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# IMPROVING THE EFFICIENCY OF WATERJET PROCESSING DUE TO THE EFFECT OF INITIATED CRACKING

**V.N. Orel**
*Kremenchuk Mykhailo Ostrohradskyi National University, Kremenchuk, Ukraine*

**A.F. Salenko*** **V.T Shchetynin** **O.O. Chencheva**
*Kremenchuk Mykhailo Ostrohradskyi National University, Kremenchuk, Ukraine*

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**Annotation**

*The paper discusses the issues of providing quality and reliability of waterjet treatment while increasing process productivity with the use of the effect of initiated cracking. It is shown that the creation of a certain cyclic stress state of the workpiece end allows to call the phenomenon of cracking with active cracks bifurcation in which originated on microdefects and adhesion surfaces cracks do not have time to develop into a trunk. Weak destructive area is treated with much less energy, but a violation of process conditions can lead to the spread of the destructive material zone beyond the area of destruction, thereby processing will be defective.*

**Keywords:** Waterjet treatment, processing on a curvilinear contour, controlled cracking, stress state.

## INTRODUCTION

It is known [1], [2] that the process of jet cutting of quasi-brittle materials can be viewed from the standpoint of linear fracture mechanics, allowing to associate cracking with the energy indicators of the process of cutting and quality parameters of formed surfaces. The authors of [4] show, that cracks that have arisen, but remained undeveloped, forming a surface destructive layer. Such a layer may be very significant, particularly when there are subjected to processing composite laminated materials which are structurally inhomogeneous. In [3] the authors propose to determine the thickness of destructive layer with dependence

$$h_d = \nu \frac{a_0}{\sqrt[n/2-1]{1 - \dfrac{CQ_m d_c}{\xi(N) m s_k k}}} \tag{1}$$

where $N$ – the number of loading cycles; $C = a_0^{n/2-1}\left(\dfrac{\sigma}{\rho}\right)^n \left(\dfrac{\rho}{\bar{c}}\right)^n$, $K = \dfrac{1}{\sqrt{\pi}(n/2-1)}$, ν – Poisson's ratio; $a_0$ – the initial crack length; $a_c$ – its current size (critical to the bifurcation moment); ρ – material density; $n$, $\bar{c}$ – material constants; $s_k$ – contouring feed rate; $Q_m$ – abrasive consumption; $m$ – the average weight of one abrasive particle.

Since it is known that the Griffith theory for elastic bodies, which includes polymer fine composites, thermoplastics and thermosets, characterizes the stable strength in all directions, you can expect a deviation in crack growth direction from the initial direction when $KII \neq 0$ (displacement) by a certain angle $\chi = -\chi_c$, which coincides with the direction of force maximum value $P$, which causes the crack development. In the case of materials cutting with cutting wedge crack development will fit. The applied external force, during which will be observed the active cracking, must be greater than the resistance to cracking.

For composites and layered-reinforced materials such postulate is conditional and depends on several factors: adhesive strength $T_a$ and cohesive strength $T_k$, the presence of disbonds areas and others. Such defects can significantly affect on the movement direction of cracks and their development.

For homogeneous materials their imperfection, total impedance for cracking will depend on the various types of fracturing (occurrence of shear cracks or detachment cracks). If we take into account that the crack growth direction is always contributing to its disclosure, the task of assessing the likely directions of development of cracks during water jet cutting from the action of the multiphase flow is reduced to the establishment of the expected epures of pressures at the front of destruction, is directly determined by the instantaneous position of the elementary planes of boundary surface [5] and stress epure of cutting area from applied to the workpiece intensifying forces.

At the free support of the workpiece in the form of an infinite plate on a rigid horizontal surface of a jet leakage on a fixed (ϖ=0), set at an angle α relative to the jet axis, barrier, which is an elementary failure plane in the cutting zone, it causes a reaction [6]:

$$P = \left[ p_1 + \frac{\rho(v_0 \pm \varpi)^2}{2} \right] f_0 \sin\alpha = \rho Q_0 v_0 \sin\alpha, \tag{2}$$

where $p_1$ –fluid leakage pressure; ρ– liquid density; $v_0$ – exhaust velocity of liquid from the nozzle; $Q_0$ – fluid consumption.

Distributed over the surface of contact, the reaction causes the stress state of the surface layer by activating the process of fracturing to a critical state, which is accompanied by a separation of the microparticles.

