Compressive strength of basalt fiber reinforced concrete (BFRC) comparing on expanded clay and gravel as BFRC aggregate

P C Chiadighikaobi*, V V Galishnikova, M Kharun, D D Koroteev and P Dkhar
Peoples Friendship University of Russia (RUDN University), Moscow, Russia
Email: passydking2@mail.ru

Abstract. It is of great important that the compression strength of concrete is known in construction. The types of aggregate used in the concrete have great effect on the compression strength of the concrete. This paper looked into the compression strength of basalt fiber reinforced concrete when it bears expanded clay as aggregate and when it bears the usual gravel as aggregate. One thing to note is that the weight of both BFRC specimens vary as, the BFRC with expanded clay showed much lighter weight than that of BFRC with gravel. This weight difference was explained in the properties of the materials. The main aim of this research paper is to express the comparison differences between the two types basalt fiber reinforced concrete researched in this paper. This paper showed some literature reviews from the papers written from other authors on close and similar topics then, an experimental analysis was conducted to investigate and compare the compression strength of the two concrete mix which the results showed visible differences in the compression strength and crack resistance. From the experiment, it is seen that the concrete with expanded clay (lightweight expanded clay concrete and lightweight expanded clay basalt fiber reinforced concrete) has a rapid strength growth after the 14th day when compared to the usual (gravel) concrete or usual basalt fiber reinforced concrete. The compatibility of basalt fiber with expanded clay is excellent and can be seen from the result analysis.

Keyword: compression strength, expanded clay, gravel, basalt fiber reinforced concrete

1. Introduction
1.1. The general background
Concrete mixtures for construction can be prepared to provide varieties of mechanical and durability properties to meet the design requirements of a structure. Generally, the compressive strength of concrete is the most used performance measures by the engineer in designing buildings and other structures. Compressive strength test results is said to be primarily used to determine the concrete mixture as delivered that meets the requirements of the specific strength $f'_c$ in the job specification [1]. Strength of hardened concrete can be measured by the compression test. The compression strength of concrete is explained as a measure of the concrete's ability to resist loads which tend to compress it. The compressive strength of concrete is measured by crushing cylindrical or cubic concrete specimens in compression testing machine.

Concrete is a mixture of varies of materials which the basic materials are cement, sand, water and gravel/expanded clay but not limited to this. There are different types of concrete seen or in use in the world of civil engineering. Those types of concrete are determined by the materials used in the mixture. Compressive Strength of concrete is mostly determined at an age of 28 days [2].

Expanded clay aggregates are used in varies of industries due to its technical features and numerous advantages when compared to many other industrial raw materials. Expanded clay is one of the materials with the greatest compressive strength among lightweight aggregates [3].
In concrete mixtures, both gravel and crushed stone produce quality concrete. Gravels have lower water demand compared to crushed stone. Gravel is preferred for exposed-aggregate concrete in walkways and decorative applications [4]. This type of concrete aggregate is found used in 80 in every 100 concrete therefore, it is believed that it is a famous construction material and concrete aggregate. Based on this, little discussion will be shown about the gravel coarse aggregate but to go direct in its experimental result.

Lightweight aggregate concrete has the characteristics of lightweight, heat preservation, thermal insulation and fire resistance [5]. However, lightweight aggregate concrete early segregation problems and improper maintenance caused by drying shrinkage or cracking etc. Chopped basalt fiber has excellent mechanical properties, and it is a kind of environmental protection fiber material, which has been widely used [6, 7]. The basalt fiber reinforced concrete can effectively enhance the strength and toughness of concrete, restrain shrinkage, reduce the generation of cracks, improve the frost resistance of concrete, and improve the durability of concrete.

Though there is limited paper on basalt fiber reinforced concrete bearing expanded clay as aggregate but the literature review section of this research paper will give a review on the papers written by other authors on lightweight concrete where expanded clay was used an aggregate. Usually, basalt fiber reinforced concrete bearing gravel or broken rocks are easily seen. This paper will be expressing and solving the above mentioned challenge on basalt reinforced concrete bearing expanded clay.

### 1.2. Analysis of the stated issue

The parameters and proportions of basalt fiber in concrete have an effect on the compressive strength of concrete. The authors of research paper [8] carried out investigations on concrete using cubic and cylindrical tests where the average compressive strength of three samples, mixed with and without basalt fibers, at 7, 14 and 28 days were determined. The results in [8] showed that the average compressive strength for the basalt fiber concrete samples was higher than the compressive strength of the normal concrete samples at 7, 14 and 28 days.

In the research of [9], the authors explained the variation of concrete compressive strength mixed with different basalt fibers content of 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 due to the cohesive decrease between the cement paste and the aggregate that plays a significant role in the compressive strength of concrete.

