutting speed. As a result, under vibration cutting conditions, the cutting real speed vector is the sum of two vectors, one constant, given by tool or workpiece movement and the other variable, given by ultrasonic oscillations. On the other hand, based on experimental research [4-6], J. Kumabe shows that in order to take advantage of ultrasonically assisted cutting, the workpiece peripheral speed must be less than the critical cutting speed

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$V_c = 2\pi a\nu$, optimal effects being achieved when the ratio of the tool-piece contact time t_c and the oscillation period T is t_c/T=1/7...1/3, where ν is the frequency and a is the oscillation amplitude.

Given these conditions, it can be inferred that time $\tau = T - t_c$, when the cutting edge is not in contact with the part, there is no real cutting speed. Also, for radial feed machining or no auxiliary movement being considered on the direction of speed, when the workpiece peripheral speed vector and the vector of the oscillation speed of the cutting tool have the same direction, the time interval when the actual cutting speed increases from 0 to $V_{max} = V + \omega a$ will not be equal to the time when the real cutting speed decreases from 0 to $V_{min} = V - \omega a$, where $\omega = 2\pi\nu$. The two time intervals are dependent on the ratio t_c/T.

Given that in the specialized literature, in the case of mathematical modeling of the ultrasonically assisted cutting, the above mentioned aspects have not been taken into account, the authors recommend to develop a new concept to characterize this process to define and calculate the real cutting speed.

A systemic analysis of ultrasonically assisted cutting (fig. 1) would show that besides the technological parameters of classical cutting (feed f, and depth of cut a_p, construction parameters of the cutting tool etc.) the acoustic parameters must be considered as input values as well (such as oscillation frequency ν and oscillation amplitude a).

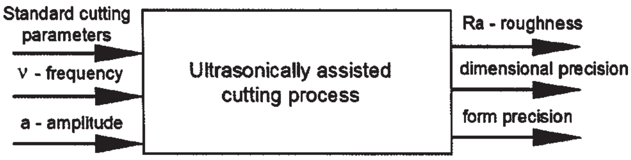

Fig. 1. Systemic approach of the ultrasonically assisted cutting

Thus, the ultrasonically assisted cutting with vibrations oriented along the direction of the main cutting component is characterized by the following features:

Real cutting speed $\vec{V}_\gamma(t)$ - momentary vector value representing the variation of the space interval covered by the tip of the tool per time unit under the conditions when the cutting tool is in contact with the workpiece (actual cutting);

Peripheral part speed $\vec{V}$ - vector value representing the variation of the space covered by a point on the outer surface of the workpiece per unit time (equal to the cutting speed in the case of normal cutting, when no auxiliary movement is considered in the sense of feed);

Oscillation speed of tool edge $\vec{V}_o$ - momentary vector value representing the variation of the space covered by the cutting edge per time unit in a kinematic reference system, as a result of ultrasonic vibration applied to the tool;

Ratio of real cutting ξ - dimensionless value representing the ratio of actual tool-piece contact time t_c and the oscillation time T: $\xi = t_c/T$;

Cuting length l_T - scalar value, the cut length during oscillation time T as measured on the outer surface of the workpiece.

Time-related average real cutting speed V_m – scalar value representing the actual cutting speed average calculated over a period of oscillation T.

Limitations on the cutting speed in the case of glass fiber reinforced polymeric materials

To calculate the real cutting speed $V_r(t)$, first real cutting time calculation t_c must be provided, within an oscillation period of time for the cutting tool. In this sense, for processing glass fiber reinforced polymeric materials, the authors have adapted and developed a model proposed by J. Kumabe [5]

Because the real cutting time t_c does not depend on the selected reference system, it has been considered that the oscillation starts at a certain point O defined as origin (fig. 2). On the A-B-C length that is equal in terms of cutting length with the D-E-J length, the cutting tool is in contact with the workpiece, the acting components are the principal component F_y and the radial component F_x of the cutting force as an impulse, and the chip 1 is formed. The chip is in contact with the front cutting surface of the cutting tool on the distance A-B. In point D, the cutting tool is again in contact with the workpiece, while F_y and F_x components operate again as an impulse on the D-E-J length, forming the chip 2, etc. Therefore, the cutting edge repeatedly and regularly gets in contact with the workpiece forming chips $1,2,...,n$.

