HYBRID FIBER COMPOSITE MATERIAL WITH OSA MECHANICAL LOAD-BEARING CAPACITY AFTER THERMAL HEATING

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Abstract. Fiber-reinforced concrete is now booming in the construction industry since it has various advantages over non-reinforced concrete. Important is the possibility of fiber concrete to withstand external mechanical loading after the first visible crack formation. Such possibility does not exist for non-reinforced concrete because it collapses. Competing with steel fibers, we have novel composite fibers (CF). In the single CF, glass or carbon or basalt etc. short microfibers are glued together with polymer resin, and in the hybrid composite fiber (HCF) combination of at least two or more short fibers of the following types - glass, carbon, basalt, etc. are glued together. In the present research, concrete with hybrid (Basalt-Carbon/Epoxy, Basalt-Glass/Epoxy, and Carbon-Glass/Epoxy) fibers is being investigated and studied for its possibility to withstand thermal and mechanical loading. Hybrid fibers are prepared from yarns twisted together (Basalt-Carbon, Basalt-Glass, and Carbon-Glass) impregnating them with epoxy resin (Epoxy/hardener ratio – 3:1). Single fiber weight was the same for all HF. The concrete mixture contains Oil Shale Ash (OSA) in the ratio of 0%, 15%, and 35% to the cement, to analyse the strength of the obtained fiber concrete. In our investigated concrete mixes cement was replaced by OSA that came from Auvere (Estonia) thermal power plant. Pull-out samples were prepared to test the binding strength between the fiber and the concrete material. One set of samples was kept aside, and the other is subjected to heating for 100 ºC, 200 ºC, and 300 ºC along with the fibers in the oven. After testing, the results were compared of the heated and non-heated specimens, as well as different concentrations of OSA. The single fiber pull-out tests were realized so that strength is reduced in variation of the concrete mixture and thermal load. Pulling–out displacement curves were obtained and analysed.

Key Words: hybrid fibers, FRC pull-out, oil shale ash, heat treatment.

1. Introduction

Fiber-reinforced concrete (FRC) is a concrete that contains short fibers to increase the structural strength and material integrity. Short fibers may be steel, glass, synthetic, natural, etc. These FRC in return give more strength to the concrete and in some situations withstand high temperatures [1-3]. The idea of reinforcing using short fibers is not new but adding OSA to the concrete as a replacement of cement in certain amount is used to check its properties. OSA is a by-product of energy production collected at thermal power plants during the burning of oil shale. It is ecologically important to find effective use of this product in building materials. OSA is used as a partial replacement to cement in some concrete, it is important for reduction of the overall CO_2 footprint of concrete and chemically how these concrete slabs react to radiation. In our investigated concrete mixes cement was replaced by OSA that came from Auvere (Estonia) thermal power plant [2; 4; 5]. Fibers are added to concrete to avoid drying shrinkage and plastic shrinkage related cracking, some fibers result in increased impact, abrasion, and shatter resistance [4; 6-8].

In this study, the characteristic features of FRC with hybrid short fibers are discussed, in the composite fiber micro-fibers are glued together with polymer resin [7], in hybrid composite fiber short micro-fibers are in a similar way glued together with polymer resin and a combination of at least two or more types of short micro-fibers is presented. It includes Basalt-Glass, Basalt-Carbon, and Carbon-Glass twisted and glued together with the help of resin (epoxy and hardener in ration of 3:1). Compared to other fiber-supported composites, hybrid composites are more sophisticated and offer a larger range of possible uses [1; 3; 7; 9]. We prepared samples according to the testing that will be conducted on these samples. For example, cubes for compression testing; pull-out test will be carried out on pull-out samples; fiber samples will be used to test the tensile strength and binding strength between them; further tests can also be performed in prisms to determine the bending moment of FRC with the hybrid short fibers in them [19].

2. Materials and methods

2.1. Preparation of fiber

Basalt-Carbon, Basalt-Glass, and Carbon-Glass (see Fig.1, a) with every fiber thread weighing 2.5 g were slightly twisted together and were fixed in a wooden frame with dampers. Light tension was created in the hybrid yarn (consisting of 50% of one type of micro-fibers and 50% of another type of micro-fibers (see Fig.1, b, c)). After binding the hybrid fibers with epoxy resin (WELA-EP 100) and hardener in the ratio 3:1, which aids in the formation of a uniform and unbreakable thread, fibers were dried out for 2 days. Then the hybrid fibers were cut into short pieces with a length of 4.8cm (see Fig.1, d), making sure they are held onto the concrete mixture mould [10-12].

