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ON THE APPLICATION OF THE FUNCTIONAL APPROACH TO THE METHODS OF PROCESSING LAYERED SUPERHARD COMPOSITES

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Abstract
Layered superhard composites are widely used in the manufacture of tool components, special products of aviation and space technology. Typically, these products are a plates of regular geometric shape, the final shaping of which is made by diamond grinding. Proposed finish processing of composite materials is to implement hybrid methods based on laser-jet technologies, with use the functional approach. In terms of composite materials processing laser-jet is a hybrid, capable of a certain way to influence the components of the composite at different levels – from nanozone to macrovolume. The hybridization process, which is consist of scribing, water-jet cutting, smoothing of the surface will allow according to the structure of the processed composite plates get high quality cuts. Field experiments were performed on laser-jet complex of LSK-400-5, equipped with a abrasive-jet head with water nozzle d_c=0,22 mm and calibration tube D_k=1,05 mm, and also a system of combining a laser jet with the liquid stream by means of flying optics. Process of cutting the plates was performed using a Nd: YAG laser with a power of 400 W, and operating at a frequency of 50 Hz. Composite plate is a layered system coated with base layer of cubic boron nitride with 2,8 mm, common plate thickness – 4,5 mm. Using a functional approach allowed us to obtain high-quality cut (the roughness of the end is 3,2 μm, the width of the slot is 0,12 mm), while the time to perform the operation of cutting at a specified contour made up only 1,8 min.

Keywords: functional approach, processing, layered superhard composites.

INTRODUCTION

Currently layered superhard composites are widely used in the manufacture of tool components, drill bits, special products of aviation and space technology.

Typically such products are like the plates of regular geometric shape, the final forming of which is produced by diamond grinding. Attempts to apply other processing methods are ineffective, that requires approach the workpiece shape to the final form during sintering process and significantly increases the cost of the product.

It is offered to implement the ultimate processing of composite materials with hybrid methods based on water jet guided laser technologies, but using a functional approach.

EXPOSITION

Its essence is as follows. According to [1], the initial state C_0 of production facility O can be characterized by a set of parameters defining the shape and dimensions of the workpiece, the material and its mechanical properties. The final state $C_к$ defines the shape, dimensions, accuracy, physical and mechanical properties, and other parameters, that are important from the exploitation viewpoint. Conversion function φ_0 of the object properties from the initial state – workpiece – in the end – the state of product – can be represented as:

$$\varphi_0 = \begin{Bmatrix} C_{n1} \\ C_{n2} \\ \\ C_{nR} \end{Bmatrix} \rightarrow \begin{Bmatrix} C_{k1} \\ C_{k2} \\ \\ C_{kT} \end{Bmatrix}, \quad (1)$$

where φ_0 – function of technological transformation properties of the production facility; C_{nr} – r-e elementary workpiece property; C_{kt} – t-e elementary products property; R – the total number of workpiece properties; T – the total number of product properties.

Formation of properties of the product and its quality indicators is carried out as a result of the implementation of a number of technological transitions, in which there is a full or partial change of initial properties. Technological transformations of workpiece in the product are achieved with targeted aggregated technological influences $N(t_k)$ of material $S_o(t_k)$ energetical $E_o(t_k)$ and informational $I_0(t_к)$ types, which makes it possible to introduce a scheme for generating the output characteristics according to fig. 1 and write: $N(t_k)=S_o(t_k)UE_0(t_k)UI_o(t_k)$.

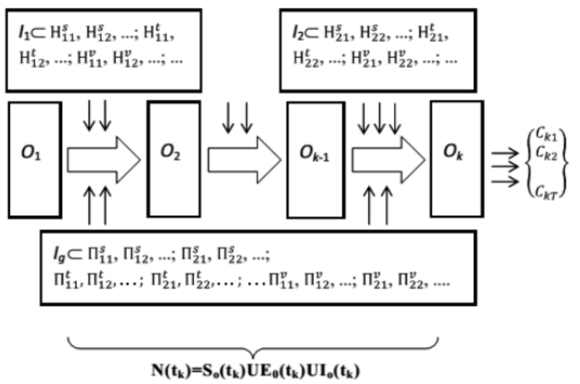

Fig. 1 – *Formation of properties of the product in the technological transitions with traditional (top) and hybrid (below) tool*

