DETERMINATION OF THE EDGE-EFFECT ZONE WITH THE HELP OF THE HOLOGRAPHIC MOIRÉ METHOD

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In parts made from materials with a distinct anisotropy, it is necessary to take into account edge effects which, as is well known [1], can slowly decay away from the edge. The size of the edge-effect zone in composite materials has been estimated many times and, in addition, the problem has been solved theoretically and experimentally [1-3]. In this work such estimates are made with the help of the method of holographic interferometry.

The edge effect is estimated by the distance ℓ^* at which the initial perturbation of the deformed state of the sample drops to 5% of its maximum value. The deformation decays nearly exponentially and for large values of the argument of the exponential approaches zero asymptotically. Then, in this zone of the sample, in order to obtain a concrete value for ℓ^* the values of the displacements must be known with high accuracy. For example, in order to achieve an error $\ell^* = 5\%$, the displacements must be measured with an accuracy of 0.7%. The required measurement accuracy can be substantially reduced if it is assumed that the displacements decrease exponentially. Then, by constructing curves of the displacements in fixed sections of the sample, for example with the help of the method of holographic interferometry, the decay constant τ can be determined as the distance at which the magnitude of the perturbation decreases by a factor of e, and the zone of penetration of the edge effect can be taken, as done in the description of transient processes, as $\ell^* = 3\tau$. Since τ is determined in the zone of the sample where the displacements are substantial, the measurement accuracy can be reduced.

As an example of the approach described above for determining the size of the edge-effect zone in composite materials we present the results of tests on a sample consisting of a matrix of epoxy resin, reinforced with steel wire 2 mm in diameter. A self-balanced load was applied with the help of a special setup to the fibers protruding from the matrix [4]. The loading scheme is shown in Fig. 1. The sample was 210 mm long, 65 mm wide, and 5 mm thick, and distance between the axes of the reinforcing fibers equalled 4.7 mm.

The test were performed by the method of holographic moiré [5]. For this, a metallized grating with a spacing of $\Psi = 1355\ \mathrm{mm}^{-1}$ was deposited on the surface of the sample (the work required to produce the metallized grating and to deposit it on the surface of the part is no greater than the work required to produce and glue on photoelastic coatings). Then a PÉ-2 high-resolution photographic plate, on which a hologram was recorded by the double-exposure method proposed by Yu. N. Denisyuk, was fastened in front of the grating with SKTN synthetic rubber. The first exposure was made in the initial unloaded state of the sample, and the second was made after the load was applied. After the second exposure the plate was separated from the sample and treated photochemically.

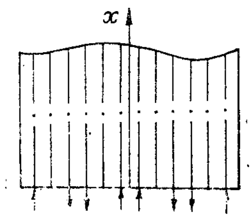

Fig. 1

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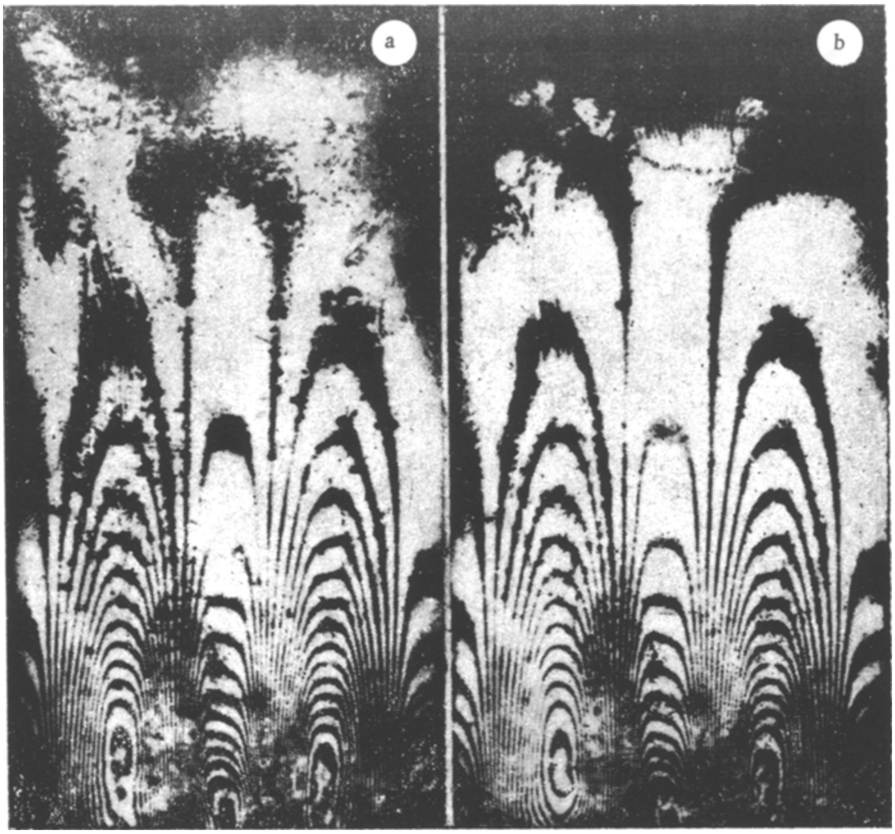

