Evaluation of the adhesion strength of linear filler fibers of composite polymer reinforcement

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Abstract. The article discusses a method for evaluating the adhesion strength of linear filler fibers by tangential stresses obtained during shear tests of end cylindrical axisymmetric beads on a composite polymer reinforcement rod. The geometric parameters and material of the tested samples, the used equipment, the measuring instruments and the results of the tests are presented.

1. Introduction.
The creation of modern, competitive structures and products largely depends on the properties of the materials used in their production. The structural strength and mechanical characteristics affect the reliability and durability of structures made of polymer composite reinforced (PCR). Strength is one of the important mechanical parameters. The normative regulation of the strength of PCR is currently carried out by the requirements of the State Standard [1], in which the ultimate strength in axial tension [1,2] is determined as for reinforcing steel, and the ultimate strength in compression is determined [1,3], as for plastics. However, the use of normative test methods for PCR does not allow assessing the adhesion strength of linear filler fibers to control the established mechanical properties and strength characteristics, because the main feature of composite materials from plastics and steels is the presence of a component that connects substances of dissimilar chemical structure: matrix and filler. It is known that PCR is cured rods made of glass, basalt, carbon, or aramid fibers (linear fillers), impregnated with a thermosetting or thermoplastic polymer binder [4]. The presence of a large number of processes (physical, chemical, etc.) acting on the rod in the production process creates certain difficulties in the theoretical analysis of product parameters. Therefore, it is extremely important to have effective means and methods for assessing the strength of PCR linear filler fibers as products with outspoken discrete structures. The development of such methods and tools seems to be relevant.
2. The Method of test for PCR samples and assessment of the adhesion strength of linear filler fibers.

The essence of the method under consideration consists in loading PCR samples on a tensile testing machine 2055-P -0.5 (figure 3) with an increasing load and recording the values of "load-displacement", and loading is performed on the axis-symmetric section of the bearing rod - a bead made with grooves , given the width and diameter along the axis of the reinforcement. The maximum load is used to estimate the adhesion strength of the adhesion of the fibers of the linear filler along the sample diameter [5-8].

To implement this method, specimens (figure 1) were prepared from glass composite reinforcement (GCR), the geometric dimensions of which are shown in figure 2.

For testing, 9 samples of various batches with a nominal diameter of 10 mm were selected, since the reinforcement of such diameters is the most demanded on the market. The equipment for the testing machine 2055-P -0.5 (figure 3) was also made: a pusher with an inner diameter $d_{cutter}$ and $d_{support}$ (figure 4). All tests were carried out at Ltd “Independent Construction Laboratory” in Izhevsk. Applied equipment and measuring instruments: electronic laboratory scales VLG-MG4 head. No. 021 verification certificate No. 0-441-03 until 04.02.2020, vernier caliper VC-II, head. No. M671665, verification, certificate No. 0-9990-01 until 02.08.2021.

The registration of the "load-displacement" value (figure 5) when shearing the beads is performed in the direction of their compression while maintaining the perpendicular position of the bead face in the direction of the shear force. The actual values of the maximum values of the adhesion forces of the linear filler of the rod $F_{ad for}$ with the same projection width $\Delta h$ are equal to the maximum shear load $F_{ad for} = F_{max}$. From the maximum load $F_{max}$ applied to the samples, which resulted in the shearing of the protrusions, the tangential shear stresses of the fibers of the PCR linear filler $\tau_{shear}$ (figure 6), were determined as the ratio of the resistance force to the maximum load $F_{max}$ to the area of its contact with the power rod $S_{shear}$:

$$\tau_{shear} = \frac{F_{max}}{S_{shear}}$$
\[ S_{\text{shear}} = \pi \cdot d_{\text{shear}} \cdot \Delta h. \]

Figure 3. The tensile testing machine 2055-P - 0.5.

Figure 4. The equipment for the testing machine.

3. Test results (table 1, figure 5-8)

| № | F, H L, mm | t, c | № | F, H L, mm | t, c | № | F, H L, mm | t, c | № | F, H L, mm | t, c |
|---|------------|-----|---|------------|-----|---|------------|-----|---|------------|-----|
| 1 | 7.8        | 0.06| 0.14| 7 | 179.5     | 0.42| 0.20| 13 | 648.0      | 0.78| 0.26| 19 | 1437.1     | 1.13| 0.32 |
| 2 | 24.1       | 0.16| 0.15| 8 | 247.2     | 0.47| 0.21| 14 | 773.4      | 0.84| 0.27| 20 | 41.1       | 1.21| 0.33 |
| 3 | 36.9       | 0.22| 0.16| 9 | 311.2     | 0.53| 0.22| 15 | 867.4      | 0.88| 0.28|    |            |     |     |
| 4 | 41.4       | 0.27| 0.17| 10| 399.7     | 0.60| 0.23| 16 | 1061.8     | 0.98| 0.29|    |            |     |     |
| 5 | 66.8       | 0.33| 0.18| 11| 472.3     | 0.66| 0.24| 17 | 1220.7     | 1.04| 0.30|    |            |     |     |
| 6 | 116.9      | 0.37| 0.19| 12| 536.2     | 0.73| 0.25| 18 | 1327.6     | 1.08| 0.31|    |            |     |     |

Figure 5. Loading curve \( F(t) \) of the sample № 1.

Figure 6. Graph of values of tangential shear stresses \( \tau_{\text{shear}}(t) \), MPa over time \( t, s \) for sample № 1.

Figure 7 shows a PCR sample with a bead made on the rod before testing. Figure 8 shows a sample with a cut bead with clearly visible fibers of linear filler.
4. Conclusions
The considered method of testing for shear of beads, performed on samples of composite polymer reinforcement, makes it possible to monitor the picture of the strength state of the bar in depth for various nominal diameters of the reinforcement.

The strength of the transverse links of longitudinally oriented fibers is an indirect indicator of the breaking strength of the reinforcing bar and is informative enough to judge the quality of the reinforcing bar and its tensile strength. In this case, not only the absolute value of the obtained values of the adhesion forces of the fibers of the linear filler is assessed, but also the deviation from the specified (reference or certification) values of the strength parameters of the reinforcement.

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References
[1] State standard 31938-2012. “Composite polymer reinforcement for reinforcing concrete structures” (edited on 2012 Russia)
[2] State standard 12004. “Reinforcing-bar steel” Tensile test methods (edited on 1981)
[3] State standard 4651 “Plastics. Compression test method” (edited on 1982)
[4] Yu V Ganziy2018 Identification of the dangers of obtaining low-quality products from polymer composite material using the example of construction composite reinforcement Bulletin of ISTU named after M.T.Kalashnikov 21(3) 13-9
[5] Vetoshkin V A, Urazbakhtin F A, Nizamov R Sh, Neplyakh S V, Pushkarev S A and Ganziy Yu V Pat. of the Russian Federation No 2709597 appl. 14.11.2018, publ. 18.12.2019
[6] Mikhailov R N, Mikhailov P N, Neplyakh S V, Bolotov I A and S A Pushkarev Pat. of the Russian Federation No 2676558 appl. 06.09.2016, publ. 09.01.2019
[7] Urazbakhtin F A, Ganziy Yu V and Otrishko M V2018 Principles of construction of the technological system for the manufacture of construction polymer reinforcement IOP Conf. Series: Materials Science and Engineering (MSE) 450 032040 doi:10.1088/1757-899X/450/3/032040
[8] Mikhailov R N et al. Pat. for invention No 2 676 558 appl. 06.09.2016, publ. 09.01.2019