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RESEARCH ARTICLE

EXPERIMENTAL DETERMINATION OF CHARACTERISTICS OF CRACK-RESISTANCE OF DISPERSE-STRENGTHENED COMPOSITES BASED ON NON-SATUTATED POLYESTERS

Alena Y. Ershova[1*], Elena L. Kuznetsova[1], Mikhail I. Martirosov[1], Lev N. Rabinskiy[2]

[1]Department of Resistance of Materials, Dynamics and Strength of Machines, Moscow Aviation Institute (National Research University), 4 Volokolamskoe shosse, Moscow, Russian Federation
[2]Department of Advanced Materials and Technologies of Aerospace Application, Moscow Aviation Institute (National Research University), 4 Volokolamskoe shosse, Moscow, Russian Federation
**Corresponding Author Email: Yershova_A@mail.ru*

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ABSTRACT

Based on the series of tests for three-point bending of rectangular bars with central cuts on a universal test machine, using the compliance and *K*-methods, experimental values of the fracture toughness characteristics of the material under investigation were obtained. In this work, the characteristics of the fracture resistance of casting artificial stone (CAS) were determined. The obtained values of the mechanical characteristics of the material are comparable to those of the natural stone. As a result of the experiments, tension-compression diagrams for CAS and also the dependence of compliance from the relative length were obtained. Considering the substantial technological advantages of this composite, it is concluded that it is practical to use this material.

KEYWORDS

Unsaturated polyesters, fracture resistance, loading scheme, experimental data, crack resistance of the material, compliance method, molded artificial stone.

1. INTRODUCTION

Disperse-hardened composites based on unsaturated polyesters are widely used in various branches of modern technology. Such materials open wide opportunities both for improving existing designs and for developing new ones. In many cases, they are even more preferable than traditional materials: metals, their alloys, and a number of non-metallic structural materials. Disperse-hardened composites are characterized by low density and high specific characteristics. In addition, the technological processes of molding products from such materials have a significantly lower energy consumption compared to the technology of processing common metal materials.

A finished product of dispersed-hardened composites is characterized by a homogeneous structure and low porosity. This material is resistant to vibrations and changes of ambient temperatures. It has high noise absorption, low thermal conductivity (high thermal insulation capacity), high electrical insulating ability, high antibacterial characteristics, wear resistance. Unlike, for example, natural stone, the material is characterized by the absence of radioactivity, resistance to some chemically aggressive media and corrosion, the ability to sustain shock and vibration loads. The material can easily be processed, as well as glued and assembled, and maintains its reparability.

Products made of such material have a long service life, excellent surface quality; beautiful appearance. The material is fully adapted for the production of goods that meet the requirements of modern design. It is a structural composite, the main components of which are unsaturated polyester resin and inert granular filler. A typical representative of such material is a casting artificial stone (CAS). Depending on the resin and filler used, it is possible to imitate the color and texture of natural stone: marble, malachite, coil, onyx, granite, jasper, etc. It does not contain substances harmful to health, it is not toxic. In each specific case, the replacement of traditional materials with new ones is accompanied by a significant amount of research work related to the study of their physical and mechanical properties and the development of methods for assessing performance characteristics. Experimental methods of investigation are of great importance here.

2. TEST PROCEDURE

In this work, the properties of a dispersion-hardened composite were determined from the results of testing samples of material on the universal testing machine ZWICK Z100 (Germany). This test machine is designed for measuring force and deformation during testing of structural materials for various types of deformations. To determine the fracture resistance, a simple device can be used to allow three-point bending tests of the notched bars. In the test procedure, experimental diagrams were obtained in force-deflection coordinates, which were used to identify the required dependency of the bar (sample) compliance on the incision depth and the limiting values of the stress intensity factor.

