Compressive and Split Tensile Strength of Dispersed Basalt Fiber Lightweight Expanded Clay Concrete

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Abstract— **The strength of construction material is influential on the durability and stability of the structure. Since the mechanical properties determine their usage in construction. This research paper presents experimental studies and results of the split tensile strength (T_S) and compressive strength (f'_c) of lightweight expanded clay concrete (LECC) reinforced by blending dispersed chopped basalt fiber (BF) in the LECC . The chopped BF has a diameter of 15 micrometers and 20 mm length; mixed with concrete in the ratio of 0%, 0.45%, 0.9%, 1.2%, and 1.6% by weight. Five (5) sample groups were tested including a control concrete mixture without BF. Each sample group has nine (9) specimen cubes, and the cube dimension is (100 mm x 100mm x 100mm). The specimens were subjected to split tensile test and compression test at 7, 14, and 28-day curing period. The split tensile and compressive strength improved significantly, which is due to the incorperation of chopped BF in the LECC. More so, the blending of BF into the concrete mixture influenced the porosity index of the concrete.**

Index Terms— **Basalt fiber concrete, expanded clay, lightweight concrete, compressive strength, split tensile strength of concrete**

I. INTRODUCTION

A. General Overview

LIGHTWEIGHT concrete (LC) is a type of air entrapped concrete. The air form small bubbles in the concret mix. These air bubbles are formed either through mechanical or chemical methods, and LC is also known as foamed concrete. Based on construction and land development around the world. Using LC in future construction is workable, they are high performance and economical for fiber-concrete in construction. LC is gaining popularity in many subject areas due to its special characteristics. Its usage in construction projects is in soaring despite its previous use about 2000 years ago. LWC is concrete but lighter than conventional concrete [1].

Although North American and European standards have provided guidelines for design of structures using Lightweight Aggregate Concrete (LAC), though and characterized inadequately properties like shrinkage, creep, tensile strength, and shear [2], [3]. The properties of LAC depends on the type of lightweight aggregate (LA) used which can vary considerably. Most research on LAC conducted by some researchers involve a given aggregate type.

To enhance the properties of concrete, an advanced material known as basalt fiber was introduced as reinforcement for concrete. The different varieties of fibers used in construction are subjected into inorganic, metallic, plant, organic fiber, and others. Recently, significant achievements have been attained in the use of fibers in concrete through research and engineering applications. The enhancement of fiber reinforced concrete (FRC) is experienced in these areas: first, the reduction in the initial cracks of organic synthetic fiber during the concrete curing period due to its low strength [4]. Then the high strength fibers (HSF) can effectively disperse and transmit loads to improve the concrete strength. After cracking, the bond between the fiber and concrete in the cracking surface depends on the strength and integrity of the concrete to improve [5]. Incorporation of fiber in the concrete prevents the development of cracks, reduces environmental effects due to harsh weather, and enhances the durability of the concrete [6].

FRC is a composite material that is relatively new, in which fibers are introduced in the concrete matrix as micro reinforcement, to improve the tensile, cracking, and other concrete properties. Compressive strength **(f'_c)** and splitting tensile strengths (T_S) are essential parameters considered in the design of concrete structures. Albeit, concrete members are not expected to take tensile stresses, concrete accounts for a small percentage of the tensile strength. Therefore, it is important to know the tensile strength capacity, which can provide an understanding of crack control of the concrete member. Viable significance of tensile strength in non-reinforced concrete structures such as dams under seismic excitation. Pavement slabs and airfield strips are designed based on bending strength and are subjected to tensile

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stresses [7]. Different test procedures can be adjusted to measure tensile strength in direct-tension, flexure, and split tensile test. The results obtained may differ based on the type of tensile strength tests. Several research investigations recommended that tensile strength can be determined through f'_c. Even though the test procedure is time-consuming, costly, and complex, laboratory tensile strength still uses the method [7]. Thus, the consideration of tensile strength for design purposes should be accounted for, similar to the compressive strength. The T_S is obtained directly on the concrete samples under normal stresses, Nonetheless, there can be challenges regarding instrumentation and calibration of test devices. The basalt fiber reinforced concrete (BFRC) serves the function of reinforcement and can extend the life of construction in the fields of housing, rail-ways, highways, urban elevated roads, ports, runways, and subway tunnels, etc. It is good for bridge and shoreline constructions. Considering the study [8], the use of basalt fiber (BF) in real construction will have a positive impact on the construction. The structural construction methods and analysis of structural systems are seen in the study [9].

Based on the points mentioned above, to implement finite element analysis (FEA) in the concrete analysis is advisable. A finite element (FE) software performs a finite element analysis by solving a series of differential equations. FEA is characterized by objectivity and generality to create FE models that mimic the behavior of the structural material. The finite element analysis is valuable for experimental investigation, they are used to verify and validate experimental work. The favorability of FEA is due to the ability to produce a realistic prediction model with very close data when compared to experimental results. Comparisons of results include load capacity, displacement, failure mode, crack patterns at various load stages.

B. Literature Review

In general, the tensile strength of concrete is influenced by the tensile strength of the aggregate, surrounding mortar, and aggregate paste interface [10], [11]. In computer simulation, studies have shown that the splitting strength of LAC can reach the lowest tensile strength of its components at best [12]. Since LA usually have lower bearing strength than the surrounding mortar, the tensile strength of LAC tends to be lower than that of the Normal-weight Concrete (NC) of the same composition.

Several authors reported that LAC has lower tensile strength than NC of the same strength [13]. However, for splitting tensile tests according to ASTM C496 [14], with specimens moist cured for 7 days followed by 21 days at 50% Relative Humidity (RH), the same document reports LWAC tensile strengths from 70 to 100% of NC to have equal strength. Besides, there are contradictory results, which could be related to the different types of aggregate, strength levels, and test conditions considered in each study.

