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SELECTION OF A RATIONAL METHOD FOR HARDENING CARBIDE CUTTING TOOLS FOR HEAVY ENGINEERING

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Abstract: An important task is to improve cutting tools for high-precision productive machining of difficult-to-machine materials by applying the latest tool hardening methods. This is especially true for carbide-cutting tools. The paper analyzes the current state of the problem of improving the tooling of new machine tools for high-precision productive machining of hard-to-machine materials. The main known methods of increasing the wear resistance and strength of carbide tools can be divided into the following groups: structural methods; mechanical hardening; wear-resistant coatings; chemical and thermal treatment; laser hardening; plasma-arc hardening; radiation hardening; ionic alloying; magnetic abrasive treatment; and pulsed magnetic field treatment. The choice of a particular hardening method depends on many factors that determine its effectiveness and costs in certain production conditions. The conditions for machining large-sized parts at heavy engineering enterprises are analyzed. It was found that, along with wear, the destruction of the cutting part in the form of pitting and fracture is significant. Statistical studies have proven that when machining on heavy machine tools, the cutting force allowed by the machine tool mechanisms does not limit the cutting modes. The maximum values of forces are up to 10 times higher than their average value, which is usually used to calculate the design parameters of cutting tools An analysis of various methods for improving the physical and mechanical properties of carbide tool materials has shown that the best combination of cost and production efficiency is observed in pulsed magnetic field treatment. The use of magnetic fields in cutting processes and tool hardening is a promising area of high-technology development in machining. Increasing tool life can be achieved by the influence of a magnetic field either on the conditions of the cutting process or on the structure and physical and mechanical properties of tool materials with ferromagnetic components.

Keywords: cutting tools, carbide tool materials, magnetic field, strength.

Introduction

The current challenge is to improve the strength of structural materials, performance ,and service life of large-sized parts by applying new efficient technologies and equipping machine-building enterprises with modern processing equipment and cutting tools. As the industry develops, the requirements for machines are becoming more stringent, as is the need to improve the accuracy and quality of their manufacture and to introduce new durable materials that enable them to achieve a higher level of performance. An important task is to improve the tooling of new machine tools for high-precision productive machining of hard-to-machine materials by applying the latest tool hardening methods. One of the most promising technologies for improving the strength, service life, and performance properties of metal products for various engineering sectors is pulsed electromagnetic field treatment. Research on the rational choice of a method for strengthening a cutting tool is actual.

Literature analysis

Methods of improving the physical and mechanical properties of carbide tool materials.

There are ways to improve the physical and mechanical properties of tool materials, although they can increase the wear resistance of the tool, the costs compared to the efficiency of such methods remain significant, and in many cases uneconomical and impractical due to loss of other valuable properties. Therefore, the development of new advanced methods of strengthening the cutting tool is an important task to increase the service life of metalworking tools.

This task is especially relevant for carbide-cutting tools. It is known that cemented carbides have, on the one hand, high heat resistance, which allows cutting tools to work at high cutting speeds. On the other hand, cemented carbides have low strength, which limits their ability to work in previous operations, where the tool has a shock load formed during the processing of the workpiece, which is made by casting or forging, abrasive dust, uneven allowance, etc.

The main known methods of increasing the wear resistance and strength of carbide tools can be divided into the following groups: design methods; strengthening by mechanical shot blasting (peening); application of wear-resistant coatings; chemical and thermal processing; laser hardening; plasma arc hardening; radiation strengthening; ionic doping; magnetic abrasive processing, pulsed magnetic field processing.

The choice of a method of hardening depends on many factors that determine its effectiveness and cost of implementation in certain production conditions.

Among the design, methods should be noted [1–16, etc.]:

– rounding of cutting edges, which leads to a change in the direction of cutting forces and reduces oscillations;

– increase in the sizes of dangerous sections of indexable inserts or their thickening;

– increasing the stiffness of the support of the cutting insert in the holder, grinding or finishing the supporting surface of the plate, hardening the holder, reducing the rear corner of the insert;

– application of substrates with high modulus of elasticity and resistance to compression at the temperature arising at support.

These methods do not lead to an increase in production costs, but their efficiency depends on certain operating conditions (material being processed, cutting mode, characteristics of equipment, devices, etc.).

One of the promising ways to increase the strength of the tool is the processing of working surfaces by plastic deformation (SPD): vibration and shot peening [1].

When processing SPD is applied, a large number of blows are applied on cutting surfaces, resulting in plastic deformation and brittle-abrasive wear of these surfaces. All phase components of the cemented carbide are plastically deformed, but to the greatest extent - tungsten carbide. At the same time, the mosaic blocks are crushed, the micro deformation of the lattice increases and compressive stresses of the order of 100–130 N/m^2 occur.

The use of SPD methods in the strengthening of carbide-cutting tools allowed to increase in the supply by 1.1–1.2 times.

The effectiveness of SPD methods is determined by the dependence of cutting tool strength on geometric parameters, and physical and mechanical properties of the material. At SPD there is a rounding of cutting edges that increases the durability of the tool.

However, the efficiency of rounding of the cutting edges and the optimal value of the radius of rounding depends primarily on the thickness of the cut layer and the hardness of the material being processed. This limits the application of SPD.

