A TEST PIECE FOR MECHANICAL TESTING OF FIBER COMPOSITE MATERIALS

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This article describes a test piece that minimizes the spread of the results of testing of composite materials on a metal base by extension in the direction of a reinforcing fiber and, from the results, determines the mechanical properties of intermediate and finished products made of these materials.

One of the significant factors determining the precision, material capacity, and duration of mechanical tests is the geometrical characteristics of the test piece. The importance of selecting optimal characteristics is confirmed by normative recommendations developed for individual groups of materials, for example, GOST 1497-84 for the testing of metals and alloys. However, for composite materials (CM) on a metal base, there are as yet no such recommendations, and the above standard for testing of relatively homogeneous objects such as metals and alloys does not satisfy the requirements for heterogeneous substances like CM, due to the enormous variety of the physical and mechanical properties of the components and the reinforcement geometry.

The large variation in the properties of the component parts of CM give rise to characteristics of the tension state of the test piece in the clamps of the test machine that cause its primary failure outside the working portion and lead, therefore, to significant spread in the results [1]. The spread is so large that the results of the tests cannot serve as the basis of unambiguous decisions and conclusions. We have developed a unidirectional-CM test piece the shape and dimensions of which provide the least spread of the results of tension tests in the direction of the fiber reinforcing the metal base.

In determining the dimensions of the working portion of the test piece, it is necessary first of all to evaluate the number of reinforcing fibers in its cross section. For this purpose the method of random secants [2] is used to determine the number of structural components in heterogeneous systems. It is based on an expression from which it is possible to calculate the number of fibers \( z \) in a cross section of the working portion of the test piece:

\[ z = \omega^3 (t/\varepsilon)^3 e (1 - \varphi), \]

where \( \omega \) is a coefficient characterizing the degree of orientation of the structural component in the direction of reinforcement (less than one for fibers in the general case); \( t \) is the Student criterion for the component of the probability of reliability; \( \varepsilon \) is the relative evaluation error; and \( \varphi \) is the degree to which the fiber fills the CM.

Table 1 gives the number of reinforcing fibers in a cross section of the working portion of the test piece required for analysis at a given error under the conditions \( \omega = 1, \varphi = 0.5 \) and a probability of reliability of 0.9544.

Thus the precision embedded in Eq. (1) determines the general precision of the calculation of the form and dimensions of the test piece.

The width of the working portion is calculated from the expression

\[ b = \pi d^2 / 4 h, \]

where \( d \) is the diameter of the reinforcing fiber and \( h \) is the thickness of the CM sheet.

TABLE 1

<table>
<thead>
<tr>
<th>(a, %)</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>(x)</td>
<td>2500</td>
<td>625</td>
<td>278</td>
<td>156</td>
<td>100</td>
</tr>
</tbody>
</table>

TABLE 2

<table>
<thead>
<tr>
<th>(b, \text{mm})</th>
<th>(l, \text{mm})</th>
<th>(b_1, \text{mm})</th>
<th>(l_1, \text{mm})</th>
<th>(R, \text{mm})</th>
<th>(l_2, \text{mm})</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>50</td>
<td>10</td>
<td>30</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>75</td>
<td>10</td>
<td>30</td>
<td>50</td>
<td>20</td>
</tr>
</tbody>
</table>

In order to guarantee a uniform state of tension (simple extension) in the working portion of the test piece, its length is selected from the condition [3] \(l = (10-15)b\).

The width \(b_1\) of the test piece in the clamps of the test machine is found from the formula

\[ b_1/b = \sqrt{0.25[((1/K)-1)/\mu-1]^2 + \gamma/2[\mu-0.5][(1/K)-1]/\mu-1]}, \]

where \(K\) is the strength reserve coefficient, equal to \(\sigma_{\text{bmax}}/\sigma_{\text{bmin}}\), i.e., to the ratio of the maximum to the minimum values of the maximum strength of the fiber; \(\mu = \sigma_0/\sigma_x\) = const; \(\sigma_0\) is the yield point of the die; \(\sigma_x\) is the transverse strength of the CM during extension in the direction of the reinforcement, which is equal to \(\sigma_{\text{bmin}}\phi + \sigma_{\text{bmin}}(1-\phi)\) according to [1]; \(\sigma_{\text{bmin}}\) is the yield point of the die; \(\eta = h/l_1\); \(l_1\) is the length of the clamped portion of the test piece; and \(f\) is the coefficient of friction of the CM over the surface of the machine clamps.

In calculating the dimensionless width \(b_1/b\) from expression (3), the magnitude of \(\eta\) can be specified from the fact that the value of \(l_1\) varies as a function of the test conditions and the magnitudes of \(h\) and \(f\) in the 15 to 50 mm range.

The radius of curvature of the chamfer is determined from the condition of the equipollence of the CM die to shear in accordance with the ratio

\[ R = [4l_2^2 + (b_2 - b)^2]/4(b_1 - b), \]

where \(l_2\) is the length of curvature of the chamfer, which is not less than \(0.5\sigma_x b/\tau\), and \(\tau\) is the shear strength in the direction of reinforcement.

The dimensions of two varieties of test pieces, calculated from relations (1)-(4), are given in Table 2.

To check the resulting ratios, tests of unidirectional aluminum—boron fiber CM with the characteristics \(\phi = 0.5, d = 0.15,\) and \(h = 1.5\) mm were performed. Using the electroerosion method, test pieces of various shapes and dimensions were cut from a sheet of intermediate product.

In Fig. 1 four variants of test pieces after failure are shown. Of the objects shown, only test piece d corresponds to calculation in accordance with formulas (1)-(4). It is precisely in this test piece that failure occurred in the working portion, which testifies to the validity of the derived equations.

The results of tests of three batches of test pieces of aluminum—boron CM are given in Fig. 2 in the form of histograms. The shape and dimensions of the test pieces of the first batch were selected in accordance with GOST 1497–84, the second corresponded to the upper (see Table 2) variety of the new test piece, and the third to the rectangular shape without chamfers (Fig. 1a). As is evident from Fig. 2, The new test piece is characterized by a smaller spread of test results and a large average magnitude of the yield point of the CM in comparison with standard and rectangular test pieces.