Several experimental investigations have been done in the past, including the study of the behavior and mechanical properties of basalt & polypropylene FRC. The inclusion of BF in the concrete has shown improvement in the compressive, split tensile, and flexural strength of concrete. The slump of concrete decreases with increasing the fraction volume of fiber and a slight increase in the splitting tensile strength with an increase in the BF [15].

The effectiveness of fiber inclusion in concrete; the specimen size investigated by Balendran et al. shows an improvement in the mechanical performance of concrete [16]. In this study, the mix aggregate compositions consist of LAC and limestone aggregate concrete. The mixes are in batches and the batch mixes have steel fibers and without steel fibers. The f'_c of the concrete mix ranged between 90 and 115 MPa and the fiber content was 1% by volume. The split tensile strength, flexural strength, and toughness index of LC are higher than normal aggregate concrete. By comparing the plain concrete and concrete reinforced with BF, the BFRC has high flexural strength and tensile strength. The compressive strength of concrete reinforced with BF increases slightly at an early age but decreases at a later age [17].

A study assessed the impact of basalt and polypropylene fibers with varying volumes concrete. Their results showed that f'_c of C30 grade of concrete obtained from these materials are different, and the corresponding fibers at different fraction volume showed a different reduction [18]. The reason for this is that added 0.3%, 0.6%, 0.9%, and 1.2% volume of BF decreased the f'_c compared to plain concrete by 9%, 19%, 1%, and 18% respectively. Furthermore, it was observed that incorporating fibers in the concrete enhances T_S.

The addition of 0.3% and 0.6% volume of BF increased the T_S of concrete by 2.6% and 22.9% respectively. On the other hand, the addition of 9% and 1.2% volume decreased the split tensile strength by 11.3% and 19.8% respectively. Therefore, the recommended BF percentage is about 0.6% to enhance T_S.

Sergeev et al. considered the energy efficiency of light-weight wall technology for the overstory of buildings [19]. From literature, it is realized that the f'_c of concrete is determined at an age of 28 days [20]. The variation of concrete f'_c mixed with different BF content of 0.1% to 0.5% is explained by Borovskikh et al. [21]. Further is the study, it was stated that the f'_c of concrete increases with increasing BF content up to 0.3%: after this, the concrete f'_c tends to decrease gradually by 12% [22].

The addition of micro silica into the cement system lowers the pH of the aqueous extract by 28 days of hardening relative to the composition without micro silica by 3%, which indicates a decrease in the CaO content in the system and improved BF preservation. It is confirmed by the absence of changes in the pH of aqueous extracts of compositions with fiber and without fiber in compositions containing micro silica MK-85 for all periods of hardening of cement stone. Therefore, to increase the durability of BF in cement systems effectively use micro silica addition, which reduces the amount of free lime in the environment of hydrating cement [23]. Series of studies and experiments on the durability of BFRC, the construction environments, and methods of construction are explained in their report [24]. The degradation and life test of products are analyzed in the study [25]. The study used Wiener degradation failure products for the analysis. This analysis can be applied in studying the lifetime expectancy of BF LECC. Due to the properties of BF and lightweight expanded clay (LEC), this concrete is suitable for hot and cold climate regions and can be used even in coastal areas.

Study of the effects arising from significant irregularities sediment, for example, cracking is currently a relevant problem. The solution to these problems can provide an answer to the question about the reliability, abilities, and possibilities of further operation of buildings and structures. The numerical implementation of the task was carried out in a finite element complex ANSYS. To consider the non-linear properties of concrete, the concrete model was used to describe the elastic-brittle behavior of the data materials. The concrete model implements volumetric stress state algorithms concrete by Willam and Warnke constitutive model [26]. This model allows the formation of cracks (chips) on-site normal to the operating main voltages when exceeding the given principal stress of a given ultimate tensile strength (compression).

ANSYS is a recognized commercial finite element analysis (FEA) package that is widely used in a variety of multi-physics modeling. The finite element (FE) application in ANSYS allows the user to create a realistic model is based on the theoretical formulation of the finite element method [27].

C. Problem statement

Compressive mechanical properties are essential in concrete structural elements. The compressive and split tensile strength of concrete is an important property that is highly needed to be checked before construction. Many researchers have done compressive and split tensile strength of fiber concrete but very few are recorded on basalt fiber lightweight expanded clay concrete. This research obtained the split tensile strength of Basalt Fiber Lightweight Expanded Clay Concrete (BF LECC) and the f'_c of ECC cube specimens, the properties, which are required for finite element analysis. Besides, environmental factors such as harsh weather and direct exposure to salt deicing on concrete created the need for a concrete mixture that can withstand these conditions and without losing its strength capacity.

II. MATERIALS AND METHODS OF RESEARCH

To prepare expanded clay concrete (ECC) specimens for the determination of T_S, the following materials were used:

--Coarse aggregate Expanded Clay (EC) with a fraction of 5-8 mm = 200 kg/m^3.

An EC material consists of a LA from clay which is heated to a temperature of 1100–1300 °C in rotary kilns. At this temperature, EC is exhibiting properties similar to the lightweight material, they have insulating properties, extremely stable, non-combustible, and durable, natural material for sustainable construction. They are also versatile, with a high drainage capacity [28], [29], [30].

The chemical composition of lightweight expanded clay aggregate (LECA) according to the analysis of some previous researchers are shown in Table I.

TABLE I
CHEMICAL COMPOSITION OF LECA

Ref. [21]	Composition				
	SiO_2	Al_2O_3	Fe_2O_3	K_2O	MgO
	66.05	16.57	7.1	2.69	1.99
	CaO	Na_2O	P_2O_5	SO_3	SrO
	2.46	0.69	0.21	0.03	-
	TiO_2	MnO	LOI	Extra oxides	
	-	-	0.84	-	

--Quartz flour (QF) as Mineral filler of 50 micrometer fraction = 100 kg/m^3 to reduce pores in concrete due to the air pores in EC.