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Then, based on the condition that the technological impact of tools on the product must be carried out from nanozones to the product as a whole, and the latter is a three-dimensional object, for the realization of the aggregate of variants of technological impacts the morphological matrix is as follows:

$$\mathrm{A}_3^{\Pi} = \left\| \begin{matrix} \Pi_{11}^{s} \; \Pi_{12}^{s} \ldots \; \Pi_{21}^{s} \, \Pi_{22}^{s} \ldots \\ \Pi_{11}^{t} \; \Pi_{12}^{t} \cdots \; \Pi_{21}^{t} \, \Pi_{22}^{t} \cdots \\ \Pi_{11}^{v} \; \Pi_{12}^{v} \cdots \; \Pi_{21}^{v} \, \Pi_{22}^{v} \cdots \\ \mathrm{H}_{11}^{s} \; \mathrm{H}_{12}^{s} \, \mathrm{H}_{21}^{s} \; \mathrm{H}_{22}^{s} \ldots \\ \mathrm{H}_{11}^{t} \; \mathrm{H}_{12}^{t} \, \mathrm{H}_{21}^{t} \; \mathrm{H}_{22}^{t} \cdots \\ \mathrm{H}_{11}^{v} \; \mathrm{H}_{12}^{v} \, \mathrm{H}_{21}^{v} \; \mathrm{H}_{22}^{v} \cdots \\ \mathrm{E}_{11}^{s} \, \mathrm{E}_{12}^{s} \ldots \; \mathrm{E}_{21}^{s} \; \mathrm{E}_{22}^{s} \ldots \\ \mathrm{E}_{11}^{t} \, \mathrm{E}_{12}^{t} \cdots \; \mathrm{E}_{21}^{t} \; \mathrm{E}_{22}^{t} \cdots \\ \mathrm{E}_{11}^{v} \, \mathrm{E}_{12}^{v} \cdots \; \mathrm{E}_{21}^{v} \; \mathrm{E}_{22}^{v} \cdots \end{matrix} \right\|, \qquad (2)$$

where Π_{11}^{s}, Π_{12}^{s}, ...; Π_{21}^{s}, Π_{22}^{s}, ...; ... Π_{11}^{t}, Π_{12}^{t}, ...; Π_{21}^{t}, Π_{22}^{t}, ...; ... Π_{11}^{v}, Π_{12}^{v}, ...; Π_{21}^{v}, Π_{22}^{v}, ...; ... – options of discontinuous technological influences on the respective axes *s*, *t* and *v* of coordinate system *s, t, v*; H_{11}^{s}, H_{12}^{s}, ...; H_{21}^{s}, H_{22}^{s}, ...; ... H_{11}^{t}, H_{12}^{t}, ...; H_{21}^{t}, Π_{22}^{t}, ...; ... H_{11}^{v}, H_{12}^{v}, ...; H_{21}^{v}, H_{22}^{v}, ...; ... – various options for continuous technological effects on the axes *s, t* and *v* of coordinate system *s, t, v*; E_{11}^{s}, E_{12}^{s}, ...; E_{21}^{s} E_{22}^{s}, ...; ... – various options of single technological influences.

Availability of variants of discontinuous technological processes allows to consider a processing of products single element in the form of a coherent aggregate of different influences. In this case, if the output property of this element is its geometric characteristics (eg, flatness, dimensional accuracy), this process can be implemented by different types of exposure, more fully relevant properties of the workpiece elements. Because the impact to ensure the conditions of minimum error forms should be carried out without having to reinstall the workpiece and change its position in the fixing device and orientation, such processes should be regarded as a hybrid.

Let some products element E_m is obtained by implementing of discontinuous technological influences Π_{ij}^{t} and Π_{ij+k}^{t}. It can be expected that for their implementation requires *k* tools respectively. However, if we take into account that the creation of the new tool is based on the known, i.e. there is an expression $R_{nj} = \bigcap_{i=1}^{\rho i} R_{si}$, where R_{nj} – field of formations new types of instruments; R_{si} – *i* set of the known technical solutions; ρ_i – the weight of a subset of the known solutions, the newly obtained tool can be combined into one unit mean for radically different effects.

Let the set of properties of the two instruments represents expression:

$$I_1 = \begin{Bmatrix} \rho_{11} S^1{}_{11} & \rho_{21} S^1{}_{21} & \rho_{k1} S^1{}_{k1} \\ \ldots & \ldots & \ldots \\ \rho_{1j} S^1{}_{1j} & \rho_{2j} S^1{}_{2j} & \rho_{kj} S^1{}_{kj} \end{Bmatrix},$$

$$I_2 = \begin{Bmatrix} \rho_{11} S^2{}_{11} & \rho_{21} S^2{}_{21} & \rho_{k1} S^2{}_{k1} \\ \ldots & \ldots & \ldots \\ \rho_{1j} S^2{}_{1j} & \rho_{2j} S^2{}_{2j} & \rho_{kj} S^2{}_{kj} \end{Bmatrix}. \qquad (3)$$

Then the hybrid instrument obtained on the basis of the morphological sorting and combining of properties, will consist of *m* elements, with $m<k+j$, because part of properties of the original tools can be combined. Thus, the rate of hybridization of created instrument $k_g = \dfrac{k+j}{m}$. This indicator makes it possible to find rational technical solutions of hybrid instrument based on combination of the required properties of treated workpieces, as well as the possibility for their achieving with available resources.

