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INVESTIGATION OF CONTACT STRESSES AND THEIR INFLUENCE ON THE PHYSICS OF CUTTING OF 45 STEEL BY CUTTING TOOLS OF HIGH-SPEED ALLOYS

A. I. Sagradyan

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The influence of shear stresses on the physical processes proceeding on the surface of contact of a cutting tool with a chip removed has been investigated. The mechanisms of appearance of contact layers and the dependence of the lengths of the elastic and plastic parts of these layers on the normal and shear stresses in the contact zone have been considered. It was established that a natural "white" layer formed in the process of cutting plays a protective role and, as a consequence, decreases the rate of wear of the tool.

The physical effects in a contact zone were investigated in [1–4]. It is known that the properties of materials subjected to high-rate deformations differ from the properties of materials tested under static conditions. In [1–3], it was shown that the contact zone formed in the process of cutting is divided into two parts, one of which is elastic and the other of which is plastic (Fig. 1). It was also established that the lower contact chip layers move with zero velocities along the frontal surface of a tool in the plastic-contact region. In the elastic-contact region ($0 < x < (C - C_1)$), the shear stress τ_F change in proportion to the normal stress:

$$\tau_F = \mu_F \sigma_N \,,$$

where

$$\sigma_N = \sigma_M (x/C)^n \,; \quad \sigma_M = \frac{N}{bC} \left\{ \frac{rC}{a\xi \, [\mu + \tan (\beta - \gamma)]} + 1 \right\} ; \quad N = 1580 \ \text{H} \,.$$

The stress σ_M was calculated for $r = C = 2$ mm. The quantity C was determined experimentally with an MMI-2 instrumental microscope. For the regime of cutting where $V = 65$ m/min, $S = 0.30$ mm/rot, $t = 2.0$ mm, $\beta = 30^{\circ}$, $\gamma = 10^{\circ}$, $a = 21$ mm, and $b = 2.83$ mm, we obtained $\xi = 2.95$ and $\mu = 0.8$. Consequently, $\sigma_M = 1828$ MPa.

The coefficient n was determined from the expression [1]

$$n = 2 \left\{ \frac{C}{a\xi \, [\mu + \tan (\beta - \gamma)]} - 1 \right\}$$

and was equal to $n = 3.54$ for the conditions of our experiments. By using the values of σ_M and n we can construct a diagram of distribution of normal contact stresses over the frontal surface of a cutting tool.

The normal and tangential forces in the contact zone were determined from the relation [2]

$$N = \frac{P_z}{\cos \omega} \cos (\omega + \gamma) = 1580 \ \text{H} \,,$$

$$F = \frac{P_z}{\cos \omega} (\sin \omega + \gamma) = 1328 \ \text{H} \,, \quad \mu = F/N = 0.8 \,.$$

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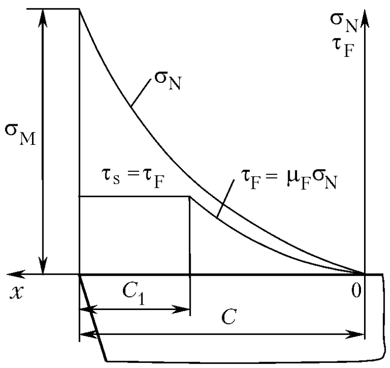

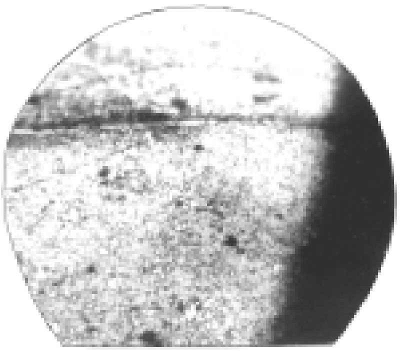

Fig. 1. Change in the contact stresses on the frontal surface of a cutting tool [1].

Fig. 2. Configuration of the "stagnant" and "white" layers across the width of a contact depending on the shear stresses.

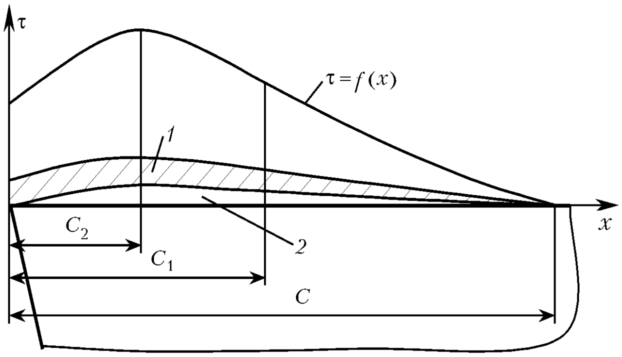

Fig. 3. Dependence of the thickness of the "stagnant" (1) and "white" (2) layers on the shear stresses and the width of the contact.

The width of the plastic contact on the frontal surface was calculated by the formula $C_1 = a[\xi(1 - \tan\gamma) + \sec\gamma]$ in accordance with [1]. We determined experimentally that $C_1 = 0.75$ mm, and it was suggested in [1] that C_1 can be equal to half the contact-width C.

Metallographic analysis (Fig. 2) reinforced the statement [3] that the plastic-contact region is divided into two parts (Fig. 3) — a region of deformation hardening (C_2) and a region of temperature softening ($C_1 - C_2$). In this case, $C_2 \approx C_1/2 = 0.375$ mm and the length of the elastic contact $C - C_1 = 1.25$ mm.

