Performance evaluation of dispersed basalt fiber on strength of lightweight expanded clay concrete

Paschal Chimeremeze Chiadighikaobi, Dafe Aniekan Emiri, Mohamed Ibrahim Abu Mahadi, Kebba Camara, Foud Adnan Noman Abdullah Al-shaibani, Majeed M. Haidar and Lina Abass Saad
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Abstract: This paper conducted an experimental investigation on the effects of dispersed basalt fiber (BF) on lightweight expanded clay concrete (LWECC). The objective is to evaluate the strength, density of LWECC containing dispersed BF with comparison on the strength derived from research of similar work. Experiments were performed on LWECC 100 × 100 × 400 mm prism for flexure and 100 × 100 × 100 mm cube for compression and split tensile tests. Additives were added to enhance the concrete strength. The compressive strength \( f_c \), density \( \rho \), flexural strength \( f_f \), split tensile strength \( f_{st} \) were obtained from LWECC containing 0%, 0.9%, and 1.6% BF, respectively. The experimental results on day 28 show that \( f_c \) recorded the highest at 1.6% BF content, and lowest at 0% BF content while with incorporation of 0.9% BF, the \( f_c \) of ECC increased by 121.82%, with incorporation of 1.6% BF the \( f_c \) of ECC increased by 162.79% and ECC containing 1.6% BF showed \( \rho \) of 1410 Kg/m\(^3\) while the \( f_f \) is highest with 1.6% BF at 6.54 MPa followed by 0.9% BF at 4.01 MPa and lowest at 0% BF at 3.72 MPa. The \( f_{st} \) is higher with 1.6 BF at 5.41 MPa. Incorporation of BF in ECC proved to have positive effect of ECC.

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PUBLIC INTEREST STATEMENT
Concrete is one of the famous structural material, however one of its major disadvantages is it self-weight. Engineers have explored various ways to reduce the weight of concrete and still retain a high strength-durable relationship. Fiber-reinforced concrete can be used to overcome this challenge, examples of these fibers are composites, hybrid fiber, and plant fiber. These materials have unique features and disadvantages. Therefore, this paper analyzed research works and experiments of previous researchers on lightweight basalt-fiber concrete. The authors propose replacement of granite with expanded clay (EC) as aggregate thus reducing the weight of concrete while basalt fibers (BFs) is used to strengthen/reinforce the concrete. EC and BFs are pure, natural, and eco clean materials that are widely available within the earth surface, they are affordable yet durable. The analysis drawn from the various authors shows the effectiveness of EC and BF.
Subjects: Geology - Earth Sciences; Environment & Economics; Testing; Composites; Materials Processing; Polymers & Plastics; Technology; Concrete & Cement

Keywords: lightweight fiber concrete; dispersed fiber concrete; expanded clay; lightweight aggregate; lightweight concrete; high strength light materials; basalt fiber

1. Introduction
Advancing technology allows the use of lightweight concrete (LWC) as a structural material to reduce the self-weight of a building. By reducing the self-weight or dead load of a structure or prismatic dimensions, engineers can minimize the harm to life and property in event of an earthquake or some negative environmental hazards. LWC can be produced using lightweight aggregates (LWA) like expanded clay (EC), volcanic stone or using admixture like silica fume powder as an air entraining agent to typical concrete mix with or without coarse aggregate (Mehta & Kumar Ashish, 2020; Rjoub, 2021; Singh, 2016). Adhikary et al. 2021 investigated the effects of carbon nanotubes on expanded glass and silica aerogel-based LWC.

Advancing technology makes is possible to develop sustainable construction material and structural members such as beams, piles, and floors either cast on site or prefabricated (Al-Hasan et al., 2020 and Adhikary et al. 2021) by replacing the larger parts of the traditional “natural” aggregate (granite or stones) with an “artificial” aggregate, made up of EC granules or schists. The structural formation of LWC with EC laterite contains no other natural or artificial lightweight inert material such as polystyrene, volcanic rocks, pumice, neither are other material are admitted.

Concrete is the most widely used structural material in civil engineering. Some remarkable mechanical properties of concrete are its high $f_c$ and good durability. However, concrete has a high dead weight, low tensile strength, poor toughness, low fracture energy, and poor impact resistance (Gong et al., 2002; Xu & Li, 2008; Xu et al., 2007). Reinforced concrete (RC) and fiber-reinforced concrete (FRC) are two of the most common building materials. Composite concrete contains fibers like steel fiber (SF), carbon fiber (CF), glass fiber (GF), BF, synthetic fiber, and plant fiber (Sun, 2013).

