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Strength and Crack Resistance of Hybrid Steel-Bfrp Reinforced Concrete Beams

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Abstract: This article presents concrete classes used for concrete beams with hybrid steel-basalt fiber reinforced polymer (BFRP), prepared cube samples and their testing, determination of strength of BFRP and steel reinforcement. In addition, data on the preparation of samples in 9 series, the results of flexural testing, strength and crack resistance are shown.

Key words: BFRP rebar, steel rebar, concrete beam, crack resistance, strength, reinforcing cage.

Introduction

In order to improve the corrosion resistance, flexibility and deformability of concrete beams, they are reinforced with FRP rebar, especially when used hybrid with steel, it increases the strength of concrete beams in addition to the above characteristics. [1-6]. In this way, BFRP reinforcement is placed closer to the tensile surface, while the steel reinforcement is deeper into concrete beam. The deeper placement of steel reinforcement has a large concrete cover that protects it from corrosion, and also plays an important role in controlling crack width, ductility and deflections. [7-10]. However, it can also be seen that in some studies, reinforcements in hybrid reinforced beams have been studied by placing them in several layers. Because FRP reinforcements do not yield, the stresses in the reinforcements in each layer vary with the reinforcement layer and the position of the neutral axis. In addition, if the same element is reinforced with different reinforcements, the stresses in each reinforcement will be different and performance will be different compared to a beam reinforced with the same reinforcement [11-13].

Methods

In this study, steel and BFRP reinforcements are used in one layer in series 1 and 2 samples (B2-1S12-2F10, B3-1S12-2F12, B5-2S12-2F12 and B6-2S10-2F12), in Series 3 (B8-3S10-2F10, B9-2S10-3F10), reinforcementa are arranged in two layers.

Table 1 Results from testing of steel and BFRP reinforcements

Group of series	Beam notation	Tensile longitudinal bar	Actual diameter, mm	Cross section of rebar $A_{s\ (f)}$, cm^2	Modulus of elasticity $E_{s(f)}$, MPa	Resistance of rebar $R_{s(f)}$, MPa
Group 1	B1-3S12	3Ø12 A-III	11,8	1,094	200000	398
	B2-1S12-2F10	1Ø12 A-III 2Ø10 БКА	11,9 9,8	1,112 0,754	200000 51560	398 920
	B3-1S12-2F12	1Ø12 A-III 2Ø12 БКА	11,7 12,0	1,075 1,131	200000 51800	398 890
Group 2	B4-4S12	4Ø12 A-III	11,9	1,112	200000	398
	B5-2S12-2F12	2Ø12 A-III 2Ø12 БКА	11,8 11,8	1,094 1,094	200000 51800	398 890

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	B6-2S10-2F12	2Ø10 A-III 2Ø12 БКА	9,8 11,7	0,754 1,075	200000 51800	399 890
Group 3	B7-5S10	5Ø10 A-III	9,6	0,724	200000	399
	B8-3S10-2F10	3Ø10 A-III 2Ø10 БКА	9,9 10,1	0,770 0,801	200000 51560	399 920
	B9-2S10-3F10	2Ø10 A-III 3Ø10 БКА	10,0 10,0	0,785 0,785	200000 51560	399 920

To define deformative and strength characteristics of BFRP reinforcement, the samples were prepared according to the requirements of GOST 31938-2012 (Fig. 1). When the diameter of FRP rebar was 10 mm, the diameter of the coupling was 35 mm, its wall thickness was 4 mm and its length was 300 mm, and base length was 40d or 400 mm. The modulus of elasticity of BFRP was taken in the range of (0.2...0.5)P of its tensile strength.

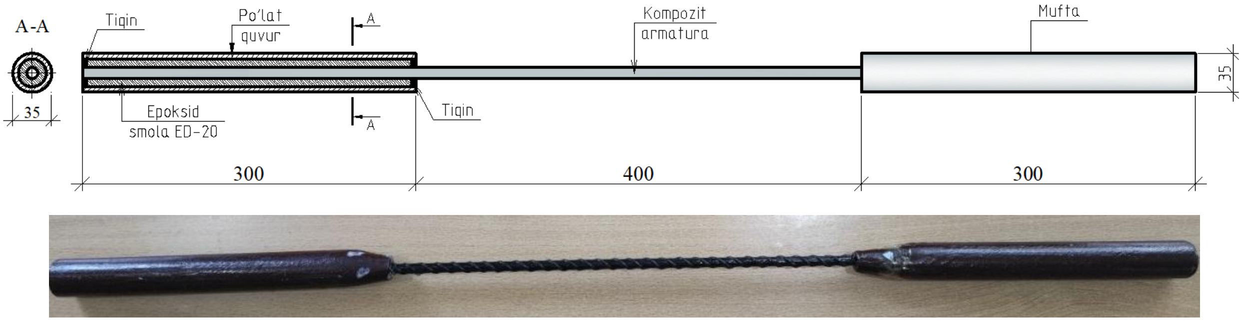


Fig. 1. Prepared sample to test BFRP

Fig. 2. Testing BFRP bar

Fig. 3. Testing steel bar

When forming the reinforcing cage, their junctions were connected using wires with a diameter of 0.9 mm. Since the beam was studied according to the normal section, stirrups were not installed in its middle part (Fig. 4).

