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Original Research Article

Durability and Microstructure Properties of Concrete Reinforced with Empty Palm Oil Fruit Bunch Fiber

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ABSTRACT

Durability of concrete structures against agents of disintegration is receiving attention because of huge amount of money that is required to repair damaged structures. Presence of pores and voids as well as their distribution in concrete have been found to influence the ability of concrete to resist agents of deterioration. This paper reports the results of investigation conducted to assess the effects of Oil palm empty fruit bunch fiber (OPEFBF) on the durability and microstructure properties of concrete. Water absorption, coefficient of water absorption and coefficient of sorptivity were the durability properties that were assessed, using 100 x 100 x 100 mm concrete cube specimens. The microstructure of concrete samples was investigated with scanning electron microscopy (SEM). Crushed concrete samples from the compressive tests of 150×150×150 mm concrete cubes after 28 days of curing were used to carry out the micro-structural investigations. In the concrete specimens, the OPEFBF was added from 0% to 1.2% by the weight of cement at interval of 0.2%. The results show that the durability properties of concrete specimens with OPEFBF measured through water absorption, coefficient of water absorption and sorptivity tests recorded values that were less than 10%, indicating good concrete. Also, the SEM morphological images of concrete with OPEFBF at 28 days of curing showed denser and less porous microstructure up to 0.60% of OPEFBF. The inclusion of OPEFBF in concrete up to 0.6% by weight of cement improved the durability of concrete and resulted in denser and less porous microstructure.

1. INTRODUCTION

Professional judgment in the selection of a material should take into consideration not only the strength, dimensional stability and elastic properties of the material, but also its durability, which has serious economic implications in the form of maintenance and replacement costs of a structure (Mehta and Monteiro, 2001). Durability of concrete structures against environmental forces is becoming particularly important to government and the society because of enormous amount of money and constructional resources that are required for repair purposes for structures whose durability is suspected (Bastidas-Arteaga and Schoefs, 2015; Sahafnia, 2018).

The agents of deterioration to which concrete may be exposed are classified into three categories (Neville, 2011). The first category is the chemical disintegration. Under this category are: alkali-aggregate reaction, alkali carbonate reaction, chloride attack, etc. Mechanical agents are in the second category; which includes impact, abrasion, erosion, etc. The physical agent of concrete deterioration, which is the third category are temperature effects, differential thermal expansion of aggregate, differential thermal expansion of concrete, etc. All these agents of concrete deterioration are usually not taken into consideration during the design stage of structural concrete.

The attention is usually focused on strength as an indication of good concrete. According to Neville (2011), developments in cement and concrete technology are geared towards achieving higher strengths until recently. The assumption being that strong concrete is durable concrete. It is now becoming apparent that for many conditions of exposure of concrete structures, both strength and durability during their service life have to be considered explicitly at the design stage (Gambhir, 2013). Furthermore, sustainability issues of structural concrete production have made it mandatory that durable materials be used in construction (Mohammad, 2013). Recent advances in research studies have shown that the use of agricultural wastes like rice husk ash (RHA), wood ash (WA), palm oil fuel ash (POFA), etc., in the production of structural concrete will enhance its sustainability and other concomitant environmental concerns (Hwang et al., 2011; Hwang and Chandra, 2016; Le et al., 2015; Foong et al., 2015; Prusty et al., 2016; Jahangiri et al., 2017). However, most of these research work concentrated on the mechanical properties like workability, compressive strength, tensile strength, etc. Structural relevance of a material however is not on mechanical fitness alone, it must also be durable (Mohammad, 2013). Thus, it is imperative that all these agricultural wastes must be confirmed to be capable of producing concrete that is not only fit mechanically but also durable during service life performance. One of these wastes is empty oil palm fruit bunch (OPEFB) fibres (Fapohunda and Kilani, 2020). In their investigations, Fapohunda and Kilani (2020) obtained results of better compressive strength performance in relation to the control samples of concrete containing OPEFB fibres up to 0.60% addition by weight of cement. Other mechanical properties like consistency, setting times, workability and tensile strength were also assessed. The durability and microstructure aspect, being absent from the study conducted by Fapohunda and Kilani (2020), did not permit the capturing of the whole structural response of OPEFB fibres in concrete. Presence of pores and voids as well as their distribution in concrete have been found to influence the ability of concrete to resist agents of deterioration (Mehta and Monteiro, 2001). Water has also been found to be the major agent of concrete deterioration, either directly, or indirectly by serving as medium of ingress of aggressive chemicals (ICE, 2019)