BF can be as a suitable material for concrete reinforcement material due to its good thermal stability, thermal insulation, good environmental compatibility, high tensile strength, and high elastic modulus (Ouyang et al., 2013; Wang et al., 2004; D. Zhang et al., 2012). Basalt fiber (BF)-reinforced concrete (BFRC) optimizes the internal structure of concrete. BF can be reinforced and toughened, also its thermal insulation and durability can be improved, among other properties (Y. C. Zhang et al., 2016; Mao et al., 2007; Yang & Wang, 2015).

In the research work (Xiao et al. 2016 and Khan et al., 2021) they stated that lightweight aggregate concrete (LWAC) is known for its excellent properties such as lightweight, high strength, heat preservation, heat insulation, fireproof, antifreeze, earthquake, and resistance to chemical corrosion. To obtain the desirable properties of LWAC, fiber modification was adopted in their work. Also, BF influence on the mechanical properties of LWAC, the toughening mechanism was analyzed, and the optimum content of BF was obtained. The result of the experiment proved that BF significantly improved the flexural strength ($f_f$), and toughness of cinder LWAC. To investigate the mechanical properties of BF on LWAC, the ($f_f$), and compressive strength ($f_c$), were tested. After the concrete was mixed with BF, concrete's $f_c$ and flexural strength increased. The $f_f$ increased significantly higher than the $f_c$. When BF content was increased to 3%, the $f_c$ increased by 2%, the $f_f$ increased by 33.4%.

(Bogas & Nogueira, 2014) characterized the tensile strength of LWAC produced with different types of EC aggregates (ECA). Their paper carried out comprehensive experimental study on
different concrete compositions with mean $f_c$ from 30 to 70 MPa and density classes from D1.6 to D2.0. Also, the influence on the splitting tensile strength ($f_{ct}$) and modulus of rupture of the curing conditions and initial wetting of LWA were studied. Concretes of equivalent $f_c$, the tensile strength are almost independent of the type of LWA. The tensile strength of LWAC was about 0.8–0.85 of that of normal weight concrete (NWC) of equal strength, decreasing to about 0.7 in LWAC with lightweight sand. In comparing the $f_c$, the LWAC with less porous aggregates had lower tensile structural efficiency than NWC. But the tensile structural efficiency of moist-cured concrete is not affected significantly by the volume and wetting conditions of aggregate. There is a reduction in the splitting strength of air-cured concrete that is not predicted in the normalization and it is greater for NWC than for LWAC. However, the modulus of rupture of air cured LWAC can only be about 0.5–0.8 of that of NWC of equal strength.

(Kim et al., 2010) developed fiber-reinforced aerated LWC to reduce concrete’s density ($\rho$) and to improve its fire resistance, thermal conductivity, and energy absorption. In their paper, compression tests were performed to determine basic properties of fiber-reinforced aerated LWC. The primary independent variables were the types and volume fraction of fibers, and the amount of air in the concrete. The LWA used in their research was made of EC. Their study provides basic information regarding the mechanical properties of fiber-reinforced aerated LWC and compares fiber reinforced aerated LWC with fiber reinforced lightweight concrete (FRLWC). The properties they investigated included the unit weight, uniaxial $f_c$, modulus of elasticity (MoE), and toughness index. Based on their results, a stress-strain prediction model was proposed. The proposed model accurately predicts the stress-strain behavior of fiber-reinforced aerated LWC.

(Ashok & Sailaja, 2018), in the process of expressing the uniqueness of basalt reinforced polymer (BRP), made mention of the lightweight of BF-reinforced polymer (BFRP). Their work shows that BFRP materials have been used as internal support for concrete individuals and external fortification for retrofitting structures. Unlike carbon fiber reinforced polymer (CFRP) and glass fiber-reinforced polymer (GFRP) materials, BFRP material have not been broadly utilized. BF from its properties, is a high-performance non-metallic fiber made from basalt rock melted at high temperature. BF strengthens solid concrete, offers more characteristics, for example light weight and great imperviousness to fire.

