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Structural Strength of Expanded Clay Basalt Fiber Concrete Exposed to Salty Environment

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ABSTRACT: So many structures in the coastal regions of Nigeria are exposed to risks that have drastic effects on the structures especially with the global warming effect and the increase in the percentage of salt in the soil. The types of materials used in constructing these buildings must provide the stability, durability, and accessibility of these structures. Most Offshore soils are known for similar characteristics which are highly chemical and alkalinity in the soil and water. Structures in the coastal regions are usually threatened by a series of problems linked to steel corrosion. The main aim of this paper is to analyze and verify the effect of the saltwater on the strength of expanded clay concrete and the best way to improve the mix by using the basalt fiber. The effect of saltwater on the basalt fiber lightweight concrete was also examined. In the process to analyze some structural materials to know their strength if exposed to a salty environment, experiments were conducted on the compressive strength of expanded clay basalt fiber concrete in the salt-free environment and when exposed to the salty environment. The mass effect percentages and retention ratio percentages of the concrete were analyzed. 0.6% and 1.2% chopped basalt fiber dosages were added to respective concrete specimens and checked on day 28. After day 28, some of the specimens were immersed in Atlantic Ocean water gotten from Nigeria. The experiments demonstrate a slight drop in the compressive strength, an increase in the young modules, and an increase in specimens' mass after exposure to salty water. The original contribution of this research is adding the 1.2% basalt fiber to the mix will decrease or eliminate the effect of saltwater on the concrete characteristics.

Keywords: Expanded clay, basalt fiber in salt, lightweight concrete, strength of basalt fiber Concretes.

Abbreviations: LECA, Lightweight expanded clay aggregate; BF, Basalt fiber; BFRP, Basalt fiber-reinforced polymer; FRP, Fiber reinforced polymer; GFRP, Glass fiber reinforced polymer; ECC, Expanded clay concrete.

I. INTRODUCTION

Due to the harsh environments in offshore engineering structures, much research has been conducted on the durability of fiber reinforced polymer FRP bars [1], [2], [3], [4]. Lightweight aggregate concrete can be defined as concrete of low density consisting of lightweight aggregate such as expanded clay [5], [6]. Lightweight expanded clay aggregate (LECA) has a small hole that can absorb and maintain environmental pollution [7], [8].
LECA is used as a coarse aggregate and fly ash is used for the synthesis of green cement as replacement materials to produce a lightweight concrete in seawater exposure.
The strength of basalt fiber reinforced polymer bars was estimated to be retained by more than 72% after a century of exposure to concrete and mortar. Fibers reinforced composite materials are widely used in automobile, machinery, structural, and many other industries [9, 10, 11, 12]. Basalt fiber is a product gotten from refined basalt stone. Basalt fiber is considered a high-tech fiber that is not harmful or dangerous to humans [13].
Basalt fibers are known to have better mechanical properties, improved thermal, and chemical stability compare to E-glass fibers [13, 14, 15]. The advantages of basalt fiber such as higher application temperature, harmlessness to humans, and excellent resistance to alkaline and acid attack, have made basalt fiber to be increasingly used to replace glass fiber as a reinforcement material in polymer, concrete and metallic matrices [13, 16, 17, 18]. However, chemical corrosion has always been one of the most challenging issues faced in utilizing composite materials [19].
In the research paper about the chemical composition analysis of degraded basalt fibers, Dhand *et al.,* [20] researched the alkali resistance of BF in sodium hydroxide (NaOH) solution. In the research, the authors found that the presence of TiO_2, MnO, Fe_2O_3, and Al_2O_3 could slow alkaline corrosion. Furthermore, Ramachandran *et al.,* [21] evaluated the corrosion behavior of basalt fibers under different alkaline solution

