Improving the reliability of FRP bars tests by increasing the adhesive strength in specimen anchor

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Abstract. Test methods for reinforcing steel is not suitable for fiber reinforced polymer (FRP) rebars because it can cause destruction of the edge zones of the samples. The polymer matrix and fibers are not able to resist compression across the fibers. Existing test methods for FRP rebars do not contain information about the equipment and composition of the adhesive composition. The purpose of the study is to clarify the adhesive composition and design of the FRP specimen anchor. Methods. There were experimental studies of fiberglass reinforcement polymer rebars samples carried out. The following factors varied: the proportion of the components of the adhesive composition; the area of the adhesive contact of the FRP specimen anchor. Results and Discussion. The proportion of epoxy glue and quartz sand providing the test of automatic transmission is determined. The influence of the thread on the inner surface of the FRP specimen anchor on the adhesive strength in the contact zone «adhesive composition-steel» is estimated. A universal three-dimensional model of the centering plug for manufacturing using additive technologies has been developed. Conclusions. The results of the investigation can be used to upgrade the FRP rebars test methods.

1. Introduction
Fiber-reinforced polymers (FRP), consisting of glass, carbon, aramid or basaltic fibers, is relatively new building material, that is used as steel reinforcement alternative in reinforced concrete constructions. The application of the FRP in Russia is regulated by specifications and technical documentation [1-3]. The features of FRP using in building constructions are considered in variety of different researches [4, 5].

When testing composite reinforcement for tensile strength according to the method adopted for steel, the forces in the grips of the test machine must exceed the load required for the destruction of the sample. These conditions cannot be observed with FRP rebars, because the polymer matrix has a small amount of compression resistance. The body of the polymer matrix is crumbling, and fiberglass (carbon fiber, basalt fiber) are not able to resist the transverse load. As a result, the edge zones of the specimens (areas in the grips of the test machine and areas close to them) lose their bearing capacity, which makes it impossible to test the samples.

The test method described in State Standard GOST 31938-2012 [1] provides protection of composite reinforcement from destruction by using a steel coupling (fig. 1), but it causes a different problem – the slip of the reinforcing bar from the coupling (more often along the border «adhesive composition-steel», less often – «adhesive composition-rebar»).
It is necessary to develop a test method and sample preparation that excludes both the destruction of the armature and its slipping out of the test coupling (which is also the destruction of the sample).

2. Methods

For solution of this problem it is necessary to carry out a number of theoretical researches and adhesive composition tests. Herewith other factors, influencing tests result, should be constant:
- reinforcement bar dimensions and materials;
- steel sleeve dimensions and materials;
- adhesive composition mixing conditions;
- conditions of pasting of FRP-bar edges into steel pipe.

In this research analysis of foreign technical standards has been produced. Particularly standards, concerning methods of FRP physicomechanical properties determining. Canadian technical standards contain guidances for applying of pure epoxy or epoxy with quartz sand in volume proportion 1:1 [6, annex B].

Sand addition in epoxy leads to following results:
- adhesive composition shrinkage reduction;
- strength increasing;
- increasing the adhesive strength to the surface of FRP rebar.

For obtaining results of adhesive joint strength estimation, not FRP bar strength estimation, we decided to reduce steel pipe length.

Five specimens for testing of each adhesive composition where prepared:
1) pure epoxy;
2) pure epoxy, mixed with quartz sand (fraction from 0 to 1.25 mm) in volume proportion 1:1.

Compliance with the specimens’ center during preparation was ensured by specially manufactured using additive technologies in the plugs, which were installed at the outer end of the couplings (fig. 2), and washers.
The hole diameter should be slightly larger than the diameter of the reinforcing bar (a gap of 0.1 mm is sufficient). This is necessary for free movement of the plug along the rod.

When manufacturing in this way, it is important to take into account the shrinkage of the part during cooling, which is due to the properties of the material (for example, for PLA plastic, it is on average 2%, for ABS plastic – 8%). This error must be set at the stage of creating a three-dimensional model of the part.

3. Results and discussion
Specimens test results are shown by Fig. 3 and 4 and Table 1.

![Figure 3. Specimens with pure epoxy test results.](image)

![Figure 4. Specimens with composition of epoxy and sand test results.](image)
Table 1. Results.

| Specimen number | Ultimate load, kN | Specimen number | Ultimate load, kN |
|-----------------|-------------------|-----------------|-------------------|
| 1               | 44.80             | 6               | 44.83             |
| 2               | 10.13             | 7               | 44.63             |
| 3               | 27.62             | 8               | 45.76             |
| 4               | 36.57             | 9               | 52.98             |
| 5               | 37.74             | 10              | 45.85             |

All specimens' destruction occurred in steel coupling. In the samples with pure epoxy glue, the «glue composition-steel» boundary was destroyed (fig. 5). In samples with a mixture of glue and sand, the rebar was destroyed in the form of a section of the winding from the rods (fig. 6).
4. Conclusions
The introduction of quartz sand into the epoxy adhesive increases the adhesive strength in the contact zone «adhesive composition-steel». The use of this adhesive composition allows you to avoid slipping the composite reinforcement in the test coupling and get more accurate results in experimental studies.

Production of caps and centering washers using additive technologies accelerates the process of sample preparation and, as a result, testing samples of composite polymer reinforcement for axial tension.

Preparation of testing specimens for axial compression, pulling out of concrete can also be performed using these results.

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