The search for a method of hardening, which combines the ability to achieve optimal rounding of the edges of the cutting tools and the depth of hardening, led to the need to study the effect of fluid on the effect of shot blasting carbide cutters, which proved to be twofold. On the one hand, the fluid reduces the impact energy and, on the other hand, removes wear products. Thus, the intensity of plastic deformation decreases, and the intensity of rounding of the edges changes to a lesser extent, which should lead to a better ratio of the radius of rounding of the edges and the depth of hardening.

The use of liquid in shot blasting increases the maximum radius of curvature by 20 percent. At the moment of reaching the maximum strength, the degree of deformation of the cutters of both types of processing is approximately the same, while the radius of curvature of the cutters, which are treated with liquid, is 10–15 percent higher. This provides an increase in strength by 1.17 times.

Vibration processing is a mechanical process of removing the smallest particles of material from the surface to be machined, as well as smoothing micro-irregularities by their plastic deformation by the working elements of the abrasive filler, which performs oscillating movements [2].

Improving the performance of carbide tools as a result of its vibration processing is achieved due to the fact that the latter provides rounding of cutting edges and other surfaces of the cutting part, a favorable change in physical and mechanical properties of the surface layer of the cemented carbide. As a result of research, it was proved that about 60–70 percent of the effect when vibrating the tool is achieved by rounding the edges and 30–40 percent – by reducing the roughness and changing the properties of the surface layer. Vibration processing is very time-consuming and therefore requires significant costs.

Shock wave energy [3] has found application in the processing of metal-ceramic alloys to increase their strength and stability.

The cutting insert made of VK8 alloy was placed in a lead container, the choice of which as a pulse “trap” was due to the relative equality of the acoustic stiffness of the alloy VK8 and lead. The formation of a flat detonation front was performed by a plane-wave generator. The “running” on the surface of the detonation front, forms an oblique shock wave in the material, the intensity of which decreases as it passes – deep into the environment. With such a spread of the impact front in the material, favorable shear conditions are created in terms of thermodynamics, which lead to a marked strengthening of compact materials and inevitably cause the destruction of fragile media. This fracture accounted for 60 percent of the volume of the cemented carbide. The conditions for the complete preservation of the plate were achieved by means of the experimentally found law of attenuation of plane shock waves in copper.

Studies of the microstructure showed significant grinding of tungsten carbide grains and refinement of the cobalt bond due to its deformation, which led to an increase in microhardness by 1.4 times. As a result of tests, it was found that the tool life increased by 2 times. This is due to the grinding of tungsten carbides, the strengthening of the cobalt bond, and the appearance of compressed stresses on the surface of the plate.

Applying a hard coating [1], resistant to abrasion, on carbide inserts can increase the durability of cutting edges several times compared to conventional inserts or at the same durability to increase the cutting speed.

Titanium carbide (TiC) coated plates with a thickness of 5–6 μm have a typical disadvantage: the presence of a decarburized brittle layer between the coating and the substrate. As a result, they could be used only for continuous cutting.

Coated cutting inserts did not have this disadvantage due to the advanced manufacturing technology. The coating thickness of these inserts was increased to 7–8 μm, and special grades of cemented carbide were used as a basis. This allowed the use of inserts for interrupted cutting.

Inserts having a coating thickness of up to 10 μm consist of 2 or more thin layers of different compositions. Titanium carbide (TiC) is most often applied to the base, and titanium nitride (TiN) or alumina (Al2O3) is applied to it. The use of inserts with a multilayer coating [2] allowed to increase in the productivity of processing by 1.5 times compared to inserts with a single-layer coating (TiC).

However, coated inserts have a number of disadvantages. When regrinding, all advantages over uncoated inserts are nullified. They should not be used where a very sharp cutting edge is required, as the cutting edges are always inevitably rounded when applied. They are not very suitable for light metals, wood, and other materials with low hardness. Unsuitable coated inserts in cases where the viscosity of their base metal is insufficient for the selected machining operation.

One of the ways to increase the stability of the carbide tool [5, 6] is the heat processing of the cutting plate. The greatest effect when using this method is achieved by heat processing in a gaseous medium: N_2 (40–60 %), CO (15–20 %), H_2 (30–35 %).

Titanium nitride (TiN) is formed on the surface of carbide inserts, which has sufficient thermal conductivity, resistance to oxidation at high temperatures, relatively low brittleness, and high abrasion resistance.

Laser processing helps to grind and saturate the dislocations of the structure of the surface layer of the tool material, which leads to increased hardness and, consequently, a significant increase in the wear resistance of the tool. Laser surface hardening is characterized by maintaining the original purity of the upper layer of the product and ensuring the locality of the process [7]. But the technological process of surface beam processing is complex, depends on a number of conventions, requires (when irradiating a multi-blade tool) significant energy costs, and is time-consuming.

Note the main disadvantages of surface laser hardening:

– hardening is carried out only at the junction of the working surface to the cutting edge;

– simultaneous strengthening of both surfaces (front and rear) is unacceptable;

– the cutting edge after laser heat processing is weakened against the action of brittle fracture forces;

– the process is long in time (when strengthening the multi-blade tool) and requires significant energy costs;

– when regrinding the tool, the established layer is removed.