Water in all its forms has many implications for civil and structural engineers. According to (ICE, 2019), a core function of all buildings is to keep their occupants and contents dry. Infrastructure such as roads, tunnels and airports must prevent the accumulation of water to perform as intended. For some structures, such as dams, river walls or coastal defenses, their only purpose is to protect other assets from water damage. ICE (2019) went further in saying that water can impart relatively large loads onto a structure, and is therefore often the cause, or contributory factor of failure in buildings and infrastructure. Furthermore, ingress of water into reinforced concrete structures results in corrosion of steel, leading to cracking and spalling of concrete cover (Gambhir, 2013)

Oil palm fruit bunch (OPEFB) fibres as potential construction material was a recent addition to list of many agricultural wastes that were previously found suitable (Fapohunda and Kilani, 2020). But the durability and microstructure of OPEFB fibres are yet to be investigated.

The present work investigates to what extent the use of OPEFB fibres in concrete can enhance the durability performance and the development of microstructure that is least susceptible to deterioration caused by water, in the resulting concrete.

2. MATERIALS AND METHODS

2.1. Materials Collection and Preparation

The materials used for this investigation are binder, sharp sand (fine aggregate), coarse aggregates (gravel), clean water and oil palm empty fruit bunch fibre (OPEFBF). Cement is the binding material of the concrete mixes. Elephant superset Portland limestone cement produced in accordance to NIS (2014) and BS (2000) was used. Sharp sand, which is also known as builders' sand, was the sand used for this investigation. The sand was collected from a stream near Ikole campus of Federal University of Oye - Ekiti, Nigeria. The sand was sun-dried to dry up its moisture content. The dried sand samples were sieved through sieve size 2.36 mm, so that sizes greater than 2.36 mm were removed in order to meet the requirement of BS (2008). The gravel used for this investigation was obtained from a quarry site close to FUOYE, Ikole campus, at Ikole Local Government area, Ekiti State, Nigeria. It was sun-dried to dry up its moisture content. The dried samples were sieved to remove the impurities. The maximum aggregate size of the gravel used was 20 mm as per the recommendation of BS 8110 (1997). The water used for this investigation had no impurities. It was sourced from a borehole located in the vicinity of civil engineering workshop of Federal University Oye-Ekiti. The empty fruit bunches of Oil Palm Fiber (OPEFBF), shown in Figure 1(a), were collected from one of the many palm oil processing industries located in Ikole Local Government area, Ekiti State, Nigeria. These samples were processed into filament. Firstly, they were soaked in warm water of about 35 ^{o}C for two days. This was done to kill germs and remove some impurities in the bunches, and for easy separation of the fiber into filament form. The soaked fibers were later removed from the water, separated into filaments as shown in Figure 1(b). The separated filaments were sun-dried to drain all its moisture content. The dried fibres were later cut into pieces to the length of 20 mm each as shown in Figure 1(c). The cut samples were added to the concrete as admixture at the dosage of 0% to 1.2% at the interval of 0.20% by weight of cement.

(a) (b) (c)

Figure 1: (a) An oil palm empty fruit bunch (b) Fresh extracted filament-fibers from oil palm empty fruit bunch after being soaked in water (c) Dried OPEFB fibers cut into 20 mm length each

2.2. Concrete Mix Design and Concreting

The concrete mix proportion of 1:2:4 and the water/cement ratio of 0.5 were used for the production of concrete cube specimens. This was adopted for this investigation to agree as much as possible to the local practice where medium quality control is envisaged. Oil palm empty fruit fibre were added from 0.20 – 1.20% at interval of 0.2 by weight of cement. The specimens without fibre served as the control. The mix proportion on the basis of this is shown in Table 1. For the durability investigation, 100 × 100 × 100 mm cube specimens were used. The samples used for microstructural investigation were taken from crushed 150 × 150 × 150 mm concrete samples at 28 day of curing.

