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Behavior of Short fiber composite materials in variation of thermal and mechanical loading

Karunamoorthy Rengasamy Kannathasan
Department of Theoretical Mechanics and Strength of Material
Riga Technical University
Riga, Latvia
Karunamoorthy.Rengasamy-Kannathasan @rtu.lv

Arturs Macanovskis
Department of Theoretical Mechanics and Strength of Material
Riga Technical University
Riga, Latvia
Arturs.Macanovskis@rtu.lv

Rajeev Ralla
Department of Theoretical Mechanics and Strength of Material
Riga Technical University
Riga, Latvia
Rajeev.Ralla@edu.rtu.lv

Eirik Gjerlow
Department of Construction, Energy and Material Technology
The Arctic University of Norway,
Lodve Langesgate 2, 8514 Narvik, Norway
eirik.gjerlow@uit.no

Abstract. **Steel Fiber Reinforced Concrete (SFRC) is widely used as it provides good characteristics and mechanical behavior. Concretes with novel type Basalt/Epoxy composite fibers are competitive and attractive for use and investigation. The special interest is for concretes with partially replaced cement by Oil Shale Ash (OSA). In this study authors will discuss basalt and steel fiber-reinforced concrete. Concrete samples were prepared in the dimensions of 40mm x 40mm x 300 mm and treated under the oven to raise the temperatures to 150^{0}C, 300^{0}C, and 450^{0}C. In the research of preparing environment-friendly concrete authors planned to use OSA as an additive replacement of cement by weight in percentage. OSA is a product of burned oil shale from thermal power plants of ESTONIA, which is added in the weight ratio of 0%, 10%, and 20% of cement. All the samples were tested by the four-point bending method and the results of samples with different ratios of OSA and different temperature gradients were compared to analyze and simulate conclusion research. The author also used image processing techniques to make a study on fiber orientation and directionality after the fabrication of concrete. Characteristics of basalt and steel fiber-reinforced concrete in different considerations and compositions were made by the author through metadata and image analysis.**

Keywords: Fiber concrete, Thermal heading, Oil Shale Ash, Basalt, SFRC.

I. INTRODUCTION

The fiber reinforced concrete is used commercially a lot because of its mechanical properties. Steel fiber reinforced concrete (SFRC) exposure to the high temperature is leading to variety of complications – concrete spalling, fibers thermal degradation and other phenomena necessary to investigate [1] [2] [3] [4] [5]. Steel fiber is the most common type of reinforcement used in fiber concrete nowadays, so authors did the research about the heat treatment of SFRC and did single fiber pullout experiments to know about the material degradation and its properties, as the continues of the previous paper here author planned to do heat treatment on FRC with two different fibers at the different temperature gradients [6].

Important problem is to use more "Green" concrete using fiber-reinforced concrete with oil shale ash as a cement partial replacement in material [7] [8]. Oil shale ash is a by-product of the mining, processing, and burning of oil shale that is produced during the energy generation process in Estonia [9] [10] [11]. The size of the particles in OSA powder ranges from hundreds of nm to µm. So, this study demonstrates the strength of composite fibers in different concrete compositions with oil shale ash functioning as a cement replacing agent.

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II. Materials and Methods

2.1. Properties of Fibers.

Fiber concretes with different size and form of steel fibers were widely investigated during last time [12] [13] [14] [15] [16]. At the same time new fibers – polymeric, basalt [17] [18] and composite [19] [20] fiber with promising properties needs for comprehensive investigation. In this set of experiments authors planned to prepare fiber reinforced concrete with two different short fibers such as Turbo integral Basalt/polymer composite fiber and hooked-ended steel fibers Dra mix 3D 80/60BG. [6]

Both the fibers are commercially available and the data about the fibers from the manufactures. Technical properties of DBF Turbo build Basalt Fibers, single filament diameter is 13±1 um, Length is 48 mm, Density was 1.9 g/cm3 Spec, breaking strength is 2670 * ± 5% MPa, moisture content was less than 0.1 % stability at tension 100% at 20oC, 92% at 200oC and 82% at 400oC. Properties of steel fiber are shown in the figure below.

