On the issue of resistance of dispersed-filled composites, the development of cracks of mixed type

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Abstract. Currently, various non-metallic materials are widely used in industry, including composite ones, which have a number of positive properties. The practice of operating products from these materials allows us to conclude that many of these are characterized by a brittle nature of destruction. Moreover, numerous experimental studies have established that the crack resistance of brittle materials is directly dependent on the type of crack opening. In many studies devoted to the study of strength issues, the essential role played by the spherical component of the stress tensor in the development of the process of brittle fracture of the material plays a significant role.

1. Goal of the pilot study

Currently, various non-metallic materials are widely used in industry, including composite ones, which have a number of positive properties. The operating practice of products made of these materials allows to make a conclusion that many of them are characterized by a brittle fracture mode. And, experimental studies have found that the crack resistance of brittle materials is directly dependent on the type of crack face opening.

At this time the essential role played by the spherical part of the stress tensor in the process of the development of brittle material fracture has been noted.

Based on the above, in order to obtain the fullest understanding of the characteristics of brittle materials cracking, it seems appropriate to find out what role factors, such as an increase of the concentration of structural inhomogeneities in the material and an increase of the hydrostatic tension level, play in the process of their destruction.

2. Formulation of a problem

For this purpose, a series of experiments was carried out, in which cylindrical specimens with annular fatigue cracks (Figure 1) were subjected to loading to failure by axial tensile force and torque. Specimens were made of an epoxy compound of cold curing based on ED-20 resin and composites consisting of the specified epoxy compound with 0.25, 0.5 volume content of the finely dispersed phase of the measure KP-3. The methodology for preparing and carrying out the experiments was performed in exact accordance with the requirements specified in the paper [3].
Figure 1. Cylindrical specimen for tests for axial tension \( d = (0.6...0.7) \) D; \( D_d = 1.5 \) D; \( h = 0.16 \) D; \( R = 0.5 \) D; \( L = 5 \) D; \( \Delta l \) — depth of the fatigue crack growth; \( P \) – tension force; \( M \) – torque.

3. Start of cracks of mixed type \( \text{типа I - III} \)

The results of the experiments carried out were the basis for determining the type of the dependence between hydrostatic tension \( \sigma_0 \) and the largest main stress in absolute value \( \sigma_{\text{max}} \) in the region of the crack top at the time of crack starting. The value of the stress \( \sigma_{\text{max}} \) near the dead end of the crack was used for indirect estimation of the intensity of micropore formation in the region of its top. The numerical values of \( \sigma_0 \) and \( \sigma_{\text{max}} \) were calculated by the formulas:

\[
\sigma_0 = \frac{2}{3} \left( \frac{K_I (1 + \nu)}{(2 \pi r)^{\frac{1}{2}}} \right)
\]

\[
\sigma_{\text{max}} = \frac{1}{(2 \pi r)^{\frac{1}{2}}} \left[ K_I (0.5 + \nu) + \left( \frac{K_I^2 (1 - 2\nu)^2}{4} + K_{III}^2 \right)^{\frac{1}{2}} \right],
\]

where, \( \nu \) – Poisson's ratio,

which are known expressions modified with the help of asymptotic representations [2] to calculate the spherical part of the stress tensor and the maximum main stresses. Substituting in formulas (1) and (2) the values of the coefficients \( K_I \) and \( K_{III} \) and which were determined from the solution of the equation for each material studied.
where $K_{I0}$ and $K_{III0}$ – experimentally deduced threshold values of stress intensity factors allowed to construct the graphs shown in (Figure 2), which qualitatively indicate the relationship between hydrostatic tension and the main stress in absolute value at the beginning of the development of the fracture process.

\[
\left( \frac{K_I}{K_{I0}} \right)^2 + \left( \frac{K_{III}}{K_{III0}} \right)^2 = 1,
\]

4. Results of a pilot study

It can be seen from these graphs that the strongest dependence of the largest main stress in absolute value near the crack top on the hydrostatic tension is observed for an epoxy compound without filler. This can be explained by a significant decrease of the material ability in the region of the crack top to resist the effect of the applied load due to the development of pore formation and loosening processes in it. For composite materials, the dependence of the value of the largest main stress in absolute value
in the region of the crack top on the degree of hydrostatic tension is practically insignificant. However, according to the authors, this does not mean that in this case, under hydrostatic tension near the crack top of the crack, the development of micropores and loosening of the material do not occur. The observed weak dependence of the highest main stresses $\sigma_{\text{max}}$ on the value of hydrostatic tension suggests that the addition of finely dispersed particles capable of acting as additional sites of micropore nucleation into the epoxy compound, finally results in not only a decrease of the static strength of the material, but also in a sharp decrease of the stresses level near the crack top due to an increase of the size of the prefraction area [3].

Table 1. Dependence of the breaking voltage on the volume destruction of the dispensary phase

| Strength property | Volume content of the dispersed phase |
|-------------------|-------------------------------------|
| $V_K$, %          | 0.0       | 12.5 | 25.0 | 50.0 |
| $\sigma_0$, MPa   | 88.2      | 64.7 | 56.7 | 49.0 |

5. Conclusions of a pilot study

Within the stated concept on the possible effect of the processes of nucleation and development of micropores on crack resistance of the brittle materials, the data published in the paper [3] on the increase of the coefficients threshold values $K_I$, with increase of the content of particles of the dispersed phase in the composite, can be explained by the prevalence of the effect of lowering the stress state level near the crack top (due to the increase of the size of the prefraction area) over the effect of decreasing the static strength of the material in this site as a result of its loosening. The apparent decrease of the coefficients threshold values $K_{\text{III}}$, of composite materials with increase of the content of fine-dispersed particles therein, which is observed in experiments in studying of brittle fracture under conditions of antiplane shear [3], is explained by the fact that under antiplane shear in the absence of the spherical part of the stress tensor, the addition of the filler to the epoxy compound substantially does not result in increase of the size of the prefraction area [4], and therefore in decrease of the stresses level in the region of the crack top.

The information given in this work allows to come down more reasonably to theoretical understanding of the difference in trends of changing of stress intensity factors under normal fracture and antiplane shear, depending on the volume concentration value in the composite of the dispersed phase particles.

Acknowledgments

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