Effects of basalt fiber in lightweight expanded clay concrete on compressive strength and flexural strength of lightweight basalt fiber reinforced concrete

P C Chiadighikaobi
Department of Civil Engineering, Peoples’ Friendship University of Russia (RUDN University), 6 Miklukho-Maklaya Street, Moscow, 117198, Russian Federation

Email: passydking2@mail.ru

Abstract. The percentages, lengths and diameters of chopped basalt fiber in concrete mixture have high influence on concrete strength. On the other hand, expanded clay contributes mostly in the weight reduction of the concrete hereby, giving what is called lightweight concrete. The collapse of concrete structures can be blamed to the effect of cracks that are born in the weak concrete structures. This paper shows how expanded clay with chopped basalt fiber of length 20mm, diameter 1.5µm affected the maximum load that the concrete samples bear and how the existence expanded clay and basalt fibers affect the concrete in terms of resistance to cracks seen through the bending (flexural) and strength on compressive of the concrete samples. The purpose of this research paper is to investigate the effect of chopped basalt fiber with expanded clay in strengthening the mechanical behaviour of concrete. Concrete specimens were mixed with chopped basalt fiber and casted, the strength checked on 7th, 14th and 28th day and evaluated based on flexural strength, compressive strength. The addition of basalt fiber in the specimens showed significant effect where the compressive strength decreased while the flexural strength increased.

Keywords: Cracks, basalt fibers, lightweight concrete, expanded clay, concrete strength

1. Introduction

1.1 General background

Generally, mechanical properties of concrete are known to strongly depend on the microstructure, mostly on the pore structure. Mineral admixtures like Quartz flour (Figure 1) added to the concrete mixture, is to reduce the pores in the concrete structure which at the same time develops the concrete properties[1], hardens concrete [2], and the increases durability of the concrete [3].
The two major concerns are cost efficiency of concrete produced using some of these admixtures and the shrinkage of the concrete. The weight of concrete should be of great importance to engineers. Some environments do not have good soil that can carry heavy concrete structures. Notwithstanding, the strength of the structure is of uttermost important. Chopped Basalt fibers (figure 2) are widely not known by many structural engineers because it is new in the market and it is being used in many studies as concrete micro-reinforcements [4-7] and the results have been encouraging. According to history, in 1998 basalt fiber was first reportedly used in a report published in the United State of America for the Highway Innovations Deserving Exploratory Analysis Project 45 [8].

Chopped basalt fiber usage in concrete as reinforcement is considerable method for strengthening and repair of structures because of their excellent properties like chemical resistance, strength, ease of application and lightness. This method of strengthening concrete is seen for their practical interest, fast application and economically reduced labour cost. Basalt fiber so far has shown its ability to enhance strength, reduce/resist cracks, ductility and it has the ability to resist harsh environmental hazards e.g. fire outbreak, earthquakes, etc of the concrete structure [9, 10].

Lightweight concrete is described as a structural material using latest technology to reduce the self-weight of the structure in the construction. Reducing the self-weight or dead load of the structure can minimize cracks, the destruction or casualties during the earthquake or any environmental impact. Lightweight concrete can be produced using lightweight aggregates like expanded clay (figure 3) or volcanic stone or by using admixture like silica fume powder as an air entraining agent to the normal mix concrete with or without coarse aggregate [11]. The possibility of producing lighter structures such as beams, piles and floors, cast on site or prefabricated, is feasible by replacing the larger parts of the traditional “natural” aggregate (gravel or stones) with an “artificial” aggregate, made up of expanded clay granules [12].

1.2 Literature review
Basalt materials can be used in certain ways to increase the concrete mechanical performance. Some researchers have conducted series of studies on the performance of basalt fiber reinforced concrete (BFRC). Research paper [8] identified that the concrete containing 0.5% of chopped basalt fiber maintain good workability. They went further to explain that adding some amount of basalt fiber has the capability to reduce concrete cracks by as high as 98%. The content percentage of chopped basalt fiber in concrete has a great effect in the concrete [13]. Furthermore, authors [14] investigated the concrete cracking and wear resistance with different contents of chopped basalt fiber. In conclusion, the authors stated that even low chopped basalt fiber content can increase the intensity of toughness, wear and crack resistance resistance of concrete structures. The effect of basalt fiber (BF) content was tested for compression failure (which cracks contributes a lot) of concrete structures [15].

