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Composite materials cohesion parameters

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Abstract. The article presents the study results of parameters of the macroporous composite cohesion with glass composite parameters, basalt composite and metal reinforcement elements by the pull-out of the bar from a concrete cube. It has been established that the best joint operation of reinforcement element with macroporous composite can be ensured by the use of glass composite reinforcement element. Ultimate strength of its cohesion with macroporous composite of B7.5 (D1400), B10 (D1600) classes is 20-45% higher than the values of cohesion strength of basalt composite and metal reinforcement elements for all options of combining the classes by strength and diameter of reinforcement elements (∅ 6,8,10 mm). With increased strength class of the composite, ultimate strength of all the studied types of reinforcement elements is growing consistently. The change in strength of reinforcement elements cohesion with macroporous composite through variation of their diameter has different patterns for the studied types of reinforcement elements.

1. Introduction

The value of ultimate strength of cohesion ensures reliable operation of constructive elements consisting of heterogeneous composite materials. This feature is the one defining the construction rigidity on the whole. Cohesion of reinforcement elements with composite is cooperation of three elements: composite, reinforcement, and contact layer area. The structure and characteristics of macroporous composite influence the adhesion together with geometric and physical-mechanical properties of reinforcement.

It should be admited that joint operation of metal reinforcement element with cement composites of different classes has been studied rather thoroughly. In addition to studying the cohesion of steel reinforcement elements with the composite, we have also obtained the results of experimental and theoretical research of fiberglass parameters and basalt plastic reinforcement elements and structures reinforced with them [1- 6]. Issues of cohesion methodology tests have been studied and recommendations on the change of the composite protective layer thickness of reinforcement element in the composite embedment ratio were suggested [7, 8]. The obtained results of the ultimate strength values of reinforcement elements cohesion with thick and light composites were received through numerical modeling of their behavior or experimentally by the method of axial pull-out of reinforcement element from the body of the composite, as the most popular one [9-11]. At the same time, influence of the type, geometry, reinforcement element surface, kind and strength of composite as well as its age and hardening conditions were evaluated [12, 13]. As a result, requirements for reinforcing elements securing the best cohesion with thick high-strength composites are well-known.

At the same time, there is no reliable information on parameters of macroporous composites cohesion with the reinforcement elements, which are considerable factors of constructions bearing capacity. This information is necessary for calculating and designing constructions based on macroporous composites [14-21].

Principal conditions ensuring reliable joint operation of composite and reinforcement element in the constructions are the following:

- cohesion of reinforcement element with composite along their connection preventing the pull-out (shift) of reinforcement element in the composite,
- the value of composite linear strain coefficient and reinforcement element.

The structure of macroporous composite will have a heterogeneous contact layer with the surface of reinforcement, which will logically influence the value of cohesion. Secondly, macroporous composite has lower strength and increased deformability compared to the other types of composites [22]. Therefore, there is a high probability of pull-out (shift) of high-strength metal reinforcement made of macroporous composite. The result is that construction potential of metal reinforcement cannot be fully used in constructional parts made of macroporous composite. Thirdly, macroporous composite does not always ensure protection of reinforcement from corrosion in contrast to thick composite.

For the mentioned above reason, the main problem of the study is the definition of requirements to reinforcement element (type, physical-mechanical properties, profile, diameter) which secure optimal joint operation of reinforcement element with macroporous composite.

This paper presents the studies results of the metal glass composite cohesion value and basalt composite reinforcing elements, different in physical-mechanical properties, with macroporous composites of density 1400-1600 kg/m^3 considered as materials for compression and bending structural elements.

2. Materials and methods

2.1. Properties of materials and factor space of the research

The following factors varied in the experiments during the study of the cohesion parameters in “macroporous composite-reinforcement” system:

1. Type and diameter of reinforcement element. In addition, all reinforcement elements had similar periodic profile.
2. Average density of macroporous composite. That said, composite mix remained the same as for mass ratio of cement to sand; average density was regulated by variation of the water amount and SAS chemical additives.