Table 1: The mix proportion for the investigation

% Fibre in the mix	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Fibre (kg/m^3)	Water (kg/m^3)
0%	343	686	1372	0.00	172
0.2	343	686	1372	0.69	172
0.4	343	686	1372	1.37	172
0.6	343	686	1372	2.06	172
0.8	343	686	1372	2.74	172
1.0	343	686	1372	3.43	172
1.2	343	686	1372	4.12	172

2.3. Characterization of Materials

The physical properties of fine and coarse aggregate used were determined, as a preliminary investigation to ascertain the suitability for concrete production. The properties were specific gravity, bulk density, water absorption, moisture content, coefficient of curvature and coefficient of uniformity. These were done in accordance to ASTM (2006) and BS (2008).

2.4. Durability Assessment

The durability characteristics of the concrete samples with OPEFB fibres were assessed through three (3) test methods described thus.

2.4.1. Water absorption

For the water absorption test 100 x 100 x 100 mm concrete cube specimens were used and determined according to ASTM (2006). The tests were carried out on the specimens at 28 and 90 days of curing by immersion in boiling water. The samples were covered by tap water and boiled for 5 hours. Before immersion, the weight (A) of the samples was determined. The specimens were then allowed to cool to atmospheric temperature of 20 to 25 ^oC for a period of not less than 14 hours. Then the weight (B) was also determined after the cooling that followed the immersion. The water absorption was calculated using Equation 1.

$$\text{Water absorption} = \frac{B-A}{A}\ x\ 100 \qquad (1)$$

2.4.2. Coefficient of water absorption

According to Powers (1968), the coefficient of water absorption measures the permeability of water. This is understood to mean the rate of uptake of water by dry concrete samples in a time period of 1 h. A total number of forty-two (42) 100×100×100 mm concrete cubes specimens were cast, cured and tested at 28 and 90 days. Prior to testing, the concrete specimens were oven-dried at the temperature of 105^{o}C for three days until constant weight was reached and then allowed to cool in a sealed container for three days. On the day of testing, the samples were positioned at their bases, and the four sides of the concrete samples were coated with silicone sealant in order to allow the flow in one direction, that is, vertically. The samples, in a vertical position, were kept partially immersed to a depth of 5 mm at one end while the rest of the portions were kept exposed to the laboratory air. This arrangement for the assessment of the rate of water absorption is shown in Figure 2 (ASTM 2004; Ganesan et al., 2008).

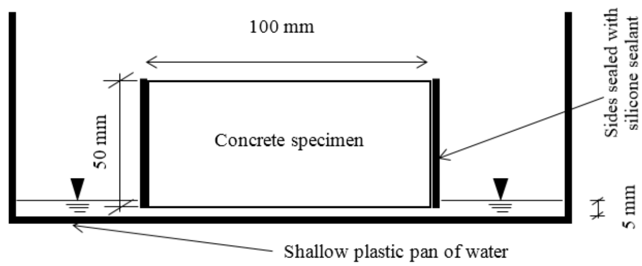

Figure 2: Arrangement for coefficient of absorption and sorptivity tests (ASTM 2004; Ganesan et al., 2008)

The quantity of water absorbed during the first 60 min by the concrete samples with EPOFBF was calculated. Coefficient of water absorption values of the concrete specimens after 28 and 90 days of moisture curing were determined using Equation 2.

$$Ka = [\frac{Q}{A}]^2 \text{ x } \frac{1}{t} \quad (2)$$

where Ka is the coefficient of water absorption (m^2/s), Q is the quantity of water absorbed (m^3) by the oven dry specimen in time (t), t is 3600 s and A is the surface area (m^2) of concrete specimen through which water percolated.

2.4.3. Sorptivity

The configuration for the determination of sorptivity, cube specimens and sample preparation used were similar to that used for coefficient of absorption as shown in Figure 2 However, the difference is that, here the tests were conducted at selected times 0, 2, 4, 8, 10, 20, 30, 60, 90 and 120 minutes. At the selected times, the samples were removed from the water, and the excess water blotted off with a damp paper towel, and then weighed. This process was repeated for the selected time periods. Then, the gain in mass per unit area over the density of water was plotted versus the square root of the elapsed time. The sorptivity value of the concrete sample was taken to be the slope of the line of best fit of these points. The sorptivity values of blended concrete specimens after 28 and 90 days of moisture curing were then calculated using the following formula suggested by Stanish et al. (1997), as expressed in Equation 3.

$$I = St^{\frac{1}{2}} \quad (3)$$

where *I* is the cumulative water absorption per unit area of inflow surface (m^3/m^2), S is the sorptivity (m/s1/2) and t is the time elapsed (s). A total number of forty-eight (48) 100 x 100 x 100 cube specimens cured for both 28 and 90 days were used. This test was conducted according to the recommendations of Hall (1989) and ASTM (2004).