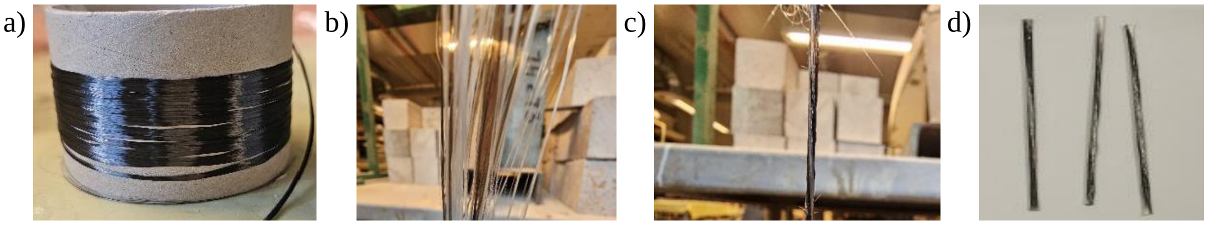

Fig. 1. **Short fiber preparation:** a – fiber yarn; b – Preparation of hybrid fiber; c – twisted fiber; d – Short fiber

2.2. Preparation of sample

Eight moulds (four for testing at room temperature and four for heated sample testing) were prepared with each mould holding seven samples. To conduct compression testing for the fiberconcrete six cubes were prepared for each pair. The use of oil shale ash (OSA) as a partial cement replacement in some concrete is another important problem of the present investigation. Oil shale ash (OSA) is a product obtained during burning oils shale for energy production. It is important to characterize how OSA can be used as a cement partial replacement in concretes [13; 14].

Various types of OSA have properties of a mineral binder. Each pair of samples is made with OSA being 0%, 15%, and 35%, all these considerations of OSA replacing cement are based on the previous research results without fiber. The mixture composition for each set is given in Table 1.

Table 1

Concrete composition

Materials	Quantity 0%	Quantity 15%	Quantity 35%
Oil shale ash (OSA)	0	0.339 kg	0.791 kg
Cement	2.26 kg	1.927 kg	1.469 kg
Water	1.7 L	1.7 L	1.7 L
Sand 2.5	7.6 kg	7.6 kg	7.6 kg
Sand 1.0	4.1 kg	4.1 kg	4.1 kg
Dolomite powder	1.75 kg	1.75 kg	1.75 kg
Plastificator	0.040 kg	0.040 kg	0.040 kg

The mould is cleaned, brushed, tightened with the size of the sample with sheets between them, and air is blown to remove any debris inside the compartment. After preparing the moulds, oil is applied to prevent concrete from sticking to the mould. One side is made per day so that the fiber angle (orientation to the stretching direction) and the length remain the same, i.e. 2.8cm from each side. The moulds are then covered with a plastic film to prevent dust particles and to maintain their humidity level [15].

The next day the same mixture was fabricated. Concrete was poured on the other side of the sample, without damaging the fiber and left in the mould for 2 days, before taking out the whole samples (see Fig. 2). After that, moulds are prepared for the next set of concrete with OSA. Content and the above steps are followed meanwhile we sprinkle water on the samples that were made. The fabricated samples were matured for 28 days.

Fig. 2. **Concrete specimens ready to be tested**

2.3. Heating procedure

After 28 days ready for testing pull-out samples were thermally loaded. One set was heated till 100 ºC, the second set till 200 ºC, and the third till 300 ºC (see Fig.3). After heating, the samples cooled and reached room temperature. On the next day, they were tested mechanically. The heated samples were tested to determine the strength of the concrete samples when subjected to heating. The samples from 300 ºC can be observed with colour change. The fibers when projected to 300 ºC made a foul smell from the burning of the epoxy resin around them. This change can be noted clearly from an electron microscope [16-19].

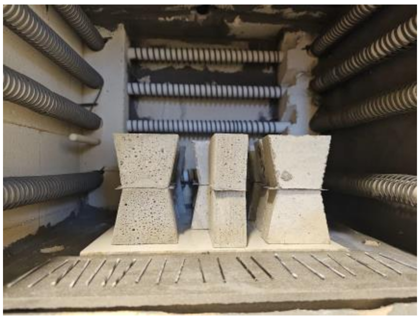

Fig. 3. **Samples placed inside the oven**

3. Results and discussion

3.1. Compression testing

Compression testing is usually carried out on cuboid or cylinder samples to determine the material behaviour under compression load on a universal testing machine. In this test, we will calculate the strength of the concrete mixes with OSA without the fiber. The samples or specimens are measured by the vernier calliper and marked with length, breadth, and height. The specimen is kept between the two platen and force is applied on top surface of the specimen [20]. The results are projected in the display and are noted. After the compression testing, the specimens are noted to have deformation in their size. It is noted that at different stages of OSA content, the strength differs from each other. From the obtained results, we calculate the stress acting on the concrete and Young's modulus is used in the simulation part. It is necessary to obtain these results to run the simulation [5; 19; 21].