In terms of handling of composite materials, water jet guided laser treatment is a hybrid, which is capable with a certain way to influence the composite components at different levels – from nanozones to macrovolumes.

Consider the features of the impact of each component of a hybrid instrument, introduced in the form of an abrasive jet head, combined with laser light transmission system (patented).

It is known [2], that the destruction of the material by abrasive jet stream occurs due to the poly deformation damage of surface with simultaneous destruction of the abrasive particle. Such a phenomenon is typical for the terms of leakage of water jet stream at angles close to normal (i.e. in cases where there is no through-cutting, and the particles bombard the surface, causing separate microdeformations and activating the birth and development of the original microdefects). Destruction of material, the nucleation and growth of hydraulic cutting well is possible by microcutting, but in this case, the surface defects resulting the initial elastic deformation at the point of impact of the particle, are possible only upon a change of motion vector of the particle. In other words, micro line is formed by a particle at the moment when it hits surface and under the influence of fast-flowing liquid stream it changes direction of movement and is removed from the zone of influence. Of course, the removal intensity is extremely low, as the supply of kinetic energy of particle is significantly reduced.

The mechanism of interaction between the abrasive particles with the material being processed is based on the creation by particles of high local loads, leading to some elastic-plastic micro- and macrodeformation of compression in local volumes of the surface layer. As we have shown in [3, 4], these loads takes basically a carbide skeleton of material. A further pickup of abrasive particles by liquid flow removes the load, so that there is a partial elastic recovery of the deformation volume of the layer surface material with the appearance of local tensile stresses, resulting in there is a redistribution of stresses between the components of the material.

Study of features of the destruction of hard alloys showed [5] that boundaries of carbides grains are destroyed first, there is plastic deformation of the cobalt binder by the dislocation mechanism. And then comes the destruction of boundaries of carbides with a binders and binders themselves, which leads to the emergence of the initial holes under the action of perpendicular oriented to the abrasive water jet stream on worpieces.

Study the pictures of material damage and the formation of microcutting wells led to a number of important conclusions:

– the speed of jet "penetration" into the treated material is not constant: first, it has a tendency to increase, and then – to decrease; upon receipt the deep (in several jet diameters D_k) blind holes it is possible a complete cessation of the cutting process because of a sharp decrease in elastic-plastic dents of the surface and increase the losses of flow energy;

– forming an initial groove for liquid discharge when providing to a stream of feed movement significantly increases the volumetric material removal and does not reduce this indicator when receiving groove; obviously, it is promoted by the fact that destruction of the material is performed not only with flow that flows down the surface, but with a peripheral portion of the jet, wherein the speed of particles motion is much higher; thus, the multipass cutting is more efficient and more practical than the single pass;

– presence on the treated surface of zones with increased hardness (caused, for example, an abnormal amount of a cobalt binder) leads to the jet deviation from the hypothetical direction of movement under given conditions of its displacement. Wherein, while the speed of linear flow is greater, the jet deviation will be larger; reduction of energy parameters of the jet while increasing groove depth causes greater deviation. That is: the feed rate at the multipass cutting should be variable, the higher at the initial moment of the process with a reduction at the funnel development.

Cutting with a focused laser beam occurs due to absorption of the radiation of surface, whereby the latter is heated locally melted and partially vaporized. Using long focus optics (more 80 mm) allows to obtain enough straight cuts in workpieces with thickness 5-10 mm without substantially tilting the cut edges. However, according to [3], the use of laser with a blow in cutting zone and without it does not give effect when processing hard and superhard materials: the reason is that the thermal effect on material leads not only to certain structural and phase changes in the contiguous zone, but also causes considerable residual thermal stresses, thereby materials are destroyed under light loads exhibiting the fragile properties.

In fact, for a Gaussian distribution of the radiation source, which is any solid state or gas laser, the density of absorbed energy is determined by the expression according to [6]:

$$q(x) = q_0 \exp\left[x^2 / r^2\right], \tag{4}$$

where q_0 – radiation power density in the center of the focusing spot; r – Gaussian beam radius.