Xiao et al. 2016 carried out experimental study on the modification of LWAC with different content of BF, and their research shows that: with the increase of amount of BF, LWAC slump decreases; $f_c$ increases gradually, then reaches a maximum thereafter decreased; the $f_t$ is obviously improved, the ratio of flexural toughness is greatly improved.

The above literatures provide valuable knowledge on BF and lightweight EC concrete (LWECC); however, they do not provide details of the effect of including materials such as EC aggregates, quartz sand, quartz flour, binder holcim Portland cement, micro silica to the concrete mix. This paper aims to fill that gap by conducting experiments with these materials, while varying the percentage of BF content with 0%, 0.9%, and 1.6%, respectively.

Developments in the construction industry is fast paced and evolving more than ever before, engineers are constantly seeking ways to reduce the weight of concrete while still retaining a high strength durable concrete. EC concrete (ECC) is known for its brittleness leading to lower strength hence the need for incorporating of BF in ECC. Building on previous works, this paper examines LWAC reinforced with chopped BF, (Figure 1) where EC replaced granite (Figure 2) as concrete aggregate with the aim of reducing the weight of concrete. EC and BF are pure natural and eco clean materials that can be found easily on or within the earth. Further
research on these two materials could possibly bring about breakthrough in high strength lightweight materials.

By observance, the LWC using the nominal size of the aggregate can still be used effectively as they are lighter in weight, greater in $f_c$.

2. Materials and methods of research

2.1. Materials based on literature review

2.1.1. Physical and mechanical properties of ECA

The coherence between concrete aggregate properties and performance in concrete is yet fully understood in many regards. The properties of concrete aggregates have great influence on concrete properties, its understanding is imperative for the development of high-quality concrete. The key properties of ECA are $\rho$, strength, and water absorption as stated by (Alexandra et al., 2016). ECA (Figure 2) are highly governed by type and dosage of the binder as well as sintering temperature and its duration. While the dimensional properties of the aggregates were influenced by the moisture content and angle of palletization used. A summary of the physical and mechanical properties of expanded clay are given below in Table 1.

Porosity alone can never govern the crushing strength of the LWA. Some other related factors such as change in the mineralogical composition, melting temperature of binders, margin of densification during sintering, bloating of the aggregate and internal defects due to thermal stresses also have significant impact on the crushing strength.
| Specific gravity | RBD (Kg/m³) | LBD (Kg/m³) | Crushing Strength (MPa) | Water absorption (%) | Fineness modulus | Reference |
|------------------|-------------|-------------|-------------------------|----------------------|------------------|-----------|
| 0.66             | 273         | -           | -                       | 26.5                 | 5.96             | ASTM C330-05, 2005 |
| 1.15             | 1068        | 613         | 6.8                     | 12.3                 | -                | Bogas et al., 2012 |
| 0.89             | -           | 720         | -                       | 20                   | -                | Murat et al., 2015 |
| -                | 1002        | 488         | 3.49                    | 24.5                 | -                | Deividas et al., 2017 |
| -                | 1100        | 700         | -                       | 29.9                 | -                | Yiuniemi & Ferreira, 2017 |
| -                | 1290        | 738         | -                       | 12.1                 | -                | Alexandre & Cunha, 2017 |
| 1.21             | -           | 621         | -                       | 16.2                 | -                | Abdurrahmaan et al., 2014 |
| -                | -           | 358         | -                       | 26.2                 | 5.77             | Bogas & Nogueiro, 2014, Munoz-Ruiperez et al., 2016. |
| 1.35             | 1092        | 681         | 5.7                     | 12.6                 | -                | Konakov et al., 2017. |
| -                | 603         | 334         | 1.4                     | 18.4                 | -                | Alexandre & Cunha, 2017 |
| -                | 1480        | 800         | 8.34                    | 26.5*                | -                | Salem et al., 2011. |

Note: RBD = Rooded bulk density; LBD = loose bulk density; *1 hr water absorption
One principal property of LWAC is water absorption rate which plays an important role on the proportioning of concrete mixtures. The porous nature of ECA is responsible for its high absorption (Hubertova & Hela, 2013). The effect of high-water absorption must be carefully considered in the development of good concrete, hence proper counter measures are necessary to arrest its negative impact on the concrete. Notwithstanding, sealing all the pores to reduce the absorption is not desirable, as this will lead to increase in the ρ of the aggregates. Smooth decline in the water absorption was observed with increase in temperature of 1180°C (Expanded Clay Aggregate, 2018). When exposed to higher temperature, formation of glassy texture on the surface of the aggregates will occur, which may hinder the inter pore connectivity (Chiou et al., 2006). Noticeable reduction in water absorption potential of the aggregates was also observed by the addition of binder in the manufacturing of the aggregates irrespective of type of binder used.

