



Simulation of Physical and Mechanical Properties to Increase the Strength of the Cutting Ceramics

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Abstract:

According to studies [1], cutting tools with plates made of cutting ceramics alloyed with carbide-forming elements have higher heat resistance than standard plates made of cutting ceramics in the delivery stage, since their properties do not meet the requirements. Cutting ceramics with the addition of a nickel alloying element to its main standard fraction has a low heat resistance. With the addition of the manganese alloying element, heat resistance and corrosion resistance and wear resistance of cutting tools equipped with cutting ceramics are reduced. The main alloying element is chromium, which, depending on its quantity, indicates increased or high heat resistance in cutting ceramics.

Keywords: Creep, Strength, Resistance, Temperature, Plate, Cutting Ceramics, Hardness, Heat Resistance, Impact Strength, Phase, Intergranular Corrosion, Carbide, Diffusion, Corrosion Resistance, Stabilizing Heat Treatment, Fluidity, Magnetic Permeability, Ductility, Plastic Deformation.

1. Introduction:

The base of the cutting ceramics alloy should contain chromium and nickel or manganese. Their quantity depends on the heat resistance required of the cutting ceramics, the greater the heat resistance, the higher the chromium and nickel or manganese content should be. This is especially indicative of the study of cutting hard-to-machine steel 12H18N10T, where the temperature in the contact zone, depending on the processing conditions, reached 700 ° C. At temperatures above 700 ° C, at low applied stresses when cutting hard-to-machine steels 12H18N10T, 14H17N2 and a very long duration of their action, deformation of a purely diffusion type occurs due to the viscous flow of cutting ceramic plates. Ya. I. Frenkel for the first time pointed to the possibility of this occurrence in crystalline bodies [1]. We tried to consider plastic deformation and destruction of cutting ceramic plates at high cutting temperatures from these positions. The important role of grain boundaries in creep was confirmed experimentally when cutting hard-to-machine steel 12H18N10T with a cutter equipped with WOK-60 cutting ceramic plates with a temperature in the contact zone (blank-tool) $\theta = 700^{\circ}\text{C}$.

2. Methods.

High-temperature plastic deformation can be carried out by two main mechanisms: shear or dislocation and diffusion [2]. In case of dislocation creep, diffusion helps to weaken the action of factors that impede dislocation movement: it facilitates the movement of clouds, coagulation and dissolution of independent phases (precipitates), which in turn facilitates the passage between

particles and the creeping through them; prerequisites are created for the diffusion of dislocations (linear, capable of diffusing).

The resistance of the cutting ceramics to plastic deformation and destruction during cutting of heat-resistant and hard-to-machine steels with high temperatures in the contact zone (blank-tool) is fundamentally determined by the same physical and physicochemical factors, namely, the interatomic bond strength, and the structure of the alloy cutting ceramics, including various structural imperfections, whose influence is often stronger than the interatomic bond [1]. If we proceed from the fact that the time dependence of strength should be quantitatively determined approximately by homologous temperature, then the room temperature is relatively low for cutting ceramics, therefore a noticeable time dependence of strength is observed here only at elevated and high temperatures during cutting (Figure 1). The role of two main factors - the strength of the interatomic bond and the structure of cutting ceramics, which are common for fracture and creep, is reflected in the following kinetic equations

$$\tau_{\text{д.п.зп}} = \tau_o \times e^{\frac{U_o - \gamma \times \sigma}{k \times T}} ; \quad (1)$$

$$V_{\text{п.о.з}} = V_o \times e^{\frac{-U_o - \gamma \times \sigma}{k \times T}} ; \quad (2)$$

Where τ – time to sample failure;

τ_o – oscillation period of an atom in the lattice;

U_o – bond energy (sublimation energy);

σ – stress;

T – absolute temperature;

γ – stress efficiency factor (depending on the structure of cutting ceramics).

The material constants included in these equations show, however, that the features that the high temperature introduces when cutting, especially hard-to-machine steels 12H18N10T, 14H17N2, are of great importance for cutting ceramics, which also will have an effect to a greater degree the longer the performance of cutting ceramic plates.

At high temperatures, diffusion phenomena begin to play an important role in the mechanism of plastic deformation and, consequently, in creep.

The main feature of the effect of high temperature on the long-term strength of cutting ceramics is the dependence of the stress diagram on the time to failure, occurring after a long cut of hard-to-machine steel 12H18N10T. In the study, we proceeded from the probability that generally reducing the strength of cutting ceramic plates with an increase in the duration of the load when cutting hard-to-machine steel 12H18N10T, is a pattern inherent in all materials at normal temperature, and the temperature increase in the treatment area makes it only more pronounced [3].