* Tel. (+380536)74-12-67, e-mail: salenko2006@ukr.net

Formed flow causes the secondary hydrodynamic loads of end surfaces of cuts grooves and cracks, which again originated or became a consequence of another branch of the main crack on these surfaces. Active development of the latter may be accompanied by a bundle of material (with σ”<[σ] at a considerable depth of the crack occurrence) or surface cleavage [6]. We have found that such defects are most typical for cutting processes of composite materials (Fig. 1a).

Thus, the process of cracking ultimately causes the orientation of the elementary fracture planes and directly connected to it. The constant change of the geometry of hydraulic fracture zone, due to the reorientation, the disappearance and the appearance of new elementary planes of the interface, causes corresponding changes in stress state of the cutting area, which makes the process of waterjet cutting of nonmetallic materials unsteady.

In [7] the author shows that under mechanical cutting there is a certain critical velocity of crack growth, after which the crack begins to branch. On the other hand, [8], the critical load increase causes some increase in the critical velocity of crack propagation, but at the same time reduces the way before its branching. There is also the conclusion about the existence of the critical velocity of cracks propagatio in the filled non-metallic material (reinforced composites), which does not depend on input energy. This phenomenon is explained by the absorption and accumulation of micro-defects that will occur in the direction χ=60º, where there are the maximum tensile stresses. Branching and secondary branching should be expected at an angle of 20º relative to the direction of the main crack. It is important that the length of the crack before branching depends on the external load and decreases with load increasing [9]. Periodic origin, development and fusion of cracks leads to the separation of material particles, determines the cyclical nature of the treatment process, in which the hydrodynamic forces at first increase to the maximum values (at the inception of the grid of cracks), and then decline rapidly (the appearance of the main crack and separation of sludge particles).

Introduction to the flow of abrasive grains alters mechanic of flow interaction with the obstacle, but the phenomenon of cracking remains in this case (Fig. 1b). However, the length of cracks reduces significantly and the appearance of secondary cracking practically does not occur.

Since the waterjet cutting is the process of impact of aggregate a certain number of microscopic cutting wedges, which are generally carried out the work of the destruction on the origin and developed cracks, such oscillations cause ranging from broadband wave phenomena in the treated body.

From linear fracture mechanics it is known that the intensity of the stress is connected with crack length with following dependence [10]:

$$k = \sigma\sqrt{\pi a}, \tag{3}$$

where $k$ – stress intensity factor; σ – operating stresses; $a$ – half of the crack length (Fig. 1). The stress intensity factor causes energy release rate, which is associated with it by following relation:

$$G = \frac{1-\nu^2}{E} A(V) k^2, \tag{4}$$

where ν – Poisson's radio, $E$ – modulus of elasticity of the first kind of material, MPa.

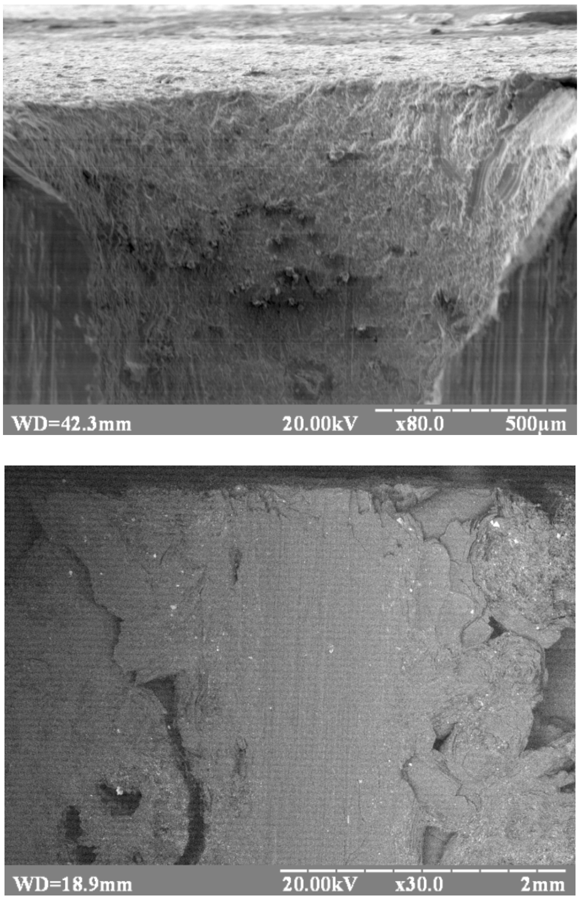



***Figure 1*** *- Formation of cutting hole (a) and cracking (b) in samples of composite workpiece*

In the zone of jet impact stresses (2.5) will be determined according to the following. In workpiece microvolumes at the point of jet leakage stresses for area *ds*, situated at an angle αt relative to the principal axes according to [11] will be:

$$\sigma_a = \sigma_1 \cdot \cos^2\alpha_1 + \sigma_2 \cdot \cos^2\alpha_2 + \sigma_3 \cdot \cos^2\alpha_3, \tag{5}$$

$$\tau_a = \sqrt{\sigma_1^2 \cdot \cos^2\alpha_1 + \sigma_2 \cdot \cos^2\alpha_2 + \sigma_3 \cdot \cos^2\alpha_3 - \sigma_\alpha^2}, \tag{6}$$