2.1.2. Physical and mechanical properties of Basalt Fiber Lightweight Expanded Clay Concrete (BF LWECC)

The concrete mix design procedures recommended for the development of BF Lightweight EC Aggregate concrete (Figure 3) completely varies from normal or the widely known aggregate concrete mix design. Most of the mixtures found in the papers reviewed were based on the fixation of either the aggregate content or paste volume of the concrete, irrespective of the aggregate characteristics and the strength requirements. It is a generally known fact that, the concrete mixture design has accentuated not only the strength properties, but also the durability of concrete. The porous feature of LWA causes the reduction in its \( f_c \) capacity and reduces the free water from the paste matrix, based on this, it is crucial to include some admixtures that reduce the porosity in concrete. Hence, it requires stone flour (Stone flour), adding some percentages of BF to the concrete mixture which will help in reducing the pores and at the same time serve as a reinforcement to the concrete (Jian-jun & Zhi-ming, 2016) also, adding large amount of cement

Figure 3. Inner view of lightweight expanded clay concrete containing dispersed chopped BF.

Figure 4. Inner view of expanded clay lightweight aggregate concrete.
### Table 2. Mechanical properties of ECAC

| C (%) | LWA | SCM | FAg. | W/C | Sl (mm) | ρ (Kg/m$^3$) | $f_c$ (MPa) | $f_s$ (MPa) | $f_t$ (MPa) | MoE (GPa) | References |
|-------|-----|-----|------|-----|---------|-------------|-------------|-------------|-------------|------------|------------|
| 560   | 226 | SP 8, FA 112, Fibers 0.9 | -    | 0.43| -       | 1320        | 45          | 1.66        | 2.96        | 13.1       | Corinaldesi & Moriconi, 2015 |
| 480   | 210 | SP 4 | 851  | 0.32| 50      | 1550        | 15          | 2.24        | 3.25        | 16.8       | ASTM C330-05, 2005 |
| 451   | 180 | FA 80, SP 0.8-6, LSP 326-330 | 414-426 | 0.34-0.5 | 150-180 | 1638-2044 | 60          | -           | -           | 20-23      | Murat et al., 2015 |
| 550   | 180 | SP 2.75 | 720  | 0.26| 145     | 1854        | 31          | 2.77        | 3.8         | -          | Payam et al., 2014 |
| 450   | 256 | -    | 591  | 0.35| 140     | 1290        | 35          | 1.86        | 2.3         | 14.5       | Alexandre et al., 2014 |
| 384   | 427 | WRA 3.6, SF 36, FA 60 | 514  | 0.35| -       | 1500        | 21          | -           | -           | -          | Abdurrahmaan et al., 2014 |

**Note:** C = Cement; FA = Fly Ash; SF = Silica Fume; SP = Super Plasticizer; FAg = Fine aggregate; LSP = Lime Silica Powder; $f_s$ = Split tensile strength, Sl = Slump, WRA = Water Reducing Admixture.
paste to achieve appropriate workability and strength (Kvande, 2001). This may affect the durability requirement for the structural concretes. Some of the key parameters that are considered for mix design of any concretes are water cement ratio, cement content, and aggregate content. In addition, proper combination of aggregate grading facilitates appropriate aggregate packing within the concrete matrix, which will reduce the cement content and enable superior properties of the hardened concrete.

2.1.3. Mechanical properties of Expanded Clay Aggregate Concrete (ECAC)

Mechanical properties of any composite material are easily determined by assessing the mechanical properties of each phase and the interaction among the phases. The behavior of manufactured LWA differs from conventional aggregates like crushed stone, it is very important to assess the mechanical properties of the lightweight EC aggregate concrete (Figure 4). A summary of the mechanical properties reviewed from previous studies are illustrated in Table 2.