The method of pull-out the reinforcement bar from the body of composite was used to evaluate the joint operation of reinforcement with composite. Embedment length depended on the diameter and accounted for 5d. Total length of reinforcement elements, in compliance with the requirements of European Standards [23, 24], was determined by the embedment length, structure of testing machine, and length of testing clutch structure so that the protruding bars could be captured by the testing machine and the pull-out sensor could be installed. Macroporous composite mixtures with property packages optimised in our previous studies were used to manufacture the samples [25] (table 1). Reinforcement elements properties were used in the experiment and parameters of their embedment into composite samples are presented in table 2.

Table 1. Properties of macroporous composite mixtures

Average density, kg/m^3	Ratio C:S	W/C ratio	Foaming agent dosage, % from the mass of cement	Superplasticiser dosage, % from the mass of cement

1400	1:1.75	0.30	0.04	0.4
1600	1:1.75	0.31	0.05	0.5

Table 2. Properties of the used reinforcement elements and parameters of their embedment into macroporous composite samples

Type of reinforcement	Production factory	Nominal diameter d, mm	Modulus of elasticity, MPa	Ultimate strength under tension, σ_b MPa	Yield strength, σ_τ H/mm ²	Values of design compression resistance, MPa	Specific elongation, %	Unrestrained bar length, mm	Embedment length, mm	Bar length, mm
Glass composite	Voronezh composite materials factory	6	50 000	800	none	300	2.2	300	30	600-800
		8						400	40	
		10						500	50	
Basalt composite	Yaroslavl composite materials factory	6	50 000	800	none	300	2,2	300	30	600-800
		8						400	40	
		10						500	50	
Metal profiled A500	OOO «Metallinvest Plus»	8	200 000	600 (ultimate strength)	500	350	Not less than 14	300	40	750-850
		10						600	50	

Cohesion with all types of reinforcement described in table 1 was evaluated in the experiments for macroporous composites of each average density.

2.2. Description of experimentation conditions

Series of sample cubes 100×100×100 mm in size were used in cohesion tests. There were 6 samples in the series for each option of type combination, reinforcement diameter, and average density of macroporous composite. The samples were manufactured in metal forms with one opening for reinforcement in each parallel side. The openings served for fixing the bar horizontally in the centre of each cube form where the reinforcement bar was mounted perpendicularly to the sides and parallel to the direction of composite laying.

Macroporous composite was manufactured by two-stage method: at the first stage water was mixed with air-entraining and superplasticing SAS additives, at the second stage bonding agent and filler were added. They were mixed in a turbine mixer at a speed of 1300 min^{-1} for 4 minutes. Once the mixture was put in the form, short time vibration was used to eliminate the air stuck near the walls of the form.

Testing of cohesion parameters was conducted through pull-out the reinforcement bar out of the sample cube using a universal static electromechanical testing system INSTRON 5982. The sample was put in a special metal frame fixed from one side in the gripping device of the testing machine. The sample in the frame was supported by a metal bearing plate and rubber interlayer between it and the frame. A displacement sensor with precision of indication of 0,01 mm was mounted on the loose end of the bar in a special carrier frame to measure the slipping of reinforcement in the composite. To measure longitudinal deformations of the reinforcement bar under tension, an extensimeter mounted in the centre of operational height of embedded bar was used. The size of the frame ensured the required distance for the installation on the protruding end of the displacement sensor bar. During the pull-out tests the value of the applied load with indications of 0,05 mm, 0,1 mm and 0,25 mm was recorded together with the value of the bar displacement under maximum load. Before the test the samples were examined and measured. The scheme of testing the samples under axial reinforcement pull-out is presented in figure 1.

In order to control the strength and density of macroporous composite, control series of unreinforced sample cubes 100×100×100 mm in size were manufactured at the same time in the volume of 24 samples for each average density.