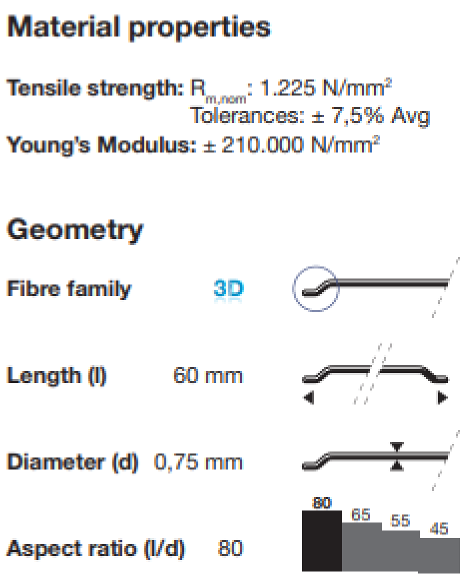

Fig.1. Steel Fiber Properties

2.2. Concrete Mix proportions

The concrete mix was designed considering the standard EN-206 and EN 196-1. The concrete mixture was prepared by adding Oil Shale Ash (from Auvere, thermal power plant Estonia) as replacement of cement in weight of 0%, 10%, and 20%. Turbo-build Integral basalt fiber obtained from Deutsche Basalt Faser and steel fibers Dra mix 3D 80/60BG were used.

TABLE 1 CONCRETE PROPORTION FOR BASALT FIBRES

Concrete Mixture with Basalt Fiber			
	B 1	***B 2***	***B 3***
Cement	6.16	5.56	4.92
OSA (Fly ash)	0	0.62	1.23
Sand (0.3-2.5)	16.2	16.2	16.2
Sand (0-1.0)	4.4	4.4	4.4
Gravel	16.0	16.0	16.0
Dolomite powder	2.9	2.9	2.9
Plasticizer Sika D190	0.225	0.225	0.225
Micro silica	0.65	0.65	0.65
Fiber	0.176	0.176	0.176
Water	3.4	3.4	3.4

TABLE 2 CONCRETE PROPORTION FOR STEEL FIBRES

Concrete Mixture with Steel Fiber			
	S 1	***S 2***	***S 3***
Cement	6.16	5.56	4.92
OSA (Fly ash)	0	0.62	1.23
Sand (0.3-2.5)	16.2	16.2	16.2
Sand (0-1.0)	4.4	4.4	4.4
Gravel	16.0	16.0	16.0
Dolomite powder	2.9	2.9	2.9
Plasticizer Sika D190	0.225	0.225	0.225
Micro silica	0.65	0.65	0.65
Fiber	0.543	0.543	0.543
Water	3.4	3.4	3.4

2.3.Specimen Preparation

Samples were designed for two different types: cubes for compression and prisms for bending. Bending and compression test samples were constructed using mould dimensions of 10x10x40cm and 10x10x10cm, respectively. Eight specimens of each type were cast, with dimensions of 100 × 100 × 400 mm. Fibers were randomly distributed and added to the concrete during the ingredient mixing process. Group S2 and B2 are concrete samples with 10% OSA, and Group S3 and B3 have 20% OSA. The number of fibers in each group was the same; the only change was the ratio of OSA substituting cement. After filling the mixture in its mould, it was kept at a relative humidity of 90% or a temperature of 27 + or -2 degrees. After that specimens were curried in the water for hydration.

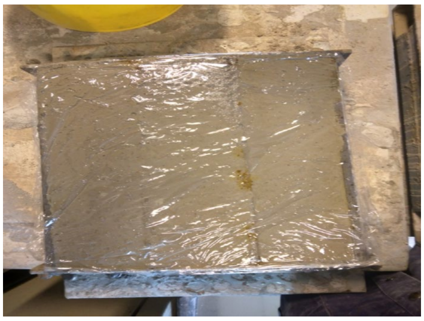

Fig.2. Prepared Specimen

2.4.Thermal and Mechanical Loading Methods

Thermal treatment is the goal of the research because SFRC weakens when exposed to higher temperatures, therefore the authors planned to heat the specimens to 150, 300, and 450 degrees Celsius. To fit inside the oven, all the prisms were reduced (cut with a concrete saw) in size to 100 x 100 x 300 mm. Oven used to thermally load the specimens is the Nabertherm LH30/13. The process chart for heat treatment can be explained though the Fig (3) as follows: T1 is the maximum temperature of the set, T2 is the time set to reach the maximum temperature, T3 is the constant time zone in which specimens were treated at the same temperature for a specific fixed time, and finally T4 is where the specimens get cooled down.