2.2. Viability of experimental research

BF and EC are used in civil and structural works. These materials have unique advantages which is hardly found in other materials. BF derived from basalt rock and melted in furnace with a high temperature of 1200 –1450 from which the fibers are produced are totally free from chemicals or other harmful products; hence, it is purely 100% natural. The properties of BF (Properties of basalt fiber LBIE 2019) and the characteristics of EC (Laterlite lightweight insulating solutions, 2019) are explained in details and buttresses on their importance. Stakeholders in the construction industry must strongly consider using BF as a concrete reinforcement and EC as an aggregate.

2.2.1. Materials and methods of experimental research

The experimental study of concrete was carried in direction of CIS Interstate Standard GOST 10180–2013, taking into account the requirements of ACI 211.1–91, 2002. The materials used in the concrete mix of LWC in this research are stated below.

(i) ECA of 8–10 mm fraction = 200 kg/m$^3$ as coarse aggregate. ECA is associated with the

| Table 3. Physical properties and sieve analysis of LECA |
|-------------------------------------------------------|
| Physical Property | Value |
| Specific gravity | 0.69 |
| Fineness modulus | 5.93 |
| Bulk density (compacted), [kg/m$^3$] | 278 |
| Water absorption (24 h), [%] | 26.4 |
| Sieve Analysis, [mm] | Cumulative Percent by weight passing |
| 10.0 | 91.7 |
| 8.0 | 5.9 |
| 5.0 | 4.2 |
| 3.0 | 0 |

| Table 4. Physical properties of QS |
|-----------------------------------|
| Physical Property | Value |
| Grain size, [mm] | 0.5–1.0 |
| Bulk density (compacted), [kg/m$^3$] | 1430 |
| Hardness (on the Mohs scale) | 7 |
| Crushability | 0.3 |
| Humidity, [%] | 1.7 |
following properties: lightweight, insulating, strong, non-combustible and fire-resistant, extremely stable and durable, natural material for sustainable construction, versatility, and high drainage capacity. A single LWA was selected for this study: EC was obtained from the Production Plant “Keramzit”, Serpukhov District in Moscow Region, Russia. Detailed properties and information on ECA have been given in subsection 2.1 of this paper. The physical properties and sieve analysis of LECA used in this study are illustrated in Table 3.

(ii) Quartz sand (QS) of 0.4–0.8 mm fraction as fine aggregate of 585 kg/m³, has a rounded part with a low content of clay inclusions and inclusions of soft rocks. The resulting QS underwent additional enrichment and drying. The moisture content is up to 0.2% [48]. QS used in the experiment were obtained from the Plant “Tytchevo”, Naro-Fominsky District in Moscow Region, Russia. The physical properties of QS are presented in Table 4. This type of sand is used in the construction industry as fillers, they have high anti-erosion ability, they are used to make acid resistant concrete and mortar (F et al., 2020).

(iii) Mineral filler Silverbond Quartz flour (QF) of 50 μm fraction and 50 kg/m³ as mineral filler. This QF is known for its properties like: hardness and abrasion resistance, high chemical resistance, anticorrosion, low oil absorption, and low coefficient of thermal expansion.

(iv) Binder Holcim Portland cement (PC) M500 42.5 N = 500 kg/m³ as the binder. This was used to increase the water retention, and give the concrete a smooth texture, and better workability compared to ordinary cement.

(v) Organic mineral-based additives: Micro Silica (MS) = 40 kg/m³, and fly ash (FA) = 40 kg/m³. It has a fineness of < 0.001 mm, with average particle size of 0.1–0.3 μm.

QF, Portland cement CEM I 42.5 N, MS and FA were obtained from the Plant “Maltovsky”, Bryansk District, Bryansk Region, Russia. The chemical compositions of QF, Portland cement, MS and FA respectively are presented in Tables 5.

(i) Super plasticizing and water-reducing additive Sika Plast concrete in liquid state = 8 l/m³. This is water reducing agent and concrete plasticizer. It enhances the compaction and hydration of semi-dry concrete mixtures by increasing the density while reducing its permeability.

(ii) Tap water = 255 l/m³ at room temperature. Generally, water that is suitable for drinking is satisfactory for use in concrete.

(iii) Chopped BF of length 20 mm and diameter 15 μm.

