

# Mechanical behavior of Composite basalt short fiber for concrete structure reinforcement

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**Abstract.** Interest to Fiber concrete - concrete reinforced with short randomly distributed in the material volume fibers is growing and obtaining more new fields of application. Initially used fibers were steel. Composite Fibers (CF) have become competitive with steel fibers, fiber concretes with such fibers are now under investigation. In the present research, authors investigated the bond strength between the fiber and concrete, as well as other mechanical characteristics of the fiber concrete with CF. CF were made of short basalt micro-fibers glued together by Epoxy resin. Basalt micro-fiber roving (250 filaments) was taken as a main source of the CF, it was impregnated with epoxy resin. The Epoxy resin to hardener ratio was 3:1. After a few days maturing prepared CF were cut down into short fibers of a size of 24 mm. The authors planned to prepare concrete samples for the single fiber pull-out test and composite fiber-reinforced concrete prisms for the four-point bending test. Another product used in the investigation was Oil Shale Ash (OSA). OSA is a class-C fly ash. OSA was used as a partial cement replacement in a concrete. The concrete mixture was prepared with different compositions in addition to Oil Shale Ash (was used OSA from Auvere, Estonia, thermal power plant) as replacement of cement in ratios of 0%, 10%, 20%, and 30%. Tests were performed to obtain the load-bearing capacity of a concrete with basalt fibers. An important property of every kind of fiber is the single fiber behavior under pull-out conditions. Microscopic analysis has been made to conclude the research.

**Keywords:** Basalt fiber, pull out, reinforced concrete, Oil shale ash.

## I. INTRODUCTION

Concrete strengthened and structurally intact by the addition of short fiber reinforcement (SFRC) [1, 2, 3]. Short fibers can be made from steel, glass, synthetic, natural, and other fibers [1] [4] [5] [6] [3] [7] [8] [9] [10]. These fibers give concrete greater strength, post cracking load bearing capacity, wearability, durability, structural integrity and etc [1] [7] [3] [10] [11]. Important role is playing composite fiber [12] [13] [14] [15] [16]. Composite fiber is produced as synthetic micro-fiber roving (bundle) with slicked together micro-fibers by matrix material. In our situation matrix material was Epoxy resin. Micro-fibers were impregnated by matrix and cut in length  $L$ . Traditionally  $L$  is changing from few millimetres (4 mm – 6 mm) till few centimetres (5 cm-6cm), forming short sticks (bars) [8] [12] [13]. Other important point in the present investigation is a use of Oil Shale Ash (OSA) as a partial cement replacement in concretes [17] [18] [19] [20] [21]. Oil shale ash (OSA) is a class-C fly ash, product obtained during long years of burning oils shales for energy production. OSA can be used as a cement partial replacement in concretes [18] [17]. Part of the OSA is collected and utilized as dry

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powder material [16]. Various types of OSA have properties of a mineral binder, the hydration type of which varies from air hardening, topozzolanic and latent hydraulic [9] [20].

In our investigated concrete mixes 0 to 30% of cement was replaced by OSA (Electrostatic Precipitator Ash) coming from Auvere (Estonia) thermal power plant. The size of the particles in OSA powder ranges from hundreds of nm to  $\mu\text{m}$ . So, this study demonstrates the strength of composite fibers in different concrete compositions with oil shale ash functioning as a cement replacing agent. Our made composite fibers were fabricated and used. [9]

## II. MATERIALS AND METHODS

Fiber reinforced concrete was planned to prepare by using the epoxy impregnated basalt short fiber and oil shale ash from Auvere plant as partial replacement of cement. Fibers were randomly distributed in the concrete samples.

### 2.1 Properties of Basalt Roving

Short basalt fibers were prepared from the market available basalt roving, epoxy, and hardener. Basalt roving properties (Supplier data) are follows,

**Properties of basalt roving**

- ▶ density: ca. 2.7 [g/cm<sup>3</sup>]
- ▶ linear tenacity: 70tex – 4800tex
- ▶ roving type: assembeled
- ▶ E-modulus: 90 – 100 [GPa]
- ▶ tensile strength: 3000 – 4000 [MPa]
- ▶ moisture absorption : 0,03 [%]
- ▶ temperature range: -260°C bis +750°C




Fig.1. Fiber properties

### 2.2 Preparation of fibers

The basalt yarn fibres (4.8 g for 1 m length Approx.) were seamed in a wooden frame with dampers and then tightened to create tension in the yarn and fibre, resulting in a straight and uniform thread sample. In which we used a brush to thoroughly coat all the basalt yarn with epoxy (WELA-EP 100) and hardener in the ratio 3:1, which aids in the formation of a uniform and unbreakable thread. Coated fibers were kept maturing and drying for 48 hours and trimmed to 24 mm to use in concrete.