The experimental data obtained show that the coefficient of friction on the frontal control surface can be defined as

$$\mu = \mu_p + \mu_e, \quad \mu_p = \mu_1 + \mu_2, \tag{1}$$

and the coefficient of friction along the length of the contact is defined as

$$\mu = \left(\frac{\tau_{F1}}{\sigma_N} + \frac{\tau_{F2}}{\sigma_N}\right) + \frac{\tau_{Fe}}{\sigma_N}. \tag{2}$$

Formulas (1) and (2) were verified experimentally (Figs. 2–4). It follows from them that, in the case of treatment of plastic steels in corresponding regimes, the shear stresses in the plastic-contact region change, unlike the model used in [1], by the parabolic law: they increase from the beginning of a cutting-tool edge to the end of the deformation-hardening region and somewhat decrease in the temperature-softening region. These stresses in the elastic-contact region change by the hyperbolic law (Fig. 3) and correlate with the distribution of normal stresses (Fig. 1).

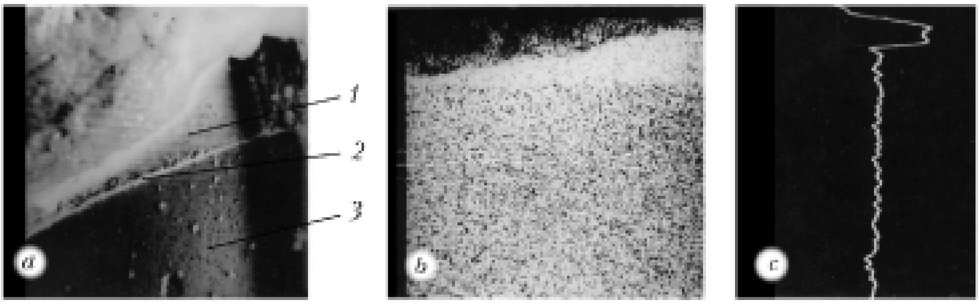

Fig. 4. Scanned region of a V14M7K25 cutting tool in the region of its elastic contact with a 45 steel: a) topography of a microsection metallographic specimen [1) "stagnant" layer, 2) "white" layer, 3) cutting tool)]; b) scanning over the area of a microsection metallographic specimen, distribution of Fe_{α}; c) linear distribution of Fe_{α} ×600.

The distribution of normal stresses along the length of the contact on the frontal surface of a cutting tool also changes by the hyperbolic law. It was assumed [1] that the shear stresses in the plastic-contact region are constant, i.e., $\tau_F = \tau_s$ (Fig. 1).

Our experiments supported the fact that the plastic-contact zone is divided into two parts, whose kinematic and deformation states are different. It has been established that the shear stresses in the plastic-contact region depend on the summary effect of two "competing" processes (Figs. 2 and 3). Metallographic analysis and x-ray microspectral probing (Figs. 2 and 4) have shown that, in the case where a 45 steel is turned by a V14M7K25 cutting tool, a "stagnant" layer and an intercontact "white" layer arise in the region of contact of the tool with the frontal surface. The thickness of these layers changes from the edge of the cutting tool to the end of the contact (plastic or elastic regions) in accordance with the change in the extremum shear stresses, i.e., the configuration of both the "stagnant" and "white" layers and their distribution over the width of the contact change with change in the shear stresses. Models in which the shear stresses in the plastic-contact region are assumed to be constant [1] can be used for engineering calculations; however, the model proposed (Fig. 3) should be used when it is necessary to determine physical effects occurring on the contact surface of a cutting tool. The white layer is a heat insulator that protects the tool from the heat released in the friction zone, decreases the adhesion, diffusion, and abrasivity effects, and serves as a natural protective coating.

NOTATION

a and b, thickness and width of the chip shear, mm; C, width of the contact of a chip with the frontal surface of a cutting tool, mm; C_1, width of a plastic contact, mm; C_2, width of the contact in the region of deformational hardening, mm; F, tangential force, N; n, degree of inhomogeneity of the σ_N distribution; N, normal force, N; P_z, force of cutting, N; r, distance from the origin of coordinates to a moving point, mm; S, feed of cutting, mm/rot; t, depth of cutting, mm; V, velocity of cutting, m/min; x, distance from the considered point on the frontal surface to the point of separation of a chip, mm; β, angle of shear, deg; γ, leading angle of a cutting tool, deg; μ, coefficient of friction for the frontal contact surface; μ_1, coefficient of friction in the temperature-softening region (region $C_1 - C_2$); μ_2, coefficient of friction in the deformation-hardening region (region C_2); μ_e, coefficient of friction in the elastic-contact region $C - C_1$; μ_F, coefficient of external friction between a chip and the frontal surface of a cutting tool; μ_p, coefficient of friction under the plastic-deformation conditions in the plastic-contact zone; ξ, coefficient of chip shrinkage; σ_M, normal contact stress near the cutting edge, MPa; σ_N, normal stress along the width of a contact, MPa; τ, shear stress along the width of a contact, MPa; τ_F, shear stress in the region of a contact, MPa; τ_{F1}, shear stress in the temperature-softening region (region $C_1 - C_2$), MPa; τ_{F2}, shear stress in the deformation-hardening region (region C_2), MPa; τ_{Fe}, shear stress in the elastic-contact region $C - C_1$, MPa; τ_s, shear stress, MPa; ω, angle of action, deg. Subscripts: e, elastic; p, plastic; s, shear; α, wavelength of radiation used for determining the amount of iron.

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