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# The influence of tribological characteristics of coated tools on cutting process and the parameters of surface layer

Key words

The parameters of surface layer, coating, turning, tool, optimal cutting speed.

Słowa kluczowe

Parametry warstwy wierzchniej, powłoka, toczenie, narzędzie, prędkość skrawania.

Summary

The influence of wear-resistant coatings having different friction coefficients on a cutting force, chip thickening coefficient, coefficient of chip friction on the face of a tool and temperature in the cutting zone have been researched.

## 1. Introduction

The most important production properties are reliability and endurance. These properties provide product safety and competitiveness. The main cause leading to breakdown of parts is fatigue cracks. Such cracks appear and propagate in thin surface layers of parts. In order to hamper crack growth, the

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surface layer has to exhibit certain features. They are roughness, residual stress, and strain hardening, which depend on the characteristics of the cutting operation.

The cutting force, temperature of cutting, the depth of wear hardening, and the degree of deformation are referring to as the main characteristics of a cutting operation. These characteristics influence on the parts' quality, reliability, and endurance. Technological conditions of cutting, such as tools geometry, processing conditions, work material properties and tooling material properties, including tribological feathers, determine the characteristics of the cutting process. Therefore, there is a need to select optimal cutting conditions to provide the required part quality. In order to select optimal cutting conditions, there is the necessity to have a special method, which takes into consideration the relationship between parts quality and technological conditions.

## 2. Theoretical parts

At the Rybinsk State of Aviation Technology academy named after P.A. Solovjev (Russia) there was developed the method, which permits one to estimate the optimal cutting conditions. On the base of this method, underlay a functional connection between cutting rate, tools geometry and the parameters of surface layer, the accuracy of machining and the rigidity of manufacturing system, including work material and tool material properties.

But all advanced tools have wear-resistant coatings that exhibit specific properties. Wear-resistant coatings have a low friction coefficient in the consequence of weak adhesion interaction between the covering material and the work material. They influence the cutting process and quality parameters of the surface layer. Tools coverings reduce chips contact length with tools surface, cutting force, the temperature of cutting, and the deformation of cut allowance. It is due to the increase of the chip flow angle.

In order to provide high part quality, one should calculate the "optimal cutting speed" $v_O$. Optimal cutting rates ($v_O$, $S_O$) correspond to optimal cutting temperature. It is constant in magnitude for the defined combination work – tool material [1]. When machining with this temperature, maximum tool life, minimal roughness of machined surface *Ra*, and minimal surface defects occur. Therefore, these cutting rates should be used when finishing work is performed for parts, which work in a corrosive medium and high temperature, because the surface layer has to contain minimal defects. For estimating the optimal cutting speed v, the equation is obtained by Silin S.S. [2]:

$$v_O = \frac{C_O \cdot a}{a_1}\left(\frac{a_1 \cdot b_1 \cdot c\rho \cdot \Theta}{Pz_{\min}}\right)^n \tag{1}$$

where $a_1$, $b_1$ – is the thickness and the width of cut respectively [m]; $a$ – is the coefficient of the temperature conductivity of the work material [$m^2/s$]; cρ – is the specific heat capacity per unit volume [$J/(m^3 \cdot s \cdot degree)$]; Θ – is the temperature in the cutting area, °C; $n$, $C_o$ – are coefficients, which depend on the properties of work material; $Pz_{min}$ – is a minimal stabilised cutting force [N].

The series of experiments were performed in this work to reach the following purposes:

1. To investigate the influence of tribological characteristics of coated tools on cutting process and the parameters of surface layer; and,
2. To define optimal cutting speed for tools with different coatings.

## 3. Experimental conditions

The wide range of cutting rates, different work materials and coated tools were selected for performing experiments (Table 1).

In the capacity of tools, replaceable inserts 120412, material – VK6R (chemical composition: Co – 6%, basis – WC) and TT7K12 (chemical composition: Co – 12%, Ti – 1%, Ta – 1%, basis – WC) were used. The different composite nanolaminated ion-plasmous coatings were deposited on the replaceable inserts: (Ti;Si)N, (Ti,Si,Zr)CN and (Ti;Si;Al)N. The other group replaceable inserts was modified by implanting of nanoparticle $TiB_2$, $Al_2O_3$, $Ta_2O_3$ and $ZrB_2$ in the work surface of tools. All selected coatings have been characterised by the minimal adhesive of the tool surfaces with the work material, and they also have been provided maximum tool life [3].