There are no standard methods for determining the characteristics of fracture mechanics for rocks and CAS. In this regard, tests to assess the fracture resistance properties of the test material were carried out in accordance with the recommendations for determining the fracture resistance of metals [1]. In accordance with the above recommendations, the tests were carried out in a three-point bending mode on rectangular cross-sectional samples with an edge cut (Figure 1).

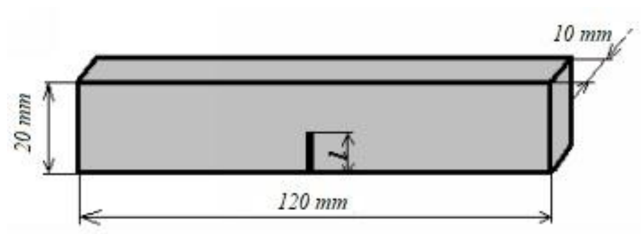

Figure 1: Sample with a notch for 3-point bending tests to determine the crack resistance characteristics of the CAS

The loading scheme is shown in Figure 2. Samples were cut from the manufactured CAS plate; the total length of the sample was 120 mm, height 20 mm. The distance between supports is 100 mm. The depth of the incision was varied at 4 levels and was 5, 7.5, 10- and 12-mm. Sample loading was carried out at a speed of 0.2 mm/s. During the tests, the experimental dependence of the shearing force on the deflection amount of the sample was recorded.

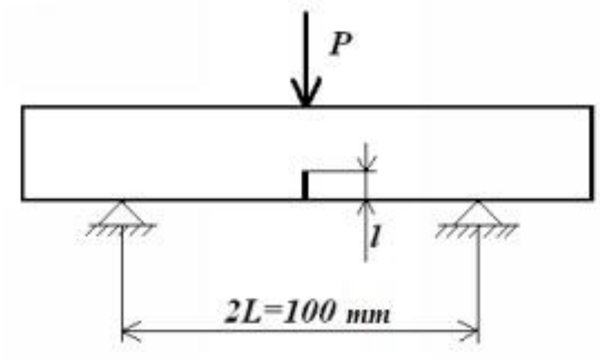

Figure 2: Scheme of loading of a specimen with a notch for a three-point and a point

The fracture resistance characteristics of the material were determined in accordance with the compliance method for determining the intensity of energy release G_{IC} and method K -tarings based on the results of tests for three-point bending of samples - beams with single edge incisions (Figure 2). To determine the dependence of the yield of the derivative on the relative length of the crack, the samples were preliminarily loaded to a deflection of 0.2 mm. The test was carried out at a deflection rate of 0.2 mm/s and a constant temperature $T = 20^0 \pm 1^0\,\mathrm{C}$. A thixotropic unsaturated polyester resin produced by ASHLAND (USA) was used to make the samples. As a filler we used quartz sand, marble chips and a number of other materials. By volume, the unsaturated polyester resin content is ~ 20%, the filler content is not less than 80% [2].

3. RESULTS AND DISCUSSION

One of the most important characteristics of the products and structures of brittle materials that determine the serviceability is the fracture resistance, which determines the resistance of the material to the formation and development of cracks. By its nature, CAS is essentially a heterogeneous material with a relatively plastic polymeric matrix-binder and rigid filler. Another source of the heterogeneity is the molding technology for the production of the material under investigation, which does not exclude the possibility of forming defects in the process of manufacturing products (in the form of shells, pores and interfacial delimitations). The presence of such defects does not prevent the material from being considered homogeneous when considering deformation processes and determining the strength characteristics.

At the same time, the process of destruction is accompanied by the formation and development of cracks formed on the inhomogeneities (defects) when the material is loaded. In this regard, to assess the performance of critical products from the CAS, one should be guided not only by the average strength values, but also by the characteristics of the fracture resistance of the material. It seems expedient in these cases to apply the known methods and approaches of linear fracture mechanics that assume the use of criteria estimates of the resistance of the material to the development of defects – cracks [1,3].