In our opinion, very important additional and sometimes decisive reasons for the initiation and development of cracks in cutting ceramics can be processes occurring at working temperature and leading to the formation of phases at the grain boundaries that lower the resistance to separation. If the separated phase is located inside the grain along the shear planes, as was observed when cutting a hard-to-machine steel 12H18N10T with a cutter with cutting plates from cutting ceramics, WOK-60, then it also facilitates transcrystalline destruction.

An important feature introduced by the high working temperature of cutting is that the pursuit of cutting ceramics to achieve thermodynamic equilibrium can be realized, which in some cases leads to a decrease in its creep resistance and destruction.

These important features of the influence of high working temperature when cutting with a hard-to-machine steel 12H18N10T cutter equipped with cutting plates from the WOK-60 ceramics determine the features of doping and thermochemical treatment of the surface layer and the structure of the plates from cutting ceramics. Studies have found that in cutting ceramics containing an increased amount of nitrogen, carbonitride phases are emitted during heating while cutting hard-to-machine steels 12H18N10T, 14H17N2 with a temperature above 550 °C, which leads to additional strengthening of the fragility of the cutting ceramics.

It should be noted that in combination with other elements in the cutting ceramics, the role of nickel may be enhanced. In addition, the feasibility of increasing the nickel content of more than 2% may be due to its effect on other properties of cutting ceramics. This question requires further study. The amount of nickel required to obtain a new structural fraction of cutting ceramics depends on the chromium content and additional alloying elements introduced into it in order to increase heat strength or heat resistance. Chromium with a content of up to 5% in combination with nickel, in contrast to its usual ferritizing effect, strongly contributes to obtaining austenitic new structural fraction of cutting ceramics. This, according to our assumptions, is the result of a complex interatomic interaction, the possible character of which was described in [2].

With a higher content of chromium prevents the austenitic structure.

The possibility of replacing part of the alloying element in nickel cutting ceramics with nitrogen was also established in a number of studies conducted by us and confirmed by experimental data.

$$\frac{Cr - 1,5C}{Ni} \leq 1,75 \quad (3)$$

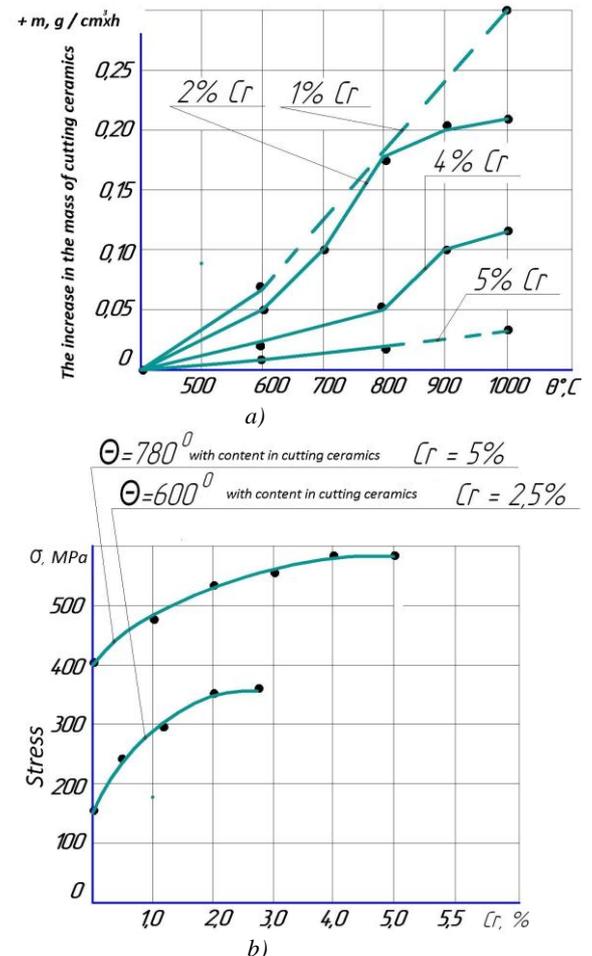


Figure 1. Dependencies of the increase in the conditional creep limit: a) on temperature 600 ... 780 °C and content in the cutting ceramics of alloying elements 5% Cr and 2% Ni; b) the effect of chromium on the creep of cutting ceramics

Research has established that the plasticity of cutting ceramics is reduced by nitrogen no more than carbon, which contains 0.2–0.25% nitrogen, when turning hard-to-machine steels 12H18N10T, 14H17N2 [3]. Therefore, in some cases, in cutting ceramics it is necessary to introduce about 0.15% N. With a low carbon content in the cutting ceramics, its effect is equivalent to nitrogen and the change in one or another property of the cutting ceramics should be considered depending on the total amount of both elements.