Using an Automax 5 loading machine, the strength of the concrete will be displayed in the machine which we have listed in the following table. The displayed result will give the strength in both MPa and Newton which can be used in the calculation part.

Table 2

Compressive load test results

Samples	0% OSA, MPa	15% OSA, MPa	35%OSA, MPa
1	38.5	29.82	26.68
2	37.51	29.67	25.62
3	39.96	40.54	20.93
4	31.1	39.8	20.6
5	33.77	39.04	20.85

3.2. Pull-out test

After marking the pull-out sample on both faces it was tested using the testing machine Zwick Z150 (see Fig.4, a). Pull-out displacement was measured with a non-contact video extensometer Messphysik. The bottom part of the specimen was fixed, and the upper part is moved 5mm per minute, typically it takes approximately 2-5 minutes to work on a sample. We tested 144 samples (see Fig.4, b), diagrams of Force – Pull-Out displacement were obtained, and the results can be seen in Tables 3-5. Here, we will use the following notations Basalt-Carbon as BC, Basalt-Glass as BG and Carbon-Glass as CG and the results obtained will be compared to the other temperature values [5; 20; 22]

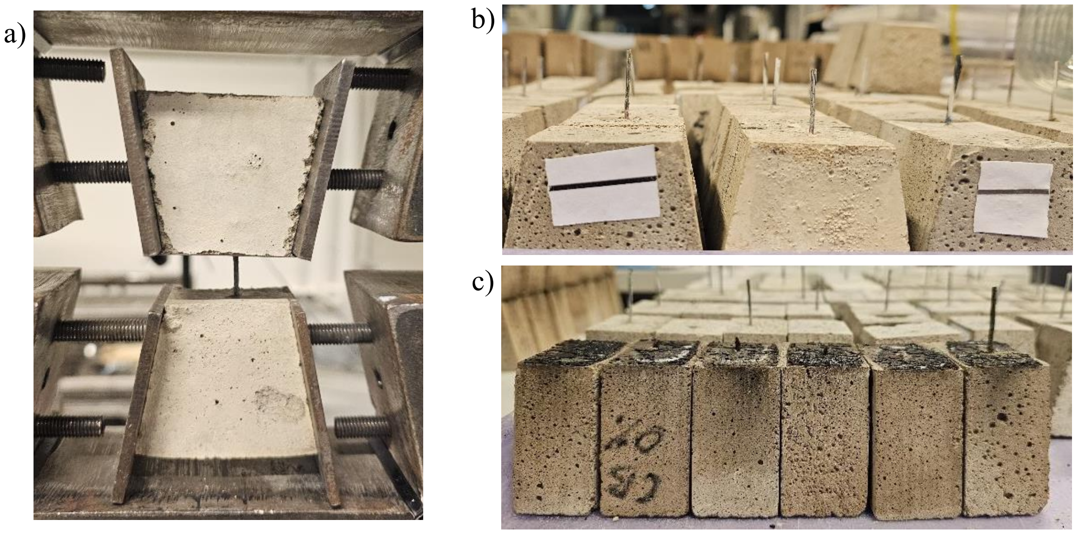

Fig. 4. **Pulled out samples while testing and after testing:** a – specimens under pull out test; b – tested specimens; c – heated samples after test

Pulled out results for 0% OSA

For all temperature gradients it was noted that the maximal value of the force on the diagram Force-Pull-Out length decreases when subjected to heating, but at certain temperature different results are exhibited. The maximal force at room temperature is given as 989.7 N for BC, 671.8 N for BG and 712.2 N for CG and for samples at 100 ºC to 702.9 N (BC), 473.2 N (BG) and 689.1 N (CG). For 200 ºC the force required is 733.1 N (BC), 714.4 N (BG) and 745.5 N (CG), and at last for 300 ºC the force required is 437.2 N (BC), 490.4 N (BG) and 554.89 N (CG). Pulled out samples heated till 300 ºC are shown in Fig. 4, c.