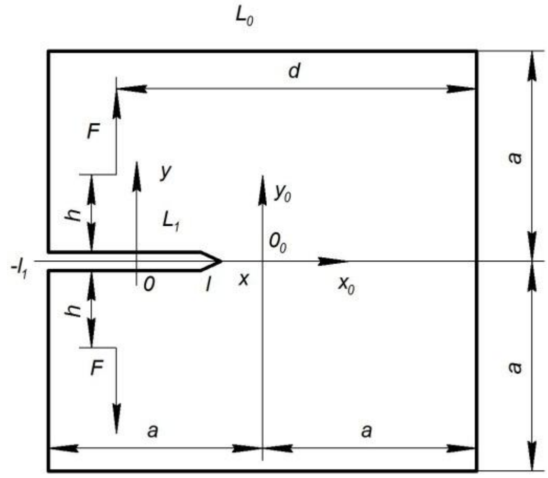



***Figure 2*** *- The emergence of a crack and its development*

ie for the vertical arrangement of the axis Oz and symmetry condition of loading of thin plate-workpiece with tick holders:

$$\sigma_a = \sigma_n \cdot \left(\cos^2\alpha_1 + \cos^2\alpha_2\right) + \sigma_3 \cdot \cos^2\alpha_3, \tag{7}$$

$$\tau_a = \sqrt{\sigma_n^2 \cdot \left(\cos^2\alpha_1 + \cos^2\alpha_2\right) + \sigma_3^2 \cdot \cos^2\alpha_3 - \sigma_\alpha^2}, \qquad (8)$$

where $\alpha_1$, $\alpha_2$, $\alpha_3$ – angles, formed by the platform normal with the direction of the load forces *R* and jet; $\sigma_1$, $\sigma_2$ – stresses due to the preload force.

Tension from the action of transient jet focused on the destruction planes $f_p$ from the jet action will be:

$$\sigma_n = \frac{\rho Q_0 v_0}{f_p} = \frac{\rho Q_0 v_0}{\pi \int_0^h f(x)\sqrt{1+f'^2(x)}dx}, \qquad (9)$$

where $f(z)$ – the curve describing the front cutting groove relative to the axis of the jet incrustations which is positioned vertically, in a first approximation $z = ax^2$, with the proviso that *h* - the thickness of the treated workpiece.

According to [12], there are several models of the perception of the plate with a crack of load for which stress Intensity factor is determined analytically.

When exceeding critical loads, ie with an increase in the energy release rate (G-R) will be an avalanche release of kinetic energy of crack growth with their active development, but the process will lose controllability. On the other hand, the insignificant loads can cause cracking beginning, but they cannot intensify the process.

However, if the load is created cyclically, on the basis of the study’s results and generalizations by Yu. Rabotnov and L. Kachalov and [13], the crack growth rate is:

$$\frac{dl}{dN} \propto \frac{\left(\Delta\sigma\sqrt{l}\right)^{\left[2+\alpha\left(1-\frac{\beta}{2}\right)\right]}}{\Delta\sigma^2}, \qquad (10)$$

or after substitution of the stress intensity factor:

$$\frac{dl}{dN} \propto \frac{K^{\left[2+\alpha\left(1-\frac{\beta}{2}\right)\right]}}{\Delta\sigma^2\sqrt{\pi}}, \qquad (11)$$

where *K* is determined by the well-known relations.

Therefore, changing the stress state of the cutting area and thus reaching a certain level of σ due to the required amplitude of loading force, regulating the amount of loads surface *N,* can be received the projected growth of the crack length $\Delta l$, for which the phenomenon of active bifurcation with the removal of productive destructions will activate cutting in general.

The destruction of the composite material may be in several ways: as destruction on separate fractions (e.g., fibers break in fiberglass under the effect of the chemical or thermo-mechanical impact), followed by destruction spread for the whole volume; as an astringent destruction (mainly for composites on metallic bonding), which takes place in three stages - resistance reducing and origin of the defect, the growth of destruction cavities, merging cavities to produce macroscopic defects; destruction by chipping - when the formed defects grows into the main crack. Destruction of this class of materials - C-C, C-49, CBA and others, is due to the manifestation quasibrittle damage spread [14].