The amount of carbides in cutting ceramics affects intergranular corrosion, primarily due to the size of the grain. With the enlargement of grain, the amount of carbides per unit of its surface increases. However, the matter is not only in their average relative amount. It was shown in [1] that with fine grains, carbides form an intermittent contour around the grains, which obviously makes penetration of intercrystalline corrosion more difficult. In cutting ceramics with coarse grains, carbides are arranged at the boundaries of a more dense chain. From our assumption it follows that the role of the chemical composition of cutting ceramics with the same composition of the carbide phase has an equilibrium potential that the solid solution. Cutting ceramics not prone to intergranular corrosion has a lower overall corrosion resistance of the solid solution containing 5% Cr. This also explains the lower sensitivity to intergranular corrosion with the introduction of 5% Cr into the basic structure of cutting ceramics; 2% Mg 2% Ni compared with cutting ceramics containing 5% Cr; 2% Ni (Figure 2).

It must be said that the catalytic electrochemical action of certain phases should lead to a simultaneous decrease in the resistance of

plates from cutting ceramics against both general and intergranular corrosion.

The positive influence of the two-phase structure $\gamma + a$ on the resistance of cutting ceramics against intergranular corrosion, in our opinion, is associated with a much higher diffusion rate in the a - phase compared with the γ phase. As a result, carbides coagulate more easily into cutting ceramics with the $\gamma + a$ structure and a smaller number of them turns out to be at the grain boundaries.

A significant decrease in the tendency to intergranular corrosion is a short-term annealing of cutting ceramics with an exposure time of 10 ... 12 min at a temperature $\theta = 1650^\circ\text{C}$, which reduces the overall corrosion resistance, which may be explained by an increase in the density of dislocations [1].

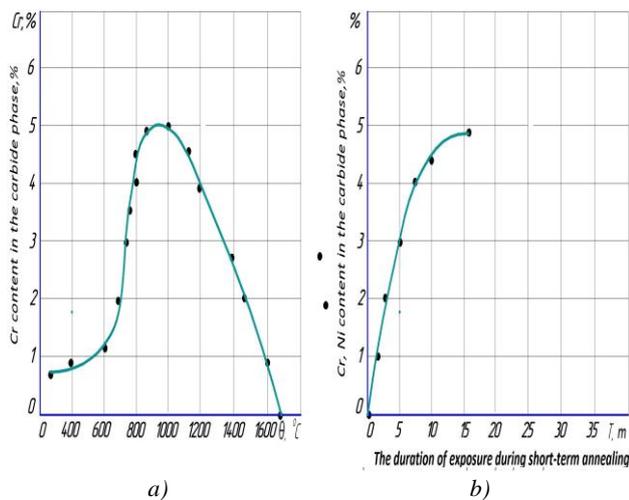


Figure 2: Dependencies of the effect of heating temperature on the content of carbide-forming elements in cutting ceramics: a) - Cr content in the carbide phase of cutting ceramics; b) - the content of Cr and Ni in the carbide phase of cutting ceramics

In addition, when the plates are heated to a temperature of 650°C , after short-term annealing, subgrains (blocks) appear in the cutting ceramics, along whose boundaries carbides will be released (at dislocations). This may be even stronger than the grinding of grain. Short-term annealing of cutting ceramics also contributes to the production of the a - phase and facilitates the coagulation of carbides in the latter, enhancing the positive effect of the two-phase structure.

From the stated point of view, it is obvious that intergranular corrosion can cause the presence of other phases at the grain boundaries, and not just carbides. For example, sulfides released at the grain boundaries may cause intergranular corrosion of cutting ceramic plates. Theoretical studies suggest that chromium and molybdenum nitrides, in contact with the ground mass in plates made of cutting ceramics, have low corrosion resistance. Thus, it was shown in [2], that nitriding of the surface layer of the WOK-60 cutting ceramic plates leads to a sharp decrease in its corrosion resistance.

When analyzing the possible cause of intergranular corrosion in plates made of cutting ceramics, in our opinion, it is necessary to take into account the fact that in order to correct them it is sufficient to apply their short-term annealing with an exposure of 10 ... 12 minutes. Although this may testify in favor of the theory of stress, however, we believe that stress cannot be the only or even the main cause of intergranular corrosion in cutting ceramic plates for the same reasons as in austenitic steels. Additional stresses caused by the rapid cooling of the cutting ceramic plates also cannot be responsible for intergranular corrosion.

If stainless steel, along with corrosion resistance, requires high strength or hardness, it should be susceptible to quenching in martensite [1]. In the modified cutting ceramics, WOK-60M,

which contains $\text{Al}_2\text{O}_3 \leq 40\%$, $\text{TiC} \geq 40\%$, $\text{Cr} \leq 2\%$, $\text{Ni} \geq 5\%$, $\text{Mo} \geq 3\%$, the limiting concentration of chromium can be increased by reducing the content of carbon in the alloy. Therefore, the mechanical properties of the WOK-60M cutting ceramics and the possibility of their regulation due to heat treatment are determined to a decisive degree by their carbon content.