The movement of the cutting edge equation is:

$$y(t) = a\sin\omega t \tag{1}$$

while the oscillation speed of cutting edge can be calculated as:

$$V_0(t) = \frac{dy(t)}{dt} = \omega a\cos(\omega t + \varphi_0) \tag{2}$$

where a is the amplitude of the oscillations, and φ_o=0 the initial phase.

Let t_1 be the time in which the cutting edge covers the distance from the origin O to its separation from the chip, when the oscillation speed $V_o(t)$ is equal to the peripheral speed V of the workpiece. So at the end of the time period t_1 it can be stated that:

$$V = \omega a\cos\omega t_1 \tag{3}$$

resulting:

$$t_1 = \frac{1}{\omega} arc\cos\frac{V}{\omega a} \tag{4}$$

on condition that $-1 \le \frac{V}{\omega a} \le 1$, that is $|V| \le 2\pi a\nu$ that.

After separation of the cutting edge from the workpiece (point C) the surface to be processed continues to move towards the cutting edge with the speed V. Taking into account the displacement of a point on the outer surface of the workpiece it can be written:

$$y(t) = a\sin\omega t_1 - V(t - t_1) \tag{5}$$

Equating again the oscillation speed of the cutting tool to the peripheral speed of the workpiece when the cutting tool comes into contact with chip for the second time (point D) it may be stated that:

$$a\sin\omega t_2 = a\sin\omega t_1 - V(t_2 - t_1) \tag{6}$$

which is equivalent to

$$a\sin\omega t_1 + Vt_1 = a\sin\omega t_2 + Vt_2 \tag{7}$$

Knowing the time t_1, given by equation (4), by numerically solving the equation (7), time t_2 can be calculated, which allows further to determine the tool – workpiece contact time

$$tc = T + t_1 - t_2 \tag{8}$$

and the ratio

$$\frac{t_c}{T} = 1 + \frac{t_1}{T} - \frac{t_2}{T} \tag{9}$$

which is one of the most important parameters of the ultrasonically assisted cutting of glass fiber reinforced polymeric materials.

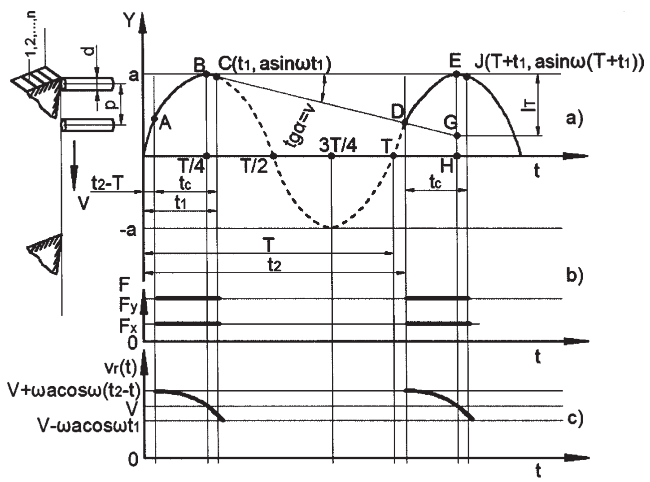

Fig. 2. Dependence of movement y, of the principal *Fy* and radial *Fx* components of the cutting force and of the real cutting speed V_r on the processing time

For values of the relation $V/V_c \leq 0.5$, the approximation $t_c/T \cong V/V_c$ can pe performed.