If we assume that $\sigma_f$ - tension in the fiber; $\sigma_{fb}$ - local limit of fiber strength; $\sigma_{f\tau}$ and $\sigma_{fm}$ - minimum stresses in the fiber at which its destruction has caused adhesive damages; $q$, $q_1$, $q_2$ - coefficients accounting abrasive fraction action for the waterjet cutting fiber reinforced materials, according to [15] is a manifestation of the following microfracture mechanisms:

- the destruction of the individual fibers, located directly in the load zone at $q_{\sigma f} > \sigma_{fb}$, destruction of tie;
- detachment of broken fibers under $q_{\sigma f} < \sigma_{fb}$ and $q_1\sigma_{fb} > \sigma_{f\tau}$;
- development of a crack in the fiber at $q_{\sigma f} < \sigma_{fb}$ and $q_2\sigma_{fb} > \sigma_{fm}$.

Cohesion failure will occur in the coverage area of the jet, simultaneously with the adhesive, whereby the individual fibers or tows will exclude from the matrix that, according to [16], may be determined by the equation:

$$l_0 = \frac{\sigma_{fb} - \sigma_{f\tau}}{13\sqrt{b'Ek_\tau\tau_\tau}} l_c \qquad (12)$$

where *b’* – crack depth; $l_c$ – critical length; *E* – elastic modulus; $k\tau$ – shear stresses; $k\tau = 0.3...1.5$

Thus pressure of the jet action determined by the equations (7), (8). Since non-uniform material lends to the processing, based on [17] the effect of load will be perceived differently by separate elements. The redistribution of stresses in the composite micro-volumes is accounted for the respective overload coefficients *K*, $K_\tau$, $K_m$, which, according to [18] can be defined as:

$$K = K_m\left(1-\frac{b'}{b}\right)\varphi(r_{ij}),\ K_m = \frac{0.105}{1+3.16\frac{b}{E_m}}c_p,\ K_v = K\left(\frac{l_0}{l_c}+1\right). \qquad (13)$$

The real breakdown is possible with any mechanism and any combination. Fracture type is determined by the structure of the material conditions, of its load or strain, the influence of temperature, etc.

From this perspective, the process of waterjet cutting of composite material with a load of jet impact area can be represented as shown in Fig. 3. The heterogeneity and differences of properties of reinforcing fibers and matrix, as well as pyrocarbon in C-C systems, leads to the fact that the output parameters of cutting process - the amount of material removal $Q_m$, depth of jet dives $h_z$ are probabilistic parameters, which are determined by the phenomena of cracking.

Let liquid jet accumulates on the work surface according to controllable volume detection circuit [19].

Then receive a quality cut is an event that provides a two unrelated events - the complete destruction of the site of action of the jet and the prior distribution of destruction due to cracking of the limits of its action:

$$P^Q(t) = \left[P_s(t)\cdot(1-P_t(t))\right]\cdot \qquad (14)$$

where $P_t(t)$ – probability of the projected ensuring of removal volume of material by abrasion with controlled fracturing; $P_s(t)$ – probability of the spread of cracking with full material damage.