Table 1. Experimental conditions

| Changing parameters | | Work material | | | | |
|---|---|---|---|---|---|---|
| | | Heat-resistant alloy (CrNi77TiAlW) EI437 | | Stainless steel (05Cr12Ni2Co3Mo2WV) EK26 | | Titanium alloy OT4 |
| Tools geometry | Cutting angle, γ° | 5 | | 8 | | 0 |
| | Relief angle, α° | 10 | | 12 | | 10 |
| | Lead angle, φ, $φ_1$° | 45 | | | | |
| | Nose radius, $r$, [mm] | 1,2 | | | | |
| Cutting rate | Deph $t$ [mm] | 0.25; 0.5; 0.75; 1 | | | | |
| | Feed $S$ [mm/rev] | 0.07; 0.14; 0.2; 0.32 | | | | |
| | Speed $v$ [m/min] | 14-170 | | 33-190 | | 15-130 |
| Tool material | | VK6R | TT7K12 | VK6R | TT7K12 | VK6R |
| Coating | | (Ti,Si)N | $Ta_2O_3$ | (Ti,Si)N | $Ta_2O_3$ | (Ti,Si)N |
| | | (Ti,Si,Al)N | $ZrB_2$ | (Ti,Si,Al) N | $ZrB_2$ | (Ti,Si,Zr)CN |
| | | $TiB_2$ | | $TiB_2$ | | $ZrB_2$ |
| | | $Al_2O_3$ | | $Al_2O_3$ | | $Al_2O_3$ |

The regular engine lathe NH 22 performed the machining. The cutting forces were measured using a universal tool dynamometer UDM – 600, which was connected with a analogue-digital converter and personal computer. The temperature was measured by means of a dynamic thermocouple of work material – tooling material.

## 4. Results and discussion

Figure 1 shows the friction coefficient, which was determined for different combinations of work materials – coated tools. As clearly shown, the uncoated tools' friction coefficient is larger then ones of coated tools. The main reason is that the tool coating decreases the adhesive interaction with a work material.

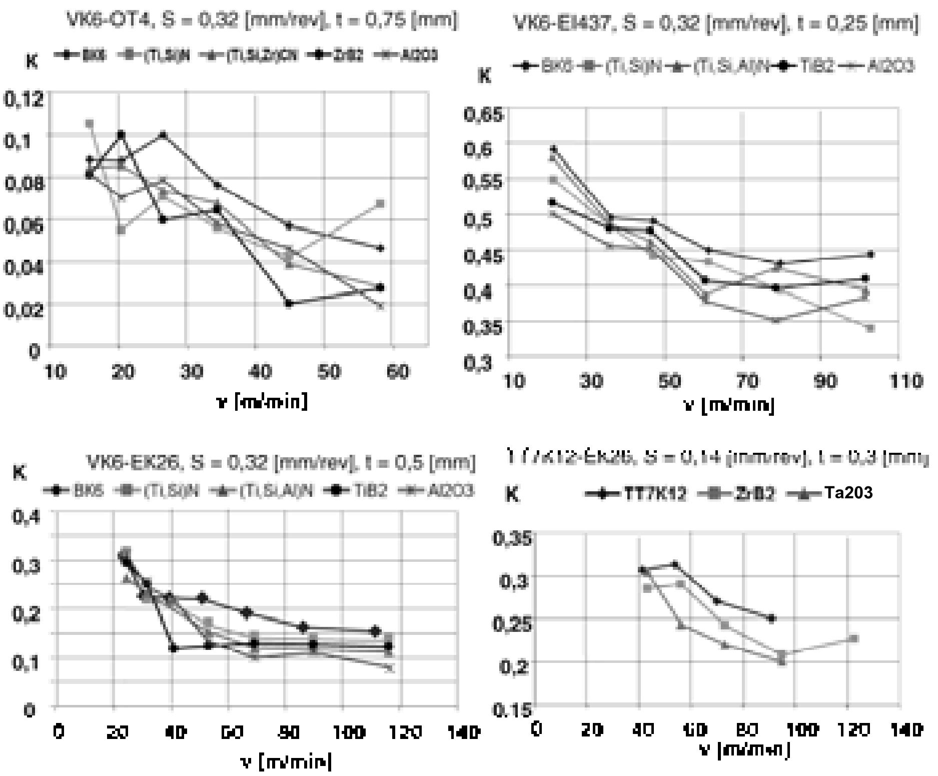


Fig. 1. Friction coefficient K against cutting speed *v* (symbols in table 1)

In order to adjust the estimate the influence of coated tools on the parameters of surface layer, one has to determine the influence of coated tools on criterion *B*. This criterion is one of the major parameters, which used for estimating of roughness, residual stress, and strain hardening in the part's surface layer.

$B = tg\beta_1$ – Is the quantity, which defines the degree of machining allowance for plastic deformation and the deformation of the part's surface layer, $\beta_1$ – is an angle of shear plane.