Distribution of heat on the absorption surface will be determined by the equation:

$$T(x,z,t) = \frac{q_{\max} r^2}{K}\left(\frac{a}{\pi}\right)^{1/2} \int_0^t \frac{P(t-t')dt' \exp\left[\frac{z^2}{4at} - \frac{x^2}{4at'}\right]}{\sqrt{t'}\left(4at' + r^2\right)}, \tag{5}$$

where q_{max} – the maximum radiation power density in the center of the spot; T – temperature as a function of depth z, measured from the surface, radial distance x from the center of the heat source and the time t from the start of the heat pulse effect; $P(t) = q(t)/q_{\max}$.

If the beam moves across the surface of a semi-infinite body with a speed v when neglecting heat loss from the surface, the surface temperature at the point with coordinates (x, y, z) be:

$$\overline{T} = \frac{16}{\sqrt{\pi}} \int_0^\infty \frac{1}{\sqrt{\left(c'^2 + t'^2\right)\left(b'^2 + \overline{t}^2\right)}} \exp\left[-\frac{\left(2\overline{x}'^2 + \overline{\upsilon}\overline{t}'\right)^2}{4\left(\overline{c}'^2 + \overline{t}^2\right)} - \frac{\overline{y}^2}{\overline{b}^2 + \overline{t}^2} - \frac{\overline{z}^2}{\overline{t}^2}\right] d\overline{t}. \tag{6}$$

The following dimensionless parameters introduced in this expression: $\overline{T} = 16\sqrt{\pi K r}T / PA_0$; $\overline{\upsilon} = \upsilon_r / 2a$; $\overline{x'} = \frac{x}{r}$; $\overline{y'} = \frac{y}{r}$; $\overline{z'} = \frac{z}{r}$; $\overline{c'} = \frac{c}{r}$; $\overline{b'} = \frac{b}{r}$; $r^2 = cb$, where A_0 – the reflectivity of the treated material; P – laser power; b, c – parameters of the Gaussian distribution.

For the case of using the liquid as a coolant at the simultaneous action of radiation on the oriented normal surface, the equation proposed in [7] can determine the temperature fields in the case where the cooler – ultra-high pressure fluid is not supplied – and then enter the initial conditions. Then:

$$\mathrm{T}(x,y,z) = \frac{\mathrm{P}}{\pi^{\frac{1}{2}} pc} \int_0^l \frac{e^{\frac{(x - v(t-z))^2}{4at + A^2} \quad \frac{y^2}{4at + B^2}}}{\left[(4at + A^2)(4at + B^2)at\right]^{\frac{1}{2}}} \times \tag{7}$$
$$\times \left[e^{\frac{z^2}{4at}} - h(\pi a t)^{\frac{1}{2}} erfc\left(\frac{z}{2(at)^{\frac{1}{2}}} + h(at)^{\frac{1}{2}}\right) \cdot e^{hz + h^2 at} \right] dt,$$

where ρ, c, λ – density, specific heat and coefficient of thermal conductivity of material, respectively; $a = \frac{\lambda}{cp}$ – thermal diffusivity of material; h – coefficient of heat transfer from the surface; A and B – greater and lesser half-axises of the elliptical beam; $P = q\pi AB$ – power of laser emitter.

The process of thermal conductivity in the workpiece volume, limited with area Ω, with the surface $\partial\Omega$, is described by a scalar field of temperature $T = T(P,t)$, vector field of the heat flux $\vec{q} = \vec{q}(P,t)$, $P = \{x, y, z\} \in \Omega$ and scalar field of the specific thermal energy $e = e(T)$.

Integral balance equation of heat energy in an arbitrary regionon $\omega \subset \Omega$ with the condition that dv and ds elements of volume and surface; $\vec{n}$ – the unit vector of the outer normal to $\partial\omega$; $(\vec{q}_T + c_g \rho_g T \vec{v}_f, \vec{n})$ – scalar product of vectors; and $\vec{q}_T + c_g \rho_g T \vec{v}_f$ and $\vec{n}$; c_g ρ_g – heat capacity and gas density is as follows:

$$\int_\omega \left[e_t + di\vec{q}_t + c_g p_g div(T\vec{v}_f) - g \right] dv = 0,$$
$$\int_\omega \frac{\partial e}{\partial t} dv = \int_\omega g dv - \oint_{\partial\omega} (\vec{q}_t + c_g p_g T\vec{v}_f, \vec{n}) ds. \quad (8)$$