QF is made by grinding chemically pure quartz sand into finer particles. The industrial processing of QF assures the stable chemical composition during grinding, and this permits the steady distribution of QF in matching sizes. The crushed QF is characterized by rounded particles with irregular, fractured edges. Quartz varies from other mineral fillers in hardness, abrasion and chemical resistance, anti-corrosion, and low coefficient of thermal expansion. Quartz is a chemically stable mineral; it dissolves in hydrofluoric acid. It has low absorption of oil, it particle's surface area is small; this makes it applicable for filling. Table II illustrates the compositions and properties found in quartz flour.

--Quartz sand (QS) of 0.6 mm = 585 kg/m^3 fraction as fine aggregate. The chemical composition of QS is illustrated in Table III. A suggested feature of quartz is its physical property as coarse-grained sand, with a large modulus of fineness up to M3.5. The quartz appears rounded it has low clay inclusions and soft rocks. Also, the enrichment and drying of quartz resulted in low moisture content [31].

--Organo-mineral based additives: Silica fume = 62.5 kg/m3, micro silica = 62.5 kg/m^3 and fly ash = 62.5 kg/m^3.

-- SikaPlast Super plasticizing is concrete water-reducing additive = 8 l/m^3.

--Binder Portland cement (PC) CEM I 42.5 N = 500 kg/m^3.

M500 D20 CEM II 42.5 N. M represents the properties of Holcim PC as labeled by the manufacturer. 500 indicates the expected 28 days average f'_c in kg/cm². D represents additives while 20 is an acceptable number of additives in percentage (up to 20%). CEM II is the cement that has additives, and the percentage of additives is 6-20%. I is the type of additives, limestone. 42.5 is the class of f'_c for 28 days and it is expected to at least be this value. Table IV shows the chemical and physical of the Holcim PC.

Chopped BF is used in this paper as dispersed reinforcement in the concrete. The chemical composition and properties are shown in Table V and VI respectively. Five different mix designs of ECC were created in this research, The mix contained the chopped BF with a diameter of 15 µm and a length of 20 mm in the ratio of 0%, 0.45%, 0.9%, 1.2%, and 1.6% by weight percentage.

TABLE II.
COMPOSITIONS AND PROPERTIES OF QF

Name of indicator	50 microns
Chemical composition	
Mass fraction of SiO_2, not less than (≮) %	99.48
Mass fraction of Fe_2O_3, not more than (≯) %	0.13
Mass fraction of Al_2O_3, ≯ %	0.25
Mass fraction of CaO, ≯ %	0.02
pH	7
Loss on ignition, %	0.12
Color indicators	
CIE L *,%, ≮	87.8
CIE a *,%,	1.6
CIE b *,%,	4.11
Refractive index	1.55
Mass fraction of sieve residue, %	
No. 0,16	2
No. 0,1	19
No. 0,063	39
No. 0,040	43
Median particle diameter, microns	
Medium D50	43
Maximum D90	123
Minimum D10	2
Oil consumption, g / 100g	17.8
Specific surface, m^2 / g	0.8
Mass fraction of moisture, ≯ %	0.2
Density	2.65
Bulk density	1

TABLE III.
CHEMICAL COMPOSITION OF QS

Fe_2O_3	Al_2O_3	SiO_2	CaO	K_2O	MgO	Na_2O	PP
0.07	0.67	98.9	0.33	0.025	0.21	0.08	0.44

TABLE IV.
PHYSICAL AND CHEMICAL PROPERTIES OF HOLCIM PC

Oxide (%)							
SiO_2	Fe_2O_3	MgO	SO_3	Al_2O_3	CaO	Na_2O	LOI
20.2	4.12	0.71	2.61	5.49	65.4	0.26	1.38
Fineness = 373 m^2/kg							
Relative density = 3.14							

--Tap water = 255 l/m^3 for mixing.
--Chopped BF.

TABLE V.
CHEMICAL COMPOSITION OF BF CHOPPED STRANDS

Chemical composition of BF (%)							
SiO_2	Al_2O_3	CaO	MgO	FeO + Fe_2O_3	TiO_2	Na_2O + K_2O	Others
51.6–59.3	14.6–18.3	5.9–9.4	3.0–5.3	9.0–14.0	0.8–2.25	0.8–2.25	0.09–0.13

TABLE VI.
PROPERTIES OF CHOPPED BF

Length (mm)	Diameter (μm)	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation (%)	Specific gravity
20	15	4100–4840	93.1–110	3.1	2.63–2.8

The T_S and f'_c tests were conducted using the CIS Interstate Standard GOST 10180-2012 [32]. The concretes were mixed in an electric mixer (see fig. 1) and pure in metallic cube mold (see fig. 2).

All ECC specimens curing were done under a controlled 19-22 °C and in a curing bath of air-humid condition of 95 ± 5%. The cubes were removed from the molds on the 48th hour after casting.

The ECC cubes are of 100mm x 100mm x 100mm dimensions. The tests were carried out by placing a cube specimen vertical with a surface serving as the support and the other surface serving as the load surface: for the compressive test (see fig. 3) and for the split tensile test, one of the rib lengths serving as the support and another the loading surface (see Fig. 4) in between the loading surface of a Universal Matest testing machine and load is applied until the failure of the cube along the vertical rib length.

The maximum load applied to the ECC cubes was recorded and average of three values taken as the representative of batches for compressive test and same number split tensile test.

Fig. 1. Concrete mixing.

Fig. 2. Metallic cube mold.