The ion implantation method [8] is used to change the mechanical properties of various metals. The method consists of the implantation of ions of a number of elements (N +, B +, In +, (Ti + N), (Ti + B)) on the surface of carbide inserts and allows the application of multilayer coatings [2]. Experiments have shown that the tool life of cemented carbide inserts with a multilayer coating increases by 1.4–1.8 times.

One of the promising methods of finishing polishing and hardening processing of the tool is the method of magnetic abrasive processing (MAP) when a comprehensive impact on the processed surface and the surface layer of parts is carried out. The analysis of MAP interaction conditions in the conditions of large magnetic slits is first of all processing at active frictional-shock interaction of the processed surface with the magnetic-abrasive tool (MAT) formed in the course of processing [4, 8]. In the implementation of the processes of predominant micro-cutting or microplastic deformation of the treated surfaces, a significant factor is a size, geometric characteristics, and shape of the particles of magnetically abrasive powder materials. It is shown that MAP of drills after their regrinding with the use of round equilibrium powders provides opportunities to strengthen the surface layer, reduce the roughness of the working surfaces of the tool and increase their stability by more than 1.7 times.

However, due to the intensification of production, one of the most acute problems is the development and application of more effective methods of strengthening metalworking tools.

Pulsed magnetic field processing [9] is based on the fact that the vortex magnetic field interacts with the carbide insert, improving the structure and properties of the latter. With this hardening, the tool is placed in the inductor so that the center of gravity is shifted relative to the geometric center of the solenoid. Due to this, when the device is turned on, the tool is drawn by the field into the solenoid with acceleration and performs relative to its geometric center-damped oscillations, the amplitude of which decreases over time under the action of friction and is zero.

Due to the heterogeneity of the crystal structure of the material, eddy currents are generated. In this case, the heat released is dissipated over the volume of the tool so that the thermal field gradient is higher, the more complex and heterogeneous the microstructure of the alloy. In places of structural inhomogeneity, as well as the concentration of stresses there is a reduced heat, which increases tenfold the local temperature of overstressed areas. As a result, the tool is subjected to "screw compression", in which electrodynamic forces compact and order the crystals of the structure, thereby reducing their internal overvoltage.

The use of magnetic fields in the processes of cutting and strengthening the cutting tool is a promising direction in the development of high technology in machining. Increasing the stability of the tool can be achieved due to the influence of the magnetic field or the conditions of the cutting process, or the structure and physical and mechanical properties of tool materials with ferromagnetic components. Accordingly, there are two directions for the application of magnetic fields in machining. The first involves increasing the stability of the tool when cutting in a magnetic field, the second involves increasing the stability characteristics of the cutting tool after processing in constant, variable, and pulsed magnetic fields due to changes in structure and physical and mechanical properties of tool material. Various researchers explain the increase in the period of tool life during cutting in a magnetic field by the removal of heat from the tool due to the manifestation of the thermomagnetic effect of Riga – Ledyuk, increasing the mechanical properties of the tool material due to the ordering of its grain size [10], the emergence of forces that cause bending of the chip roots, reducing the area of contact of the chips with the tool, changing the shear angle and reducing cutting forces. The effect of increasing the period of resistance to cutting in a magnetic field depends on the direction of magnetic flux, the magnitude of the magnetic induction [11], and cutting parameters. The influence of the external magnetic field on the conditions of the cutting process allows, in addition to increasing the tool life of the tool, to increase the optimal cutting speed, reduce the optimal surface wear [12], to improve the quality of the treated surface [13].

On the other hand, in the works [13] it is shown that the tool, which is subjected to magnetic processing, has an increased tool life in the absence of an external magnetic field in the cutting zone. In this case, the increase in the tool life is due only to changes in the structure and physical and mechanical properties of the tool material after magnetic processing. The literature provides various information about the increase in the tool life of the cutting tool as a result of magnetic processing and its causes. The increase in the stability of cutting tools and drills made of high-speed steels after processing in constant and alternating magnetic fields is explained by the decay of residual austenite in the surface, a re-hardened layer of steel formed by sharpening the tool [14]. In the works [15] the effect of increasing the tool life of the high-speed tool after processing in constant magnetic fields is associated with the polarity of its working part after magnetization. In [16] the increase of the tool life of the steel tool at processing by a static magnetic field or with the one-time influence of the field, or with the movement of the tool which is strengthened, in a magnetic field is specified. In [4] the reduction of wear of tool steels as a result of remagnetization by relatively weak fields is noted, which is explained by the authors in terms of changes in structure and properties of steel surface due to diffusion of tungsten atoms and other elements from internal volumes of material after field exposure.

The most promising direction of using magnetic fields to increase the tool life of the cutting tool from materials containing ferromagnetic components is pulsed magnetic field processing (PMFP), which allows to obtain the most stable increase in tool life by changing the physical and mechanical properties of tool material. The pulsed nature of the magnetic field in PMFP allows you to easily make an intense energy impact on the material with the help of electromagnetic waves. A kind of pulsed electromagnetic shaking of condensed systems with many real defects accelerates the rate of relaxation and structural adjustment in them [2]. The choice of a pulsed magnetic field has also simplified the requirements for power supplies and made installations compact and portable. In this case, the equipment for PMFP can be installed in the mechanical shops of the enterprise, and the parameters of the processing modes vary depending on the tool material in order to optimize the characteristics of the plate [2].