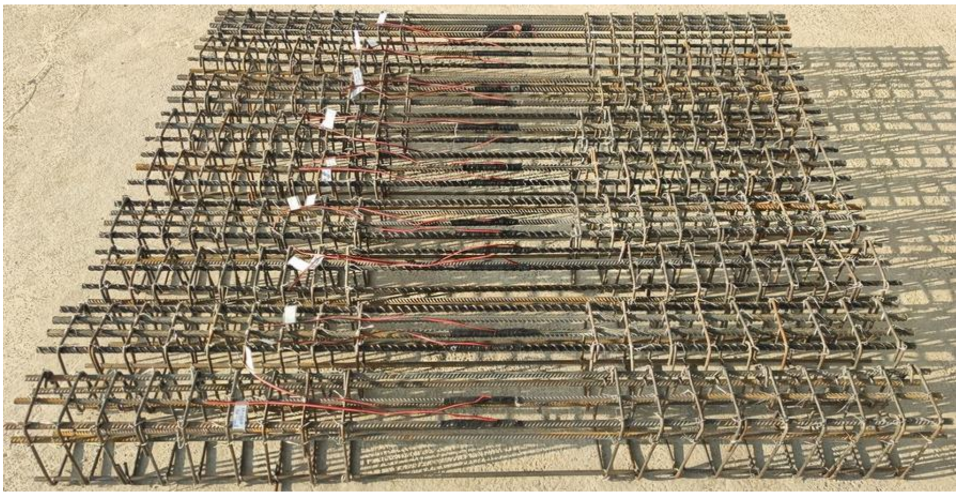


Fig. 4. Reinforcing cage

Strength and deformation characteristics of concrete were determined by testing cube samples with nominal dimensions of 100x100x100 mm. A total of 9 cube samples were prepared. The concrete classi is equal to B30. For concrete, river gravel with a size of 0.5-15 mm, fineness modulus of sand Mk=2.0...2.5 and ПЦ400Д20 cement were used. Cube specimens were taken from the prepared mixture for concrete beams and tested in a hydraulic press after 28 days of storage and a loading rate was 0.8 MPa/s (Fig. 5 and 6). When determining the strength of concrete, the scaling factor was assumed to be equal to 0.95.

Results and discussion

Table 2 Results of compressive strength of concrete cube samples

No	Group of beams	Size $a \times b \times h$, mm	Destruvtive force P, kN	Strength, R_i MPa	Average strength, R_m MPa	Normative strength, R_n, MPa	Concrete grade	Elastic modulus E_b, MPa
1	Group 1	101x100x98	384,31	36,5	35,1	33,3	B30	31087
2		101x101x100	368,35	35,0				
3		99x102x100	355,84	33,8				
4	Group 2	100x101x101	356,61	33,9	33,3	30,4	B30	30373
5		100x100x101	324,84	30,9				
6		100x100x100	369,08	35,1				
7	Group 3	102x101x99	366,86	34,9	38,7	33,6	B30	32409
8		100x101x101	408,48	38,8				
9		101x101x100	447,02	42,5				

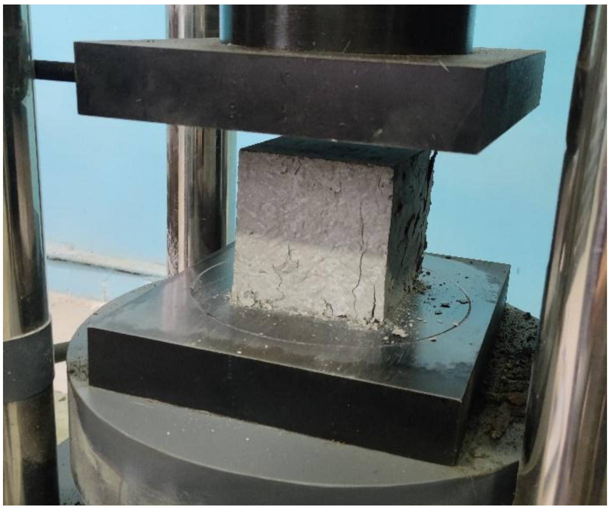


Fig. 5. Testing cub samples

Fig. 6. Tested cube samples

Wooden forms with a thickness of 40 mm were used for the preparation of beam samples (Fig. 7). In order to ensure that they do not absorb moisture from the concrete, the forms were lubricated before concreting and special attention was paid to their compaction after the concrete was placed. The prepared samples were removed from the forms after 24 hours and tested after 28 days of storage.