In extreme conditions, which are determined by:

$$cp = \frac{dT}{dt} - \lambda \Delta T = \frac{(1-R_0)kP}{\pi AB}$$
$$\exp\left[-2\left(\frac{(x-vt)^2}{a^2} + \left(\frac{y}{b}\right)^2 \right) \right] \cdot \exp(-kz), \quad (9)$$
$$\lambda = \left.\frac{dT}{dz}\right|_{z=0} = a(T)(T - T_p).$$

$T(x,y,z,t) = T_0$ at approximation the growth of coefficient of heat transfer with dependency $h(T) = h_m \exp\left(\frac{(T-T_m)^2}{\Delta T^2} \right)$.

And the temperature on the top of layer will be:

$$T(t) = T_{\max} - \frac{q_l \delta}{\lambda} \left[\frac{2}{\sqrt{\pi}} \frac{\sqrt{a(t-\tau)}}{\delta} + \exp\left(\frac{a(t-\tau)}{\delta^2} \right) erfc\left(\frac{\sqrt{a(t-\tau)}}{\delta} \right) \right], \quad (10)$$

where δ – depth of penetration of heat, $q_l = f(f_c, p, t)$.

Therefore, the simultaneous action of water jet guided laser stream more locates fracture zone, but the effect of cutting with immersing of the groove in the material body gradually decreases.

Thus, we can assume that the hybridization of the processing, which is in sequential scribing, cutting and hydroabrasive burnishing the surface, will allow to obtain high-quality productive cuts in accordance with the structure of processed composite plates.

Full-scale experiments were performed on a water jet guided laser complex LSK-400-5 equipped with a jet-abrasive head with a water nozzle d_c=0,22 mm and a gauge tube D_k=1,05 mm, and the system of combining a laser beam with a liquid stream by means of flying optics.

Cutting of plate was performed with Nd: YAG laser, 400 W and operates at a frequency of 50 Hz.

Beams focusing was performed according to traditional methods, checking alignment of the beam and the correct hit of all its modes on the focusing barrel lens. Purging of the influence zone was carried out with common compressed air, which entered into the nozzle with a diameter 2,8 mm at a overpressure of 0,05 MPa; air was filtered and fed from the receiver. Liquid supply was provided from the nozzle of diameter 1,5 mm directly in the center of the laser focus. Working feeding for obtaining groove of 2,0 mm was established at 300 mm/min, there was provided linear motion for the laser head, and the distance between the nozzle section and the cut surface was set with the condition of arrangement of focal plane on the plate surface, that is, at a distance of 7,2 mm. This would make it possible to obtain the highest temperature at the point of impact of the beam. Of course, this distance allowed to be a sufficiently small, such because for such length of beam focus the effect of beam trimming can be significant. Therefore, it was expected that the groove has to be shallow with rounded edges. However, microscopic analysis of the cut, executed with such regimes, revealed the following. When feeding of 300 mm/min it was failed to receive 0,13-0,14 mm wide groove with depth of 2,5-2,6 mm; wherein cutting sidelong didn’t exceed a few angular degrees, and the surface roughness was at level in *Ra* 6,3 micron (Fig. 2).

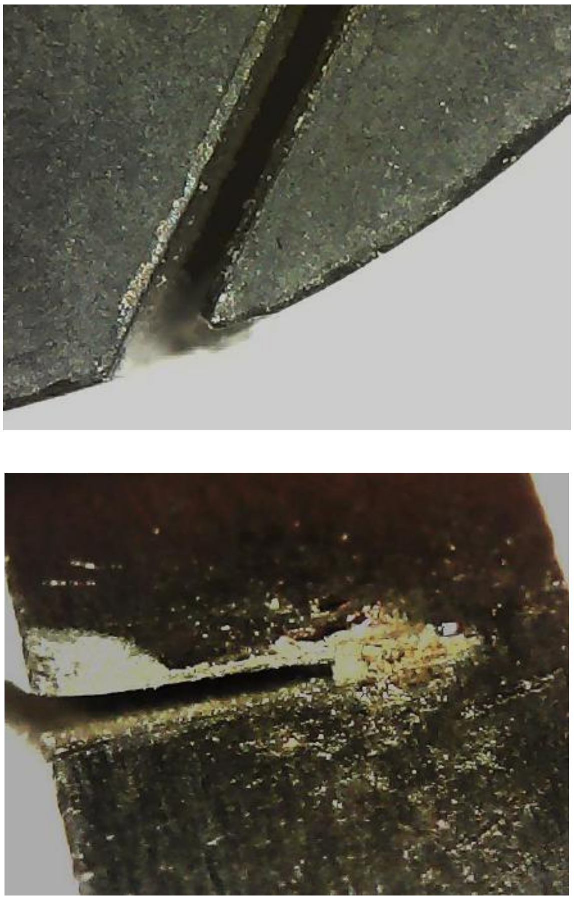


***Fig. 2** – Groove obtained by cutting feed rate of 300 mm/min, Nd: YAG-laser: a photo from the working plane and from an end face; grooves from the liquid droplets which fell on an end face from the air flow and the has been activated with laser*