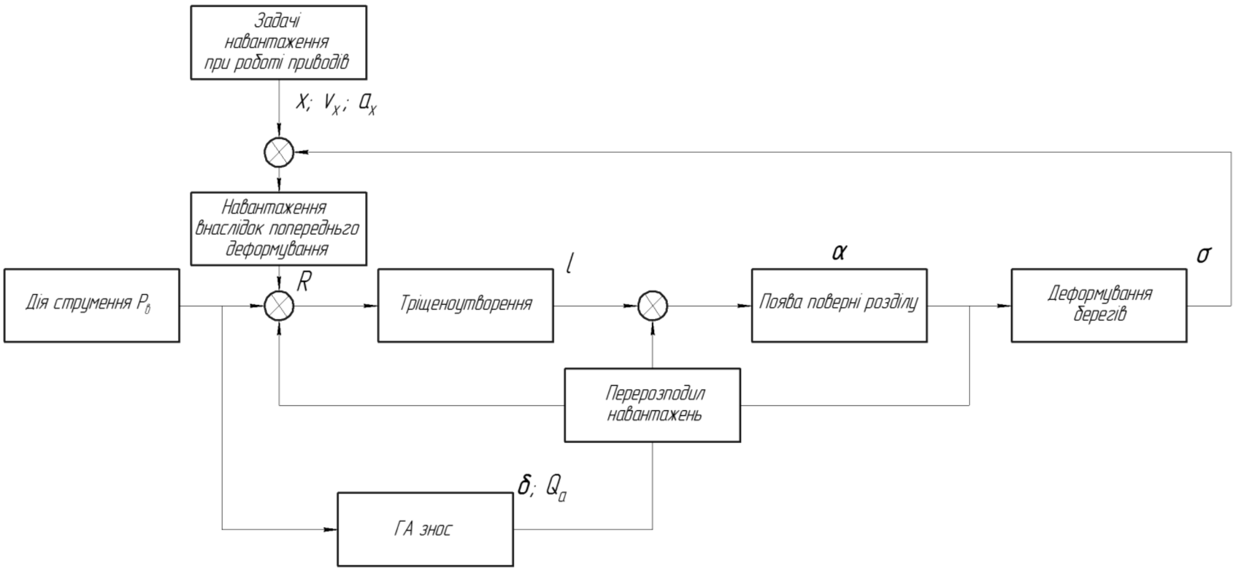



***Figure 3*** *- Block diagram of the process of waterjet cutting of composite with a pre-load of the jet impact zone*

Let us denote $f_l(\sigma)$ – the probability of failure from one defect - emerged crack - under stress σ. Then $(1 - f_l(\sigma))$ – the probability that failure will not be in the presence of a single defect; $2\,(1 - f_l(\sigma))$ – probability that the material remain intact (even with a damaged structure) under stress σ in the presence of two defects; $[1 - f_l(\sigma)]Nd$ – probability that there is no destructions in the presence of $Nd$ cracks with length $l_0$, where $R >> G$. That is, in this case, for $Nd$ cracks with length $l_k$, the probability of material destruction immersed with stress σ is:

$$f_{Nd}(\sigma) = 1 - [1 - f_l(\sigma)]Nd \qquad (15)$$

Hereof $1 - f_{Nd}(\sigma) = [1 - f_l(\sigma)]Nd$ providing that $Nd = \frac{\sum_{i=}^{m} l_i}{l_k}$. If we assume that

$$\lim_{n\to\infty}\left(1-\frac{x}{n}\right)^n = \exp(-x) \qquad (16)$$

Then for $Nd \to \infty$ will be

$$1 - f_{Nd}(\sigma) = \exp[-Nd \cdot f_l(\sigma)]. \qquad (17)$$

According to the first position of the fragile connection, the number of defects $Nd$ is proportional to the volume.

In [20] Wallin has shown that the effective volume $V_{eff}$, where destruction develops, is only a function of the parameter of $K_I$, ie $V_{eff} = C_1 K_I^4$. If on the basis of [21], to assume that parameter $m_1$ is a measure of inhomogeneity distribution of defects and $m_2$ represents the scattering in results measurement of destruction, probability of macro destruction will be

$$P_f = 1 - \exp\left[-C_2 Nd(\sigma)^{2m_i-2}\right]. \qquad (18)$$

Because the $Nd$ – the number of defects in the considered volume of workpiece is also a function of time, the probability of complete eruption of workpiece without the propagation of cracks beyond the zone of influence is:

$$P^Q(t) = \left[P_s(t)\cdot\left(\exp\left[-C_2 Nd(t,\sigma)^{2m_i-2}\right]\right)\right]. \qquad (19)$$

The obtained model is the basis for the determination of cutting conditions of materials, the boundaries and the type of the attached additional load that causes a controlled cracking.

Parameter $Nd$ is unknown in the model, which can be set based on the analysis (11). However, in this case you need the definition of proportionality coefficient $C$ between its left and right sides.

Considering that in the processing of the material the creation of the stress-deformation state of the jet impact zone is possible by the load application to the end of workpiece [22], the values of proportionality coefficient $C$ for analyzing class of materials are experimentally determined with tensometry method.