Fig. 7. Forming concrete beams

Table 3 shows the values of bending moment and load-carrying capacity of the beams and their ratios.

As a result of the experimental testing of beams, the formation of cracks in beams reinforced with steel reinforcement developed later than in hybrid beams, that is, the first visual cracks were observed at 19...21% of the beam load capacity. But in hybrid beams were 15...17%. Theoretically, the formation of cracks was formed at 10...15% of the ultimate moment (Table 3).

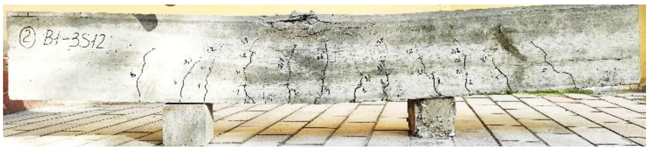
Table 3 Values of bearing and cracking moment in beam samples

Beam notation	Theory			Experiment		
	M_{crc}^{the}, kN·m	M_u^{the}, kN·m	$M_{crc}^{the} / M_u^{the}$	M_{crc}^{exp}, kN·m	M_u^{exp}, kN·m	$M_{crc}^{exp} / M_u^{exp}$
B1-3S12	3,31	22,46	0,15	5,37	25,43	0,21
B2-1S12-2F10	3,13	25,58	0,12	4,18	26,61	0,16
B3-1S12-2F12	3,16	28,40	0,11	4,95	31,52	0,16
B4-4S12	3,11	28,74	0,11	6,76	31,85	0,21
B5-2S12-2F12	2,98	29,02	0,10	4,88	32,46	0,15
B6-2S10-2F12	2,88	27,10	0,11	4,84	30,86	0,16
B7-5S10	3,16	23,98	0,13	5,16	27,07	0,19
B8-3S10-2F10	3,12	28,15	0,11	4,57	27,18	0,17
B9-2S10-3F10	3,03	28,56	0,11	4,48	29,52	0,15

The increase in the amount of FRP reinforcement in the beam caused the cracking moment to be small. Also, the distance between the cracks and their length was greater than that of ordinary beams. Since hybrid steel-BFRP reinforced beams are more deformable than steel reinforced beams, the crack development is uniform until the specimen failures. It should be noted that the opening width of cracks in steel reinforced concrete beams are small before steel yielding, but after yielding, the width and number of cracks increased rapidly. Due to the low modulus of elasticity of BFRP reinforcement, branching of cracks in the tensile zone was observed. In case of ordinary concrete beams, this phenomenon occurred only after steel yielding (Fig. 8).

Fig. 8. Stages of formation and development of cracks in beams under load

The failure of steel reinforced concrete beams (B1-3S12, B4-4S12, B7-5S10) occurred as the 1st case of normal section failure, i.e. failure of balanced reinforced concrete. Initially, the cracks were formed in the tensile zone, the reinforcements took the stress in the sections where the cracks were formed, and the concrete and the reinforcement worked together between and above the cracks. After the reinforcement in the section where the cracks were formed has reached the yield strength, the cracks have increased beyond the permissible values, and then the concrete crushed in the compressive zone. After the reinforcement reached the yield strength, the stiffness of the reinforced concrete beam decreased, and the cracks and deflection increased rapidly in the beam (Fig. 9).



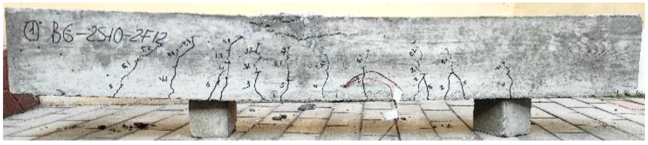
B1-3S12

B4-4S12

B2-1S12-2F10

B5-2S12-2F12

B3-1S12-2F12



B6-2S10-2F12

B7-5S10

B8-3S10-2F10

B9-2S10-3F10

Fig. 9. Failures of beams after experimental test

Conclusion

Following results obtained and conclusions were reached:

1. The tensile strength of BFRP rebar is 2 times greater than yield strength of steel bar.
2. In hybrid steel-BFRP reinforced concrete beams, initial cracks were formed at 15...17% of the ultimate load, while in ordinary reinforced concrete it was 19...21%.
3. Crack formation in hybrid steel-BFRP reinforced concrete beams developed and branched earlier than in steel reinforced concrete beams.

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