concentrations at room temperature. It was discovered that the element contents of aluminum, calcium, and iron of the fiber surface were not sensitive to the concentration.
Briefly, on the tensile properties of degraded basalt fibers, Li *et al*., [22] analyzed the BF degradation exposed to 25 and 55 °C alkaline solution. It is seen in the results that tensile strength decreased by 33.8%, 18.0%, 10.2%, and 5.8% respectively at a temperature of 25 °C after an aging period of 7, 18, 34, and 66 days. When the temperature rose to 55 °C, the strength decreased by 33.0%, 17.7%, 10.6% and 0%, respectively.
Basalt fiber reinforced polymer (BFRP) bars recently have increasingly been used in offshore structures, which are exposed to seawater corrosion and wet-dry cycles during the service period. In the research study conducted by Wang *et al.,* [23], the authors evaluated the alkali-salt resistance performance of BFRP bars with different resin matrix types under wet-dry cycles where tensile and shear strength of BFRP bars was tested. The results demonstrated that the alkali-salt resistance of vinyl resin matrix BFRP bars was superior to that of epoxy resin matrix BFRP bars under wet-dry cycles [24].
Fiber-reinforced polymer (FRP) bars are a type of corrosion-resistant material with advantages such as lightweight and high strength. FRP materials have become an alternative to steel reinforcement in concrete [25] [26] [27] [28] [29]. In recent years, basalt fiber reinforced polymer usage is in high demand because of its properties and cost efficiency [30] [31] [32].
Wang *et al.,* [33] investigated the degradation, short-beam tests, and moisture absorption weighing of basalt fiber reinforced polymer bars under alkaline conditions. Results from their analysis showed that, compared to GFRP bars in the literature, BFRP bars exhibited relatively high resistance to alkaline corrosion, maintaining more than 60% of their original strength at 55°C in the alkaline solution after 9 weeks. However, most of the corrosion processes conducted in the laboratory are simulated by continuous immersion in a corrosive solution. From research, it is seen that only a few scholars have studied fiber-reinforced polymer degradation under wet-dry cycles.
More recent work by Qasim *et al.,* study the effect of different proportions of salt like (0, 10, 20, 30, 40, and 50) grams per liter on concrete. The researchers examined the effect of each percentage of salt on the compressive strength, splitting tensile strength, and flexural strength at different ages. the result shows a positive effect of saltwater at the early ages (7 and 14 day) of concrete and a negative effect at the age of 28 days[34].Likewise, the Calcium sulfate effect on mechanical properties of normal and light weight concrete was examined by Naser and Zainab (2020). The study used four different percentage of Calcium sulfate which include (0.28%, 0.5%, 1.0%, and 1.5%)[35].
To analyze this, this paper must identify the problems of salt/salty environment to structures and how these problems can be solved. This section should be succinct, with no subheadings.

II. MATERIALS AND METHODS

The experimental study of expanded clay concrete is carried out following the CIS Interstate Standard GOST 10180-2012 [36], considering the requirements of ACI 211.1-91 [37].
In the plan of study, the following materials were used to prepare ECC specimens for determination of compressive strength:

- Expanded clay with a fraction of 5-10 mm = 200 kg/m^3 as the coarse aggregate.
- Quartz sand with fraction 0.4-0.6mm = 585 kg/m^3 as the fine aggregate.
- Quartz flour of 50 μm = 100 kg/m^3 as the mineral filler.
- Portland cement CEM I 42.5 N = 500 kg/m^3 as the binder.
- Silica fume = 62.5 kg/m^3, micro silica = 62.5 kg/m^3 and fly ash = 62.5 kg/m^3 as the organo-mineral based additives.
- Sika Plast concrete = 8 l/m^3 as the super plasticizing and water-reducing additive.
- Tap water = 255 l/m^3 for mixing at room temperature.

Three different mixes of expanded clay concrete for the specimens were accepted for this research, containing the above mixes and the chopped basalt fiber with a diameter of 15 μm and length of 20 mm in the percentage of 0.6% and 1.2% and the control specimens without the addition of chopped basalt fiber. Each of the basalt fiber percentage concrete specimens 4 cube specimens where 2 cube specimens are not exposed to the salt environment and 2 exposed to saltwater. Each of the control expanded clay concrete 4 cube specimens with no basalt fiber in the mixture where 2 cube specimens are not exposed to salty water while 2 are. The experimental set testing days are on day 28 for the specimens without being exposed to salty water. After day 28, some of the specimens were immersed in a bath of salty water for 7 days, then let dehydrate for 7 and 14 days and tested on.
The salty environment used in this research study is water scooped from the bank of the Atlantic Ocean in Nigeria. Some of the properties of salty water used are stated in table 1.
The expanded clay concrete specimens test was produced from the listed compositions with dimensions of 100x100x100 mm.
An experimental study of ECC and BFECC specimens was carried out on a MATEX hydraulic press of up to 1500kN at the compression test. This part should contain enough detail so that all procedures can be repeated. It can be divided into subsections if several methods are described.
Plant organisms do not destroy concrete, as they absorb carbon dioxide in the process of photosynthesis and thereby reduce its concentration in the near-wall layer of water. Thus, the destruction of concrete in sea/ocean water is due to the combined action of the chemical, mechanical and biological processes. The destruction of concrete because of chemical interaction with water is accelerated by mechanical action, tidal oscillations, and shock waves.

Table 1: Properties of seawater with 35% salinity.