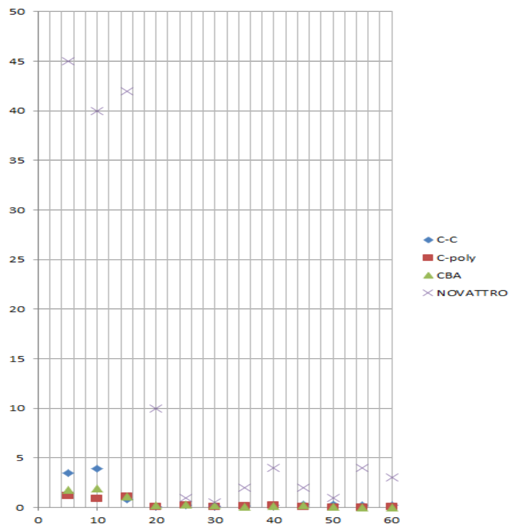



***Figure 4*** *- Changing the crack growth rate under cyclic low-amplitude loads depending on the frequency of power impact*

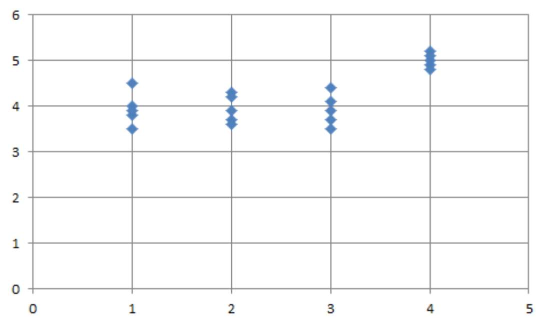



***Figure 5*** *- Changing the growth rate of microcracks from polycyclic controlled load depending on load forms: 1 - quasiharmonic; 2 - semiperiodic; 3 - stair-step; 4 – sawtooth*

The calculation $C$ was performed according to the equation

$$C=\left(\frac{\Delta\sigma^2\sqrt{\pi}}{K^{\left[2+\alpha\left(1-\frac{\beta}{2}\right)\right]}}\right)\frac{dl}{dN}, \qquad (20)$$

$$K_I=\frac{\sigma\sqrt{l}}{2\sqrt{\pi}}\left[\begin{array}{c}\arcsin\frac{c}{l}-\arcsin\frac{c}{l}-\\ -\sqrt{1-\frac{c^2}{l^2}}+\sqrt{1-\frac{b^2}{l^2}}\end{array}\right]+\frac{\tau(c-b)}{2\sqrt{\pi l}}\times\frac{\eta-1}{\eta+1} \qquad (21)$$

where $\Delta l$ crack growth was evaluated after removing the load by means of scanning electron microscopy, $\Delta N$ - is determined by the number of loads cycles between stages of electron-microscopic measurements.

The formulas also indicated: $\sigma$, $\tau$ – minimal stresses acting on the surface of the jet leakage and are measured in the absence of actions of means of creation additional load; $\Delta\sigma$ – stresses increase to the maximum values determined by a strain gauge measurement oscillograms.

The values $\sigma$ and $\tau$ were removed from tensor bridge with automated measuring instruments, providing a supply of pulses packets on executive engines; $\alpha$, $\beta$ - material constants, $l$ - the length of the initial crack in the test plate, $b$ - width of the crack edges disclosure.

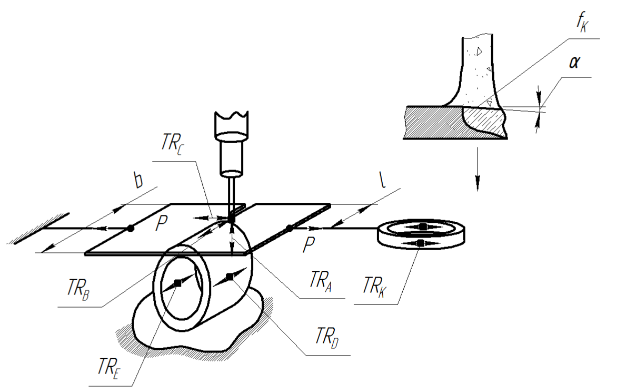



***Figure 6** - The scheme of measurements and photos from the microscope along the length of the cracks*

During studies the workpieces were subjected to electron microscopic examination on SEM-106I (Fig. 6). To calculate the coefficient of proportionality $C$ it was measured the length of microcracks formed from the impact of the additional cyclic loading of workpiece by means of electronic measuring instruments. Accuracy on the raster × 1000 - not less than 0.5 microns.

Three-fold duplication of measurements can more accurately determine the search parameter Δl, microns.

In studies there were changed not only the amplitude and waveform, but also the conditions of additional cyclic loading applications. Microelectronic photos of cracking zones in the polycarbonate NOVATTRO are shown in table 1.

It was established following. Searching proportionality coefficients are: for carbon-carboxylic compounds $C$ = 1,65 10-4, for carbon-polymer materials – $C$ = 7,5 10-5, for fiberglass CBA $C$ = 1,55 10-4; for acryl – $C$ = 6,1 10-3. In each series of measurements by varying the thickness of the processed materials $h$, and, accordingly, the level of the stresses, the difference between the coefficient values of a random variable in general obeys the normal distribution and the whole set of measurements can be attributed to the same general population (figures are the expectation of manifestations of values search value).