According to [10], the author studied the effect of using different basalt fiber lengths of 12mm and 24mm on the compressive strength of concrete, using a cubic sample with dimensions of 100x100x100mm. The author tested a total of 126 concrete samples: 18 of the samples were not reinforced, while 108 were reinforced, with basalt fibers. The analytical results showed that the compressive strength of concrete increases by 58% when reinforcing concrete with basalt fiber 12mm in length, and increases by 25% when reinforcing concrete with basalt fiber 24mm in length. The authors in [11] have shown that, as the basalt fiber content increases in the concrete mixture, the compressive strength of the concrete decreases, when testing concrete strength after 7 days. The authors further in their explanation stated, when testing concrete strength after 28 days, the compressive strength of the concrete increases with an increase in basalt fiber content to reach its maximum value at fiber content of 0.1%.

Authors of [12] concluded that as compared with the plain concrete, concrete reinforced with Basalt fibers have high flexural strength and tensile strength. But the compressive strength of concrete reinforced by Basalt fibers increases slightly at the early age and even decreases at the late age.

Looking on the lightweight concrete, the authors of [13] in their paper, the compressive strength of a wide range of structural lightweight aggregate concrete mixes is evaluated by the non-destructive ultrasonic pulse velocity method. The study involves about 84 different compositions tested between 3 and 180 days for compressive strengths ranging from about 30 to 80 MPa. The influence of several
factors on the relation between the ultrasonic pulse velocity and compressive strength is examined. They explained that these factors include the cement type and content, amount of water, type of admixture, initial wetting conditions, type and volume of aggregate and the partial replacement of normal weight coarse and fine aggregates by lightweight aggregates. It is found that lightweight and normal weight concretes are affected differently by mix design parameters.

In [14] stated, the purpose of this report is to investigate the types, advantages, mechanical properties of LWC. And what additions act in the strength of LWC. This report presents the results of the Investigation of the response of lightweight concrete to elevated temperature. The author went further to explain that this report investigates the effects of steel fibers on some properties of light weight concrete as compressive strength, splitting tensile strength and flexural strength. Also this report investigates the effect of porous aggregate on strength of concrete and investigated influence of pre-wetting aggregate on mechanical properties of concrete. The performance of structural lightweight aggregate concrete could be further studied with various cement content at constant w/c ratio.

In [15, 16], compressive strength comparable to that of normal weight concrete is obtained by the use of lightweight concrete. High compressive strengths of up to 7000 psi are used in the production of structural precast members. However, generally more sacks of cement per cubic yard of concrete are required when manufacturing lightweight concrete instead of normal weight concrete.

Through the years, by judicious selection of the lightweight sand and careful proportioning, semi-lightweight cement mortars having high compressive strengths have been made [17]. Although such strength is not necessary in many structural applications, there are advantages to the use of very high strength lightweight cement concrete in such applications as offshore drilling platforms. Such lightweight concrete has greater buoyancy and thus is easier to tow in shallow waters, and less excavation is required in construction of the dry dock compared to heavier structures. There is one instance where such lightweight concrete has been used for oil drilling platforms in the Arctic [18]. In addition to its lighter weight, which permits savings in dead load and so reduces the cost of both super structure and foundations, this concrete is more resistant to fire and provides better heat and sound insulation than concrete of normal density [19-21]. For lightweight concrete structures, as for structures of normal weight concrete, there is a well-established trend toward using higher compressive strengths. This permits the use of smaller member sizes, which in turn permits further reduction in dead load with attendant cost savings, and extends the practical range of span as well [22-24].

In the experimental study on the effect of short basalt fiber on the properties of lightweight aggregate concrete [25], the authors conducted an experimental study on the modification of lightweight aggregate concrete with different content of basalt fiber was carried out. The result showed that with the increase of amount of basalt fiber, lightweight aggregate concrete slump decrease; compressive strength increase gradually, when reaching a maximum and then decreased; the flexural strength is improved obviously, improves the ratio of flexural toughness is gradually improved. SEM photo shows that the interface of basalt fiber and cement paste is good, the porosity of concrete is decreased, and the frost resistance of concrete is significantly improved.

1.3. The problem statement
This paper has a task to solve which is, to investigate the compression strength of basalt fiber concrete which it has gravel as an aggregate and when it has expanded clay as an aggregate. Considering the properties of the both aggregates, it is necessary to find out which of the aggregates works better with chopped basalt fiber. The two concrete mixtures contain the same admixtures based on their ratios.

