THE METHOD FOR RELIABILITY ESTIMATION OF THE MACHINE ELEMENTS UNDER LOW TEMPERATURE CONDITIONS

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Abstract

The subject considered are the theoretical dependences between parameters in a small scale yielding zone length, and a plastic zone at cave-in spherical indentor. The loadings of a spherical (D=5 mm) indenter in the range from 147 to 11875 N within absolute temperature range 77-293 K were applied. According to this model, fracture conditions occur when the stress σ_z in the centre of ball impression exceeds critical stress of brittle fracture σ_f. Then the indentation energy, corresponding to condition HM $=\sigma_f$, where HM and σ_f are the Meyer's hardness and the material's critical cleavage fracture stress, was calculated. The comparison of fracture toughness K_{Ic}, and specific energy of plastic deformation on depth of a plastic zone at introduction spherical indentor u_p values reveals linear relation-ships $K_{Ic}(u_p)$ for all steels in all the investigated temperature range. For the purposes of non-destructive S_k estimation, the relation-ship between S_k and misses stress σ_i, in the centre of impression at the temperature 77 K was established. At last fracture toughness values can be calculated from the single unified equation for all investigated steels. The model proposed can be used for predicting the cracking resistance of the machine elements in a low temperature range.

***Keywords**: low temperature, fracture toughness, ball indentation testing, intensity of plastic deformation, specific plastic strain energy*

1. Introduction

All characteristics of a material for machine elements at various kinds of mechanical tests are macroscopical displays of its concrete physical nature, features of structure and a chemical compound. Therefore resistance of weariness, fracture toughness, properties at a tensile test, contact deformation by all means should be connected with each other.

There is known that increase in strength of a material usually is accompanied by reduction of plasticity and fracture toughness. It occurs because at high-strength materials the energy absorbed at destruction is small. The level of this energy is determined by the size of small scale yielding zone. If at introduction indentor in a surface of a counterbody in a zone of contact there is a residual dent around of it always there is plastically deformed area extending on some depth h_s. This area is limited to the closed surface on which the condition of plasticity is satisfied $\sigma_i=\sigma_T$.

Observable at increase strength, decrease in temperature, increase in speed of deformation reduction of plastically deformed volume (so also works of plastic deformation) at tests for hardness and fracture toughness are investigation of the same phenomenon: decrease reductions in mobility of dislocations.

In works [1 - 4] the method of calculation of the specific surface plastic strain energy γ_p in a small scale yielding zone before front of a crack has been offered. Existence of dependence between K_{IC} and $\sqrt{\gamma_p}$ a wide temperature range for steels having various structures and levels of mechanical properties is shown. If between power parameters of plastic zones at top of a crack and at cave-in spherical indentor connection will be established. It will appear an opportunity for predicting the cracking resistance of metals through the results of ball indentation testing will appear will be established.

2. Analysis

Depth h_s is determined as

$$h_s = \sqrt{\frac{P}{2\sigma_y} - 1.2\left(\frac{d}{2}\right)^2}\ , \tag{1}$$

where:

P – the enclosed loading,
σ_y – yield stress ,
d – values of diameters of residual prints.

For construction of the generalized curve of current $\sigma_i = f\ (\varepsilon_i)$ in a plastic zone under a print along an axis of cave-in it is necessary to calculate the current values of intensity of pressure in the centre of contact σ_i at each value of loading. In work [5] the size of intensity of stress in the centre of contact σ_i was offered for determining as

Further the current values of energy of plastic deformation u_i, for any point on depth of distribution of a plastic zone expected at cave-in along an axis *z* from 0 up to h_s

$$u_i = \frac{\sigma_y + \sigma_i}{2} \cdot \varepsilon_i\ , \tag{2}$$

where:

σ_i and ε_i - the current values of intensity of stress and deformations along an axis *z* on depth of distribution of a plastic zone at the cave-in, designed on known dependences.

Integrating dependence u_i (z) from 0 to h_s, of the eq. (2) gives the value of specific energy of plastic deformation on depth of a plastic zone at introduction spherical indentor:

$$u_p = \int_0^{h_s} u_i dx\ . \tag{3}$$

3. Discussion

For verification of model data, obtained in [6] for steels, the 10G2FB, VSt 3kp, 17GS, 17G1S-U, 06G2NAB, 15KH2MFA were taken. The plane strain fracture toughness test, Charpy test and tension testing of steels were carried out by Krasowsky and Krasiko at the Institute of Strength Problems (Kiev, Ukraine). Hardness measurements were then carried out at the Volgograd State Technical University (Russia) for work [7]. Experiments on contact deformation specified steels carried out spherical indentor in diameter *D=5* mm at loadings P from 150 to 11800 N and temperatures from 77 to 293 K on devices TSH-2 (Brinell) and TK-2 (Rockwell).