The change in the properties of ferromagnets after PMFP is achieved due to the directed orientation of the free electrons of matter by the external field, as a result of which there are physical preconditions for changes in the structure and stress state of the material. Based on the works [13] it can be argued that the PMFP has a complex effect on the material of magnetostrictive processes and mechanical deformations caused by them, thermal and electromagnetic vortex fluxes localized in places of magnetic flux concentration and directionally oriented processes, spin characteristics of outer electrons of boundary zone atoms. PMFP is a combination of electromagnetic and thermodynamic methods of controlling the imbalance structure of the material. Changes in the structure of the material as a result of PMFP can be due to force (magnetostrictive) or thermal factors. Structural changes in the material occur as a result of the activation of dislocation or diffusion processes.

According to S. M. Postnikov, at the PMFP of high-speed steels, there is an interaction of the elastic field caused by magnetostrictive deformation with the elastic field of the material's own real dislocation structure. This interaction leads to the appearance of local overvoltages, in the locations of which the probability of thermofluctuation rupture of interatomic stress bonds increases sharply. In those places where local overstrains exceed the limits of elasticity of the material, sources of plastic deformation are formed and the processes of reproduction and displacement of dislocations are intensified. With increasing dislocation density, the steel acquires a kind of slander, which is expressed in changes in the parameter of the crystal lattices of martensite. The increase in the mechanical characteristics of high-speed steel as a result of PMFP is due to the release from the metal matrix of fine carbide particles as a result of magnetic dispersion hardening due to the above structural processes. It is Postnikov's concept of magnetostrictive hardening and magnetically dispersion hardening of high-speed steels that is the only integral scientific theory of the PMFP of a cutting tool.

The results of studies of the influence of PMFP on the tool life of the cutting tool and the physical and mechanical properties of tool materials are presented in [13–16, etc.].

Purpose of work and problem statement

The aim of the work is to increase the efficiency of machining parts on heavy machine tools by choosing a rational method of hardening carbide-cutting tools.

The following tasks are set in order to achieve the above objective:

1) to analyze the working conditions of cutting tools at heavy engineering enterprises;
2) to propose a rational method of hardening carbide-cutting tools for heavy engineering.

Working conditions of cutting tools at heavy engineering enterprises

Statistical studies have shown that when machining on heavy machines, the cutting force allowed by the machine mechanisms, torque (Fig. 1), is not restricted by cutting conditions and can reach extremely high values. The maximum values of forces up to 10 times exceed their average value, which is usually used to calculate the design parameters of the cutting tool.

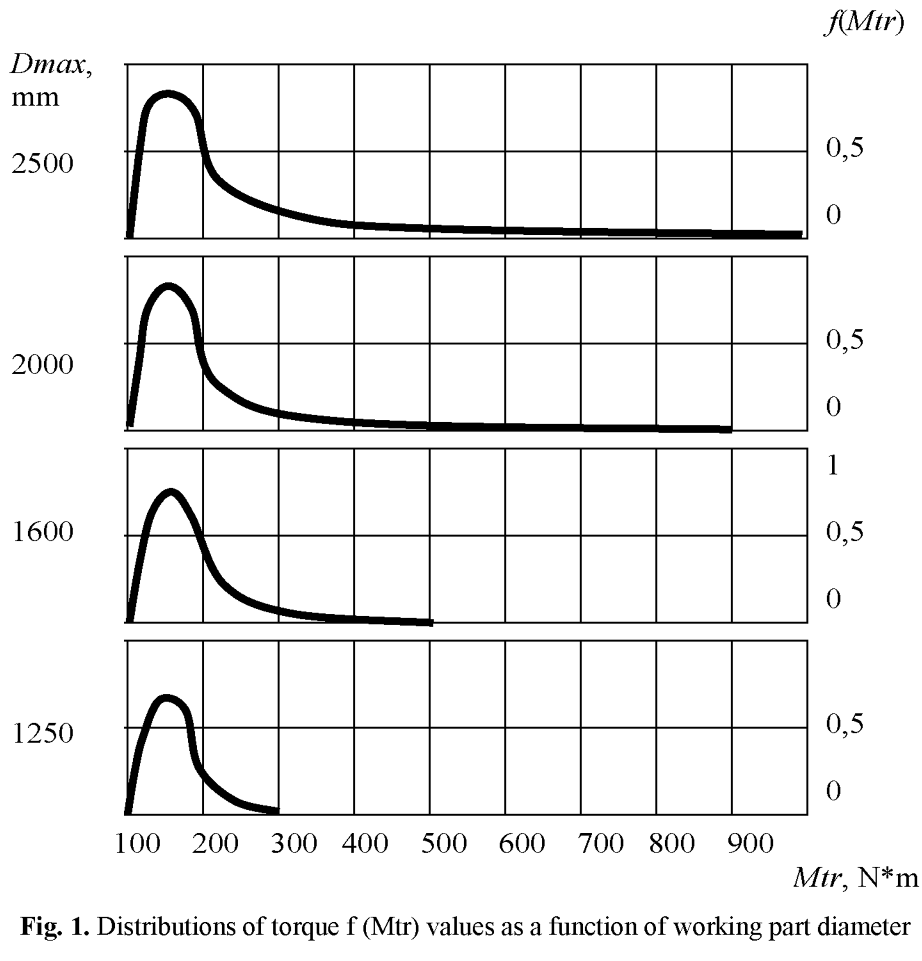


Fig. 1. Distributions of torque f (Mtr) values as a function of working part diameter

A significant limitation on the modes of cutting when machining existing structures on heavy machines is the weight of the part, which does not allow in some cases to increase the speed.