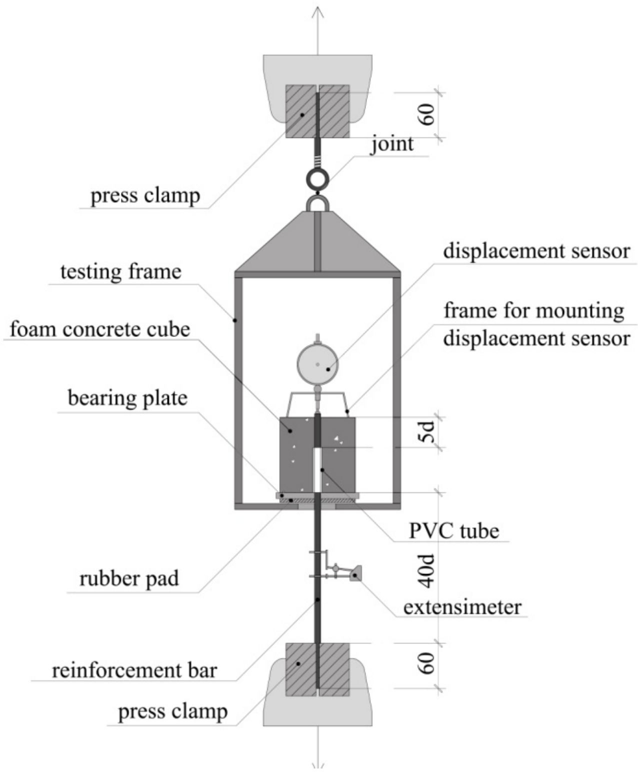


Figure 1. Scheme of testing the samples for pull-out

The samples hardened in normal conditions for 28 days. Strength tests were performed by standard method using universal 4-column static hydraulic testing system 1500HDX by INSTRON. Test results defined statistically-valid class by strength and brand by average density according to regulated standard procedures [18, 19].

2.3. Cohesion value calculation method

Strength of reinforcement cohesion with macroporous composite was evaluated by the value of resistance of pull-out the reinforcement bars from the composite. The calculation is based on defining the values of shear stress along the boundary of reinforcement cohesion with the composite realised under maximum load obtained through stretching a sample until it is destroyed regardless of the place of destruction – along the bar or along the boundary of reinforcement cohesion with the composite. Cohesion strength, according to International Standard [26], was determined by the formula (1).

$$\tau = \frac{P}{cL_{fb}}, \quad (1)$$

P is applied load, N;
c is nominal circumference of the bar, mm;
L_{fb} is length of bar embedment into composite, mm.

Processing of the test results included designing "cohesion stress – slipping" charts for each diameter. Cohesion stress for each sample was calculated for the values of applied load under the indications of bar slipping sensor at marks of 0.05; 0.1; 0.25 mm, as well as under maximum load causing the slipping of the loose end of the bar. Then, average cohesion value was calculated for each series of the samples.

3. Results

Complex test results analysis (table 3, figures 2,3,4) allowed to establish the following. During the tests, slipping of all the studied reinforcement types and diameters in the composite was determined. Pull-out of reinforcement elements of all types was accompanied by the damage in “composite – reinforcement” contact area, rupture of reinforcement element was not observed (see figure 2).

3.1. Reinforcement element type influence

The highest cohesion values were recorded for glass composite reinforcement element. Ultimate cohesion strength of this type of reinforcement element is 1.3-1.8 times higher than for basalt composite element and 1.2-1.9 times higher than for steel element for all the studied diameters of reinforcement elements and classes by composite strength. In addition, for macroporous composite of B7.5 and B10 classes the pull-out value of basalt composite reinforcement elements in control displacement points of the bar is comparable to metal reinforcement element under the condition of equal nominal diameter. Comparison of the destruction nature with “cohesion stress – slipping” charts show that it is conditioned by the nature of destruction when pulling the reinforcement element out of the composite body.

As you can see on the presented “cohesion stress – slipping” characteristic charts (figure 4), pull-out of glass composite reinforcement element is accompanied by significant slipping deformations, which leads to the increase of the effort required for its pull-out. As for fiberglass reinforcement element, local layer separation of coiling from the bar was observed when pulled out (figure 2a). This allowed assuming that this type of reinforcement element has higher cohesion of coiling with composite than with the body of the bar. Pull-out of basalt composite reinforcement bar from macroporous composite was done exactly along “composite – reinforcement element” contact area (figure 2b) without breaking the coiling, as in this type of reinforcement element the coiling is partly sunk in longitudinal fibre. Pull-out of metal reinforcement element was accompanied by partial destruction of composite near the area of contact with reinforcement element (figure 2c).