Properties	Pure water	Seawater
Density at 25 ℃, g/cm3:	0.9971	1.02412
Viscosity 25 ℃, Millipoise:	8.90	9.02
Steam pressure at 20 ℃, mm.Hg:	17.54	17.35
Maximum density temperature, ℃:	+3.98	-3.52 (supercooled liquid)
Freezing point, ℃:	0.00	-1.91
Surface tension at 25 ° C, dyne / cm:	71.97	72.74
Sound speed at 0 ° C, m / s:	1407	1450
Specific heat at 7.5 ° C, J / (g · ° C):	4.182	3.898

III. RESULTS AND DISCUSSION

Table 2 expresses the results from the experimental specimens that were not that is before being immersed in salty water while tables 3 and 4 express the experimental results from the specimens after immersion in salty water. Some of their properties are stated in the tables.

Table 2: Compression test cubes immersion in pure water for 28 days.

Number of specimens	BF, (%)	Weight. Kg/m3	Volume V, (m3)	Density p, kg/m3	Young modules E, (GPa)	Breaking load F, kN	Compressive strength R, MPa	Mean Comprehensive strength R, MPa
1	0	1.331	0.001	1331	32.16	723.64	72.36	72.13
2	0	1.346	0.001	1346	33.24	718.93	71.89	
1	0.6%	1.400	0.001	1400	34.48	748.56	74.86	75.15
2	0.6%	1.495	0.001	1495	35.68	754.28	75.43	
1	1.2%	1.497	0.001	1497	36.23	760.59	76.06	77.15
2	1.2%	1501	0.001	1501	37.85	782.31	78.23	

Table 3: Compression test results for cubes immersed in saltwater.

7 days in seawater (drying 7 days)							
Number of specimens	Weight. Kg	BF, (%)	Density p, kg/m^3	Young modules E, (GPa)	Breaking load F, kN	Compressive strength R, MPa	Mean Comprehensive strength R, MPa
1	1.483	0	1483	24.74	630.52	63.05	65.19
2	1.475	0	1475	25.90	633.20	63.32	
1	1.501	0.6%	1501	25.41	684.58	68.46	68.29
2	1.507	0.6%	1507	25.79	681.27	68.13	
1	1.604	1.2%	1604	26.36	712.71	71.27	72.24
2	1.627	1.2%	1627	26.89	732.12	73.21	

Table 4: Compression test results for cubes immersed in saltwater.

7 days in seawater (drying 14 days)							
Number of specimens	Weight. Kg	BF, (%)	Density p, kg/m3	Young modules E, (GPa)	Breaking load F, kN	Compressive strength R, MPa	Mean Comprehensive strength R, MPa
1	1.334	0	1334	23.78	634.04	63.40	64.06
2	1.341	0	1341	24.32	647.10	64.71	
1	1.429	0.6%	1429	25.58	706.81	70.68	70.87
2	1.437	0.6%	1437	26.61	710.4	71.05	
1	1.482	1.2%	1482	27.05	742.72	74.27	74.74
2	1.494	1.2%	1494	28.25	752.14	75.21	

The density of concrete can be grouped as either normal, lightweight, or heavyweight concrete. Based on the results, the density of the lightweight expanded clay concrete and lightweight expanded clay basalt fiber concrete varied from 1331 to 1627 kg/m^3.

The densities of all the concrete specimens are below 1800 kg/m^3 therefore, they are grouped into lightweight concrete. Fig. 1 shows the experimental graph results on comprehensive strength for lightweight concrete specimens with and without exposure to the salty environment. The results of compressive strength for BF lightweight concrete shows high strength even using the LECA as a replacement of coarse aggregate and exposed in seawater exposure. The bond strength between concrete mixed BF and LECA shows better bond strength and stability in seawater immersion compared to coarse aggregate.

Fig. 2 shows the experimental graph on the effect of fiber quantities on the modules of elasticity.