The efficiency of the cutting tool is also affected by variable loads, the quality of its manufacture, the scattering of physical and mechanical properties, etc. Ultimately, the combined effect of many random factors can lead to unforeseen failure due to catastrophic wear or accidental destruction of the tool.

The decrease in the average cutting speed while processing on heavy machines compared to medium and small machines, in addition to the increased cross-section, is due to the fact that these speeds require in some cases the use of spindle speed, which is on the verge of power of machines (Fig. 2).

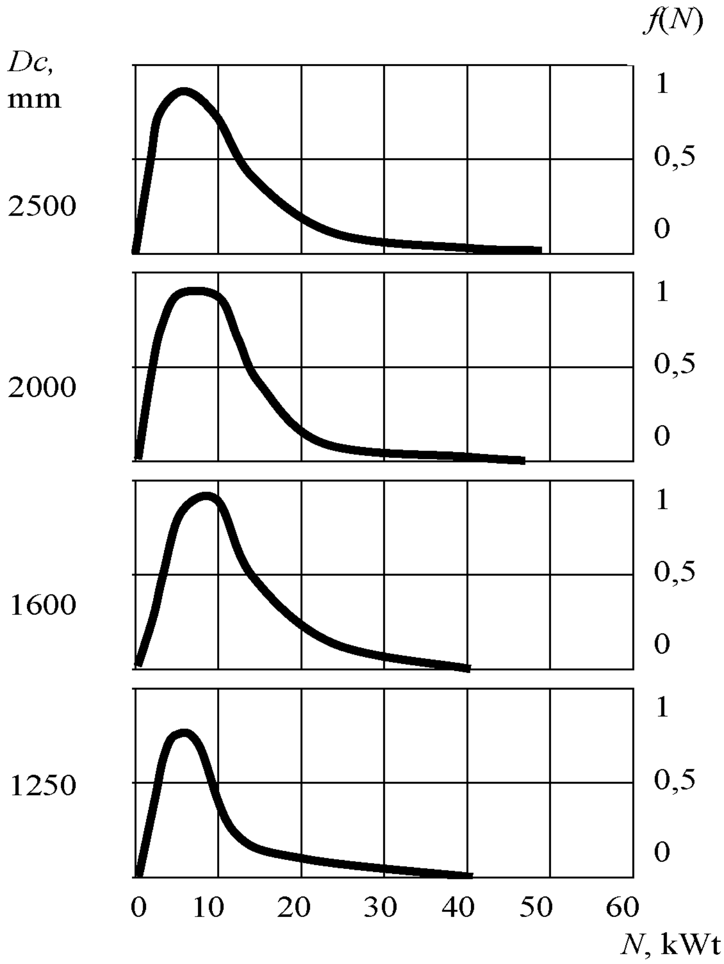


Fig. 2. Distributions of cutting power f (N) per carriage of a heavy lathe

Fig. 3 shows the distribution of the applied speed n of the spindle of heavy lathes. The restriction zone covers a different part of the spindle scattering field for machines with different Dmax values, which is due to the design features of the machines and once again confirms the need to take into account the size of the machine when determining rational operating regulations.

During the study of the tool life period of the cutting tool of heavy lathes, the actual tool life of the cutting tool in the transition from machines with $D_{max} \leq 1600$ mm to larger sizes of machines increases. This is due to the following reasons: the size of the tool holder increases ($H = 80$ mm) and its weight, the weight of parts increases.

