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CONCEPTS OF MICROMECHANICS OF DESTRUCTION IN THE PROCESS OF TEACHING A PHYSICS COURSE

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Abstract. The article analyzes the role of microcracks in fractures and evaluates the strength of solids in the framework of continuum mechanics concepts. It is shown that although the assessment of the role of microcracks in the fracture and strength of solids proposed by Griffiths was an important step, this approach does not take into account the dynamic role of the occurrence of microcracks and the relaxation nature of the absorption of the released elastic deformation energy. The involvement of the concepts and achievements of micromechanics of destruction in teaching the relevant topics of the course of physics makes it possible to acquaint pupils and students with the real problems of modern science and thereby increase the efficiency of the educational process.

Key words: theoretical and real strength, microcrack, elastic deformation energy, absorption energy, teaching physics.

The properties of resisting a solid to an external load are called strength. Strength is the most important physical and mechanical characteristic of solids. Despite the enormous achievements in crystal physics, the strength of crystalline bodies is still determined experimentally by laboratory methods.

The calculation of the strength of crystals by means of the interaction potential of atoms (theoretical strength), which was made by a number of scientists, showed that it significantly (100-1000 times!) exceeds the real strength [1, p.13]. It was necessary to find out the reason for this discrepancy.

Griffiths, an English scientist, attributed the reason for the decrease in real strength to the presence of microscopic cracks, which are present in almost all real solids [2]. It is clear that the mechanical stress at the tip of the microcrack is significantly higher than the average. Academician A.F.Ioffe, in experiments with salt crystals, showed that when etching the crystal surface (with water), the strength

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of the crystal increases 5-7 times [3]. S.N.Zhurkov and A.P.Alexandrov experimentally showed that, as the diameter of the glass filaments decreases, their strength increases sharply [4].

Thus, the calculation of the theoretical strength and its strong difference from the real strength became the reason for scientific research in order to find out the reason for such a discrepancy and to find ways to increase the strength of solids. Since the margin of safety up to the theoretical strength was quite a lot. These studies in the physics and technology of solid bodies have yielded two important results. Firstly, various methods have been developed for the production of filamentous crystals, the strength of which is close to theoretical. [5]. Secondly, a new theory on the strength of solids was developed, the thermofluctuation (kinetic) theory of the destruction of solids [6].

Nevertheless, the kinetic theory does not deny the role of microcracks in the process of destruction of solids. On the contrary, in the Zhurkov-Regel scientific school, the occurrence of submicrocracks in a loaded body is considered as a consequence of thermal fluctuations.

Professor Lexovsky and his students, based on an in-depth study of the origin and development of microcracks in polymers and polycrystalline metals in an electron microscope chamber, showed that, firstly, microcracks appear explosively, and secondly, their interactions have a relaxation nature almost until the end of the sample's life [7, 8].

In a direct experiment using an electron microscope and statistical analysis of acoustic signals that occur during deformation of a fibrous composite, it is shown that: the transition from accumulation of dispersed defects (microcracks) to catastrophic (uncontrollable) destruction occurs where and when the released elastic deformation energy (when a defect occurs) cannot be absorbed by the surrounding volume. Such a state occurs as deformation occurs, when all channels of energy dissipation of elastic deformation are exhausted.

That is, the ratio of the energy of elastic deformation, which is released in a unit of time during the explosive appearance of microscopic defects in a loaded body, and the ability of a solid body to absorb this energy determines the further fate of the loaded body. If a loaded solid is able to absorb the released elastic deformation energies, then the body can maintain its integrity. However, if the energy of elastic deformation released in a unit of time cannot be absorbed by the surrounding volume, then the body collapses – the destruction becomes catastrophic [9, 10].

Due to the importance of the task of predicting the transition from dispersed to catastrophic destruction, the article (report) provides detailed information on the calculation of real strength and the role of microcracks in the process of destruction of solid bodies.

Consider Griffiths' approach. Suppose a tensile stress σ is applied to a thin plate of a brittle solid (Fig. 1). According to the law of conservation of energy, the work of external forces during deformation accumulates in the volume of the body in the form of elastic deformation energy. Let's try to calculate the elastic deformation energies.

When deformed by Δl in a cross-sectional sample S and the modulus of elasticity E an external force does the work:

$A = \overline{F\Delta l}$ (1)

Where is it $\overline{F}$- average strength. It is clear that at the beginning of the deformation F=0. When deformed by Δl the external force will reach the maximum value of the modulus, which is equal to the elastic force $F_{max} = F_\text{ч}$. Therefore, the average force is equal to

$\overline{F} = \frac{1}{2}F_m$ (2) .

Taking into account (2), we get: $A = \overline{F}\Delta l = \frac{1}{2}F\Delta l$ (3).

On the other hand: $F = \sigma \cdot S$ (4) .