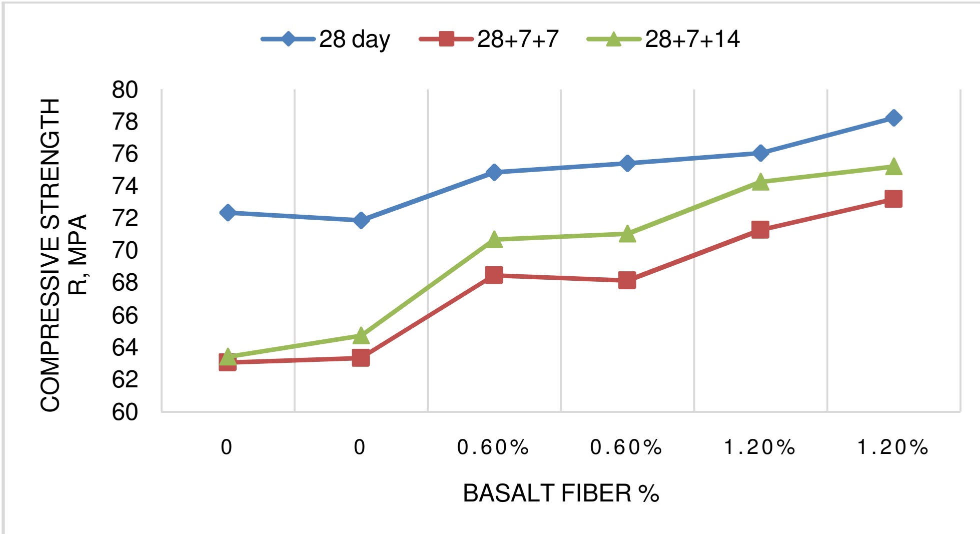

Fig. 1. The effect of basalt Fiber percentage and saltwater on compressive strength of LECA.

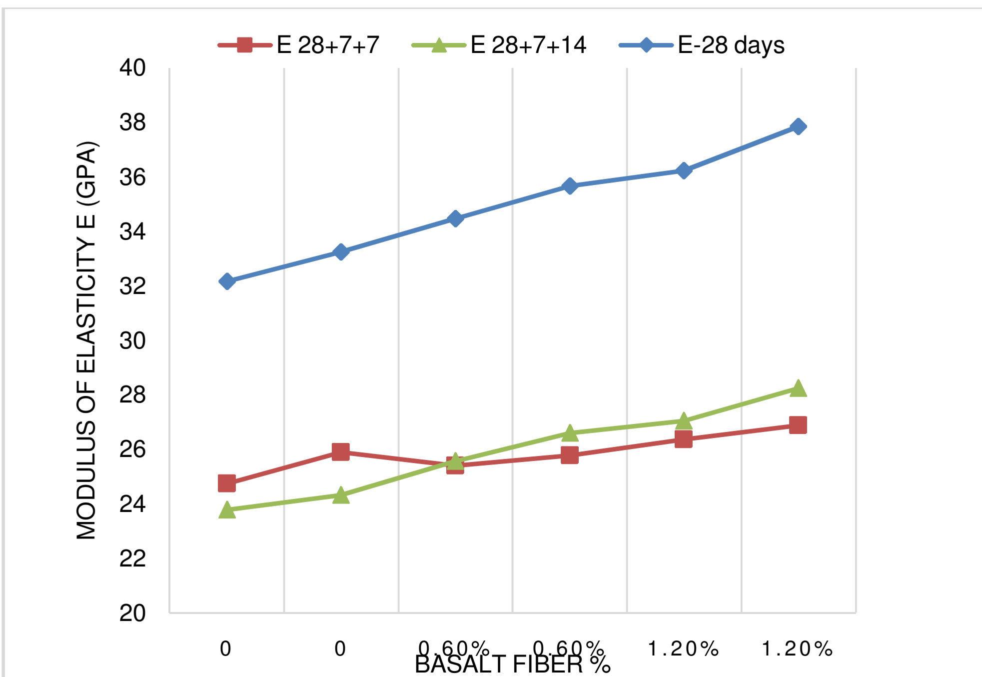

Fig. 2. The effect of basalt Fiber percentage and saltwater on the modulus of elasticity of LECA.

IV. CONCLUSION

Based on the study, the following conclusion may be drawn:

1. Basalt fiber content in concrete mixes has a great effect on concrete strengths and durability. Higher BF content produces higher compressive strength. After 7 days, the strength increases between 4.2% to 7% by adding BF 0.6% and 1.2% respectively.
2. The strength of concrete mix (7+14) days present 10.6% and 16.7% higher than the plane concrete mix.
3. The strength of concrete mix (7+7) days present 8.1% and 14.3% higher than the plane concrete mix.
4. The plane concrete mix decreased the compressive strength by 12.4% and 11.2% after immersed in saltwater for 7 days and dried for 7 and 14 days respectively.
5. The saltwater decreases the strength of the concrete mix by 9% and 6.4% for BF of 0.6% and 1.2% respectively after 7 days dried period.

6. On the other hand, after 14 days drying period. The strength of concrete mix decreases 5.7% and 3.1% for BF of 0.6% and 1.2% respectively.

7. In general. The density and modulus of elasticity of the concrete mix increased by increasing the percentage of BF.

V. FUTURE SCOPE

Future research on the strength of BF ECC will be done to check the durability of BF ECC in a salty environment and in an acidic environment. A comparison of the strength of ECC reinforced with different fiber materials: their efficiency and implementation.

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