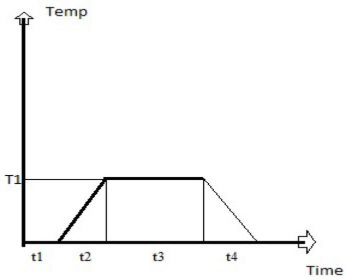

Fig.3. Heat treatment chart.

After heat treatment, all the specimens underwent 4-point bending and compression tests to establish the concrete's load carrying capacity. We used an Automax 5 loading machine. During testing, prism deformations were measured using a frame outfitted with two HBM WA20 and Linear Variable Displacement Transducers (LVDTs) on each side.

Fig.4. Oven setup for heat treatment

The cube should be placed in the compression testing equipment with its smooth faces resting on the steel plate on the bottom side. The finished cube's top surface should never meet the machine's platens, as this generates uneven loading across the cube due to the uneven, rough surface, as opposed to the faces along the smoother side of the mould. For this test, we used the normal dimensions of 10 x 10 x 10 cm. The loading was done continuously, with weights rising at a constant rate of 150 Kg/cm2/minute until the concrete specimen cracked, broke down, or was crushed.

III. RESULTS AND DISCUSSION

3.1. Thermal Loading of Specimen

Heat treatment of the sample takes place after 28 days of hydration and additional 10 days kept it out for samples dry. At first samples were set to treatment of 150 degree Celsius for 150 minutes with rising time limit of 30 minutes.

Fig.5. Damaged Oven

Same cycle repeated for all the set of samples at 300 degrees Celsius for the time limit, when it comes to 450-degree Celsius basalt specimens (BFRC) were broken inside the oven at temperature of 380c and steel specimens (SFRC) at temperature of 416oC.

Fig.6. Broken SFRC Specimens

In both basalt and steel reinforced prism we obtained some broken and cracked pieces of specimens with 0% and 10 %OSA, but specimens with 20 % OSA all the specimens vanished into small chips and pieces.

3.2.Compression test.

Compressive strength of the specimens was given based on temperature gradient while considering the specimens heated until 150oC and 300oC more OSA content samples were possess comparatively less load bearing capacity.

TABLE 3 CONCRETE PROPORTION FOR STEEL FIBRES

Compressive strength MPa (150ºc)			
	0% OSA	***10% OSA***	***20% OSA***
SFRC	74.42	56.23	41.82
BFRC	67.3	45.69	39.07

TABLE 4 CONCRETE PROPORTION FOR STEEL FIBRES

Compressive strength MPa (300ºc)			
	0% OSA	***10% OSA***	***20% OSA***
SFRC	63	43.02	36.18
BFRC	59.4	41.82	26.6

3.2.Four-Point Bending test.

The prism was loaded at a steady rate until the sample failed. The specimen's bending deflection was calculated by averaging the data of both sensors, in this set of experiment all the heated samples were failed to withstand long after rupture or bending moment.

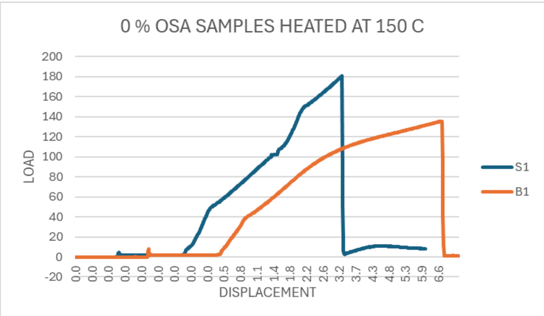

Fig.7. Bending results of 0% OSA at 150 C

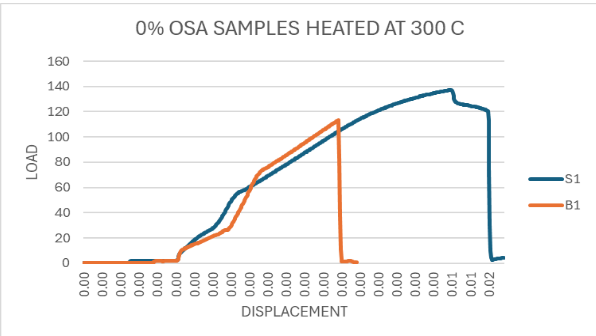

Fig.8. Bending results of 0% OSA at 300 C

The average load was applied to bend heated 0% OSA at 150 and 300 deg Celsius samples are (a). For S1 samples 182.6 and 139.2 bar, (b). For samples B1 it is 138.46 and 116.78 bar respectively.