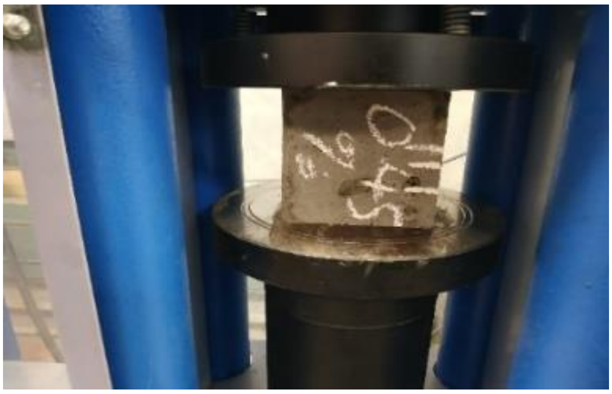

Fig. 3. Loading ECC cube specimen on the testing machine for compressive strength test.

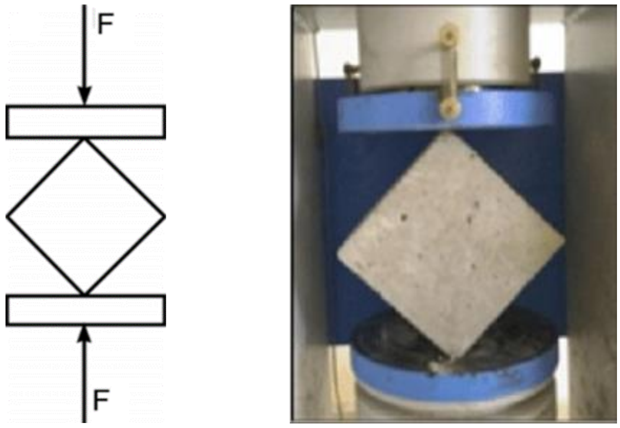

Fig. 4. Loading ECC cube specimen on the testing machine for split tensile strength test.

A total of five (5) groups of ECC test specimens were produced from the experimental concrete compositions with ECC cubes of 100mm x100mm x100mm dimensions. Each group comprises nine (9) specimens, this equals forty-five (45) specimens for split tensile tests and the same quantiles and dimensions for compressive strength. All ECC specimens curing were done under a controlled 19-22 °C room temperature and in a curing bath of air-humid condition of 95 ± 5%.

The ECC cube testing for strength was conducted on curing days 7, 14 and 28 on a Matest hydraulic press of 1500 kN at compression (see Fig. 3). The computation of experimental data was completed using probability theory and mathematical statistics. After the laboratory experimental analysis, the finite element model (FEM) of the cubes was done in ANSYS. The properties derived from the experimental results like density, modulus of elasticity (MoE), and f'_c were inputted in the software to derive the expected results. Solid65 Concrete was used as the ANSYS material property. The support used in the boundary condition is all degrees of freedom (All DOF). The FEA was done on the plain ECC and the ECC with BF percentage ratios.

III. Results

In this research, the experimental determination of the f'_c and the T_S of ECC with and without incoorperated BF were conducted. The results of this experimental study are gotten at structural strength.

A. Porosity evaluation

The porosity index (γ) is defined as the volume fraction of permeable pores which are contained in a specimen of hardened concrete. This is determined according to ABNT [33], by means (1):

$$\gamma = \frac{M_{sat} - M_s}{M_{sat} - M_i} \quad (1)$$

where M_{sat} is the water saturated ECC cube weight, M_s the weight of the dry ECC cube, and M_i the weight of water saturated ECC cube immersed in water. The values are illustrated in Table VII.

TABLE VII
POROSITY OF LIGHTWEIGHT ECC

ECC type	ECC weight, Kg			γ
	M_{sat}	M_s	M_i	
0% BF (Plain) ECC cube	2.60	1.33	1.75	1.49
0.45% BF ECC cube	2.65	1.37	1.84	1.58
0.9 % BF ECC cube	2.73	1.42	1.91	1.59
1.2% BF ECC cube	2.77	1.45	1.94	1.59
1.6% BF ECC cube	2.83	1.49	2	1.61

Equation (1) verified that incoorperation of BF into the ECC mixture gave a porosity index of about 1.61 and 1.49 for 0% BF (Plain) ECC cube.

B. Compressive strength

In Table VIII and fig. 5, the results of compressive strength (f'_c) test test based on the average results of three ECC cube specimens for each mix design are shown.

The f'_c results differ from some of the experimental studies done by previous authors where the authors analyzed the f'_c of high strength conventional concrete (CC) with the addition of chopped BF and in their results. The results from the previous authors showed that the incoorperation of dispersed chopped BF in CC specimens reduced the compressive strength of the concrete [34], [35].

As load increases, cracks appeared and developed until the cube reached its maximum load strength. The amount of cracks gradually increased and same as the width, as the compressive stress increased. From the results in Table VIII, the maximum split tensile strength increased by 66.3% for 7 days, 58.3% for 14 days, and 60.8% at 28 days.

TABLE VIII
COMPRESSIVE STRENGTH OF BF LECC (MPa)

% of Basalt Fiber	Compressive strength (MPa)		
	Day 7	Day 14	Day 28
0	14.17	19.79	22.54
0.45	15.86	21.61	25.13
0.9	18.25	24.96	28.52
1.2	20.19	27.75	31.93
1.6	23.57	31.33	36.24

The f'_c of LECC is higher in ECC with 1.6% BF content. This increment in the ECC strength can be related to the percentages of BF blended in the ECC, proportion of concrete mixture and additives to improve properties of the concrete.

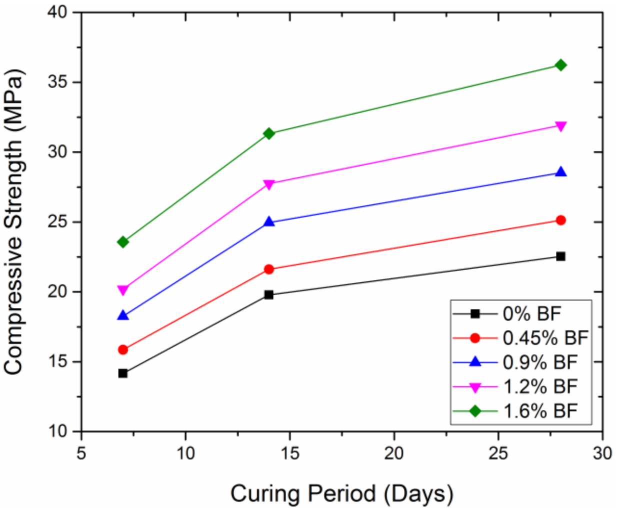

Fig. 5. BF LECC results on Compressive strength.