Microscopic examination of the end of the workpiece proved that rather deep grooves of spattering formed on it that can be attributed with liquid drops formed as a result of an air stream entering into the liquid bath, and above which was located the workpiece. The destruction of the surface was of a number of processes, due to the presence of water on the surface activated with laser beam.

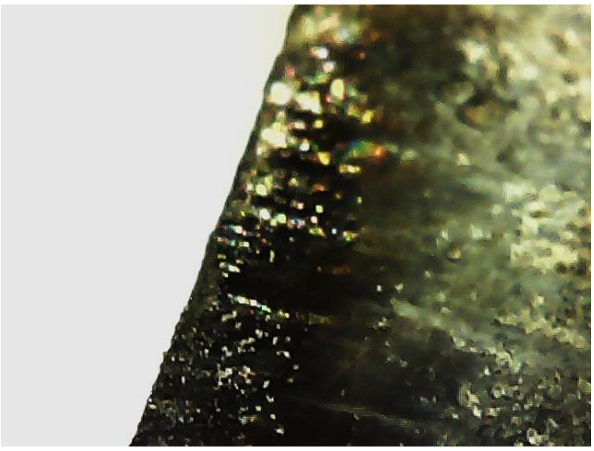
Increasing the depth of the groove is obviously due to the action of the fluid, which not only cools the surface, but also creates a kind of much refractive focusing system – additional "semitransparent mirror", which precedes to radiation dissipation and leads to an increase in the absorption capacity of the material. Also, it can be assumed that water, which under the influence of concentrated heat source, dissociated on H^+ and OH^-, participates in chemical reactions and promotes nucleation of low temperature plasma.

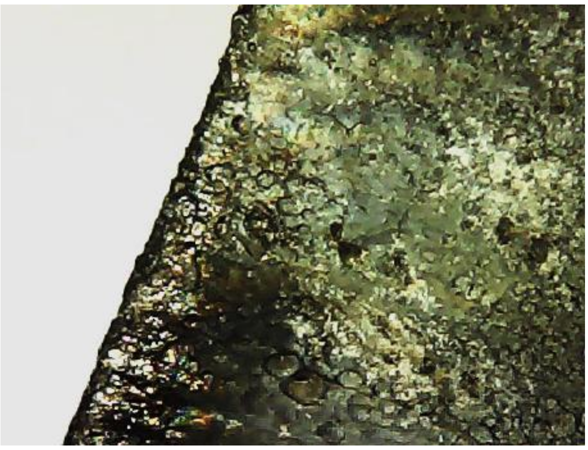
A more detailed study of photomicrographs of the end face of cut from the side of beam incidence and from the opposite side showed that cut is heterogeneous in structure and in the number of surface defects (Fig. 3). At the same time, significant defects and damages of the surface are not detected.

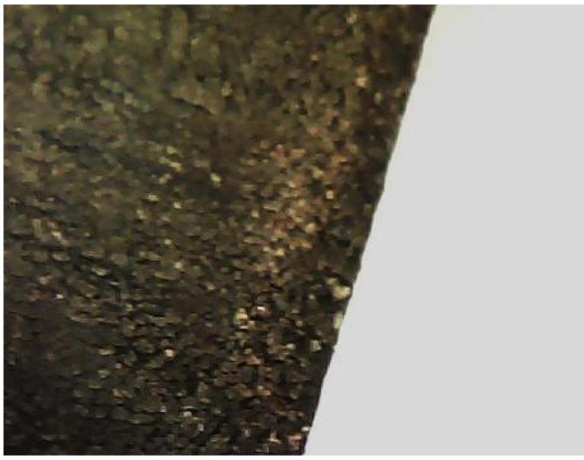
Thus, the use of water as a coolant supplied to the laser exposure zone under low pressure, can significantly enhance the cutting effect, it provides a better cutting edge and reduces the thickness of the destructive layer. Differences between the estimated depth of the groove with the experimentally obtained are advisable to consider by introducing additional factors in simple empirical equations, which may be obtained by known means of experimental design and producing of multiple regression equations.