According to authors [16], in their paper, they carried out the experimental study on the modification of lightweight aggregate concrete with different basalt fiber portions, and the results show that with the increase in the amount of basalt fiber, lightweight aggregate concrete slump decreases; compressive strength increases gradually, when reaching a maximum and then decreased also, the flexural strength is improved obviously, improves the ratio of flexural toughness is greatly improved.
The authors [17] developed fiber reinforced aerated lightweight concrete to reduce concrete's density and to improve its fire resistance, thermal conductivity, and energy absorption. The authors carried out compression tests to determine basic properties of fiber reinforced aerated lightweight concrete. The basic independent variables were the types and volume fraction of fibers, and the amount of air in the concrete. The lightweight aggregate used by the authors in their research was made of expanded clay. Further to explain, their study provides basic information regarding the mechanical properties of fiber reinforced aerated lightweight concrete and compares fiber reinforced aerated lightweight concrete with fiber reinforced lightweight concrete. The authors investigated some properties: unit weight, uniaxial compressive strength, modulus of elasticity, and toughness index.

The parameters and quantity of chopped basalt fiber in concrete have a unique effect on the compressive strength of concrete. The authors of research paper [18] carried a research on concrete by the use of cubic and cylindrical tests. The results in [18] expresses that the mean compressive strength for the chopped basalt fiber concrete samples was significantly higher than the compressive strength of the usual concrete samples without chopped basalt fiber at 7, 14 and 28 curing days.

In the research paper [19], the authors explained the comparisons of concrete compressive strength mixed with different chopped basalt fibers content varying from 0.1% to 0.5%. The compressive strength of concrete increases with increasing basalt fiber content up to 0.3%: after this, the concrete compressive strength tends to decrease gradually by 12%. The authors explained that this is as a result of cohesive decrease between the cement paste and the concrete aggregate that plays a significant role in the compressive strength of concrete.

In paper [20], a 24.3 mm basalt fiber length with diameter 13 $\mu$m was used. The author investigated the effect of different chopped basalt fiber lengths of 12 mm and 24 mm on the compressive strength of concrete. The results from the analysis showed an increase in the compressive strength of concrete by 58% when reinforcing concrete with chopped basalt fiber length 12mm, and increases by 25% when reinforcing concrete with basalt fiber length 24 mm.

According to [21], the authors showed that as the content of BF in the concrete mixture increases, the concrete compressive strength decreases after 7 days curing period. However, after 28 days, the compressive strength of the concrete increases with an increase in chopped basalt fibre content to 0.1%.

The author [22] after 7 days checked the flexural strength of concrete, with the inclusion of chopped basalt fiber and without. The results from author's analysis show that addition of 1% of chopped basalt fiber to the concrete decreases the flexural strength of the concrete.

Furthermore, the results of experiment of [23] show that flexural strength of the concrete increases with increase in the chopped basalt fiber content in the concrete.

### 1.3 The Problem Statement

This paper has a task to investigate the effect of basalt fiber in lightweight expanded clay concrete on compressive and flexural strength of lightweight expanded clay basalt fiber reinforced concrete (LWECBFRC). Considering the properties of chopped basalt fiber, it is important to find out the influence of the fiber on the lightweight concrete.

### 2. Materials And Methods

To prepare concrete with chopped basalt fiber and expanded clay (figure 2 and figure 3 respectively), quality materials were sourced for.

#### 2.1 Technical characteristics of the chopped basalt fiber from OOO TD RUSSIAN BASALT [24]

- Tensile strength = 3500 MPa
- Modulus of elasticity = Not less than 75 GPa
- The coefficient of elongation in % = 3.2
- Melting point in °C = 1450
- Alkali and corrosion resistance = High
- Density g / cm³ = 2.60

**Figure 2. Chopped basalt fiber.**

2.2 Technical characteristics of expanded clay from Belsnab [25]

This expanded clay which is a porous material is one of the most effective for thermal insulation, which is in great demand in the production of building materials (expanded clay concrete, lightweight concrete, etc.) and in the insulation of residential buildings (insulation of the columnar foundation, floors on the first floor of the house, etc.). The main properties of expanded clay are: grain fraction, bulk density and strength.

Expanded clay gravel (Figure 3) has different size fractions varies 0-40 mm. It is used as filler in the production of lightweight concrete, with thermal insulation of horizontal surfaces on the roof and on the floors [26].

Chopped basalt fibers are added into concrete mixture to change and enhance the physico-mechanical properties of concrete. The use of chopped basalt fiber increases resistance of concrete and limits formation of shrinking cracks in the case of high temperatures; in particular, it limits the process of explosive spalling [27-30].