Based on the above calculations and applying the new proposed concept according to which the real cutting speed only exists as physical value during t_c when the tool is in contact with the workpiece, the formula of the real cutting speed has been determined (fig. 2) as follows:

$$V_r(t) = \begin{cases} 0\ for\ t \in [0;\ t_2 - T) \cup (t_1; T] \\ V + \omega a cos\omega t\ \ for\ t \in \left[t_2 - T;\ \frac{T}{4}\right] \\ V - \omega a cos\omega t\ \ for\ t \in \left(\frac{T}{4};\ t_1\right] \end{cases} \quad (10)$$

The average value of the real cutting speed v_m calculated for one oscillation time interval T is:

$$V_{rm} = \frac{1}{T}\int_0^T V_r(t)dt = \frac{1}{T}\int_{t_2-T}^{T/4}[V + \\ + \omega a cos\omega t]dt + \frac{1}{T}\int_{T/4}^{t_1}[V - \omega a cos\omega t]dt \quad (11)$$

By solving integrals of equation (11) using the relation $y_1 = asin\omega t_1$, as well as the ratio (9), by elementary calculation it can be obtained:

$$V_{rm} = V\frac{t_c}{T} + \frac{2a}{T} + \frac{a}{T}sin\omega t_2 - \frac{y_1}{T} \quad (12)$$

It is evident that in the case of common cutting when $t_c = T$, $a = 0$ and $y_l = 0$ and based on relation (12) it can be stated that $V_{rm} = V$.

An important parameter of the ultrasonically assisted cutting is the cutting length within one oscillation time period of the cutting tool edge because it highlights the need to use high frequency oscillation. In figure 2a, the sine curve shows the movement of the tool tip according to equation (1), while the straight line CG shows the movement of one point on the workpiece. Point D is located at the intersection of the straight line CG with the sinusoid and it is the point where the tool comes into contact with the chip. In point C the tool gets away from the chip, when the speed of point C belonging to the workpiece equals the oscillation speed of the cutting edge and represents the slope of straight line CG, tangent to sine in point C:

$$tg\alpha = \frac{dy}{dt}\Big|_{t=t_1} = \omega a cos\omega t_1 = V \quad (13)$$

Cutting length l_T is the distance covered by the tip of the tool during t_c when the latter is in contact with the chip that is segment JG, which can be calculated, from triangle C-J-G, while taking into account the fact that CJ = BE = T using equation (13) as follows:

$$l_T = CFtg\alpha = VT = \frac{V}{\nu} \quad (14)$$

According to formula (14), the cutting length l_T decreases with the peripheral speed reduction of workpiece at a constant value of the frequency ν. If the value V remains constant, the increase of oscillations frequency results in the reduction of the value l_T. Thus, knowing the peripheral speed of the workpiece, it can be selected a resonance frequency value that should provide an optimal value of the ratio between contact time t_c and oscillation time T ($t_c/T=1/7...1/3$), as well as the smallest value of the cutting length l_T. It can be seen that if $V = V_c = 2\pi af$, the result is $l_T = 2\pi a$ that shows the case in which the tool gets no longer off the workpiece.

In the case of ultrasonically assisted cutting of glass fiber reinforced polymeric materials, it is necessary that for the time t_{oc} in which the tool is no longer in contact with the workpiece:

$$t_{oc} = T - t_c = t_2 - t_1 \quad (15)$$

a point on the peripheral surface of the workpiece would travel on a distance of maximum $p + d$, where p is the distance between reinforcement fibers, and d is their diameter, because otherwise there is the risk that there are uncut fibers. This restriction can be written:

$$V\,(t_2 - t_1) \leq p + d \quad (16)$$

and the result is

$$V \leq \frac{p+d}{t_2-t_1} \quad (17)$$

On the other hand, so that during the contact of tool and workpiece at least one fiber is cut off, the condition is that the cutting length l_T is greater than the diameter of a fiber d. Using equation (14) this restriction can be written as follows:

$$l_T = \frac{V}{\nu} \leq d \Rightarrow V \leq \nu d \quad (18)$$

Finally, if we take into account restrictions (17) and (18), restriction $V \leq V_c = 2\pi af$, and the condition that the cutting speed is lower than speed V_t at which the basic polymer material melts, it results that:

$$\nu d \leq V \leq min\left(V_t, \frac{p+d}{t_2-t_1}, 2\pi a\nu\right) \quad (19)$$

Relation (19) is the fundamental condition for sellection of cutting speed values in ultrasonically assisted cutting of glass reinforced polymeric materials.