C. Split tensile strength

In Table IX, the results of split tensile strength (T_S) test based on the average results of three specimens for each mix design are shown.

With increase in the load capacity, there was crack development in the vertical direction of the specimens. The number of cracks in the specimens increased gradually together with the crack width as the compressive stress increased. Finally, the ECC cubes reached their T_S with a sharp and deep crack after experiencing major crack developing on the ECC specimens. The average test results of the T_S are illustrated in Table IX and Fig. 6. The density of concrete lightweight expanded clay concrete cubes ranges from 1400kg/m^3 to 1500kg/m^3.

Based on analytical data (see Fig. 7 and Table X), using the probability theory and mathematical statistics, a mathematical model of the ECC T_S based on the percentage of cement and curing period was developed.

The regression equation is performed by using the Minitab program. The relationship between the BF percentage and curing time in days was presented below (2), where T_S is split tensile strength of ECC in MPa; t is curing period, day ($t \leq 28$ days); f is BF proportion in ECC.
which depends on Table VIII. The R^2 is equal to 95.73%.

$$T_S = 0.650 + 1.638f + 0.07510t \qquad (2)$$

Results of the performance parameters of BF in this paper confirm the effects of BF in the splitting tensile tests in [13, 14]. From the results in Table IX, the T_S has a maximum increase of by 42.6% on day 7 while 96.8% increment on day 14 and 17.7% on day 28.

TABLE IX
T_S OF BF LECC (MPa)

% of BF	T_S (MPa)		
	Day 7	Day 14	Day 28
0	1.015	1.407	2.415
0.45	2.007	2.933	3.831
0.9	2.820	3.192	4.113
1.2	3.147	3.911	4.839
1.6	3.477	4.176	5.258

The T_S of BF LECC is higher in ECC with 1.6% BF content. This variation in the strength is as a result of the percentages of BF blended in the ECC, proportion of concrete mixture and additives to improve properties of the concrete.

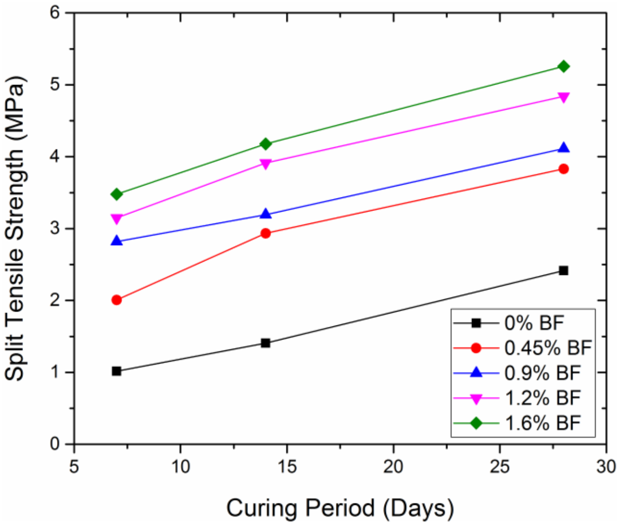

Fig. 6. Split tensile strength result of BF lightweight expanded clay concrete.

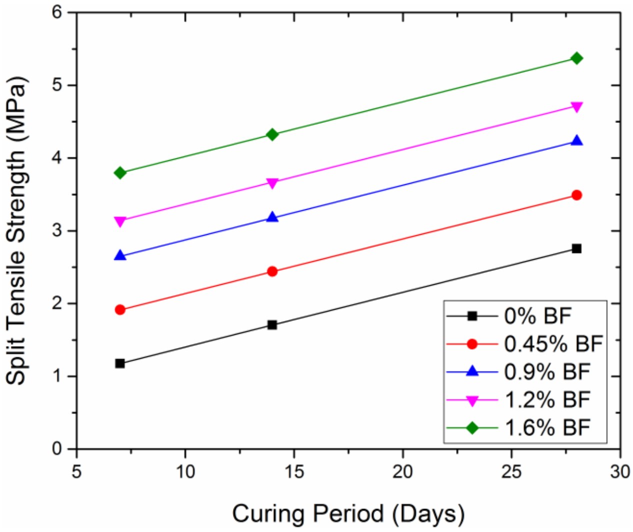

Fig. 7 The dependency of the T_S of ECC on the BF % and the curing period.

TABLE X
DEPENDENCY OF THE T_S OF ECC ON THE BF% AND THE CURING PERIOD

% of Basalt Fiber	T_S [MPa]		
	Day 7	Day 14	Day 28
0	1.176	1.704	2.753
0.45	1.913	2.439	3.489
0.9	2.649	3.176	4.227
1.2	3.141	3.667	4.718
1.6	3.797	4.322	5.374

D. Modulus of Elasticity

The value of Modulus of Elasticity (MoE) in the finite element model is obtained from the density and compressive strength of the ECC. Furthermore, the amplitude of MoE was changeable for different types of concrete density. For instance, adding 1.6% BF to ECC resulted to increase in MoE by 120% rather than the density of ECC with 0.9% BF according to Equations (3) and (4). To determine the MoE of ECC, two points should be considered as stated below:

- MoE with a density less than 1440 kg/m^3
- MoE with a density of more than 1440 kg/m^3.

Results are illustrated in (see Fig. 8 and Fig. 9).

Density has an important effect on the calculating theory and mathematical concrete MoE's (See Fig. 8 and Table XI).

According to ACI 318-08 section 8.5 [36].