Fig. 2. Preparation of fibers



Fig.3. Prepared basalt Fibers 24 mm

### 2.3 Concrete Mix Design and Materials

The concrete mix was designed using the standard EN-206. Concrete mix consists of Portland cement, fly ash, sand (0.3-2.5 mm) & (0-1.0 mm), quartz aggregates (4-8 mm), dolomite powder, super plasticizer (SP), admixture silica fume, fibre, water. The concrete mixture was designed in four different sets by adding Oil Shale Ash (we used OSA from Auvere, thermal power plant Estonia) as replacement of cement in ratios of 0% (EB-1), 10% (EB-2), 20% (EB-3), and 30% (EB-4). Measurements of all the ingredients in the table are in kg.

Table. 1 Mix proportion

Concrete Mixture				
	EB-1	EB-2	EB-3	EB-4
<b>Cement (CEM II)</b>	6.16	5.56	4.92	4.33
<b>Oil Shale Ash</b>	0	0.6	1.23	1.83
<b>Sand (0.3-2.5 mm)</b>	16.2	16.2	16.2	16.2
<b>Sand (0-1.0 mm)</b>	4.4	4.4	4.4	4.4
<b>Gravel (4-8 mm)</b>	16.0	16.0	16.0	16.0
<b>Dolomite powder</b>	2.9	2.9	2.9	2.9
<b>SP Sika D190</b>	0.225	0.225	0.225	0.225
<b>Micro silica</b>	0.65	0.65	0.65	0.65
<b>Fiber</b>	0.176	0.176	0.176	0.176
<b>Water</b>	3.4	3.4	3.4	3.4

### 2.4 Preparation of Samples

Samples were planned to prepare for three different kinds of experiments which are Pull-out, Compression and Bending. Pull-out samples were produced with two concrete prisms separated by plastic film. The fibers should be positioned at the middle of the prism. So, each fiber is indicated in the centre and must be exactly positioned, and the concrete mix for the pull out was made without fibers, as described in the concrete mixture table.

Bending and compression test samples were created with mould dimensions of 10x10x40 cm and 10x10x10 cm, respectively. [9] [22]

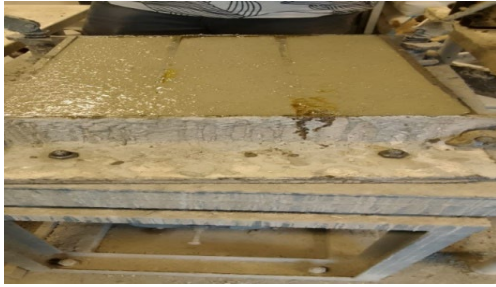


Fig.4. Preparation of samples

After that, all the ingredients were added to the concrete mixture machine and stirred for five to seven minutes to regulate the consistency of the mixture, producing a homogeneous mixture. The mixture was filled into the appropriate moulds for maturing. Then samples were taken out of the mould and after 48 hours in water, were brought into the lab for further curing. Samples were then covered with plastic wrap and stored in a laboratory with a required 90% relative humidity.

### 2.5 Mechanical Testing Methods

After 28 days of curing from the fabrication, the specimens were tested for single fiber pull-out, 4-point bending and compression test. Test machine Zwick Roell Z150 was used to determine the fiber pull-out force. [9] [22]

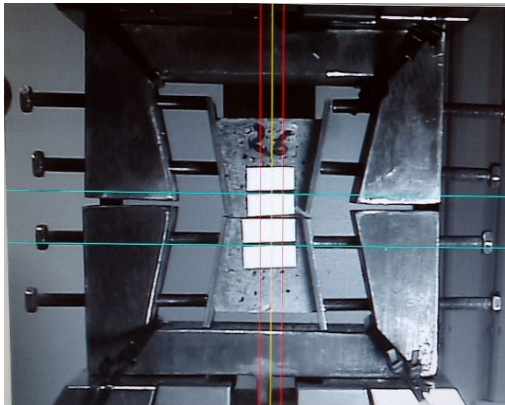


Fig.5. Single fiber pull-out.

Compression tests and 4-point bending tests were done to measure the strength of the concrete which we used to make the specimens, using an Autamax 5 loading machine. During the tests, prism deformations were recorded using a frame with two HBM WA20 and Linear Variable Displacement Transducers (LVDTs) on each side.