It is tested the possibility of using water jet guided laser treatment for durable and heavy-duty plates. This method provides presence of special water jet guided laser head and a liquid supply into the processing zone at high pressure, with the laser beam focusing in a particular section [8, 9].

Under water jet guided laser impact the workpiece perceives simultaneously (or almost simultaneously, when it comes about the use a pulsed laser) two effects causing the destruction of the material. The total capacity of the effects will be expressed as the sum of $A = h \cdot \rho \cdot A \dfrac{d\overline{z}_1}{dt} + 0{,}5 \cdot \rho \cdot \dot{z}^2 \cdot F \dfrac{d\overline{z}_2}{dt}$, where F – jet area; z – jet speed; $d\overline{z}_1$ – the depth of penetration withdrawal under the action of laser radiation; $d\overline{z}_2$ – the depth of penetration withdrawal under the action of high-speed jet.







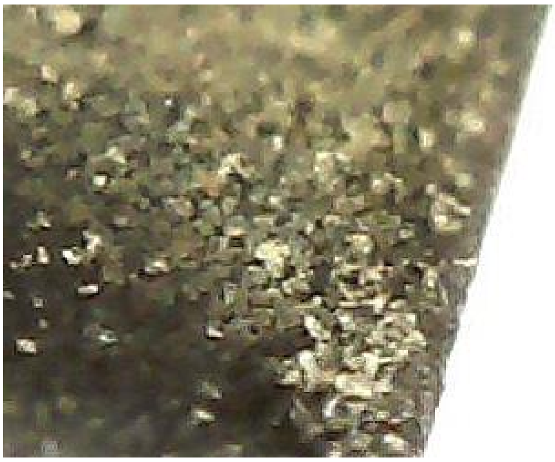


Fig. 3 *– Cross section of cut: from the side of laser action is observed thermal degradation of the surface layer, obviously, due to the existence of zones of small thermal influence*

In this equation, the first term is due to laser radiation, evenly distributed over the surface with area A, the second term – over the action of swift jet applied to the surface with area F.

Part of the material falling under the action of laser radiation, melts and evaporates, and at last spent a large proportion of the radiation power. Typically, laser radiation affects to a depth less than the value $\delta - \overline{z}$, where δ – thickness of the workpiece. The process of water jet guided laser cutting can be arranged so that the fast-flowing stream provides almost instant a heat sink and eliminates the distribution of heat exposure outside of the molten bath. In this case we can write:

$$A = h \cdot \rho \cdot A \frac{d\overline{z}_1}{dt} + 0{,}5 \cdot \rho \cdot \dot{z}^2 \cdot F \frac{d\overline{z}_2}{dt} - \\ - h \cdot \rho \cdot A \frac{d(\delta - \overline{z}_1)}{dt} - \lambda \cdot \rho \cdot A \frac{d\overline{z}_3}{dt} + c \cdot \rho \cdot A \frac{d\overline{z}_3}{dt}, \quad (11)$$

where λ – material specific heat of melting; $\overline{z_3}$ – the linear size of the molten material; c – the specific heat of the molten material.

The sum of the power of the external forces and the quantity of heat, wrapping up outside, is equal to power of the internal forces. For hard-plastic body the power of the internal forces is expressed as follows:

$$A_{in.f} = \sigma_S \left[A(d\bar{z} + d(\delta - \bar{z}) + Fd\bar{z})\right]^{0,5} \times \\ \times (z_1 \cdot \dot{e}_1^2 + z_{12} \cdot \dot{e}_1 \cdot \dot{e}_2 + z_2 \cdot \dot{e}_2^2)^{0,5}, \quad (12)$$

where σ_S – yield strength;

$(z_1 \cdot \dot{e}_1^2 + z_{12} \cdot \dot{e}_1 \cdot \dot{e}_2 + z_2 \cdot \dot{e}_2^2)$ – the volume of deformation zone; $\dot{\varepsilon}_1, \dot{\varepsilon}_2$ – the scalar value of the speed of movement under the influence of high-speed jet.

These considerations allowed to suggest the original technology for composite plate cutting, which is the layer system with layer of polycrystalline cubic boron nitride of 2,8 mm thick coated on hard alloy base. The total plate thickness – 4,5 mm. Sector diameter of 3,5 mm (Fig. 4) was cut out with the hybrid process.