Modified WOK-60M cutting ceramics containing 5% Cr and possessing very high corrosion resistance remain ferritic even with significant carbon content. Therefore, the introduction into its structure of an increased amount of carbon to increase the strength does not reach the desired goal. The hardness of the WOK 60M cutting ceramics with a content of 5% Cr with an increase in the amount of carbides in the ferritic base mass increases to $\sim 97 \dots 98$ HRA. During heat treatment of cutting ceramics with a content of 2% Cr with high temperatures, it fixes only up to 10% C in a solid solution. However, the release of carbides during subsequent tempering here either leads to a noticeable decrease in hardness [2, 50] or to an insignificant, at $\theta = 600 \dots 760^\circ\text{C}$.

Therefore, modified WOK-60M cutting ceramics plates containing 2% Cr are recommended for equipping the cutting tool when machining hard-to-machine steel 12H18N10T, 14H17N2, which requires high resistance to highly oxidizing media or high heat resistance. Modified cutting ceramics with a content of up to 2% Cr with a content of up to 20% C carbon still have quite satisfactory chemical resistance. However, it is necessary to reckon with their low toughness and ductility.

Low ductility and especially toughness, as well as increased brittleness due to coarse grain, is the main drawback of the modified WOK-60M cutting ceramics. They are also prone, at a temperature of 500°C , to increased brittleness. For WOK-60M cutting ceramics with a 5% Cr content, low toughness can be partly related to the $c \sigma$ phase [2]. It was shown [1] that the toughness of cutting ceramics is significantly increased during heat treatment in vacuum in a muffle furnace.

Results. Research has shown that the weakening of intergranular corrosion after short-term corrective annealing is accompanied by increased corrosion of the grain, and longer heating promises almost full stability to the cutting ceramics. Obviously, for plates made of cutting ceramics, in which the rate of diffusion processes is much higher than in austenitic steel, such heating is sufficient so that the composition of the precipitated phases becomes close to equilibrium. It must be said that the boundary layer of the grain (intergranular layer) in the cutting ceramics of WOK-60M, having an increased free energy, can be enriched, in particular, with chromium compared to the grain. For this reason, the formation of a new phase, including carbides, during the decomposition of the solid solution is facilitated in it [1]. Thus, the depletion of chromium in the release of carbides can play a significant role in the grain, especially when the chromium content in the cutting ceramics of the WOK-60M, close to the first boundary of chemical resistance, and a very small role in the boundary layer of the grain. The study revealed that with an increase in the amount of nickel, the short-term strength of the cutting ceramics increases, and the creep resistance, starting from a certain nickel content, remains almost constant.

Conclusion. The nature of the processes causing and eliminating intergranular corrosion in cutting ceramics is very complex and not yet clear. The theory of intergranular corrosion explains the release of chromium and titanium carbides in the modified plates from the cutting ceramics of the WOK-60M at the grain boundaries, which leads to the impoverishment of these elements of the solid solution around the carbides in the peripheral areas of the grains. The decrease in the amount of chromium and titanium in the solid solution of cutting ceramics to values below the boundary of chemical resistance according to the law of $n/8$ mole causes the destruction of the peripheral layers of grains. The role of titanium and niobium is reduced to the fact that, by bonding

carbon, they prevent the peripheral zones of the grain from being crushed by chromium from the WOK-60M cutting ceramics. Presumably, the cause of intergranular corrosion is the depletion of the peripheral zone of the grain with chromium.

In our assumption about the nature of intergranular corrosion of the modified WOK VOK-60M cutting ceramics, we assume that due to the role of the kinetic factor at relatively low tempering temperatures, metastable carbide should stand out, although this does not lead to a maximum, but only to a relative change in the free energy system. In cutting ceramics such a carbide can be highly titanium-enriched chromium carbide $(Cr, Ti)_{23}C_6$. As the tempering temperature rises, the emitted carbide more and more approaches the stable $Cr_{23}C_6$. A long exposure at the tempering temperature also leads to the establishment of thermodynamic equilibrium, in other words, to a gradual enrichment of the carbide with chromium to a stable composition of $Cr_{23}C_6$, and the time required for this is shorter, the higher the tempering temperature. It is obvious that a change in the composition of the carbide released at the grain boundaries in the WOK-60M cutting ceramics, with a change in tempering temperature and duration of exposure, will also lead to a change in the kinetics of the electrochemical dissolution of the system, which consists of carbide and solid solution in contact with it.

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