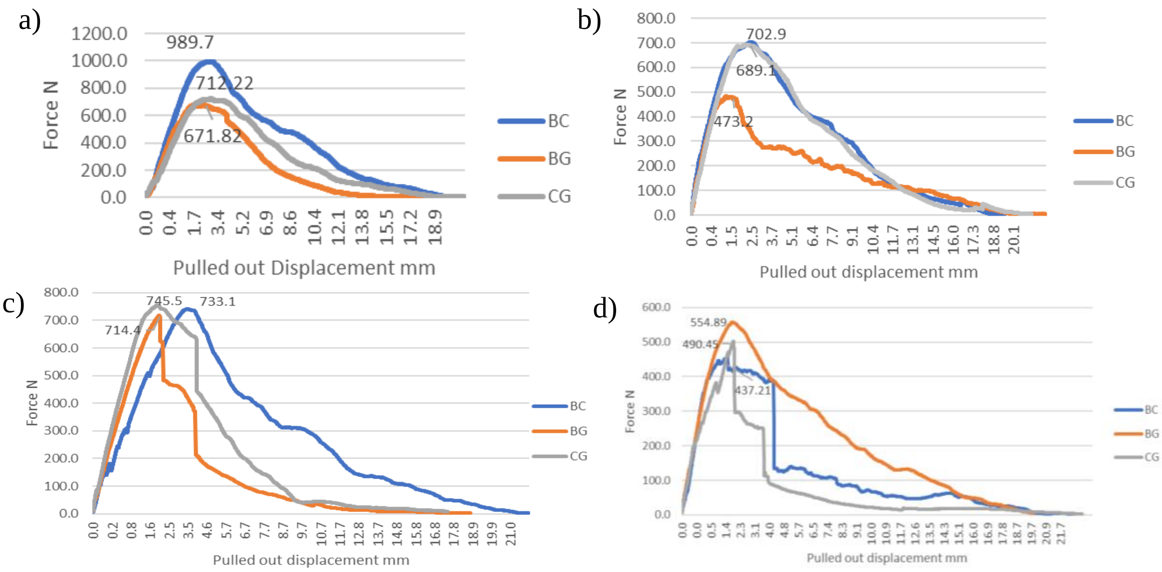

Fig. 5. **Force vs pulled out displacement for 0% OSA:**
a – ambient temperature; b – 100 ºC; c – 200 ºC; d – 300 ºC

Pulled out results for 15% OSA

For all temperature gradients, the maximum force required to pull the fiber is 932.3 N (BC), 483.5 N (CG) and 668.2 N (BG), at 100 ºC the force required is 806.5 N (BC), 648.9 N (BG) and 739.6 N (CG), at 200 ºC as 873.6 N (BC), 802.2 N (BG) and 768 N (CG), for 300 ºC the force is 498.5 N (BG), 500.4 N (BC) and 513.6 N (CG).

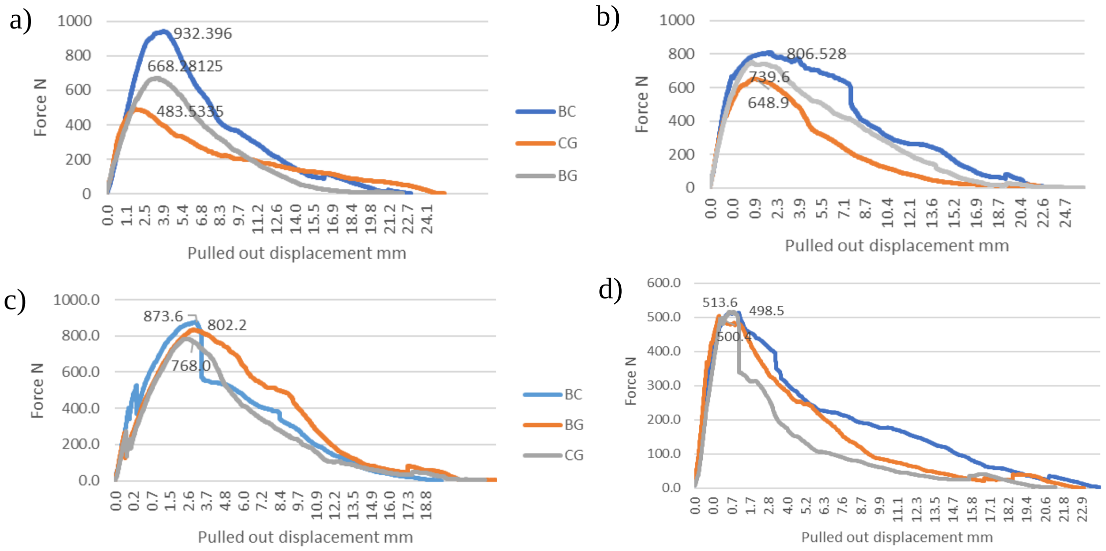

Fig. 6. **Force vs pulled out displacement for 15% OSA:**
a – ambient temperature; b – 100 ºC; c – 200 ºC; d – 300 ºC

Pulled out results for 35% OSA

For all temperature gradients. From the below Fig.7, it can be noted that the force required to pull the fiber at room temperature is 659 N (BC), 460 N (BG) and 431.9 N (CG). At 100 ºC the force required is 580. N (BC), 513.4 N (BG) and 402.4 N (CG), at 200 ºC the force required is 514.4 N (BC), 472.2 N (BG) and 353.2 N (CG), at 300 ºC the force required to pull the sample can be given as 403.2 N (BC), 215.7 N (BG) and 354.4 N (CG).