The plastic zone radius ahead of a crack is defined as

$$r = \frac{(1-2\nu)^2}{2\pi} \cdot \left[\frac{K_{IC}}{\sigma_y} \right]^2 . \tag{4}$$

Comparison of values r and h_s has shown that the size of a plastic zone before front of a crack is more sensitive to decrease in temperature, than at cave-in indentor. Therefore it was offered to count, that the sizes of plastic zones correspond each other at temperature 77K load 150 N, 213 K - 1000 N, 243K - 5000 N, 293K - 11800 N.

The results of calculations of the eq. (3) are presented on Fig. 1. As can be seen from Fig. 1 the dependency of the specific surface plastic strain energy density, γ_p, on specific energy of plastic deformation on depth of a plastic zone at introduction spherical indentor, value for all steels investigated is described by single linear function.

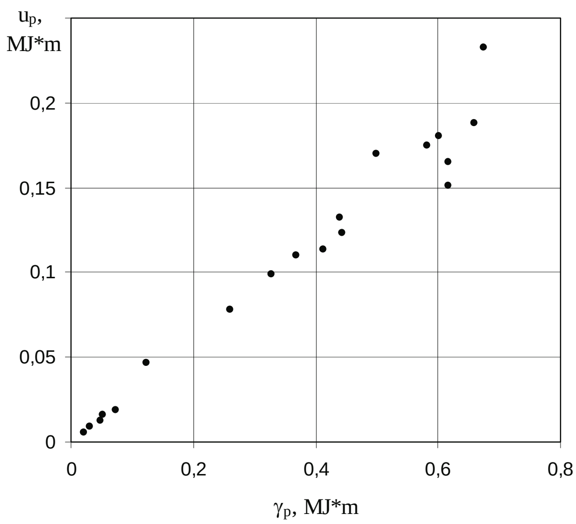

Fig. 1. The relationship between u_p, and γ_p

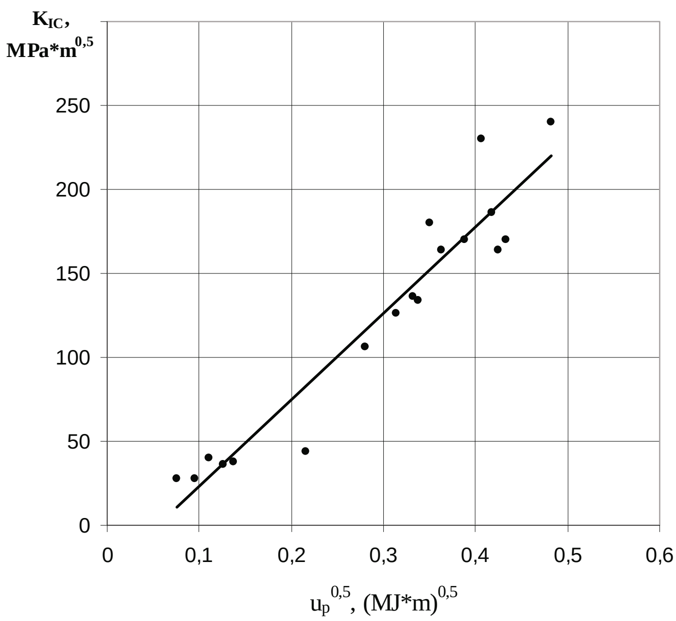

Fig. 2. The relationship between K_{IC}, and $\sqrt{u_p}$

Analogous dependencies between fracture toughness K_{IC} and $\sqrt{u_p}$ are presented on Fig. 2 [1–4]. This relationship is shown on Fig. 2 and is described by the following equation:

$$K_{IC} = 514{,}01 \sqrt{u_p} - 27{,}785. \quad (5)$$

4. Conclusions

The results obtained in this work supported the following conclusions.

The theoretical dependences between parameters in a small scale yielding zone length, and a plastic zone at cave-in spherical indentor is analyzed.

Analogous dependencies between fracture toughness K_{IC} and $\sqrt{u_p}$ a wide temperature range are found in [1 – 4].

The discussed results provide the possibility of the cracking resistance of the machine elements estimation through the results of ball indentation testing.

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