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Bond Strength of GFRP Bar with Concrete

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Abstract: In this article, the bond strength between GFRP rebar and concrete is investigated, and the differences compared to the bond between steel rebar and concrete are analyzed.

Keywords: Concrete, FRP bar, steel bar, bond strength.

Introduction:

In order for reinforced concrete structures to perform reliably, sufficient bonding between concrete and reinforcement is required, as the transfer of stresses between these two materials is a crucial factor [1–3]. Although the bond strength between steel reinforcement and concrete is well-documented in literature and design standards, the bond behavior of fiber reinforced polymer (FRP) reinforcement with concrete differs significantly [4–5]. This difference arises from the unique characteristics of FRP compared to conventional steel reinforcement, such as surface texture, modulus of elasticity, shear brittleness, and tensile strength. Therefore, a clear understanding of the bond strength between concrete and FRP is essential [6–7].

To determine the bond strength between FRP and concrete, tests are conducted in accordance with the requirements of GOST 31938-2012 [8]. According to this standard, bond strength is assessed by performing a pull-out test, where the rebar is extracted from a concrete cube specimen (Fig. 1). This method is based on evaluating the shear stresses developed along the interface between the concrete and the surface of the composite reinforcement. The test is performed under the maximum load recorded during pulling, regardless of the failure mode (either along the reinforcement or at the bond interface between the concrete and reinforcement).

If the diameter of the reinforcement is 10 mm or less, a concrete cube with 100 mm edges is used; for diameters of 12–18 mm, a 150 mm cube; and for diameters above 18 mm, a 200 mm cube is required. The bonded length of the FRP in the concrete should be equal to 5 times the diameter of the reinforcement. The unbonded portion of the rebar inside the concrete must be protected with a polyvinyl chloride (PVC) plug or sleeve. During testing, a closed steel fixture with side dimensions of at least 200 mm and a minimum thickness of 20 mm is used. This fixture must have a central hole for the rebar to pass through.

The bond strength between FRP reinforcement and concrete is determined using the following expression:

$$\tau_r = \frac{P}{cL_{fb}} \qquad \textbf{(1)}$$

where: P – tensile force, кН;

c – nominal length of the outer circumference of the reinforcement, $c = \pi d$, mm;

L_{fb} – embedded bond length of the reinforcement, мм.

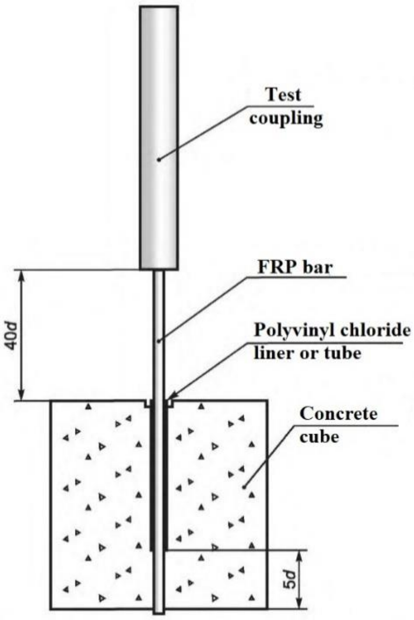


Figure 1. Setup diagram for embedding GFRP rebar in a concrete cube

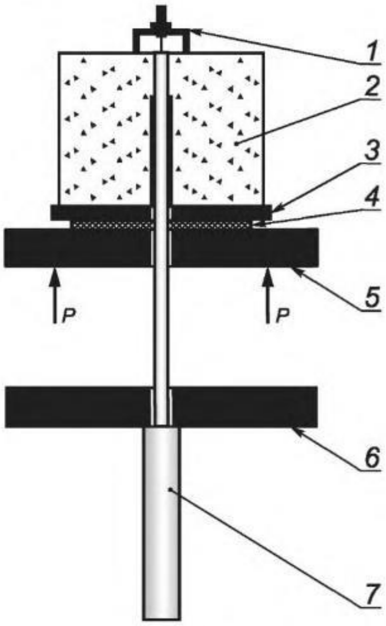
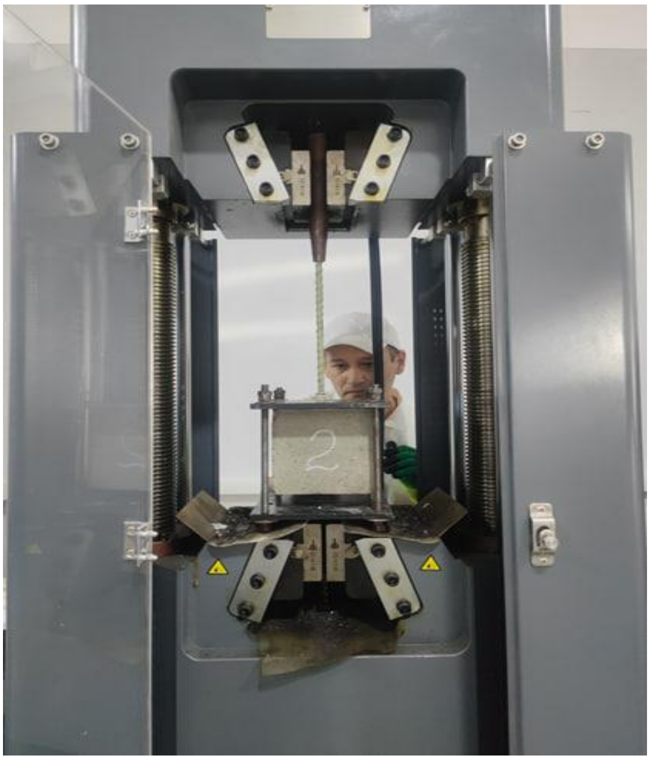