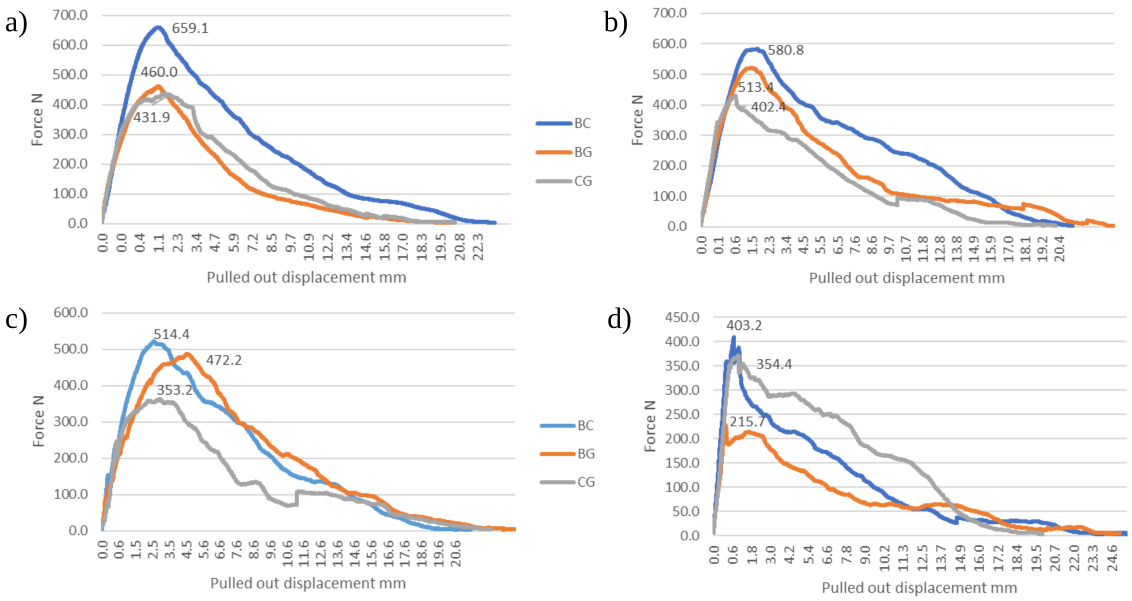

Fig 7. **Force vs pulled out displacement for 35% OSA:**
a – ambient temperature; b – 100 ºC; c – 200 ºC; d – 300 ºC

The results of the pull-out and compression test give clear figures that addition of OSA to concrete leads to the reduction of strength as well as heat treatment of samples also influences the material degradation and reduces the strength. Comparatively the concrete samples without OSA provide 20-

30% higher strength over the samples with OSA, at the same time thermal loaded concrete samples pose around 40% of difference over the non-headed concrete samples.

4. Conclusions

The compression strength evaluation results show us that OSA content in the mixture affects the strength of the concrete. The concrete with OSA content of 0% and 15% heated at 200 degrees Celsius exhibit more strength than 100-degree Celsius heat concentration samples, we obtain higher bonding strength from the samples with less composition of OSA. Also, when sorting the tested samples, we get that at the temperature 300 ºC the concrete and fibers are degraded when compared to the non-heated samples. Analysing hybrid fibers in all sets, GB hybrid fiber with epoxy gives great average strength and bond.

It is evident that temperature affects the bonding strength of the specimens which can be seen from the analysis of the heated samples. As for the concrete matrix, the fly ash content present in the mixture gives variant results for heated samples at 300 ºC, the bond strength is weakened, and the sample broke before change in displacement took place.

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Author contribution

Conceptualization, K.R.K. and I.N.; methodology, K.R.K., I.N. and E.G., software, S.J.M.M.; validation, K.R.K., M.V. and E.G., formal analysis, M.V. and E.G.; investigation, K.R.K. and S.J.M.M.; writing K.R.K.; original draft preparation, K.R.K. and I.N.; writing – review and editing, K.R.K.

All authors have read and agreed to the published version of the manuscript.

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