The strongest measurement kurtosis is observed for composites C-poly and CBA, which can be explained by the effect of reinforcing fibers in a thin layer on the expression of mechanical properties and that the polyamide resins that are used as matrix, significantly reduces crack formation in the material; the phenomenon of violations adhesive contact of the reinforcing from fibers and the matrix is also observed on microelectronic photos, which leads to changes in direction of crack propagation, although the total length of the cracks (and, accordingly, the kinetic energy of crack motion, is exempt from the potential deformation energy) is projected.

A comparison the value of the proportionality coefficients for C-poly and CBA leads to the conclusion about the identity of the fragile properties of these two materials; accordingly, reference processing modes can also be identical.

Changing the frequency of load application $N$ in the range of 5-50 Hz showed the following. With the increasing frequency of load average crack growth rate for each subsequent cycle slows down sharply, with the simultaneous growth of cracks joints. In this case, cracks begin bifurcation, extending in different directions relative to the line of action of the power load.

This phenomenon most typically appears in the composites, and it is less common for homogeneous materials (particularly acrylic). Therefore, we can conclude that the efficiency of the abrasive jet cutting due to managed cracking is only possible when creating vibrations in the load range of 10-15 Hz.

Waveform analysis showed that significant difference from the average measurement results of crack growth is only in the case of the sawtooth load application, from action of which cracks grow to 20-25% compared to the quasi-harmonic load. All other types of loads have not significant differences.

Comparison of the calculated values of the speed of cracks propagation and the results of microelectronic analysis shows that the stress intensity factors are adequate only for the case of the initial crack propagation and load cutting zone stretch with force. When the load with moment results have a significant difference, which can be explained by the difference in the stress-strain state of the cutting zone in the workpiece from ideal conditions.

Changing the initial incision length leads to an increase in stress at constant load and a progressive increase in the rate of formation of cracks.

In general, experimental studies have established the following. Creating of cyclic stresses in the plane of the material within 40-60 MPa at a frequency of 50-250 Hz ensures crack growth at rates that do not lead to the emergence of large chips on the edges of treatment. In addition, these stresses in the plates of thickness to 1.5-3.0 mm do not lead to significant deformation, therefore, the form error of finished products at the expense of the original workpiece deformation will be minimal, which is very important in practical aspect.

Thus, with increasing length of the cut load the cutting zone should be reduced to avoid uncontrolled crack growth rate.

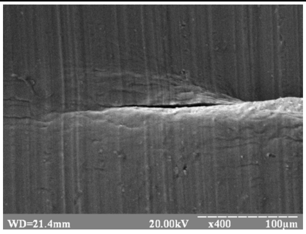
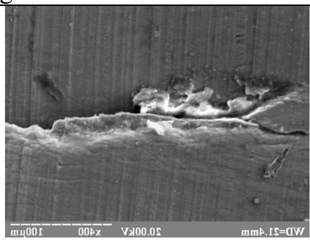
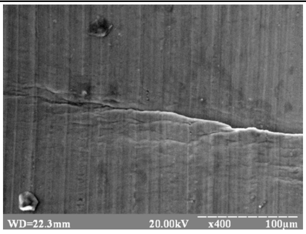
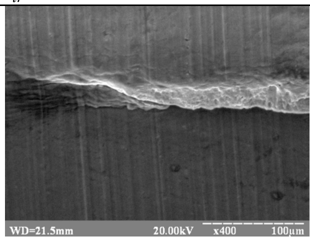
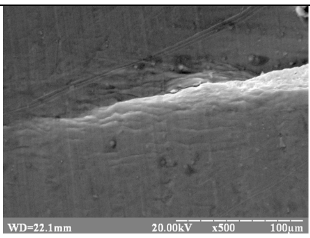
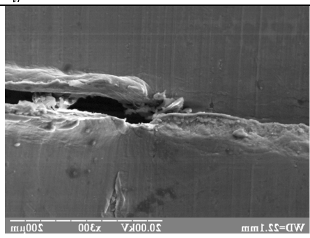
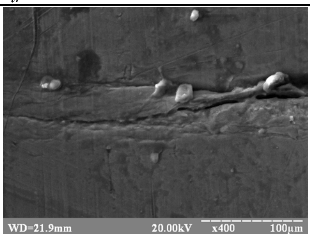
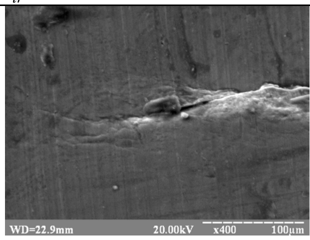
Grid of initial cracks at the beginning of cutting from the end with the perpendicular jet input makes branches of 0.05-0.35 mm length, propagating within angles ± π / 6. Wherein, the increase in the load frequency leads to more cracks branching and reducing their length, which is generally consistent with the provisions of the Griffith theory.