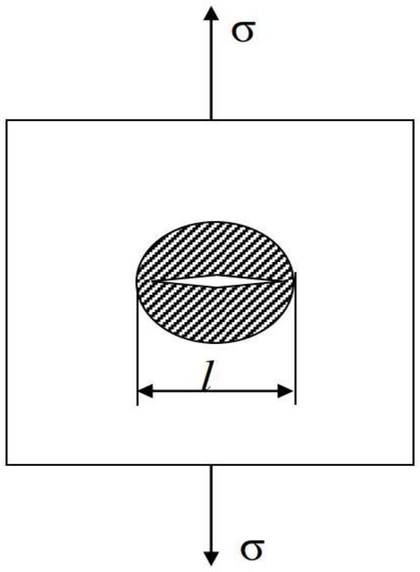


Fig. 1

Putting expression (4) on (3) we get the following:

$$A = \frac{1}{2}\sigma \cdot S\Delta l \qquad (5)$$

It is known that $\varepsilon = \frac{\Delta l}{l}$ from here: $\Delta l = \varepsilon \cdot l$ (6) meaning Δl in expression (6) we put on (5) and get:

$A = W = \frac{1}{2}\sigma \cdot S \cdot \Delta l = \frac{1}{2}\sigma \cdot S \cdot \varepsilon \cdot l = \frac{1}{2}\sigma \cdot \varepsilon \cdot V$ (7)

From Hooke's Law $\varepsilon = \frac{\sigma}{E}$ (8)

We set the value from (8) to (7) and get the formulas for the elastic deformation energy:

$$W = \frac{1}{2}\sigma \cdot \frac{\sigma}{E} \cdot V = \frac{\sigma^2}{2E} \cdot V \qquad (9)$$

Hence the energy density of elastic deformation (ω):

$$\omega = \frac{W}{V} = \frac{\sigma^2}{2E} \qquad (10)$$

Suppose, under the influence of external mechanical stress, a microcrack of length l occurs in the sample, which covers the entire thickness of the sample δ . As a result of the occurrence of a crack inside the sample,

free surface $S \approx 2l \cdot \delta$

This leads to an increase in the energy of the sample by $\Delta W_1 = 2l \cdot \delta \cdot \alpha$ (11) . Where here α the energy of the free surface. On the other hand, as a result

the occurrence of a crack in the volume of the sample $V = l^2 \cdot \delta$ it is released from mechanical stress. As a result, the elastic deformation energy of the sample decreases in quantity

$$\Delta W_2 = l^2\delta \cdot \sigma^2/(2E) \qquad (12)$$

Changing the energy of the sample ΔW as a result of the formation of a crack:

$$\Delta W = 2l \cdot \delta \cdot \alpha - l^2 \delta \cdot \frac{\sigma^2}{2E} \qquad (13)$$

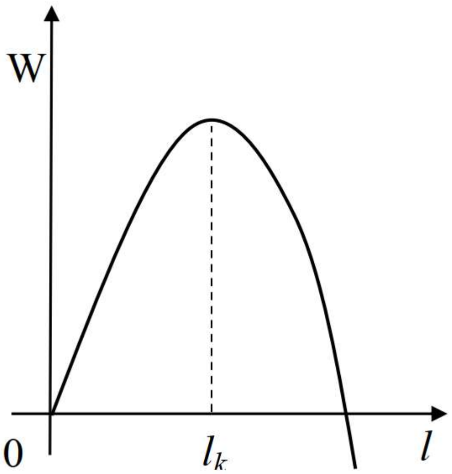
Figure 2 shows the dependence of energy on the crack length. This dependence has a maximum where the energy derivative of the length is zero.

$$\frac{dW}{dl} = 2\delta \cdot \alpha - l \cdot \delta \cdot \frac{\sigma^2}{E} = 0 \qquad (14)$$

The length of the crack corresponding to the maximum is denoted by l_k . From the last expression we get: $l = 2\alpha \cdot E/\sigma^2$ (15)

Setting the values of the values α, E and σ for a copper crystal ($\alpha \approx \frac{1{,}7\text{Љ}}{\text{м}^2}; E = 1{,}2 \cdot 10^{11}\text{Па}$ и $\sigma_\text{р} = 1{,}8 \cdot 10^8\text{Па}$) in formula (15) we get: $l \approx 10 \cdot 10^{-6}\text{м}$ [11].

Therefore, when a microcrack occurs, the value $\sim 10\text{мкм}$, the destruction becomes irreversible.



From Fig.2 at $l \leq l_k$, an increase in the crack length leads to an increase in energy. By $l \geq l_k$ As the crack length increases, the energy of the sample decreases (the principle of minimum energy). This leads to a spontaneous increase in the crack, which leads to catastrophic destruction.

Fig. 2

Using (15), Griffiths obtained an expression for calculating the real strength of solids, assuming that solids almost always have microcracks:

$$\sigma_\text{Њ} = (2\alpha E/l)^{1/2} \qquad (16)$$

Although Griffiths' theory was a serious step to explain the difference between the theoretical and real strength of solids, however, this theory does not take into account the role of thermal motion of atoms and the dynamic nature of the occurrence of microcracks in loaded bodies. Indeed, the energy of elastic deformation, which is released during the explosive occurrence of microcracks in a loaded body, is an important factor that can significantly affect the development of the fracture process.

For filamentous crystals and glass fibers with high strength, the appearance of a single accidental microcrack leads to macro-destruction of the sample. In the case of plastic materials, this transition is quite slow. The creation of an adequate theory predicting the transition from dispersed microfractures to catastrophic destruction requires taking into account not only the size of microcracks appearing in the volume of the loaded body, but also the power ratio of the elastic deformation energy and energy absorption of the material. Using the concepts of micromechanics of destruction in teaching the relevant topics of the physics course allows students to familiarize students with the real problems of solid state physics and thereby increase the effectiveness of the educational process.

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