The symbols in (3) and (4) are illustrated as follows:

E_c is Modulus of Elasticity in GPa; ω_c is density in kg/m^3; f'_c is compressive strength in MPa.

$$E_c = \omega_c^{1.5} \times 0.043\sqrt{f'_c} \quad (3)$$

This formula is valid for values of ω_c between 1440 and 2560 kg/m^3.

For normal-weight concrete.

$$E_c = 4700\sqrt{f'_c} \quad (4)$$

For example, according to (4), MoE of 0% BF ECC is calculated based on the density of 0% BF ECC (see Table XI). Since the density of 0% BF ECC is less than 1440kg/m^3, MoE is calculated using (4). From Table VII, the compressive strength of 0% BF ECC is shown.

On the other hand, 1.2% MoE is calculated according to (3). The density of 1.2%BF ECC is more than 1440kg/m^3 therefore (3) is used. The compressive strength and density of 1.2% BF ECC are obtained from Table VIII and XI, respectively.

TABLE XI
MoE OF ECC AND DENSITY

% of Basalt Fiber	Density kg/m^3	MoE [GPa]
0	1331	22.31386564
0.45	1346	23.55164325
0.9	1400	12.02915912
1.2	1495	14.04525744
1.6	1497	14.99323164

Mathematical formulas show that MoE in concrete is related to the square root of f'_c and density of concrete (3) and (4). The amount of MoE in 0% BF ECC was less than that of 0.45% BF ECC because the density of 0.45% BF ECC was more (see Fig. 9). As well as this amount improved in both 1.2 % BF and 1.6% BF in ECC respectively due to density and the percentage of BF (Fig. 9).

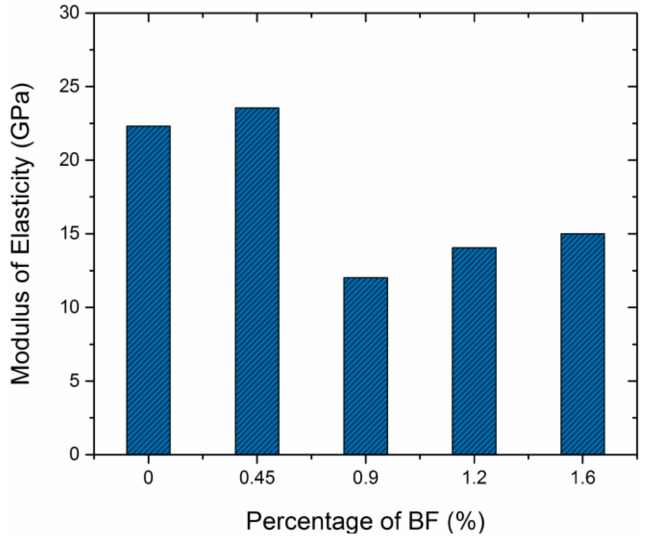

Fig. 8. The Effect of Basalt Fiber Percentage on MoE according to ACI 318-08 section 8.5.

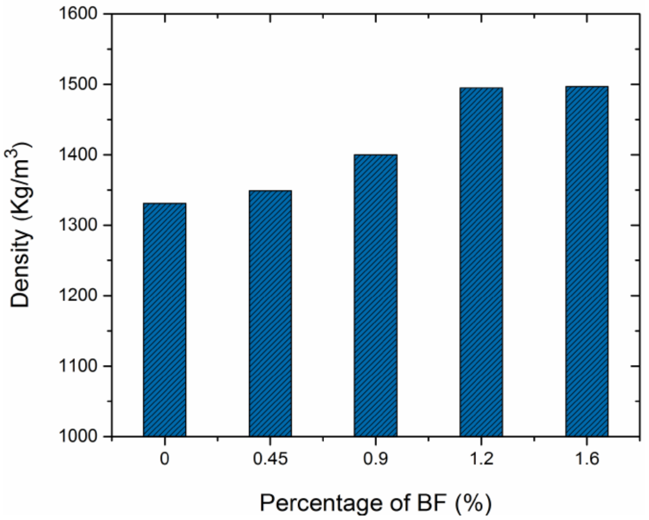

Fig. 9. The Effect of BF% on the Density of LWECC.

E. Finite Element Analysis Results

From the laboratory experimental results, it was discovered that the ECC with 1.6% BF gave the best f'_c and T_S. Based on these, the control specimens (plain ECC cube) and ECC with 1.6% BF cube was modeled for FEA.

--Expanded clay concrete cube specimen without dispersed chopped basalt fiber (plain ECC). Fig. 10 shows the maximum deformation of the plain ECC cube specimen analysed in ANSYS as 0.100697 mm. Fig. 11 shows the cube specimen maximum and minimum displacements as 0.098607 mm and 0 respectively. Fig. 12 shows the stress analysis of the cube specimen with maximum stress 24.6901 N/mm^2 and minimum stress 12.9817 N/mm^2. Fig. 13 shows the 0.001115 and 0.587E-03 as maximum and minimum strain of the cube specimen respectively.

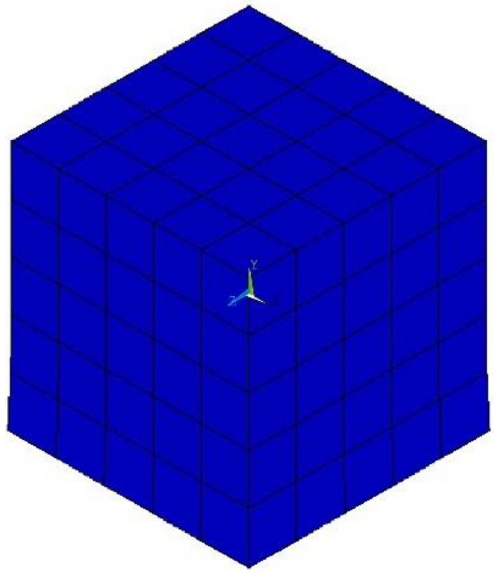

Fig. 10. Deformation of plain ECC cube specimen in ANSYS.