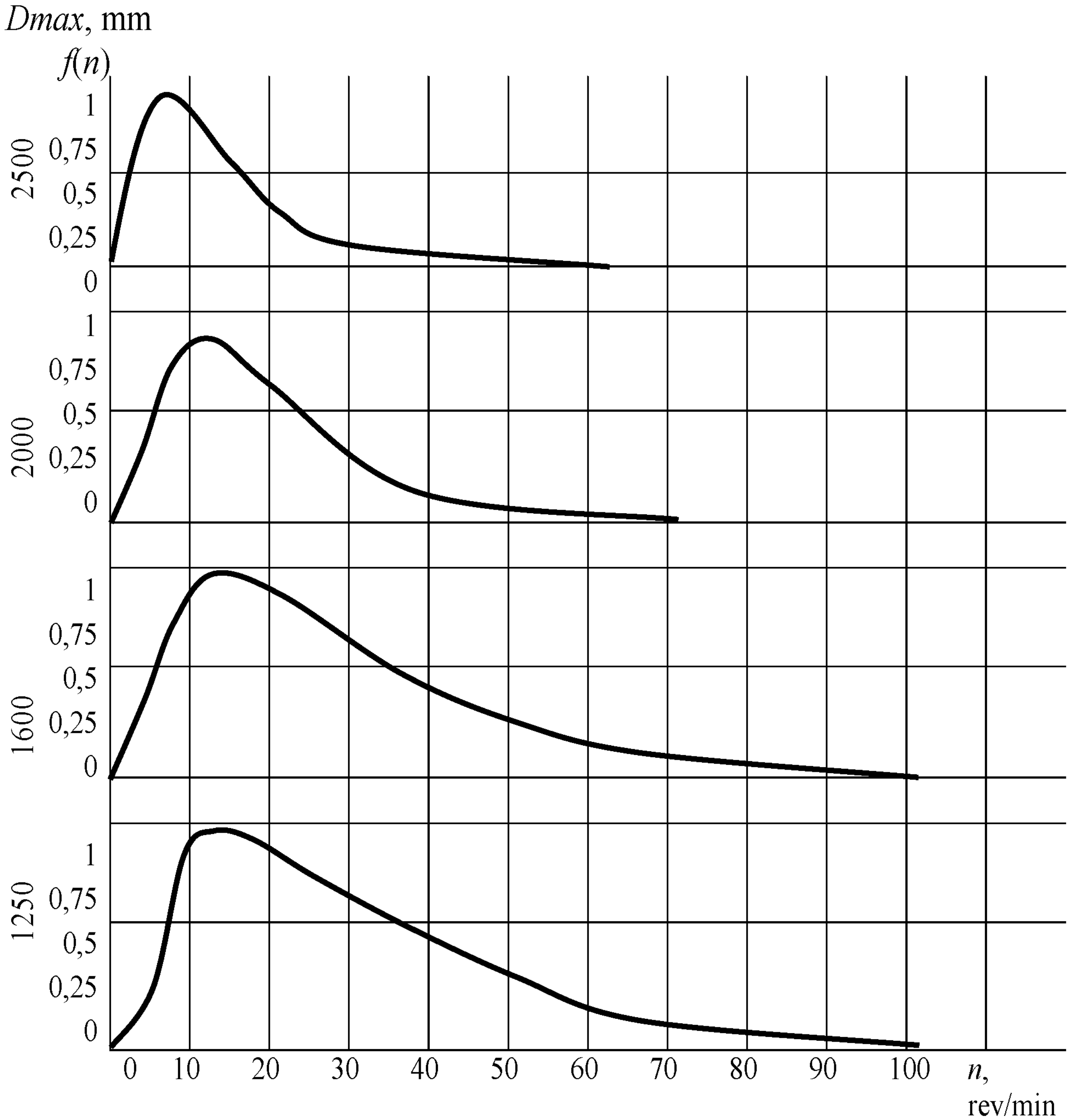


Fig. 3. Spindle speed distribution f (n) used on heavy lathes

As the load on the tool increases, the coefficient of variation of the tool life increases, which leads to an expansion of the range of its scattering. Along with the average tool life, one of the most important indicators of reliability is the tool life with a given probability *T* (*P*) or gamma percentage tool life, which is determined depending on the nature of the distribution of the tool life. This reliability indicator is especially important when machining parts on heavy CNC machines.

Research into machining conditions of cutting tools in the processing of parts on heavy machines shows that along with wear process significant place belongs to the destruction of the cutting part in the form of chipping and breakage (Fig. 4–5).

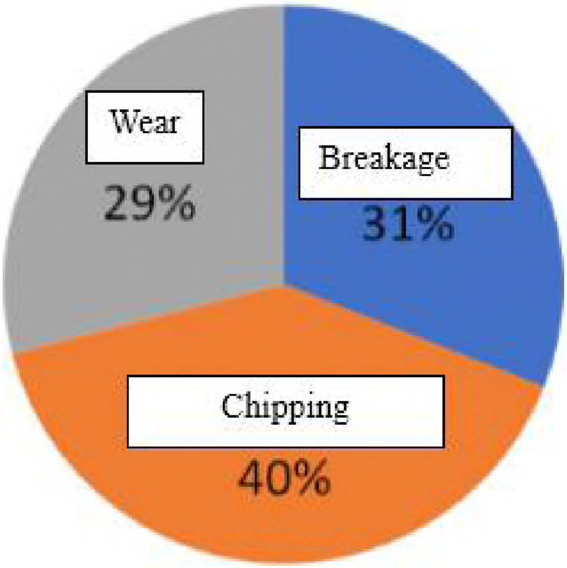


Fig. 4. Distribution of failures of cutting tools when turning parts on heavy machines (in general)