2. Materials and methods
2.1. Experimental procedure
In this experiment, the materials and admixtures used are: Portland cement, aggregate (expanded clay or crushed granite), modifier MB10-50C, modified silica fume MK-85, quartz sand, superplasticizer
Sikaplast, quartz flour, water, and chopped basalt fiber as the basic research material of high strength concrete (HSC).

Experimental study of HSC was carried out with the following composition: Portland cement M500 type I = 500 kg/m³, concrete modifier MB10-50C = 125 kg/m³, modified silica fume MK-85 = 62.5 kg/m³, quartz sand with the fineness modulus of 0.8-1.4mm = 585 kg/m³, aggregate (expanded clay of 5-8 mm = 198 kg/m³ or crushed granite of 5-20 mm 1005 kg/m³), water = 255 l/m³ for expanded clay concrete while 187.5 l/m³ for crushed granite concrete, and chopped BF of 12 mm length with 1.5nm for BF, Superplasticizer Sikaplast = 1%, Quartz flour = 20%. Experimental study was carried out in accordance with the CIS Interstate Standard GOST 10180-2012 [26]. The machine used in testing the compression strength is a universal matest testing machine in the laboratory.

2.1.1. Compression tests on chopped basalt fiber lightweight concrete cubes (BFRC with expanded clay). To achieve the required procedure, a total of 18 cubes (9 with chopped basalt fiber and 9 without chopped basalt fiber), comprising of cube concrete of 100mm x 100mm x 100mm. The strength of the concrete was checked on the 7th, 14th and 28th day. A 1.6% chopped basalt fiber is used for the reinforcement.

2.1.2. Compression tests on chopped basalt fiber normal weight concrete cubes (BFRC with gravel crushed stone). To achieve the required procedure, a total of 18 cubes (9 with chopped basalt fiber and 9 without chopped basalt fiber), comprising of cube concrete of 100mm x 100mm x 100mm. The strength of the concrete was checked on the 7th, 14th and 28th day. A 1.6% chopped basalt fiber is used for the reinforcement.

3. Results and discussion
Results of the laboratory tests are shown in tables 1, 2 and figures 1, 2.

**Table 1.** Compression test ($R_c$) 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                      | 18.57                                         | 10.56                                         |
| 14                     | 26.94                                         | 42.27                                         |
| 28                     | 86.65                                         | 89.72                                         |

**Table 2.** Compression test results of crushed stone 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                      | 57.62                                         | 44.68                                         |
| 14                     | 74.32                                         | 57.76                                         |
| 28                     | 91.72                                         | 68.21                                         |
Figure 1. Compressive comparison result of concrete with crushed stone and with expanded clay with 0% BF.

Figure 2. Compressive comparison result of concrete with crushed stone and with expanded clay with 1.6% BF.

From the results in figure 1 and 2, it is seen that basalt fiber works better with expanded clay as the days keep growing. In the course of this experiment, it is seen that the crack appearance on the lightweight expanded clay concrete and lightweight expanded clay basalt fiber reinforced concrete is practically not visual because of the compatibility of basalt fiber with the expanded clay and the high strength of the expanded clay also of basalt fiber. The expanded clay glues very well with the concrete mixtures and in the process of compression. The properties of expanded clay and that of basalt fiber are compactible.

4. Summary and conclusions
From the experimental result and analysis, it is seen that;

i. The physical and mechanical properties like the compressive strength, and the cracks are differentiable from the two different types of specimens.

ii. The weights of the concrete with expanded clay showed more than 50% lesser the weight of the concrete with crushed stone.

iii. In the process of the concrete missing, concrete with expanded clay absorbed water faster than the concrete with crushed stone which contributed to the low strength experienced on the 7th and 14th day.
iv. The lightweight expanded clay concrete though with lesser compressive strength on the 7th and 14th days still was able to retain it crack resistance capacity as it show-cased little or poor visible cracks.

v. From the experiment and research, it was seen that the usage of Basalt fibers in low cost composites for civil infrastructure applications gives good mechanical properties like strength and lower cost predicted for basalt fibers.

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Authors’ background

| Name              | Prefix               | Research Field               | Email                     |
|-------------------|----------------------|------------------------------|---------------------------|
| P C Chiadighikaobi| PhD Candidate        | Building materials, Structural design | passydking2@mail.ru |
| V V Galishnikova  | Full Professor, DSc, PhD | Building materials, Structural design | galishni@yandex.ru |
| M Kharun          | Associate Professor, PhD | Building materials, Structural design | miharun@mail.ru |
| D D Koroteev      | Associate Professor, PhD | Building materials, Structural design | Koroteev_dd@pfur.ru |
| P Dkhar           | Assistant Professor  | Building materials           | dkhar.prashanta@gmail.com |