ECA was washed to remove the dust in the aggregate. After washing the aggregate, it was spread on the metal surface for 48 hours to dry up. Before adding ECA to the concrete mix, the coarse aggregate was pre-immersed in the water for 24 hours before mixing. The ECA was removed from the water and placed on a sieve for 2 hours to dry off the water to reach almost saturated surface dry condition. The ECC specimens were moulded in 100×100×100 mm and 100×100×400 mm moulds, respectively, for cubes and rectangular prisms according to CIS Interstate Standard GOST 10180–2012. After pouring the ECC in the moulds, they were covered with polyethylene and kept at room temperature (20 ± 5) °C and relative air humidity (95 ± 5) % . After 24 hour, the ECC specimens were removed from the moulds and kept in wet sawdust at the room temperature (20 ±5) °C.

2.2.2. Experimental test
Two different ECC mixes (compositions) containing the above mixes and the chopped BF with diameter of 15 μm and length of 20 mm in the percentages 0%, 0.9%, and 1.6% BF were added in the concrete mixes separately.
## Table 5. Chemical compositions of QF, Portland cement, MS, and FA in percentage (%)

| Chemical Elements | SiO₂ | Al₂O₃ | Fe₂O₃ | K₂O | CaO | MgO | SO₃ | P₂O₅ | TiO | MnO | Na₂O |
|-------------------|------|-------|-------|-----|-----|-----|-----|------|-----|-----|------|
| QF                | 99.63| 0.23  | 0.12  | -   | 0.02| -   | -   | -    | -   | -   | -    |
| PC                | 21.90| 4.86  | 3.3   | 0.56| 65.77| 1.15| 2.1 | -    | -   | -   | 0.36 |
| MS                | 98.77| 0.23  | 0.07  | 0.26| 0.31| 0.04| 0.17| -    | -   | -   | 0.15 |
| FA                | 66.24| 19.81 | 6.41  | 1.39| 3.13| 1.21| -   | 0.36 | 0.86| 0.05| 0.54 |

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A total of 36 ECC test specimens were produced from each of the stated compositions with dimensions of $100 \times 100 \times 100$ mm for compressive test—12 specimens, $100 \times 100 \times 400$ mm for flexure—12 specimens and $100 \times 100 \times 100$ mm for split tensile test—12 specimens.

Experimental studies of ECC were carried out on days 7, 14, and 28 curing periods on a Matest hydraulic press (Figure 5) of up to 1500 kN at the compression and split tensile tests, and up to 150 kN at the flexural. To generate a compression zone on the top side of the beam, one symmetric point load was applied to form the three-point flexural test. The density of the ECC specimens were derived by dividing mass of the ECC specimen by the volume of the ECC specimen.

3. Results and discussion
The results shown in this research paper are average results on each concrete testing sets on each specific day (see, Table 6).

Figures 6 and 7 shows pictures of the experimental results from the Matest universal hydraulic press shown on Figure 5.

From the literature review, (Corinaldesi & Moriconi, 2015), was chosen as a comparison to the experimental results due to its close similarities in the materials for concrete mix as well as the fiber content used in this laboratory experiment.

Figure 8 compares the $f_c$ tests results from the literature reviewed in Table 2 with the experimental results (see also, Table 6 for the results comparison). The $f_c$ recorded the highest at 1.6% BF content, and lowest at 0% BF content. On day 28 curing period, with incorporation of 0.9% BF, the $f_c$ of ECC increased by 121.82% while with incorporation of 1.6% BF, the $f_c$ of ECC increased by 162.79%. The $f_c$ for (Corinaldesi & Moriconi, 2015) at 0.9% fiber was 45 MPa while that of the experimental result is 26.35 MPa giving a 70% difference of the $f_c$.

As showed in Figure 9, on the 28th day, the $\rho$ of ECC without BF (0% BF) was 1400 Kg/m$^3$ and the $\rho$ of ECC containing 1.6% BF was 1410 Kg/m$^3$, the increase in $\rho$ is negligible, however at ECC with 0.9% BF, the $\rho$ drops by more than 50% when compared to the other two. Figure 9 compares the $\rho$ results of (Corinaldesi & Moriconi, 2015) in Table 2 to the $\rho$ of experimental results (see, Table 6 for the summary). The $\rho$ from (Corinaldesi & Moriconi, 2015) and the experimental results shows a difference of 6.6%.