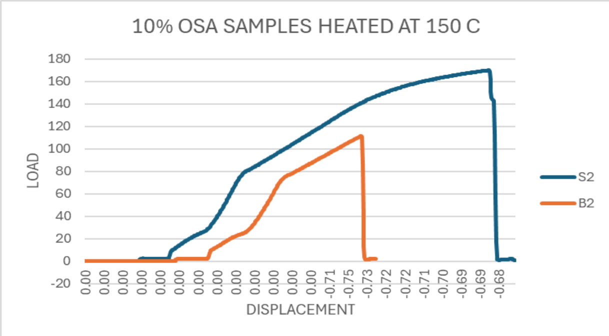

Fig.9. Bending results of 10% OSA at 150 C

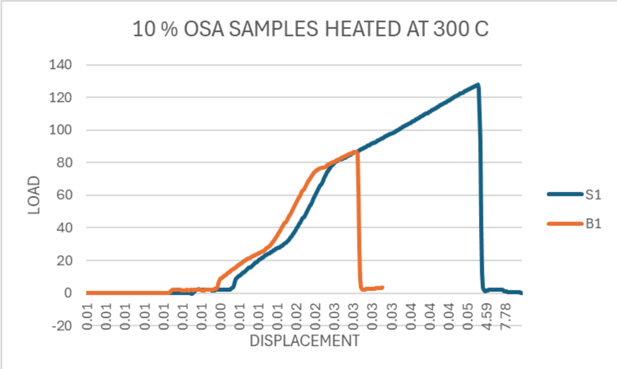

Fig.10. Bending results of 10% OSA at 300 C

The average load was applied to bend heated 10% OSA at 150 and 300 deg Celsius samples are (a). For S2 samples 169.46 and 126.82 bar, (b). For samples B2 it is 111.02 and 87.93 bar respectively.

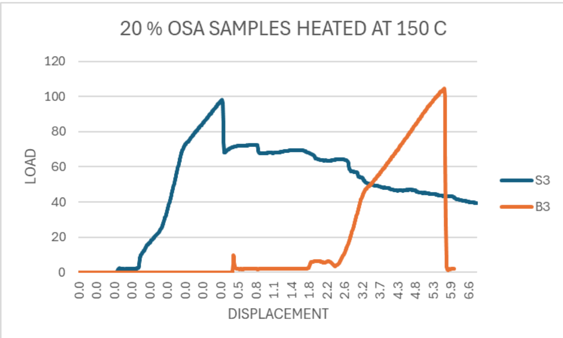

Fig.11. Bending results of 20% OSA at 150 C

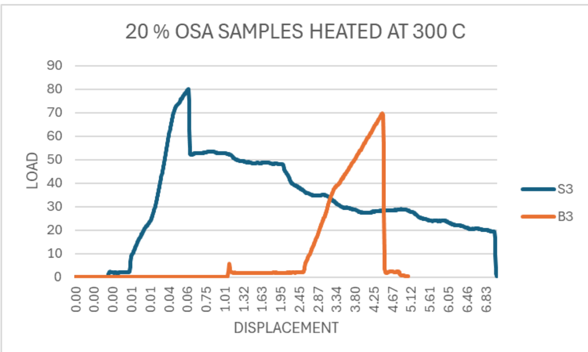

Fig.12. Bending results of 20% OSA at 300 C

The average load was applied to bend heated 20% OSA at 150 and 300 deg Celsius samples are (a). For S2 samples 98.65 and 79.76 bar, (b). For samples B2 it is 107.53 and 69.36 bar respectively.