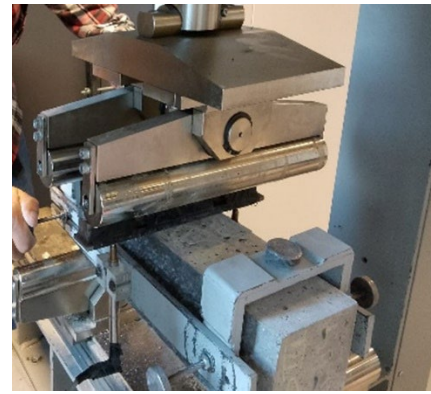


Fig.6. Four-point bending machine setup.

## III. EXPERIMENTAL RESULTS AND DISCUSSION

### 3.1 Compression Test

The Standard dimensions (10 x 10 x 10 cm) samples were made for the cube test and throughout the testing, load should be added at a constant rate of 150 kg/cm<sup>2</sup>/minute until the concrete sample is shattered. The rough surface of the cubes placed into the compression testing apparatus should not place on the bottom steel plate and the machine's platens because it may cause unbalanced loading over it. Compression testing results are shown in table 2.

Table 2. Compression test results

Samples	Compressive strength MPa			
	EB-1 (0% OSA)	EB-2 (10% OSA)	EB-3 (20% OSA)	EB-4 (30% OSA)
Sample 1	61.12	52.16	52.02	37.8
Sample 2	58.73	53.13	51.54	36.4
Sample 3	58.08	56.95	49.4	36.05
Sample 4	60.24	54.73	49.61	39.82

From the obtained results we can see that the compressive strength is reduced when compared to the concrete samples with no replacement of cement by oil shale ash. This tendency increases when the amount of OSA is bigger than 20%. Important to notice, OSA addition is rapidly decreasing liquid concrete mix rheological properties.

### 3.2 Fibers Pull-Out

In figures 7-10 is possible to see pull-out tests results. Sample consisting of two concrete parts, bridged by the fiber immersed in both parts at the same depth is slowly stretched with the constant loading speed till fiber rupture or its fully pull out with one end [20]. The results show the process of removing epoxy impregnated basalt fibers from the concrete matrix, as well as the maximum load required to remove the 24mm fiber. The specimen will contain two strips used to measure the gauge length. With a starting loading, fibers remain in the matrix without any pull-out, when the force reaches 150 N, the fiber begins to pull out at the predetermined speed of 5 mm/min. The first step is characterized by fiber delamination from the surrounding

concrete. Mainly, it happens by a thin polymer layer (that is wrapping the fiber) tearing off.

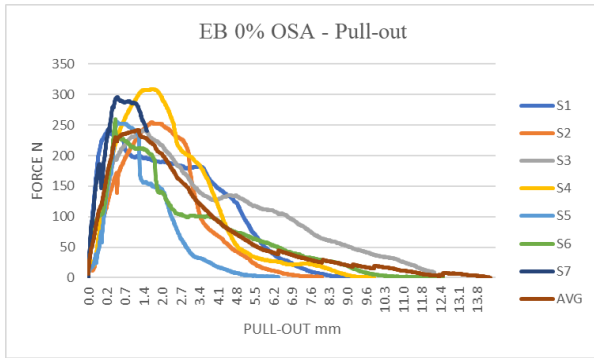


Fig.7. Force and Displacement graph for 0% OSA.

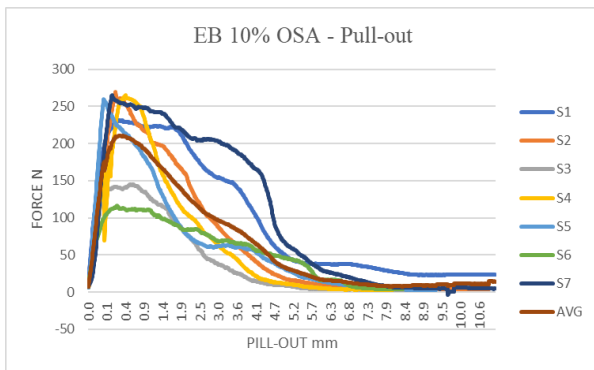


Fig.8. Force and Displacement graph for 10% OSA.

A difference in force was observed throughout the pullout process, which could be attributed to vibration, microparticles of the concrete matrix being pulled with friction-forming plugs, and epoxy blended with the concrete matrix being present at the weak interface. The study of this interfacial behavior is essential for understanding mechanical behavior.