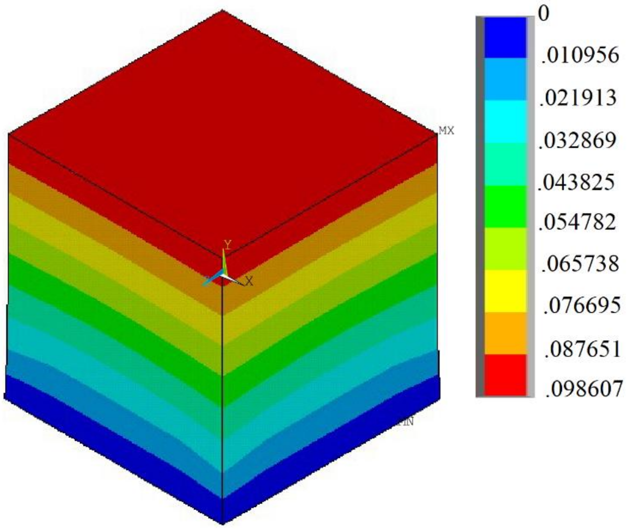

Fig. 11. Plain ECC cube specimen DOF Solution: Y-Component of displacement on nodal solution in ANSYS.

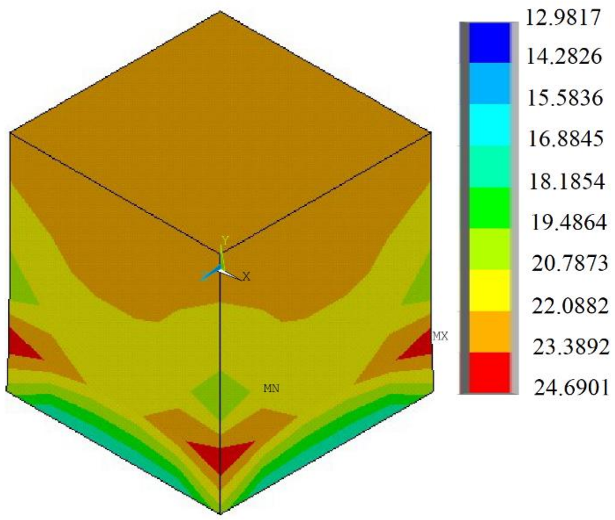

Fig. 12. Von Mises stress of Plain ECC cube specimen on nodal solution in ANSYS.

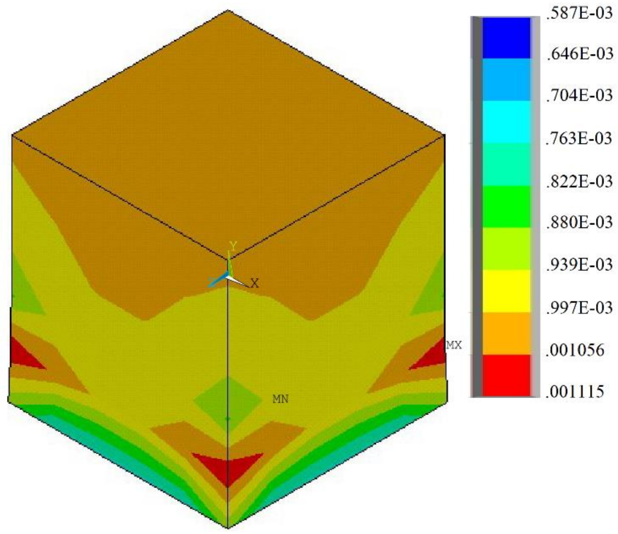

Fig. 13. Von Mises total mechanical strain of plain ECC cube specimen on nodal solution in ANSYS.

--ECC cube specimen with 1.6% dispersed chopped BF. Fig. 14 shows the maximum deformation of the cube specimen analysed in ANSYS as 0.240946 mm. Fig. 15 shows the cube specimen maximum and minimum displacements as 0 and -0.235946 mm respectively. Fig. 16 shows the stress analysis of the cube specimen with maximum stress 39.697 N/mm^2 and minimum stress 20.872 N/mm^2. Fig. 17 shows the 0.002667 and 0.001405 as maximum and minimum strain of the cube specimen respectively.

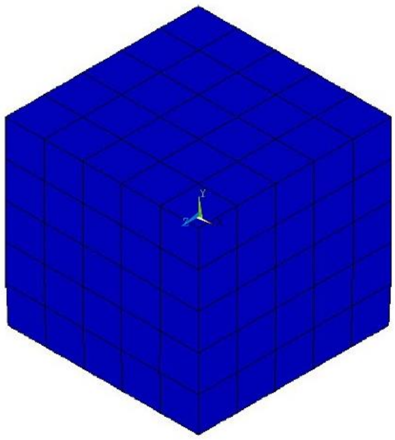

Fig. 14. Deformation of ECC with 1.6% BF cube specimen in ANSYS.

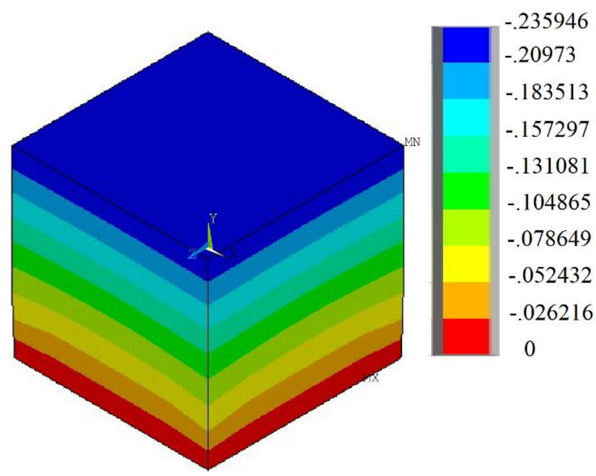

Fig. 15. ECC with 1.6% BF cube specimen DOF Solution: Y-Component of displacement on nodal solution in ANSYS.