3.2. Influence of reinforcement element diameter

Change of cohesive strength of reinforcement element with macroporous composite under the variation of its diameter has different patterns for the studied types of reinforcement elements (table 3, figure 3).

Glass composite reinforcement element of B7.5 class has shown the best result of cohesive strength for the bars of diameter 6, then the value reduced by 25% and remained the same with the increase of cross section. Basalt composite reinforcement element within class B7.5 has not shown clear cohesion dependence on the change of diameter (figure 3a). As for class B10, reduction of cohesion with macroporous composite as the diameter is increased was recorded for composite reinforcement element of two types.

However, metal element shows an increase of cohesive strength by 20% for B7.5 class composite with the change of its diameter from 8 to 10 mm (figure 3b). Deterioration of cohesive strength values is noticed in class B10.

3.3. Influence of composite strength

With the increase of composite compression strength class, ultimate strength limit of cohesion of reinforcement elements with macroporous composite naturally grows (table 3). As the composite class is increased, ultimate strength limit of cohesion grows to a variable degree depending on the diameter of reinforcement element:

- by 1.3 times for glass composite reinforcement element for bars ∅ 6 mm, by 1.6 times for bars ∅ 8 mm, by 1.3 times for bars ∅10 mm;

- by 1.7 times for basalt composite reinforcement element for bars ∅6 mm, by 1/3 times for bars ∅8 mm, by 1/1 times for bars ∅10 mm;
- by 1.8 and 2.2 times for metal reinforcement element, for bars ∅8 mm and ∅10 mm correspondingly.

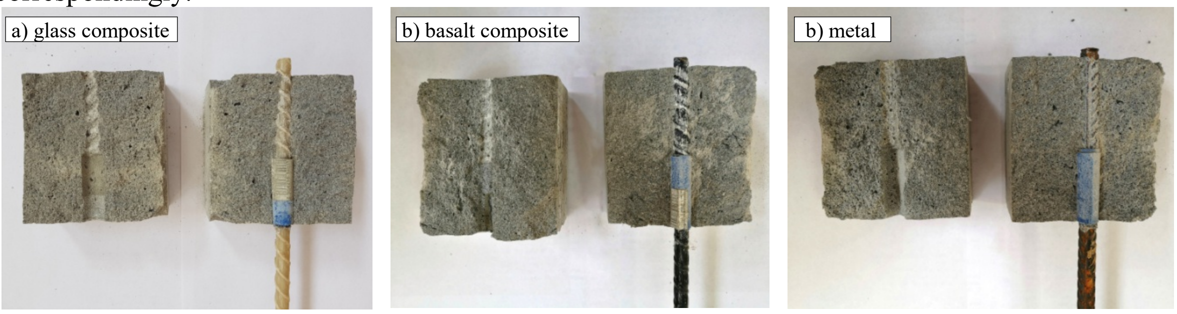


Figure 2. Nature of reinforcement elements cohesion failure with macroporous composite

Table 3. Test results of determining the value of reinforcement elements cohesion with macroporous composite

Strength class	Density grade	Type of reinforcement element	Diameter	MAX pull-out value P, kN	Displacement of A for P_{max}, mm	Cohesive strength limit with concrete, MPa
B 7.5	D 1400	Glass composite	6	4.01	3.28	7.21
			8	5.05	2.55	5.36
			10	8.63	1.63	5.36
		Basalt composite	6	1.38	1.40	3.08
			8	3.94	1.55	4.05
			10	5.84	1.88	3.81
		Metal	8	2.90	0.85	2.80
			10	5.68	0.35	3.36
B 10	D 1600	Glass composite	6	5.08	2.80	9.12
			8	8.46	2.93	8.98
			10	11.57	1.38	7.19
		Basalt composite	6	2.29	3.30	5.12
			8	4.91	2.20	5.04
			10	7.42	1.80	4.84
		Metal	8	6.34	0.48	6.11
			10	10.08	0.33	5.97