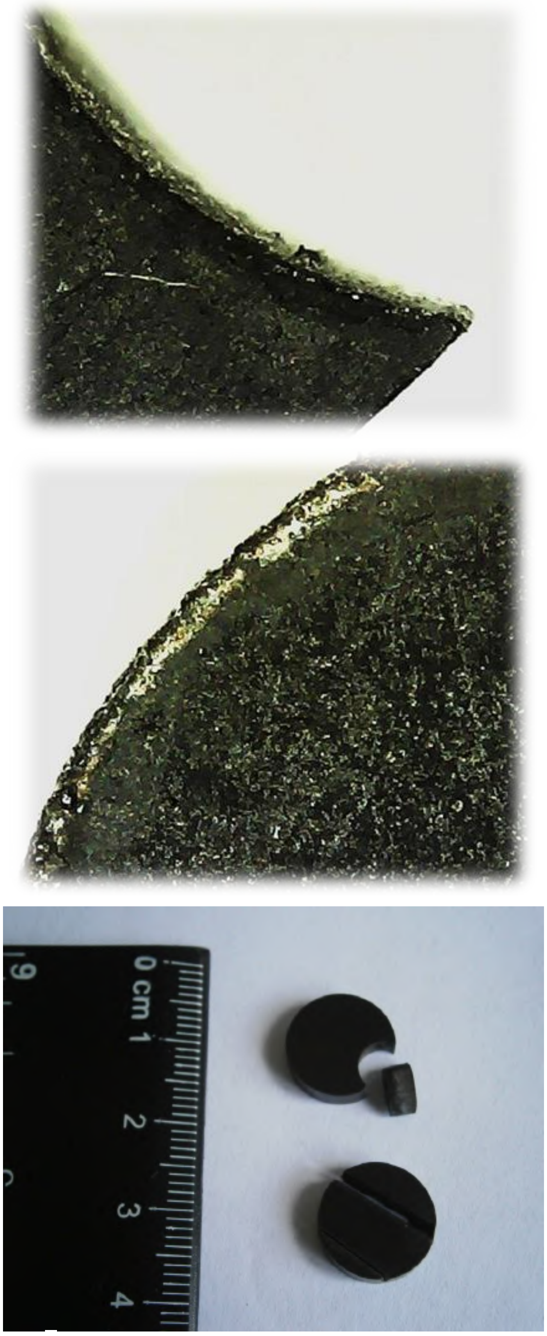


***Fig. 4** – Sector carved out from the research composite plate SVN+WC (TiS) and the enlarged photos of obtained surfaces*

CONCLUSION

Using functional approach allowed us to obtain a high quality cut (roughness of end face – 3,2 microns, the slot width – 0,12 mm), the time to perform the operation at the specified cutting contour was only 1,8 minutes. Attempts to cut the plates in another way did not have the result, because cohesive and adhesive damages occurred in the plate, which made impossible its future work.

REFERENCES

[1] French M. J. Design principles applied to structural functions of machine components. Journal of Engineering Design, 3(3) (1992) 229-241

[2] Salenko A.F., Shchetinin V.T., Fedotyev A.N. Improving accuracy of profile hydro-abrasive cutting of plates of hardmetals and superhard materials. J. of Superhard Mat. 36(3) (2014) 199-207.

[3] Salenko A.F., Shchetinin V.T., Fedotyev A.N. and et. Methods of cutting for workpieces of hardmetal and CBN-based polycrystalline superhard material. J. of Superhard Mat. 54(6) (2015) 78-96.

[4] Klimenko S.A., Mel'nichuk Yu.A., Vstovskii G.V. Interreation between the Structure Parameters, Mechanical Properties of Sprayed Materials and the Tool Life in Cutting Them. J. of Superhard Mat. 30(2) (2008) 115-121.

[5] Fedotyev A., Fedotyeva L. The prospects of carbolloies waste utilization as wearproof coverings Journal of the Technical University of Gabrovo. 39 (2010) 30-33.

[6] V. Ivanova, A. Balankin, I. Bunin, A. Oksogoev. Synergetics and Fractals in Material Science M.: Nauka, 1994.

[7] P. Gindin. Mathematical model of thermal splitting of brittle anisotropic materials Surface. 1 (2010) 14-18.

[8] Simulation of Laser Cutting / W. Schulz, M. Niessen, U. Eppelt, K. Kowalick. The Theory of Laser: Mat. Proces. 119 (2009) 21-69.

[9] Salenko O., Gabuzyan G., Myronov Ya., Nikitin V. About some results of processing SiC-microarrays by Hydroabrasive Precision Jet. JOURNAL of MECHANICAL ENGINEERING NTUU «Kyiv Polytechnic Institute». (2013) 178-184.