The quantity $\beta_1$ was estimated by means of Tim's I. A. formula using a chip reduction coefficient $k_a$. It was determined experimentally [2].

$$k_a = \frac{\cos(\beta_1 - \gamma)}{\sin\beta_1},$$

where γ – is a cutting angle.

Figure 2 shows the dependence of criterion *B* on technological conditions of operation.

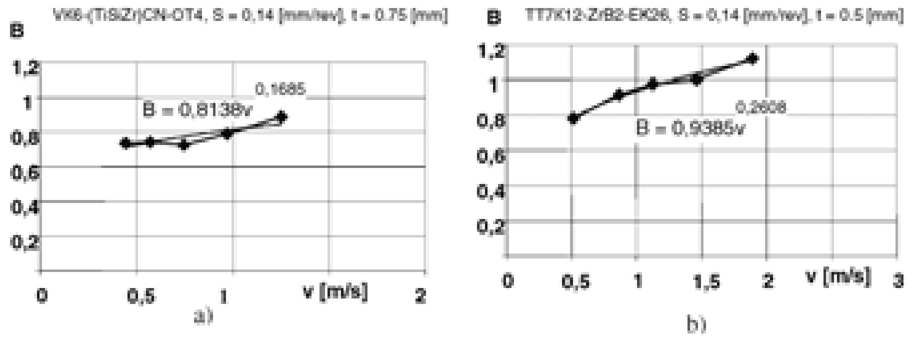


Fig. 2. Comparison the criterion B and technological conditions of operation: a) Work material – the titanium alloy OT4, tool – VK6R, coating – (Ti,Si,Zr)CN; b) Work material – the stainless steel EK26, tool – TT7K12, coating – $ZrB_2$

It is clearly shown that during increasing cutting speed *v* the criterion B increases too. It is the reason for increasing of an angle of shear plane $\beta_1$. The angle of shear plane $\beta_1$ increases, because the materials ultimate stress $\sigma_B$ is reduced by reason of the increasing of rate of deformation and temperature in the cutting area.

The criterion B dependence on criterion Pe in the form of equation $B = C_1 \cdot Pe^{n_1}$ has been performed. The example of equation is illustrated by Figure 3.

In order to estimate optimal cutting speed $v_O$ the dependencies of cutting force and temperature on cutting rate have been performed. Figure 4 shows that the optimal cutting temperature is $\theta_{OPT}$ = 840°C.

$$Pe = \frac{v \cdot a_1}{a}$$

Criterion Pe defines the degree of influence of the cutting rate $v \cdot a_1$ as compared with the coefficient of the temperature conductivity of the work material $a$.

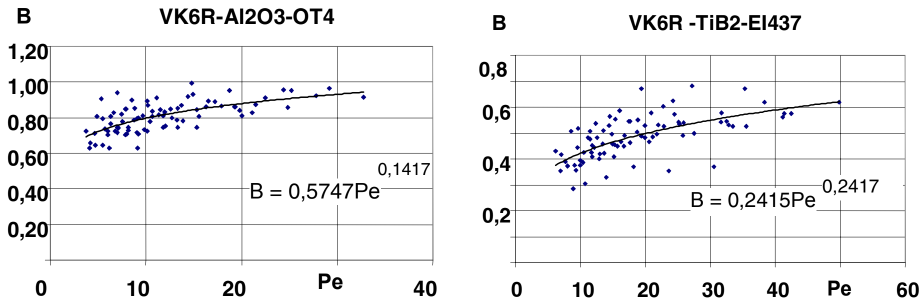


Fig. 3. Comparison the criterion B and Criterion Pe

Thus, using the equation in the form of $B = C_1 \cdot Pe^{n_1}$, one can estimate criterion B in a wide-range of cutting rate and tool shape.

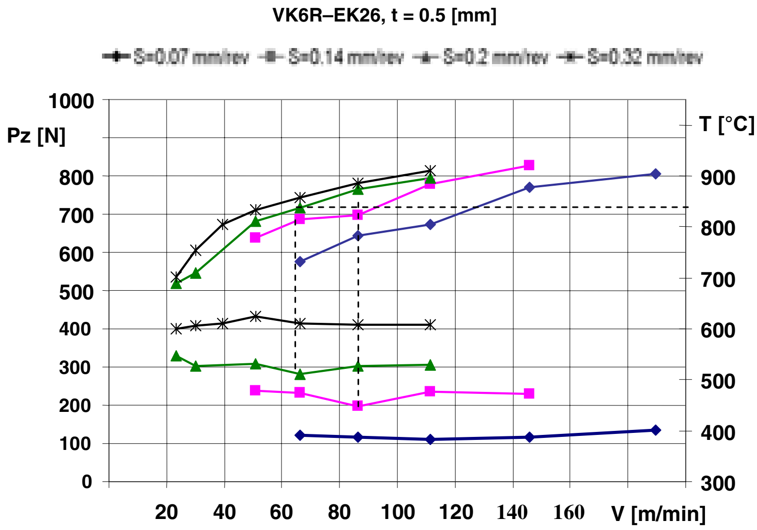


Fig. 4. Comparison the cutting force *Pz* and temperature of cutting *T* against cutting speed *v* and feet *S*, work material – stainless steel EK26, tool – VK6R