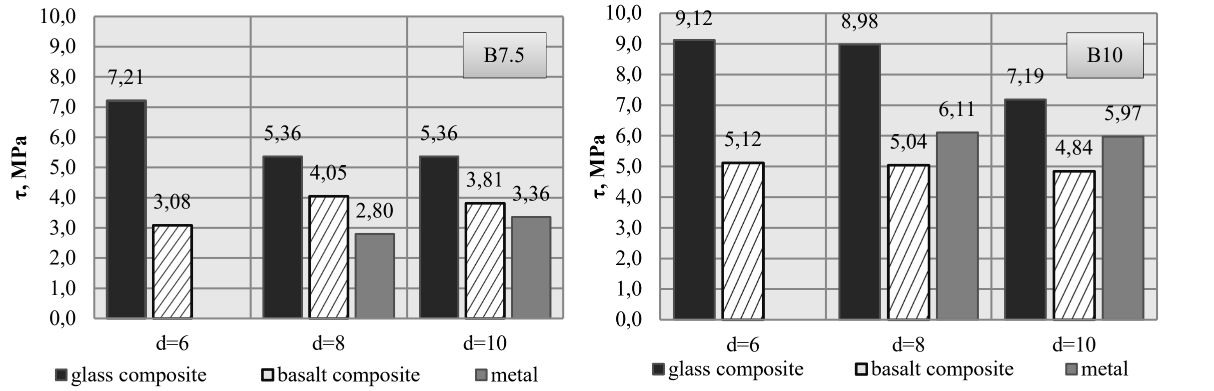
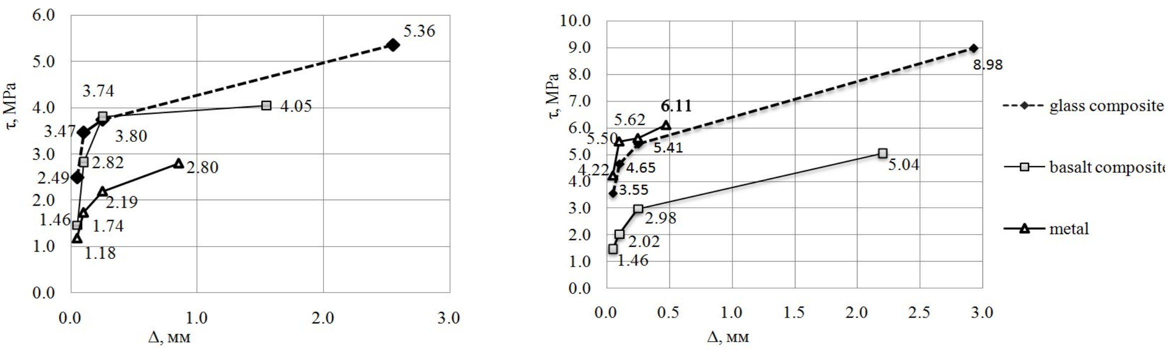


Figure 3. Cohesive strength of different types of reinforcement elements with macroporous composite of classes



a) Strength class B7.5 b) Strength class B10

Figure 4. Dependence on reinforcement elements cohesion of the 8 mm diameter with macroporous composite of classes from slipping

4. Conclusion

It has been established that best joint operation of reinforcement elements with macroporous composite can be ensured by using glass composite reinforcement element. Ultimate strength of its cohesion with macroporous composite of classes B7.5 (D1400), B10 (D1600) is 20-45% higher than the values of cohesive strength of basalt composite and metal reinforcement element for all types of combining the classes by strength and diameters of reinforcement (∅6,8,10 mm). It is conditioned by the nature of destruction at the pull-out of reinforcement elements from the composite body. As for fiberglass plastic reinforcement element, cohesive strength in the “composite – reinforcement element” contact area is higher than coiling cohesion forming the profile of the reinforcement element with the body of the bar. Basalt composite reinforcement element has the lowest cohesive strength with macroporous composite, when pulled out it is destroyed right along the “composite – reinforcement element” contact area. Pull-out of high-strength metal reinforcement element is accompanied by partial destruction of the composite near the contact area with the reinforcement element.

