FIBRE COMPOSITE MATERIALS

REALIZATION OF THE PROPERTIES OF CARBON FIBRES IN COMPOSITE MATERIALS.

PART 1. REALIZATION OF THE ELASTIC-STRENGTH PROPERTIES OF CARBON FIBRES IN UNIDIRECTIONAL CARBON-FILLED PLASTICS (REVIEW)

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Materials consisting of two or more components separated into phases are called composite materials (CM), and each one gives the CM certain properties whose realization is a function of the interfacial interaction of the components and the features of their behavior during use of the CM. Of construction CM, materials reinforced with fibres are of the greatest interest, since they have a number of extreme characteristics due to the maximum anisotropy of the structure, primarily a high strength and modulus of elasticity. CM with a different arrangement of the fibres have been used in practice, but unidirectional CM (UCM) occupy a special place, since they allow maximum realization of the elastic-strength properties of the fibres.

An important feature of CM is the possibility of designing not only the articles made from them but also the material itself. The behavior of CM is calculated during the design process based on the properties of the components and the specific features of their interaction. In performing these calculations, the characteristics of a monolayer of UCM is used as the basic unit, which additionally confirms the importance of assessing the properties of UCM.

The elastic characteristics of UCM during stretching along the axis of the fibre in the region of strains before perturbation of the continuity of the material obeys the rule of additivity:

\[ E_c = E_f V_f + E_m (1 - V_f) \]  

where \( E \) is the modulus of elasticity; \( V \) is the volume fraction; subscripts \( c, f, \) and \( m \) refer to the UCM, fibre, and matrix, respectively.

In contrast to the modulus of elasticity, the strength of UCM is not an additive characteristic, since it is determined in conditions of perturbation of the continuity of the material up to its total fracture, and is thus a function of the mechanism of this process. The mechanism of fracture of UCM in stretching along the axis of the fibres is primarily determined by the ratio between the breaking strain of fibre and matrix. From this point of view, it is useful to divide matrices into plastic (with a higher breaking strain than in the fibre) and brittle (with a lower breaking strain than in the fibre). The strength of the bond between fibre and matrix, whose optimum value ensures maximum realization of the strength of the fibre in UCM, plays an important role in fracture of UCM. This bond arises during fabrication of CM and in some cases (for example, in fabrication of CM from carbon fibre and an aluminum matrix) can be excessive and can decrease the properties of the CM.

In examining the mechanism of failure of UCM, the micro- and macromechanics of this process are usually separated, where micromechanics are defined as the stage of failure in the region of a single fibre, and macromechanics means failure in bulk, affecting the ensemble of fibres up to the entire volume of the CM.

Of the fillers for CM, carbon fibres (CF) have the highest elastic-strength indexes: their strength goes up to 7 GPa, and the modulus elasticity goes up to 900 GPa. The elevated thermal and chemical stability of CF allows using them for fabrication of CM with almost all existing types of matrices — polymer, metal, carbon, and ceramic. The highest mechanical
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The properties of CF can be analyzed from different points of view [1]. In the present case, we are interested in the characteristics of the behavior of CF on stretching related to their defectiveness. The high moduli of elasticity and low elongation at break of CF make these fibres brittle bodies whose strength is due to the existence of defects of different degrees of danger. The analysis of the types of defects in CF [2] shows that their nature can differ, beginning from gross inclusions [3] and ending in disorientation of the planes in microcrystallites relative to the axis of the CF [4].

When fibres break, the danger of a defect present in a given sample determines its strength, so that the statistical character of distribution of defects in a fibre results in the corresponding strength distribution of the fibres. In the general case, this distribution can be multimodal, reflecting the existence of groups of defects in a fibre with a strength level characteristic of each group (Fig. 1 [5]). Naturally, the probability of the presence of the most dangerous defect increases with an increase in the size of the sample. As we will show below, the statistical dependence of the strength of fibres on their length, the so-called "strength scale effect," is the most important for the mechanism of fracture of UCM on stretching.

The theoretical correlation of the strength of fibres (σ) with their length (l) is frequently in the form of the integral distribution function proposed by Weibull:

\[ F(\sigma) = 1 - \exp \left\{ -l/l_0 \left( (\sigma - \sigma_m)/\sigma_0 \right)^\beta \right\}, \]

where \( \beta, \sigma_0, \) and \( \sigma_m \) are constants (distribution parameters); \( l_0 \) is the base length of the fibre.

For simplification, three-parameter equation (2) is frequently converted into a two-parameter equation by assuming that \( \sigma_m = 0. \) However, as Fig. 1 suggests, setting the minimum strength equal to zero for even one sample out of the set investigated is not always justified. At the same time, simplification of Eq. (2) allows finding the experimentally confirmed power dependence between \( \sigma \) and \( l, \) approximated by a linear dependence in binary logarithmic coordinates:

\[ \log \sigma = A - B \log l, \]

where \( A \) and \( B \) are constants.

The effect of the length of the sample on the probability of the appearance of the most dangerous defect and the danger level is manifested by a corresponding change in the strength distribution function of the CF. It was shown in Fig. 1 that a decrease in the length of the sample not only shifts the function toward higher strengths but also toward redistribution of the number of the most dangerous defects between samples. This confirms the notion of the statistical distribution of the most dangerous defects over the length of the fibre and their responsibility for its strength.