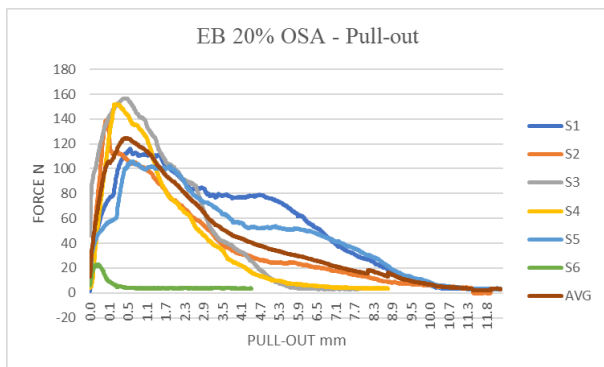


Fig.9. Force and Displacement graph for 20% OSA.

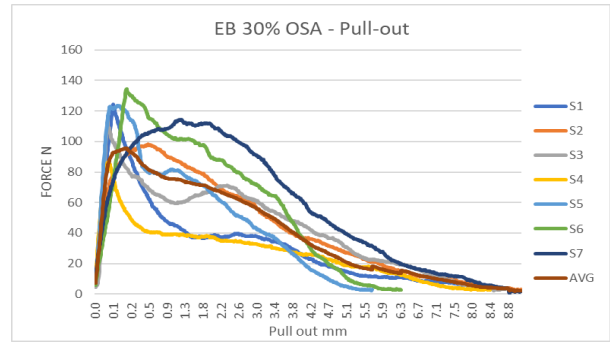


Fig.10. Force and Displacement graph for 30% OSA.

Important to mention, addition of OSA is decreasing the maximal value of necessary applied load for fiber pull out. It happens constantly with an increase of the amount of cement (10%-30%) replaced by OSA.

### 3.3 Four-point bend test

The prism was marked 5 cm from the edge to ensure proper fit in the bending machine. The loading happened with constant loading speed till the sample failure. The specimen's midpoint deflection was obtained in real-time by averaging the values from both sensors (on both sides of the prism). The load was applied until the specimens were destroyed; maximum average deflection reached is 11.5 mm for 0% OSA samples at 31.5 kN, then it deformed with some internal cracks on its elastic state and samples it didn't withstand additional load rupture occurs during deflection of 1 – 1.5 mm. Because fiber length (24 mm), it failed to hold the concrete after [9] the rupture. Minimum load as 17 kN took for EB4 samples i.e., 30% OSA and in some samples amount fibers distributed and orientation of the fiber on the cracked surface also less.

### 3.4 Examine fibers.

An impregnated epoxy basalt fiber with a cut edge and surface is examined using optical microscopes to determine the strength of the binding between the fiber and epoxy.

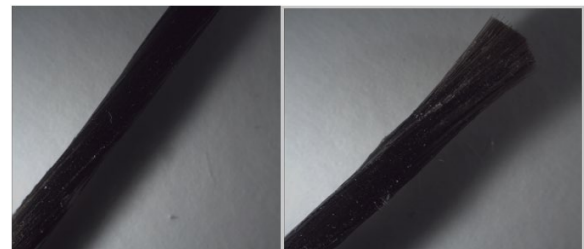


Fig.11. Fibers before testing



Fig.12. Fibers after testing

The fibers utilized for single fiber pullout underwent analysis prior to being inserted into the concrete matrix. Following this, all the tested samples were gathered and reexamined under a microscope to verify that the fibers had broken and to look for surface cracks.

#### IV. CONCLUSION

Strength and mechanical behavior investigation were performed for fiber concrete with cement gradually replaced by Oil Shale Ash and composite fibers 24 mm long. Fibers were fabricated with Basalt micro-fibers impregnated by Epoxy resin. Single fiber Pull -out program was realized.

Experimentally was obtained:

1. Maximal pull-out force decreased for concrete mixes with higher amount of OSA which is Average force required for samples without OSA is 246.9 N but for the samples with OSA (30%) is 98.45 N.
2. Compressive strength of concretes with constant fibers weight fraction decreased for mixes with higher amount of OSA. Tendency became more intensive for concentrations bigger than 20% i.e., from 59.54 to 37.52 MPa.
3. Bending strength for fiber concrete prisms decrease with increase of OSA in the concrete mix.

Fiber pull-out happens by thin polymer layer, that is wrapping the fiber tearing off.

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