Figure 10 compares flexural tests results of the literature review (Corinaldesi & Moriconi, 2015) in Table 2 with the experimental results summarized in Table 6. Figure 10 shows a relationship between ECC with BF content of 0%, 0.9%, and 1.6%, respectively, and $f_c$ of ECC is highest with 1.6% BF with 6.54 MPa followed by 0.9% BF with 4.01 MPa and lowest at 0% BF with 3.72 MPa.
Table 6. Average results of the laboratory tests of ECC specimens in comparison with results from [Corinaldesi & Moriconi, 2015](https://doi.org/10.1080/23311916.2022.2137007)

| LWC mechanical properties | 0% BF | 0.9% BF | 1.6% BF |
|---------------------------|-------|---------|---------|
|                           | Day 7 | Day 14  | Day 28  | Day 7 | Day 14  | Day 28  |
| $f_c$ (MPa)               | 11.31 | 16.25   | 21.63   | 18.79 | 21.04   | 26.35   | 45      | 27.31 | 29.77  | 35.211 |
| $\rho$ (Kg/m$^3$)         | 1411  | 1407    | 1400    | 1416  | 1409    | 1406    | 1320    | 1422  | 1417   | 1410   |
| $f_t$ (MPa)               | 2.86  | 2.96    | 3.72    | 3.51  | 3.85    | 4.01    | 2.96    | 2.98  | 3.52   | 6.54   |
| $f_{ft}$ (MPa)            | 1.99  | 2.17    | 2.83    | 2.25  | 2.91    | 3.05    | 1.66    | 3.04  | 3.92   | 5.41   |

Current experimental results 0.9% BF

Corinaldesi & Moriconi, 2015 at 0.9% fiber
Figure 6. Experimental results on cube for compressive strength using 100 × 100 × 100 mm specimen.

Figure 7. Experimental results on rectangular prism for flexural strength using 100 × 100 × 400 mm specimen.

Figure 8. ECC compressive strength ($f_c$) results.

Figure 9. ECC density ($\rho$) results at varying % of BF content.
Figure 11 compares split tensile test results of (Corinaldesi & Moriconi, 2015) with the experimental results summarized in Table 6. The result for the split tensile test of ECC as shown in Figure 11 shows a relatively higher value at 1.6 BF content compared to that of (Corinaldesi & Moriconi, 2015) at 0.9% BF content after 28 days. Figure 11 shows a relationship between the percentage of BF content of 0%, 0.9% and 1.6%, respectively, and split tensile of ECC. The $f_{st}$ with 0.9% BF is 3.05 MPa is significantly lesser (almost twice) than ECC with 1.6% BF that obtained 5.41 MPa.

Consequently, from the review analysis drawn from the various authors in the research on lightweight concrete reinforced with BF and lightweight concrete with EC as an aggregate show that EC in concrete has better mechanical, physical, chemical, and thermal properties when compared to granite commonly used as a concrete aggregate. EC is a lightweight aggregate, formed by baking clay in a rotary kiln at 1100 has the capacity to withstand fire outbreak and other thermal effect that could cause instability, cracks, and other deformities in a structure.
4. Summary and conclusions

(1) Incorporation of dispersed chopped BF improved the $f_c$, $f_t$ and $f_{st}$ of LW ECC. The $f_t$ increased significantly higher than the $f_c$, thereby greatly improving the folding ratio of LWAC, which significantly improved the toughness of LWAC.

(2) After the BF is mixed with LWAC, the $f_t$ capacity of the LWAC is significantly improved.

(3) Concretes having $f_c$ between 11.31 MPa to 35.211 MPa and density 1400 kg/m$^3$ to 1422 kg/m$^3$ were produced. ECC with $f_{st}$ from 1.99 MPa to 5.41 MPa was produced. The positive result from the experiments opens the prospects for further development of structural concrete.

(4) The $f_c$, $f_t$, $f_{st}$ obtained from the literature review of (Corinaldesi & Moriconi, 2015) were compared with experimental result of ECC containing 0% BF, 0.9% BF and 1.6% BF, respectively. The experimental results show that $f_c$ was highest with ECC of 1.6% BF and lowest with ECC of 0% BF, $f_t$ was highest with BF of 1.6% and lowest with BF of 0% while $f_{st}$ was highest with BF of 1.6% and lowest with BF of 0%.

(5) The results gotten in this research work is slightly unusual when compared with the finding from other researchers because some factors like durability of the concrete, adaptability and resistance to external environmental factors that are harmful to concrete were considered hence the use of some additives like quartz flour, silica fume (micro silica), sika super plasticizer that also improves the strength of concrete at the same time solving the issues of the above-mentioned factors.

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