**Figure 3. Expanded clay with fractions 5-8 mm**

2.3 Experimental Procedure

In this experiment, the materials and admixtures used are: Cement, Expanded clay, Modifier MB10-50C, Modifier Silica fume MK-85, Quartz Sand, Superplasticizer Sikaplast, Quartz flour, Water and Experimental study was carried out based on the CIS Interstate Standard GOST 10180-2012 [31]. The machine used in testing the compressive and bending strength is a universal matest testing machine (figure 4) installed in the laboratory of the department civil engineering, academy of engineering of Peoples Friendship University of Russia (RUDN University).
2.3.1 Bending Tests on Chopped Basalt Fiber Lightweight Concrete Rectangular Prisms.
Bending tests were made on total number of 18 specimens (9 with chopped basalt fiber and 9 without chopped basalt fiber) to determine the exact material strength of the basalt fiber concrete. The chopped basalt fiber has a parameter of 20 mm length and 1.5 µm diameter and a 1.6% portion of chopped basalt fiber was added to the concrete mixture. Concrete strength was checked on the 7th, 14th and 28th day with the stipulated sample specimens. The dimensions of the rectangular prism used as beam are Length 160 mm x Width 40 mm x Height 40 mm.

![Matest universal testing machine for compression and bending test](image)

**Figure 4.** Matest universal testing machine for compression and bending test

2.3.2 Compression Tests on Chopped Basalt Fiber Lightweight Concrete Cubes.
Total of 18 cubes specimens (9 with chopped basalt fiber and 9 without chopped basalt fiber), comprising of cube concrete of 100 mm x 100 mm x 100 mm. The strength of the concrete was checked on the 7th, 14th and 28th day with 18 (9 with basalt fiber and 9 without basalt fiber) specimens respectively after they stayed in room temperature for 7, 14 and 28 days per 3 specimens stipulated samples respectively.

3.  Test Result

3.1 Bending (Flexural) concrete test specimens
The concrete specimens without basalt fiber showed high visual cracks when compared to specimens with basalt fiber. Significant visual results are seen in Figure 5 and 6 respectively on the 14th day.

![Rectangular concrete specimens with 0% basalt fiber (BF) after bending](image)

**Figure 5.** Rectangular concrete specimens with 0% basalt fiber (BF) after bending

![Rectangular concrete specimens with 1.6% basalt fiber (BF) after bending](image)

**Figure 6.** Rectangular concrete specimens with 1.6% basalt fiber (BF) after bending

3.2 Compression test on rectangular specimens
In the specimen results seen in figure 7 and 8 respectively, it can be seen that the cube specimens still without fiber was able to resist cracks thereby showing very little or no cracks. The results seen on the specimens proves the crack resistance ability of lightweight expanded clay concrete with or without basalt fiber on the 14th day.
Figure 7. Cube concrete specimens with 0% basalt fiber (BF) after compression

Figure 8. Cube concrete specimens with 1.6% basalt fiber (BF) after compression

Table 1. Flexural test result of specimens test results.

| Basalt fiber content (%) | Basalt Fiber length = 20 mm, Diameter 1.5 µm | Flexural strength MPa on: |
|--------------------------|----------------------------------------------|--------------------------|
|                          |                                              | 7 day | 14 day | 28 day |
| 0                        |                                              | 0.236 | 0.291  | 0.501  |
| 1.6                      |                                              | 0.512 | 0.706  | 1.612  |

Table 2. Compression test results of lightweight expanded clay basalt fiber reinforced concrete.

| Curing period, in days | Average $R_c$ of specimen with 0% Basalt fiber, MPa | Average $R_c$ of specimen with 1.6% Basalt fiber, MPa |
|------------------------|-----------------------------------------------------|-----------------------------------------------------|
| 7                      | 18.47                                               | 11.46                                               |
| 14                     | 26.84                                               | 43.17                                               |
| 28                     | 86.55                                               | 88.82                                               |
Table 1 shows the figurative result derived from the experiment and Figure 9 illustrates the comparison test results of lightweight expanded clay concrete with 1.6% basalt fiber and without basalt fiber. From the graph figure, flexural strength of the lightweight concrete is much higher with lightweight expanded clay basalt fiber reinforced concrete (LWECBFRC) than lightweight expanded clay concrete (LWECC). The concrete strength growth is confirmed in bending of the rectangular specimen with basalt fiber.

Figure 10 shows the test results derived from Table 1 derived from the experiment compared between lightweight expanded clay concrete with basalt fiber and without basalt. A significant raise in compressive strength is seen in the lightweight expanded clay concrete (LWECC) and lightweight expanded clay basalt fiber reinforced concrete (LWECBFRC).

4. Conclusion
   i. From the tests results, expanded clay lightweight concrete shows more strength on compression than in flexure (bending) at 0% BF.
   ii. It is generally known that fiber reduces the compressive strength of concrete and increases the bending strength of concrete. This is true but, in the case of lightweight expanded clay basalt fiber reinforced concrete, it is seen just a slight decrease in the concrete compressive strength.
iii. There is significant growth in the strength of concrete on the 28th day compared to the strength on the 7th and 14th day.

iv. On compression, basalt fiber concrete with expanded clay show low or slow strength lost.

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