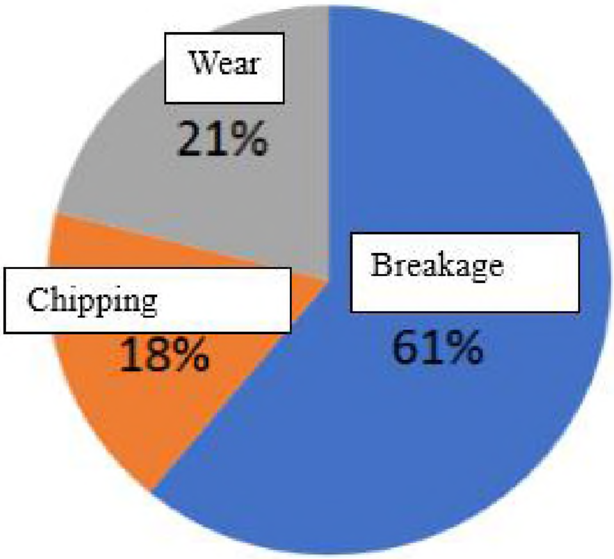


Fig. 5. Distribution of failures of cutting tools during machining on heavy machines (pre – processing)

The analysis of tool failures also revealed the heterogeneity of the degree of degradation of different parts of the indexable inserts of turning inserts and milling tools, inherent for heavy machines (Fig. 6).

Failures, including unforeseen, are due to random fluctuations in the physical and mechanical properties of the material being processed, especially during rough turning in the presence of crusts.

The efficiency of the cutting tool is also affected by the scattering of physical and mechanical properties of the tool material, its defect in the form of agglomerates of carbide grains and pores, which leads to instability of bending strength and hardness of tool cemented carbides.

The destruction of carbide inserts when machining on heavy machines is due to the fact that large values of the undeformed chip thickness cause an increase in the magnitude and distributiob tensile stresses on the front surface of the tool.

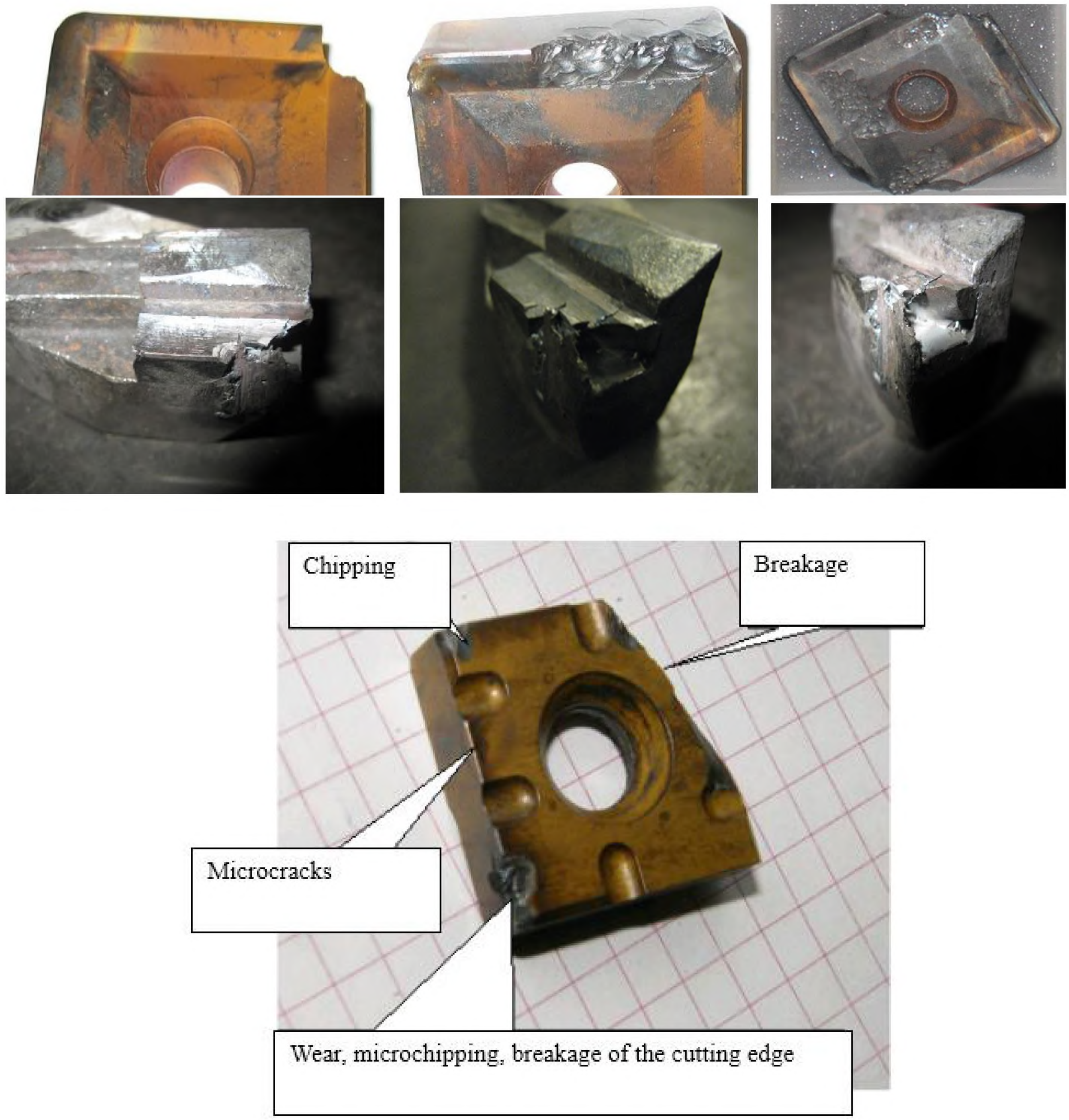
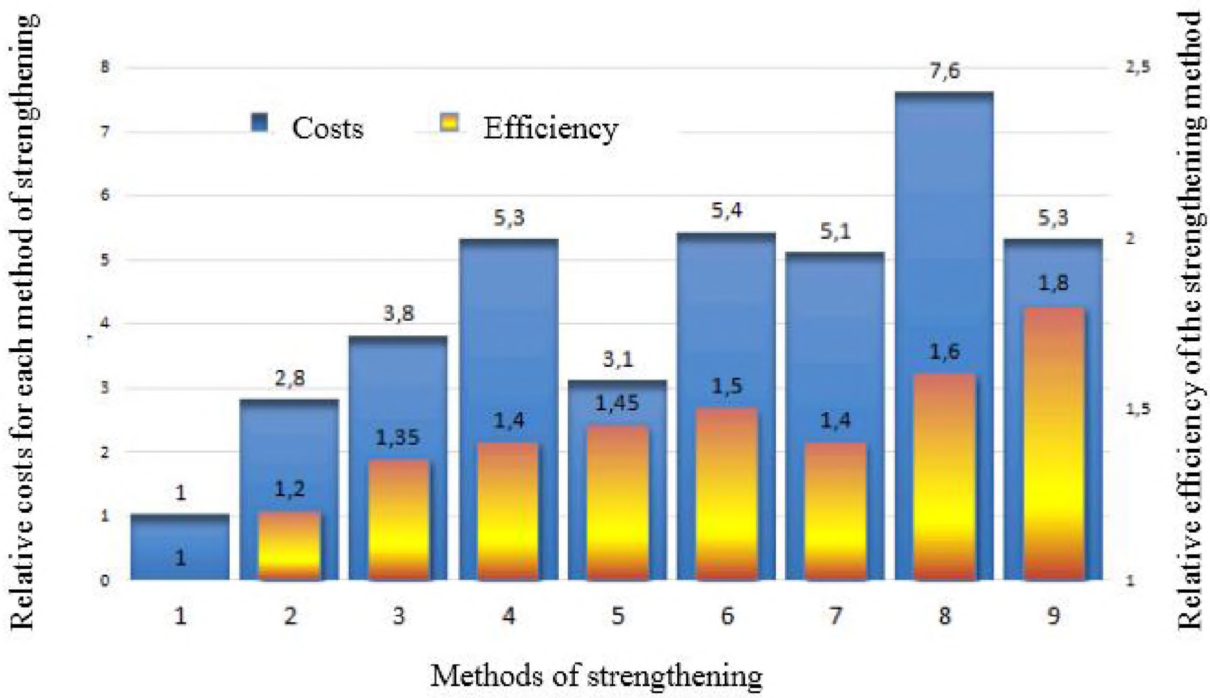