Fig. 2

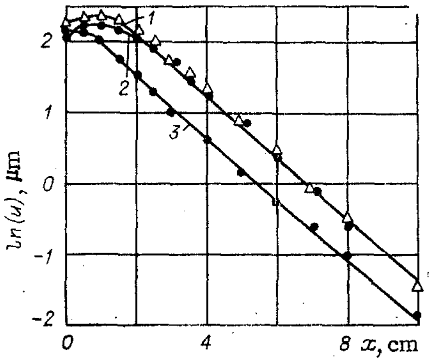

Fig. 3

The interferograms obtained were reconstructed in white light. Figure 2 shows photographs of the interferograms observed in reflected +1 (a) and −1 (b) orders of diffraction. The position of the interference fringes is determined by the displacement of identical points of the sample between exposures and is determined by the equation

$$u \sin \alpha + w(1 + \cos \alpha) = N\lambda,$$

where $\sin \alpha = n\lambda\Psi$; n is the number of the diffusion order; u and w are the components of the displacement vector tangential and normal to the plane of the sample; N is the order of the fringe; and λ is the wavelength of the light. If N^+ and N^- are the numbers of the fringes in the +1 and −1 orders of diffraction, then taking into account the fact that $\sin \alpha^+ = -\sin \alpha^-$ and $\cos \alpha^+ = \cos \alpha^-$, the displacement in the plane of the sample can be calculated according to the formula

$$u = (N^+ - N^-)\frac{\lambda}{2 \sin \alpha} = (N^+ - N^-)\frac{1}{2n\Psi}.$$

Figure 3 shows the curves of u on a logarithmic scale in two longitudinal sections of maximal stretching of the sample and in the compressed section at the center (curves 1-3). The curves have two distinct sections. These sections can be interpreted as follows. In the first section, the magnitude of the displacements produced by the edge effect, caused by the nonuniformity of the load distribution over the thickness of the sample, increases. In this case, the displacements can be described by the expression

$$u = u_{max}(1 - e^{-x/\tau_1}),$$

where x is the coordinate along the axis of the sample (see Fig. 1) and τ_1 is the damping constant for the transverse edge effect. Because the depth at which the reinforcing fibers are located is not constant, the value of τ_1 is different and fluctuates from 0.4 cm for the compressed section to 0.7 cm for the stretched section.

In the second section the displacement u decreases because the perturbation produced by the self-balanced load applied to the sample decays, and is described by the expression

$$u = u_{max}e^{-x/\tau_2},$$

where τ_2 is the damping constant of the main edge effect; τ_2 = 2.26 and 2.17 cm for the stretched and compressed regions, respectively. The penetration depth of the edge effect, determined by the formula $\ell^* = 3\tau$, equals 6.78 and 6.52 cm in the region of stretching and in the compressed zone, respectively.

In [1] the formula $\ell^*/H = 1 + 0.04\eta$ for determining the penetration depth of the edge effect was derived theoretically and checked experimentally. Here, H is the size of the perturbation zone (in our case, equal to one-half the width of the sample, i.e., 3.25 cm), and η is the anisotropy parameter, determined by the relation

$$\eta = E_1F_1/(Gha),$$

where E_1 and F_1 is Young's modulus and the area of the transverse cross section of the reinforcing fiber, G is the shear modulus of the binder, h is the thickness of the sample, and a is the distance between the centers of the reinforcing fibers. For the sample described, η = 23, i.e., the theoretical size of the zone of penetration of the edge effect equals 6.24 cm, which is 8% smaller than the value obtained experimentally for the stretched zone and 4% less for the compressed zone.

Thus, evaluation of the penetration depth of the edge effect based on the decay constant reduces the accuracy required in determining the displacements, and the size of the edge-effect zone obtained by this method is virtually identical to the size obtained by other methods.

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