The Figure 3 shows the experimental dependences of the concentrated force P from displacement δ, obtained when testing samples with a notch depth of 5 and 12 mm. Similar data were used to determine the experimental dependence of the yield of the bar l from the relative crack length (notch) l/b. A natural feature of this dependence is that compliance gives rise to an increase in the depth of the incision, and a monotonic function can be used to approximate the experimental dependence (an exponential function was used in the work).

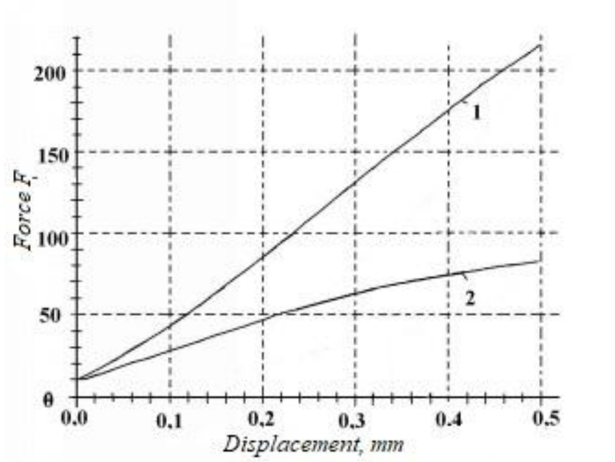

Figure 3: The experimental dependence of the concentrated force P on the displacement δ of samples with different notch sizes: l -5 mm, 2-12 mm

Figure 4 shows the experimental dependence of compliance λ from the relative length of the initial crack (notch) l/b. The obtained dependence $\lambda\left(l/b\right)$ was approximated by an exponential dependence:

$$\lambda(\beta) = 2{,}12 \cdot 10^{-3} + 9{,}7448 \cdot 10^{-6} exp(0{,}1023\beta)\,, \beta = l/b \quad (1)$$

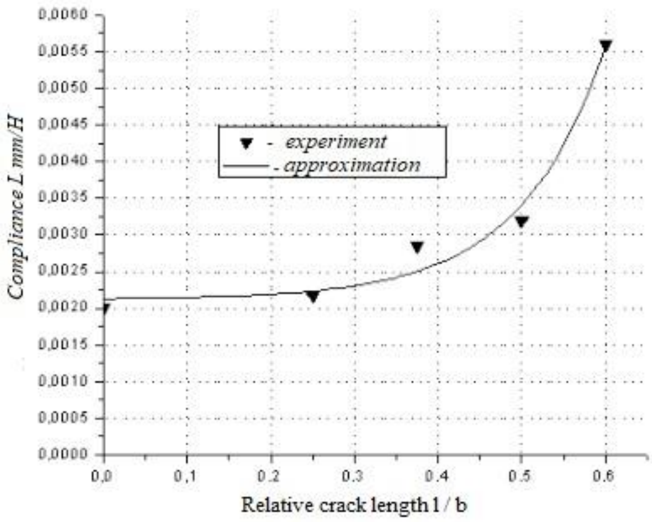

Figure 4: Dependence of compliance l of the relative crack length l / b

In accordance with the adopted procedure, fracture toughness is determined by the formula

$$G_{IC} = \frac{P^2}{2hb} \cdot \frac{d\lambda}{d\beta}. \quad (2)$$

The values of the derivative of the compliance with respect to the relative length of the crack were found by approximation (1). Experimental estimates of the fracture resistance of the samples were obtained for the following notches: l = 5mm and l = 12 mm. Destructive loads were $P_{кр}$ =212H and $P_{кр}$ =83 H , respectively.

As a result, for these two variants of notches according to the formula (2), the following values of the intensity of energy release are obtained: G_{IC} = 110.1 N / m, G_{IC} = 57.7 N / m. Differences in the values of the intensity of energy release for samples with different incision depth are due to a natural spread of material properties and measurement errors.