Fig. 6. Types of damage and destruction of indexable inserts

The presence of tool failures significantly affects the efficiency of turning large parts, because there is a need to spend unplanned time and money to restore them.

Therefore, the urgent problem is to optimize the technology of materials and elements for extreme conditions in terms of strength and performance. Thus, the direction in solving the problem of extending the life of tools for heavy engineering is to increase surface and bulk strength and also its hardness. Ways to obtain tool materials with a set of characteristics required in the conditions of processing on heavy machines should be considered surface modification technologies that control the defects and strength of the surface layers of tool materials, as well as volumetric modification of cutting tool material.

As can be seen from Fig. 7, the best combination of cost and production efficiency is observed in the method of pulse magnetic field processing. The high efficiency is due to the volumetric nature of the hardening, as a result of which the increase in stability persists after regrinding. For other post-regrinding methods, reinforcement must be repeated to increase stability.



1 – constructive methods; 2 – strengthening by mechanical blasting; 3 – application of wear-resistant coatings; 4 – pulsed laser processing; 5 – plasma arc hardening; 6 – radiation hardening; 7 – ionic doping; 8 – surface laser hardening; 9 – pulsed magnetic field processing.

Fig. 7. Dependence of costs and production efficiency on methods of strengthening cutting tools from a cemented carbide VK6

Conclusions

A study of the operating conditions of cutting tools when machining parts on heavy machine tools shows that, along with wear, the destruction of the cutting part in the form of staining and fracture is significant. An urgent problem is the optimization of materials and elements technologies for extreme conditions in terms of strength and performance. The directions in solving the problem of extending the service life of tools for heavy engineering are to ensure surface and bulk strength. The ways to obtain tool materials with a set of characteristics necessary for machining on heavy machine tools are surface modification technologies that allow controlling the defectiveness and strength of the surface layers of tool materials, as well as volumetric modification of materials and tools. The analysis of various methods for improving the physical and mechanical properties of carbide tool materials showed that the best combination of cost and production efficiency is observed with the method of pulsed magnetic field treatment. The methodology for determining the rational modes of pulsed magnetic field treatment of hard alloys and the modes of operation of hardened tools require further development.

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