Precision of macrogeometric shape

The radial component of the cutting force $F_x(t)$ in the case of ultrasonically assisted cutting can be easily decomposed in Fourier series, as follows [5]:

$$F_x(t) = \frac{t_c}{T}F_x + \frac{2}{\pi}F_x\sum_{n=1}^{\infty}\frac{1}{n}sin\left(n\frac{t_c}{T}\pi\right)cos(n\omega t) \quad (20)$$

where *Fx* is the radial cutting force.

The time-related average radial cutting force maintains the first term of relation (19) [5]:

$$F_{mx} = \frac{1}{t_2-t_1}\int_{t_1}^{t_2}F_x(t)dt = \frac{t_c}{T}F_x + \\ + \frac{2}{\pi(t_2-t_1)}F_x\sum_{n=1}^{\infty}\frac{1}{n^2}\sin\left(n\frac{t_c}{T}\pi\right)sin\left(\frac{n\omega(t_1-t_2)}{2}\right)cos\left(\frac{n\omega(t_1+t_2)}{2}\right) \quad (21)$$

where t_1 and t_2 are any two points in time. Similar relations can be written also for components F_z and F_y of the cutting force.

For smaller values of the relation $V/V_c \cong t_c/T = 1/7...1/3$, the second term of the relation (21) can be neglected with the following result:

$$F_{mx} = \frac{t_c}{T}F_x \approx \frac{V}{V_c}F_x = \left(\frac{1}{7},\dots,\frac{1}{3}\right)F_x \qquad (22)$$

Relation (22) justifies reduction of cutting forces in ultrasonically assisted cutting.

Since $V_c=2\pi a\nu$, the result is:

$$F_{mx} \approx \frac{V}{2\pi a\nu}F_x \qquad (23)$$

It can be seen that cutting forces diminish with the increase of oscillation amplitude, and if the tool does no longer get away from the workpiece ($t_c = T$), both from formula (20) and the ratio (22) we obtain the force value in the case of ordinary cutting.

One of the most important factors determining the processing accuracy is the dynamic movement of the workpiece u_{dp} during machining which is directly dependent on the size of the cutting forces and the grip of the workpiece. The components Fx, Fy and Fz of cutting force (fig. 3) generate the displacement of the technological system components, which if a linear behaviour is admitted, will have the total deformation on the direction of axis OX [3, 12]:

$$u = u_p + u_i + u_{pf} + u_c \qquad (24)$$

where u is the overall technologic system deformation u_p, the static deformation of the workpiece u_i, the deformation determined by the workpiece rotation at angle φ in embedding, u_{pf} – the translation of the workpiece axis due to bending of fixed headstock, uc – the deformation of sledge.

Dynamic movement can be calculated by using the coefficient μ representing the ratio of dynamic displacement u_{dp} and static movement u_p:

$$\mu = \frac{u_{dp}}{u_p} \Rightarrow u_{dp} = \mu u_p \qquad (25)$$

When turning on the universal lathe with clamping, considering the working piece to be a beam embedded at one end, the static movement in a section located at distance z from the point of embedding u_p can be calculated by means of the following ratio [12]:

$$u_p = \frac{F_{xy}Z^3}{3EI_y} \qquad (26)$$

where F_{xy} is the resultant force between F_x and F_y, E is the elasticity modulus of the workpiece material and $I_y=\pi d^4/64$ is the cross-sectional moment of inertia of the workpiece. Maximum static displacement value is obtained at the free end of the workpiece ($x=L$) and in the case of ultrasonically assisted cutting will take the formula:

$$u_{pmax} = \frac{F_{mxy}L^3}{3EI_y} \qquad (27)$$

where F_{mxy} shows the resulting value between the time-related average radial force F_{mx} and the time-related average tangent force F_{my}.