With increased strength class of composite, ultimate strength of all the studied types of reinforcement elements is growing consistently. However, the change in strength of reinforcement elements cohesion with macroporous composite through variation of their diameter has different patterns for the studied types of reinforcement elements. As for composite reinforcement element, the strength of cohesion with composite is inclined to decrease as its diameter grows, and it is exactly the opposite for metal reinforcement element.

The prospects of further research are related with the solution of the following tasks:

- comprehensive experimental-theoretical studies and tests of constructive macroporous composite elements reinforced with different types of reinforcement elements;
- development of recommendations for calculations and design of macroporous composite constructions based on the results of experimental research.

References

[1] Dong-Uk C, Sung-Chul C and Sang-Su H 2012 *Eng. Struct.* **34** 303-13
[2] Baena M, Torres L, Turon A, Barris C 2009 *Compos. Part B: Eng.* **40**(8) 784-97
[3] Jabbar A A S, Farid B H S 2018 *Karbala Int. J. Mod. Scien.* **4(2)** 216-27
[4] Okelo R, Yuan R L 2005 *J. Compos. for Constr.* **9(3)** 203-213
[5] Bazli M, Ashrafi H, Oskouei AV 2017 *Constr. Build. Mater*. **148** 429-443
[6] Aydin F 2018 *Constr. Build. Mater*. **163** 1-8
[7] Hao Q, Wang Y, Ou J 2008 *Eng. Struct.* **30(11)** 3239-46
[8] Carvalho E P, Palhares M M, Fernandes D S G and Alves G V 2018 *Constr. Build. Mater.* **83** 243-52
[9] Phan TS, Rossi P, Tailhan J-L 2015 *Cem. Concr. Compos.* **59** 1-9
[10] Baena M, Torres L, Turon A, Barris C 2009 *Compos. Part B: Eng.* **40(8)** 784-97
[11] Caro M, Jemaa Y, Dirar S, Quinn A 2017 *Eng. Struct.* **147** 448-57
[12] Rolland A, Quiertant M, Khadour A, Chataigner S, Benzarti K and Argoul P 2018 *Constr. Build. Mater.* **173** 136-148
[13] Li T, Zhu H, Wang Q, Li J and Wu T 2018 *Constr. Build. Mater.* **185** 545-54
[14] Bilek V, Bonczková S, Hurta J, Pytlík D and Mrovec M 2017 *Proc. Eng.* **190** 243-247
[15] Al-Shannag M, Charif A 2017 *J. King Saud Univ. – Eng. Sci.* **29(4)** 365-372
[16] Novidis D, Pantazopoulou S 2008 *4th Int. Conf. on FRP Composites in Civil Engineering* (July 22-24, Zurich: Switzerland) pp. 323-333
[17] Song X, Wu Y, Gu X and Chen C 2015 *Constr. Build. Mater*. **94** 209-217
[18] Sancak E, Simsek O , Apay A 2011 *Int. J. Phys. Sci.*, **6 (14)** 3437-54
[19] Shang H-S, Cui F-K, Zhang P, Zhao T-J, Ren G-S 2017 *Constr. Build. Mater*. 150 529-537
[20] Yoo D-Y, Shin H-O 2018 *Cem. Concr. Compos.* **93** 206-217
[21] Hassan AA, Hassan K M A and Lachemi M 2010 *Constr. Build. Mater*., **24** 520-530
[22] Novikov M V, Chernyshov E M, Slavcheva G S 2016 *Constr. Mater.* **11** 26-31
[23] EN 10080, 2005 Steel for the reinforcement of concrete - Weldable reinforcing steel – General European Standards
[24] EN 12390-3 2009 Testing hardened concrete - Part 3: Compressive strength of test specimens European Standards
[25] Slavcheva G S, Chernyshov E M, Novikov M V 2017 *Constr. Mater.***7** 20-24
[26] ISO 10406-1:2015 Fibre-reinforced polymer (FRP) reinforcement of concrete-Test methods-Part 1: FRP bars and grids International Standards