3.4. Image Processing.

Image segmentation is an important step to analysis the sample image and divide it into separate regions of interest that are homogeneous properties such as brightness, reflectivity, texture, and color respectively. Segmentation method can catalogues based on dominant features, global knowledge of the image it is usually analyzed with histogram of image feature, Edge- based segmentation and region based. Edge based segmentation is done for the sample images, we can identify separation of the targeted objects in the image based on threshold values. The following image segmentation process is performed on the slice of 9.5 cm * 9.5 cm of steel and concrete mixture. There are two desired regions want to explore, steel density and porosity density of the given slice. Edge detection method can be used to detect the specific region and can measure the area of interest [21].

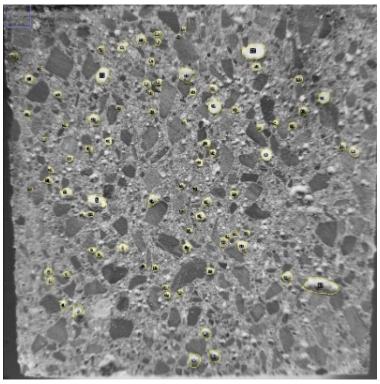

Fig.13. SFRC Specimen processed image (a).

TABLE 5 CONCRETE PROPORTION FOR STEEL FIBRES

Slice	Steel Density	Porosity Density	% Of Porosity Density
S 1	1.244	2.615	2.897
S 2	1.494	1.409	1.561
S 3	1.596	2.733	3.028
S 4	1.589	3.106	3.441
S 5	1.472	2.833	3.139

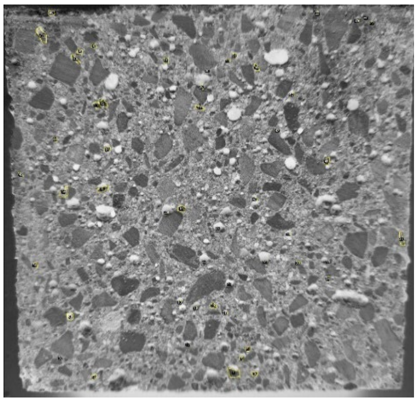

Fig.14. SFRC Specimen processed image (b).

The targeted regions are basalt and steel occupation in the given sample image and conduct statical estimation and calculate the percentage of occupation the basalt and steel in the sample. An open platform ImageJ for image segmentation and image analysis are specifically used to perform this study, initial steps are conversion of image into 8-bit type. Acuity is to detect details in an image is the major concern and extract the target source from the image. Contrast is the changes in the brightness of the image, based on contrast and acuity we can identify the target region, since every set of regions have contrast color with background color [22].

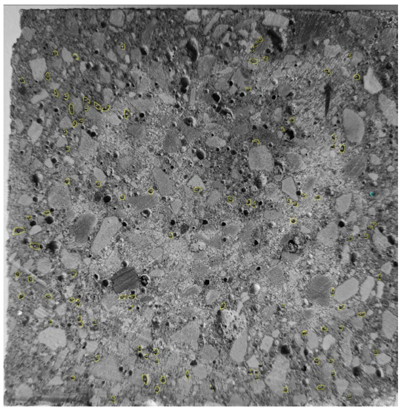

Fig.15. BFRC Specimen processed image.

TABLE 6 CONCRETE PROPORTION FOR BASALT SPECIMENS

Slice	Basalt density	Basalt percentage
Slice 1	2.472	1.631
Slice 2	2.824	2.021
Slice 3	2.637	1.813
Slice 4	2.376	1.524
Slice 5	2.493	1.654

The conditional contrast effects in the regions can improve and provide information of edges of the regions. Through ImageJ, calculation of occupation of basalt and steel are systematically studied. Edge detection techniques are often used to identify the smallest contrasting edges and calculate the area occupied. This processer is continued for the basalt and steel elements identification.

IV. Conclusion

1. Two fiber concretes were investigated in the present research. Fiber concrete with steel fibers and with composite fibers by using oil shale ash as replacement of cement.
2. The compressive strength and Bending force was decreased for concrete mixes with higher amount of OSA when treated under temperature, at the same time when samples heating temperature reaches 400 deg Celsius it exploded in oven itself.
3. Edge detection technique for image analysis and process certainly provides the information to study targeted region systematically. Edge detection and object recognition techniques helped to identify the percentage of occupation of the basalt and steel in the given sample.

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