Based on formulae (22) and (23) we obtain:

$$F_{mxy}\,\frac{V}{2\pi a\nu}\sqrt{F_x^2 + F_y^2} \qquad (28)$$

Introducing equations (28) and (25), as well as the moment of inertia I_z into formula (27), we shall obtain the dynamic movement equation f_{dp} :

$$u_{dp} = \frac{32\mu V Z^3}{3\pi^2 E d^4 a\nu}\sqrt{F_x^2 + F_y^2} = \frac{V}{2\pi a\nu}u'_{dp} \approx \frac{t_c}{T}u'_{dp} \qquad (29)$$

It can be noticed that in the case of ultrasonically assisted cutting the dinamic movement of workpiece u_{dp} is inversely related to the amplitude a and the frequency ν of oscillations and represents a fraction $\xi = t_c/T \approx V/2\pi a\nu$ of the dinamic movement value u'_{dp} in the case of classical cutting.

Deformation u_i is to be calculated from the ratio:

$$u_i = \varphi \cdot z = \frac{M \cdot z}{K_\varphi} = \frac{F_{mxy} \cdot Z^2}{K_\varphi} \qquad (30)$$

Where M is the embedment bending torque, K_φ is the angular rigidity corresponding to the rotation φ under the action of torque due to force F_{mxy} against embedment; this torque is in the case of shaft machining:

$$M_z = F_{mxy} \cdot z. \qquad (31)$$

By similar calculations, the same conclusion can be stated for movements u_{pf}, u_c as well as for the overall dynamic movement u_d.

Thus, for the calculation of other movements that are shown in (24) we will use the formulae of the specialized literature [3,12] corresponding to classical turning and the formula (22):

$$u_i = \frac{F_{mxy} \cdot Z^2}{K_\varphi} = \frac{V \cdot z^2}{2\pi a\nu K_\varphi}\sqrt{F_x^2 + F_y^2} \qquad (32)$$

$$u_{pf} = \frac{F_{mxy}}{K_{pf}} = \frac{V}{2\pi a\nu K_{pf}}\sqrt{F_x^2 + F_y^2} \qquad (33)$$

$$u_c = \frac{F_{mxy}}{K_c} = \frac{V}{2\pi a\nu K_c}\sqrt{F_x^2 + F_y^2} \qquad (34)$$

where u_{pf} and u_c are the rigidity values of the fixed headstock and sledge, respectively.

If we integrate relations (32), (33) and (34) into the formula (24), the total technologic system dynamic

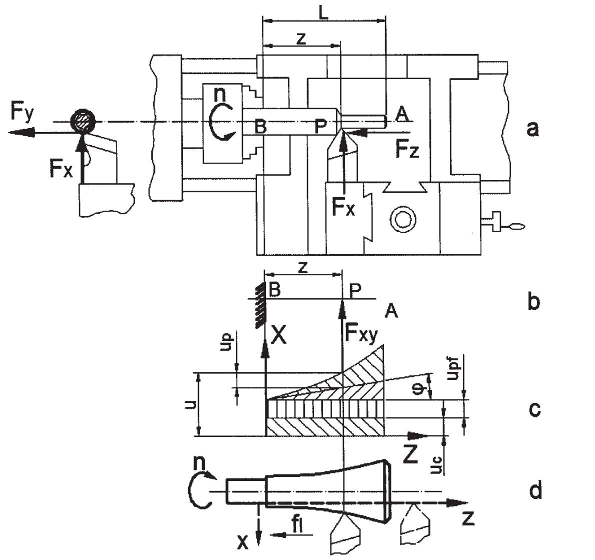

Fig. 3. Technologic system deformation in case of turning

deformation will be obtained in the case of ultrasonically assisted cutting:

$$u_d = \frac{\mu V}{2\pi a \nu}\left[\frac{L^2}{K_\varphi} + \frac{1}{K_{pf}} + \frac{1}{K_c} + \frac{64L^3}{3E\pi d^4}\right]\sqrt{F_x^2 + F_y^2} \quad (35)$$

For practical applications, it is of high significance to analyse the dynamic behaviour of the technological system in two typical instances: processing of a long workpiece by applying constant cutting force (uniform stock left for machining) and processing of short length workpiece (z variation can be neglected), with a cutting force which varies during processing. In the first case, due to high levels of distance z, deformation also reaches high values, the component u_{dp} in principal. The latter varies greatly along the axis as it is proportional to the cubed distance z, and causes a deviation from cylindricity (fig. 3.d). As a result, in the case of normal turning, the overhang length of the workpieces must be limited to the domain $l \leq 3D$ [3] where D is the average diameter of the semiproduct. Taking into account the formula (29) it follows that in the case of ultrasonically assisted cutting, this high length limit may be increased through multiplying by the ratio V_c/V under the conditions of obtaining the same deviation from cylindricity.