The criterion A dependence on criterion Pe in the form of equation $Pe = C_O \cdot A^n$ has been performed. The magnitude of coefficients $C_O$ and $n$ for some combination work material – coated tool are in Table 2.

$$A = \frac{S \cdot t \cdot c\rho \cdot \Theta}{Pz}$$

*A* – energy criterion, which defines the relationship of chip quantity of heat with general quantity of heat.

Table 2. Magnitude of coefficients $C_O$ and $n$

| Material | VK6R–EK26 | VK6R–EK26–(Ti,Si)N | VK6R–EK26–$Al_2O_3$ |
|---|---|---|---|
| Equation | $Pe = 13.16 \cdot A^{2.47}$ | $Pe = 13.6 \cdot A^{2.48}$ | $Pe = 13.53 \cdot A^{2.53}$ |

The examples of power dependencies for estimating of minimal cutting force *Pz*, which depend on cutting rate *t* and *S*, have been given in Table 3.

Table 3. Power dependence $Pz_{\min} = c_{Pz} \cdot t^{x_0} \cdot S^{x}$

| Material | VK6R–EK26 | VK6R–EK26–(Ti,Si)N | VK6R–EK26–$Al_2O_3$ |
|---|---|---|---|
| Equation | $Pz = 1700 \cdot t^{0.77} \cdot S^{\frac{0.72}{t^{0.083}}}$ | $Pz = 1598 \cdot t^{0.685} \cdot S^{\frac{0.7663}{t^{0.106}}}$ | $Pz = 1269 \cdot t^{0.737} \cdot S^{\frac{0.695}{t^{0.044}}}$ |

Thus, on the base of obtained power dependencies, one can make a equation of machinability to estimate of optimal cutting speed $v_O$ for different combination work material – coated tools. The equations of machinability for considered examples are given in Table 4.

Table 4. The equations of machinability

| Materials | VK6R–EK26 | VK6R–EK26–(Ti,Si)N | VK6R–EK26–$Al_2O_3$ |
|---|---|---|---|
| Cutting rate | t = 0.5 [mm]; S = 0.32 [mm/rev] | | |
| Equation | $v_O = \frac{2{,}31 \cdot a}{a_1}\left(\frac{a_1 \cdot b_1 \cdot c\rho}{t^{0{,}77} \cdot S^{\frac{0{,}72}{t^{0{,}083}}}}\right)$ | $v_O = \frac{2{,}76 \cdot a}{a_1}\left(\frac{a_1 \cdot b_1 \cdot c\rho}{t^{0{,}68} \cdot S^{\frac{0{,}766}{t^{0{,}106}}}}\right)^{2{,}4}$ | $v_O = \frac{4{,}76 \cdot a}{a_1}\left(\frac{a_1 \cdot b_1 \cdot c\rho}{t^{0{,}737} \cdot S^{\frac{0{,}695}{t^{0{,}044}}}}\right)^{2{,}5}$ |
| Friction coefficient **K** (fig. 1) $v$=80[m/min] | 0.17 | 0.14 | 0.1 |
| $v_O$ [m/min] | 66.5 | 82.8 | 119.2 |

## 5. Conclusion

The optimal cutting speed of coated tool exceeds the optimal cutting speed of the uncoated tool. Therefore, the lower the coating friction coefficient, the higher the optimal cutting speed.

## References

[1] Makarov A. D. The optimization of cutting operation. Moscow. 1976 p. 278
[2] Silin S. S. Similitude method of cutting. Moscow. 1979 p. 152
[3] Bruhov V. V. The increasing of tools lifetime after ion-implanting. Tomsk. 2003 p. 120

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**Wpływ charakterystyk tribologicznych narzędzi z powłokami na proces skrawania i własności warstwy wierzchniej**

S t r e s z c z e n i e

Przedstsawiono wyniki badań wpływu powłok przeciwzużyciowych, wykazujących zróżnicowane współczynniki tarcia na siłę skrawania, tarcie wióra na powierzchni narzędzia skrawajacego oraz temperaturę w strefie obróbki.