CHARACTERISTICS OF THE FAILURE OF TOOL MATERIALS*

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Tool materials for metal cutting tools, with hardness exceeding 62 HRC as a rule, are destroyed, in distinction to most structural steels and alloys, by brittle failure without any noticeable macroscopic deformation. The article examines the characteristics of such failure.

It is known that failure of brittle metallic materials proceeds in two stages: I) nucleation and growth of a crack with length \( l \) to the critical length \( l_{cr} \); II) uncontrolled propagation of the crack with length \( > l_{cr} \) up to complete destruction. The first stage occurs as a result of the increase of the acting stress, the second stage entails its spontaneous decrease. In this case the propagation of the crack with \( l_{cr} \) occurs on account of expenditure of elastic energy stored by the material at the first stage of failure.

In ideally brittle materials dealt with by Griffiths failure at both stages proceeds without plastic deformation. In ductile structural steels and alloys both stages entail noticeable plastic deformation. In hard tool materials with modest fracture toughness \( K_{lc} < 78 \text{ N/mm}^3/2 \) (25 MPa m\(1/2\)) the crack at the first stage develops by the plastic dislocation mechanism, i.e., by shear, whereas at the second stage failure is due to brittle spalling, i.e., detachment [1] (Fig. 1). This process of destruction of high speed steels, hard alloys, and cermets was pointed out in several publications [2-5]. However, experimental proof of these characteristics of destruction of superhard synthetic materials (diamond, boron nitride) has not yet been found.

The pattern of two-stage destruction of tool materials can be represented in the following way, with the experimental results of many investigations taken into account. In the vicinity of point \( O' \), which lies on the path of the crack (Fig. 2), the plastic mechanism of failure changes to the brittle mechanism. The more the crack with length \( l < l_{cr} \) approaches point \( O' \), the greater is the stress \( \sigma_v \) in front of the crack tip, and at any point of the line segment \( OO' \) it is the greater, the closer the tip \( O \) of the growing crack to this point is (Fig. 2). When the stress at point \( O' \) exceeds the yield point \( \sigma_y \), then the entire material between points \( O \) and \( O' \) is affected by strain-hardening whose degree increases from point \( O' \) to point \( O \). When the crack attains its critical length \( l_{cr} \), \( \sigma_v \) at point \( O' \) increases to its maximal value \( \sigma_y^u \). Directly at the crack tip the stress \( \sigma_v = \sigma_y^u \) is attained, and that brings about brittle crack propagation: \( \sigma_y^u > \sigma_y > \sigma_y \). It should be noted that \( \sigma_y^u \) is larger than the nominal tensile strength \( \sigma_y \) because the concentrated stress \( \sigma_y \) at the tip of the crack with \( l = l_{cr} \) affects the adjacent material. Strain-hardening in the region \( OO' \) brings about a structure with the greatest density of defects, and the generation of dislocation loops by the sources ceases; these loops, when merging, form microcracks within the region \( OO' \). Such a microcrack, propagating in the maximally hardened material by the mechanism of spalling, joins the tip of the primary crack and ensures its start by the mechanism of brittle spalling, too.

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†In these materials \( l_{cr} \) is so small that they already contain cracks with that length, consequently there is no first stage of failure (editorial note).
Experimental confirmation of the formation of a ductile zone at the crack tip at the first stage of failure was obtained by several authors, e.g., [6].

It should be emphasized that hard tool materials are a suitable object for the analysis of their failure with the aid of linear fracture mechanics because under tension they fail with almost zero ductility, the fracture plane in which the crack lies is perpendicular to the acting stress and forms a straight fracture, and the zone of plastic deformation at the crack tip is considerably smaller than the critical crack length.

We take this circumstance into account, and in the study of the failure of a smooth specimen of hard tool material, in which a surface (edge) crack nucleates and grows (Fig. 2), we use the relation of linear fracture mechanics* where $l_{ic}$ is the fracture toughness; $\sigma^u$ is the stress ($\sigma_y$) at the tip of the edge crack $l_{cr}$ ensuring the start of its brittle propagation under extension of the smooth specimen.

$$K_{Ic} = 2\sigma^u \sqrt{l_{cr}} ,$$

At point $O'$ (Fig. 2) directly before the onset of brittle failure

$$K_I = 2\sigma_y \sqrt{l_{cr}} + \Delta_{cr} \ .$$

Since $\sigma_y \sigma^u$ and $\Delta_{cr} \rightarrow 0$. $K_I \equiv K_{Ic}$. Then

$$K_{Ic} = 2\sigma_y \sqrt{l_{cr}} + \Delta_{cr} \ .$$

*According to Griffiths Eq. (1) has the following form: $\sigma_{br} = 2\sigma^u \sqrt{\frac{l_{cr}}{c}}$; where $c$ is the acuteness of the crack, mm. Hence the radicand is a dimensionless magnitude, and the parameters in the equation already have a "normal" dimension, viz., N/mm$^2$ (and not N/mm$^3/2$). (Editorial remark.)