In the second case the rigidity of technological system is constant along the machined surface and it increases the more so as the overhang z has lower values. Deformation variation is only caused by the variation in cutting force, which according to formula (22) is 3, ..., 7 times smaller in the case of ultrasonically assisted cutting, function of the ratio $\xi = t_c/T$.

From the above mentioned, it can be inferred that the ultrasonically assisted cutting tool gives the technological system a very favorable dynamic behaviour enabling the miniaturization of its components.

Conclusions

On the basis of this work, we can draw the general conclusion that ultrasonically assisted cutting allows to obtain higher processing standards in the case of glass fibers reinforced polymeric materials. With this end in view, the peripheral speed of the workpiece must be less than the critical cutting speed $V_c = 2\pi a\nu$. The best effects are obtained when the ratio tool-workpiece contact time and the oscillation time period is $t_c/T = 1/7...1/3$. When selecting the cutting speed values, the following must be considered: fiber diameter and the distance between reinforcement fibers, the melting temperature of the base polymer material and the critical speed specific cutting vibration $V_c = 2\pi a\nu$. A particularly important parameter is the actual tool-workpiece contact time t_c and the oscillation time T, $\xi = t_c/T$, which directly influence the technological system static and dynamic movements, resulting in three to seven times improved macrogeometric precision.

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References

1. ALTSHULLER G., Creativity as an exact science: The Theory of the Solution of Inventive Problems, Gordon and Breach Science Publishers, New York, 1984.
2. BALCU, I., DANCASIU, M., Aspecte privind cinematica procesului de vibroaşchiere cu vibraţii tangenţiale; Timişoara, Simpozionul „Robotizarea în industrie", 1984 (in Romanian)
3. EPUREANU, S., ş.a., Tehnologia construcţiei de maşini, Bucureşti, Editura Didactică şi Pedagogică, 1983 (in Romanian)
4. KUMABE, J., Study of precise vibration planing, Seimitsu kikai, 1976, T 42, No. 11 (in Japanese)
5. KUMABE, J., Vibration Cutting, Tokyo, Jikkyou Publishing Co, 1979 (in Japanese)
6. KUMABE, J., SAITO, T., Ultra - Precission Turning by applying ultrasonic vibration, Journal of the Japan Society of Precision Engineering 47, no. 10/1981, p. 1252...1257
7. MARKOV, A.I., Kinematica protesa rezania pri vozbujdenii ultrazvukovîh kolebania instrumenta, Moskva, Ulitrazvikovaia tehnica nr. 3/1964 (in Russian)
8. MARKOV, A.I., Ulitrazvukovoe rezanie trudnoabrabativaemî materialov, Moskva, Masinostroienie, 1968 (in Russian)
9. DUMITRAŞ, C., OPRAN C., Prelucrarea materialelor compozite, ceramice şi minerale, Bucureşti, Editura Tehnică, 1994 (in Romanian)
10. PANAIT, S., ROMANESCU, I., Mecanismul deformării plastice la aţchierea cu vibraţii, Iaşi, Sesiunea de comunicări Stiinţifice „Concepţie Tehnologie şi Management în Construcţia de Maşini", 22 - 23 mai, 1992 (in Romanian)
11. PODURAEV, V.N., Abrabotka rezaniew s vibratiamu, Moskva, Masinostroienie 1970 (in Russian)
12. POPESCU, I., Optimizarea procesului de aşchiere, Craiova, Editura Scrisul Românesc, 1987 (in Romanian)

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