The experimental data obtained in the bending tests for specimens with notches allow us to determine another characteristic of the crack resistance of the material-the critical value of the stress intensity factor K_{IC}. To do this, the *K* -marketing method was used. In accordance with this method K_{IC} is defined as the limiting value of the stress intensity factor for the bending of a specimen with a crack with given geometric dimensions [1].

$$\frac{K_{IC} h b^2}{P_{кр}\sqrt{l}} = Y_1(\beta), \quad (3)$$

Where $P_{кр}$ – is the limiting value of the force, corresponding to the destruction of the sample; *h* and *b* – is height and thickness of the sample; *l* is the depth of the initial crack; $Y_1(\beta)$ – a correction factor that takes into account the final dimensions of the sample.

For the selected sample geometry and the test scheme, the function $Y_1(\beta)$ has the form [4]:

$$Y_1(\beta) = A_0 - A_1\beta + A_2\beta^2 - A_3\beta^3 + A_4\beta^4, \quad (4)$$

$$Y_1(\beta) = 1{,}0375 - 2{,}99\beta + 14{,}3125\beta^2 - 24{,}8275\beta^3 + 25{,}655\beta^4 \quad (5)$$

As a result of the calculations according to formula (3), the following values were obtained K_{IC} for the studied material with notches with depth *l* = 5mm and *l* = 12mm:

K_{IC} =1,11 MPa m $^{1/2}$ and K_{IC} = 1,1 MPa m $^{1/2}$.

The linear fracture mechanics correlations were used to estimate the brittle fracture resistance of samples from the material under consideration, which make it possible to calculate the intensity of energy release G_{IC} from known values K_{IC} and the elastic characteristics of the material obtained in [2].

$$G_{IC} = \frac{K_{IC}^2}{E}, \quad (6)$$

Where the factor *k* depends on the type of loading. For the selected test scheme $k = 1 - \mu^2$, where μ is the Poisson ratio obtained in [2]. Using the values obtained in the work K_{IC} and the elastic characteristics of the material (E = 14 300 MPa, μ = 0.276) [2.4] the calculated values G_{IC} for these two notches are as follows: G_{IC} = 77.1 N / m and G_{IC} = 63.8 N / m, which is in satisfactory agreement with the values obtained using the compliance method.

The following characteristics of natural granite are given in: K_{IC} = 1.08 MPa m$^{1/2}$, ultimate tensile strength σ_B = 19.5 MPa [5]. It should be noted that the fracture toughness of a dispersively hardened CAS type composite practically coincides with this characteristic for granite. Data on the strength of natural material slightly differ from the data for the material under study, presented in this work. Nevertheless, it should be noted that for natural rocks (including granite) there is a wide range of mechanical characteristics. So in the elastic modulus values for granite, values are in the range from 35,000 MPa to 100,000 MPa [6-16]. The mechanical characteristics of natural granite depend on many factors, for example, from the deposit of a specific stone, from the depth of occurrence, the geological structure of the massif, and so on [17-26].

4. CONCLUSIONS

In this work, the fracture resistance characteristics of CAS were determined. The experimental values of the fracture resistance characteristics of the test materials were obtained by the methods of compliance and *K*- attainment: the energy release rate G_{IC} and the critical value of the stress intensity factor K_{IC} .In accordance with the method, a series of tests was performed for three-point bending of rectangular bars with central notches on the universal testing machine ZWICK Z100. Based on the results of mechanical tests using modern measuring equipment, the elastic characteristics of a new class of granular composites based on unsaturated polyesters – molded artificial stone were determined for the first time. The values of the elastic characteristics obtained using a standard force and extensometer are in satisfactory agreement with the experimental data obtained by using the tensometric method of measuring deformation in the process of loading the sample with tensile and compressive forces. The obtained values of the mechanical characteristics of the material are comparable to those of the natural stone. Considering the substantial technological advantages of the composite material, it can be concluded that it is practical to use this material.

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