Analysis cracks measurement results shows that the active growth of the cracks length leads to destructive layer of significant thickness. Based on data obtained by the authors [23] can be concluded that exceeding a certain critical cracks length will not only lead to productivity improving, but also lead to thickness increasing of the destructive layer. That is, to have a case of a sharp deterioration in the quality of treatment that can be considered as parametric failure.

Then, the probability of destruction spread over the permissible value is $N_j = P_{j-1}$, $N_j = exp(-C_2Nd(t))\times 2m-2$. After taking the logarithm, the last expression can be reduced to an equation $N_j=b_0+b_1Nd$ or in a form which corresponds to the controlled quantities:

$$\ln N_j = -b_0 + (2m-2)\ln(Nd) \tag{22}$$

Table 1 - Photomicrographs of the samples of metallised polycarbonate NOVATTRO (thickness = 1.2 mm, the thickness of the metallization layer - 5 microns)

| Influence of the tensile force to the sample, and the cracks length | The amplitude and frequency of the tensile efforts load | Influence of the tensile force to the sample, and the cracks length | The amplitude and frequency of the tensile efforts load |
|---|---|---|---|
|   $l_{tr}$ = 450 microns | $P_{max}$=120 N, $P_{min}$=12 N, 50 Hz |  $l_{tr}$ = 620 microns | $M_{max}$=8,0 Nm, $M_{min}$=1,0 Nm, 50 Hz |
|   $l_{tr}$ = 380 microns | $P_{max}$=90 N, $P_{min}$=15 N, 50 Hz |   $l_{tr}$ = 730 microns | $M_{max}$=4,0 Nm, $M_{min}$=0,5 Nm, 250 Hz |
|   $l_{tr}$ = 560 microns | $P_{max}$=120 N, $P_{min}$=20 N, 250 Hz |  $l_{tr}$ = 810 microns | $M_{max}$ =10,0 Nm, $M_{min}$=1,0 Nm, 50 Hz |
|   $l_{tr}$ = 330 microns | $P_{max}$=90 N, $P_{min}$=15 N, 250 Hz |   $l_{tr}$ =410 microns | $M_{max}$=4,0 Nm, $M_{min}$=0,5 Nm, 250 Hz |

The resulting dependence of the probability of failure-free operation of the system with a controlled fracturing when changing the number of initial defects in the cutting area for the material C-C are shown below:

$$\ln N_j = -0{,}004 + 1{,}062\ln(Nd)\,, \tag{23}$$

from whence the constant $m$=3,124.

Significance testing of the equation coefficients $b_0$, $b_1$ was performed using Student's t-test, the values of which were calculated $t_{01}$ = 4,74, $t_{02}$ = 2,96, and accordingly, the condition of the chosen at the significance level α = 0,01 and the number of freedom degrees for is performed.

Since $Nd$ is determined by the time of load action, we have the condition of limiting the frequency and amplitude of the loads of jet cutting zone with probability to get a quality cut. An example of curve of probability of failure-free operation is shown in Fig. 7.

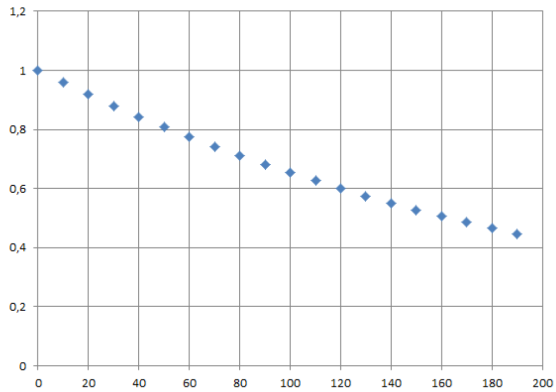



***Figure 7** - Changing the probability of failure-free of the process with an increase in the number of initial defects*

## CONCLUSION

Thus, it is shown that a controlled crack formation under certain conditions can extend beyond the expected destruction zone formed on the cutting edges. The frequency and amplitude of the cyclic loads directly affects not only the crack growth rate, but also on the number of such defects, the growth of which lead to a progressive drop in the reliability of the process.

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