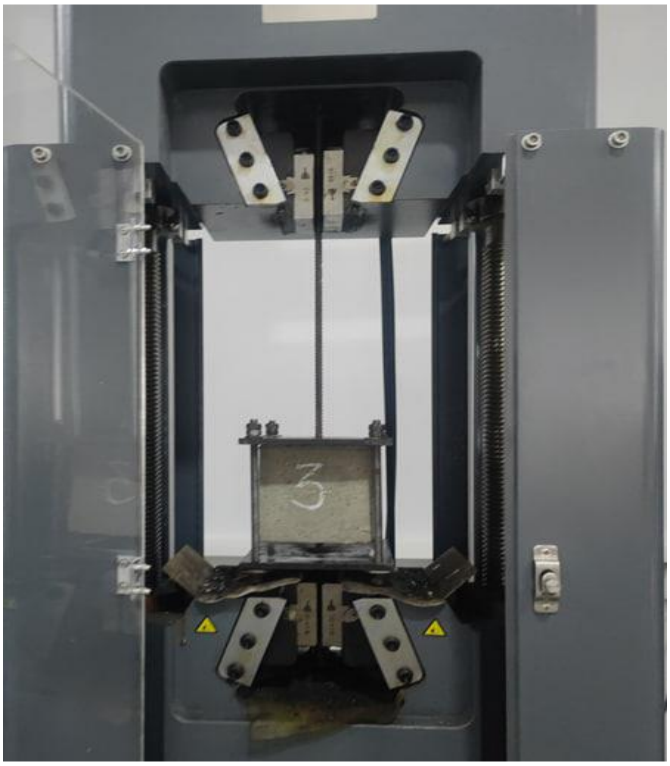
Figure 2. Test setup diagram for pulling GFRP rebar out of a concrete cube:
1 – measuring device; 2 – cube specimen; 3 – support plate; 4 – soft plug; 5 – movable crosshead of the testing machine; 6 – fixed crosshead of the testing machine; 7 – coupling.

Testing of the GFRP bar specimens was conducted in accordance with GOST 31938–2012 [8], while testing of the steel bar specimens followed the international standard GOST R 57357–2016 [9], using a universal hydraulic machine (Figure 3).

For this study, both types of reinforcement were used GFRP and steel bars with a diameter of 10 mm. The specimens were anchored into concrete cubes with edge dimensions of 150 mm. To accurately evaluate the bond between the reinforcement and concrete, all concrete cube specimens were prepared with identical dimensions and kept under standard conditions for 28 days.

Since the surface texture of the GFRP bars was non-uniform and there was a risk of slippage during compression due to the serrated grips of the hydraulic press, a special metal coupling (Figures 1 and 2) was installed for the GFRP specimens during testing. This coupling ensured reliable performance of the reinforcement during the pull-out process. In contrast, due to the mechanical properties of the steel reinforcement and the requirements specified in the standard (GOST R 57357–2016), the use of additional couplings was not required for this type of reinforcement.





a) b)

Fig. 3. Test for determining the bond strength between concrete and GFRP (a) and steel (b) reinforcement

To study the bond between concrete and reinforcement, six specimens were prepared for each type of reinforcement: GFRP and steel. In the case of GFRP specimens, reliable results could be obtained only if the rebar was firmly connected with the coupling and behaved as a single unit. According to the test results, there was no significant difference observed in the bond performance between GFRP and steel reinforcement. The average bond strength of the GFRP bars was 18.63 MPa, while that of the steel bars was 20.85 MPa (Table 1). If the ribs on the surface of the GFRP bars are securely attached to the bar body, they can provide high bond strength with concrete, comparable to that of steel reinforcement.

Table 1. Test results of bond strength between GFRP and steel reinforcement with concrete

Series	Bar type	Concrete strength R_n, MPa	Tensile for P, kN	Slip, mm	Bond strength, МПа	Mean bond strength, MPa
G1-10	GFRP	30.2	29.2	17.8	18.59	18.63
G2-10	GFRP	30.2	29.9	17.1	19.03	
G3-10	GFRP	30.2	28.6	17.4	18.21	
G4-10	GFRP	30.2	30.1	17.6	19.16	
G5-10	GFRP	30.2	28.2	16.8	17.95	
G6-10	GFRP	30.2	29.6	17.2	18.84	
S1-10	A-III (steel)	30.2	34.1	19.2	21.71	20.85
S2-10	A-III (steel)	30.2	28.7	16.9	18.27	
S3-10	A-III (steel)	30.2	33.6	17.5	21.39	
S4-10	A-III (steel)	30.2	34.2	18.3	21.77	
S5-10	A-III (steel)	30.2	32.1	18.9	20.44	
S6-10	A-III (steel)	30.2	33.8	19.0	21.52	

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