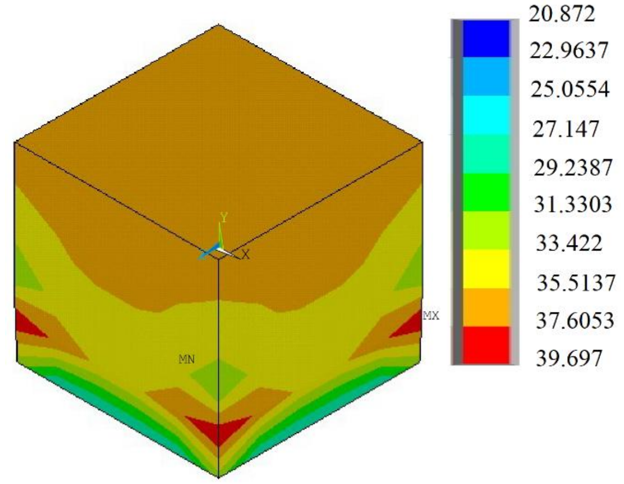

Fig. 16. Von Mises stress of ECC with 1.6% cube specimen on nodal solution in ANSYS.

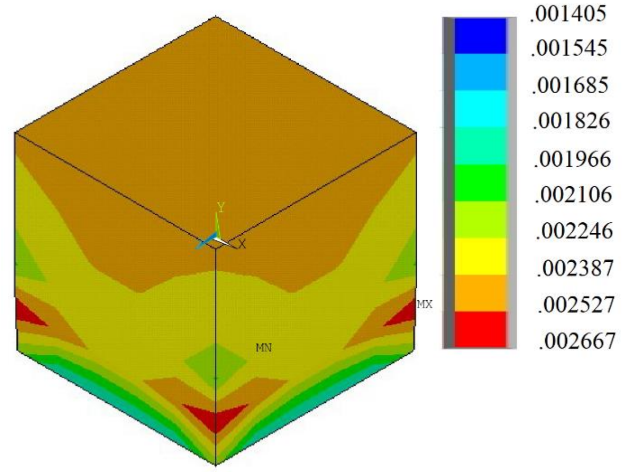

Fig. 17. Von Mises total mechanical strain of ECC with 1.6% BF cube specimen on nodal solution in ANSYS.

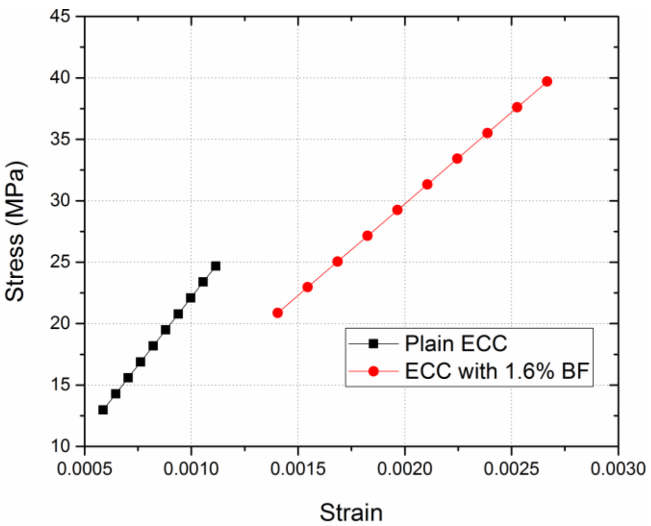

Fig. 18. Stress-strain of ECC plain cubes and ECC cubes with 1.6% BF.

The stress-strain results of plain ECC and ECC containing 1.6% BF are compared in fig. 18. From this fig., ECC with 1.6% BF showed more strength. It shows that maximum stress of ECC with 1.6% BF is 62% and maximum strain ECC with 1.6% BF is 42% more than that of pain ECC.

IV. Conclusion

The findings of this paper can be summarized in the following points:

1. Inclusion of BF into the ECC mixture yielded a porosity index of 1.61 while, the porosity index of plain ECC is 1.49.
2. The use of chopped BF advantageously improved the split tensile and compressive strength without affecting the workability of concrete.
3. The increase in the BF proportion from 0% to 1.6% increased the split tensile strength of ECC from 2.415 MPa to 5.258 MPa after 28 days which is 17.7% higher than ECC without BF and the compressive strength of ECC from 22.54 MPa to 36.24MPa after 28 days which is 60.8% higher than ECC without BF.
4. The density of ECC confirmed that the concrete specimens are LC.
5. The inability of the ECC with BF to spilled 100% into two parts proves the compatibility of BF with ECC.
6. The proposed mathematical model can be used to calculate the split tensile strength of ECC for ages between 7 and 28 days with high accuracy. The R^2 of the equation is equal to 95.73%.
7. The amount of MoE is relative to the percentage of BF, square root of compressive strength and density fiber, or specific weight of concrete.
8. The increase in the ratio of BF in ECC strengthened the material due to an increase in MoE and density of ECC, these are necessary parameters for calculating MoE.
9. Mathematical modeling for calculating MoEs did not have suitable reliability because MoE was analyzed in two parts according to the density of the concrete.
10. From the research works of previous authors, it was suggested that the added on BF in low-cost composites for construction purposes showed satisfactory mechanical properties such as strength and lower cost predicted for BF.
11. The finite element analysis of expanded clay concrete structural elements was investigated. The accuracy of the FE models is assessed by comparising the experimental results to that of FEA, which must be in agreement.
12. The stresses and strains of concrete structural elements were derived from the finite element analysis in ANSYS.
13. The displacement and deformation diagrams and results from ANSYS are comparably the same as the laboratory experimental results of the ECC structural elements.

Further research on this topic will be to investigate the split tensile strength of BF LWECC in a harsh environment like salty water, acidic situation, crude oil, spilled soils, coastal regions.

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