2.5. Microstructure

The specific characteristics within the concrete reinforced with OPEFB fibre was visualized through a scanning electron microscope (SEM) shown in Figure 3. The SEM equipment was set to back-scattered electrons (BSE) mode. The concrete samples were collected from the crushed 150×150×150 mm concrete cube samples with different percentages of OPEFB fibre content range from 0% to 1.2% with 0.2% increase interval.

Figure 3: JOEL – JSM 7600F scanning electron microscope

During the investigation, the samples were put in appropriate sizes to fit in the specimen chambers and are generally mounted rigidly on a specimen holder called a specimen stub. The samples were coated with platinum coating of electrically conducting material, deposited on the samples by low-vacuum sputter coating. The SEM instrument placed the specimens in a relative high-pressure chamber where the working distance is short and the electron optical column is differentially pumped to keep the vacuum adequately low at the electron gun. The high-pressure region around the sample in the SEM neutralizes charge and provides an amplification of the secondary electron signal. Low-voltage SEM is typically conducted in an FEG-SEM because the field emission guns (FEG) is capable of producing high primary electron brightness and small spot size even at low accelerating potentials.

3. RESULTS AND DISCUSSION

3.1. Characterization of Materials

The physical properties of the aggregate used are presented in Table 2. From the Table, it can be observed that the specific gravities of both fine and coarse aggregate are respectively 2.63 and 2.67. These values were with 2.6 to 2.8 specified by ACI (1999). Similarly, the densities for both the fine and coarse aggregate respectively of 1667 kg/m^3 and 1600 kg/m^3 fell within range of 1280 to 1920 as per the recommendations of ACI (1999). Furthermore, the values obtained for the water absorption was 2% for both fine aggregate and coarse aggregate. This value compared well with the range specified (0 to 8%) by ACI (1999). Other properties, as can be observed from Table 2 were in agreement with ACI (1999). This suggested that the aggregate met the necessary requirements for concrete production.

Table 2: Physical properties of the aggregate

Properties	Fine aggregate	Coarse aggregate	ACI (1999)
Specific gravity	2.63	2.67	2.6 – 2.8
Bulk density (kg/m^3)	1667	1642	1280 – 1920
Water absorption (%)	2.00	2.00	0 – 8
Moisture content (%)	0.00	0.00	0 – 2
Coefficient of curvature (Cc)	0.88	0.98	< 1.47
Coefficient of uniformity (Cu)	3.00	2.43	NA

3.2. Durability Characteristics

The results of durability examinations of concrete samples containing empty oil palm fruit fibre bunch through water absorption, coefficient of water absorption and sorptivity tests are shown respectively in Tables 3 and 4 as well as Figure 4. Taking a look at the numerical values obtained as shown in Tables 3 and

4, it was observed that none exceeded 10%. This is an indication that inclusion of OPEFB fibre in concrete will resulted in good and durable concrete (Neville, 2011). Notwithstanding this, the following comments on each of these parameters, in relation to what is measured, are necessary.

Table 3: Water absorption of samples with OPEFB Fibre at 28 and 90 days

% of OPEFB fibre in the mix	Water absorption (%)	
	28 days	90 days
0	0	1.460
0.2	0.901	3.061
0.4	0.699	2.381
0.6	0	0.781
0.8	2.985	1.667
1.0	1.379	1.515
1.2	0.763	0.800

Table 4: Coefficient of water absorption of samples with OPEFB fibre at 28 and 90 days

% of OPEFB fibre in the mix	Ka (m^2/s) x 10^{-8}	
	28	90
0	0.050	0.033
0.2	0.067	0.033
0.4	0.067	0.033
0.6	0.067	0.033
0.8	0.050	0.050
1.0	0.050	0.033
1.2	0.100	0.017

The water absorption determines the total amount of water absorption in a porous body, like concrete, in the absence of external pressure (ASTM C642, 2006). In this case, the total water absorption is a function of pores in the samples, irrespective of their sizes, numbers and distribution. What the values obtained in this investigation indicated was the fact that the inclusion of OPEFB fibres will not result in concrete whose total pores is significant enough, to the extent that it weakens the ability of the concrete by disintegration due to water ingress. Similarly, the coefficient of water absorption is the measure of permeability of water in concrete sample.

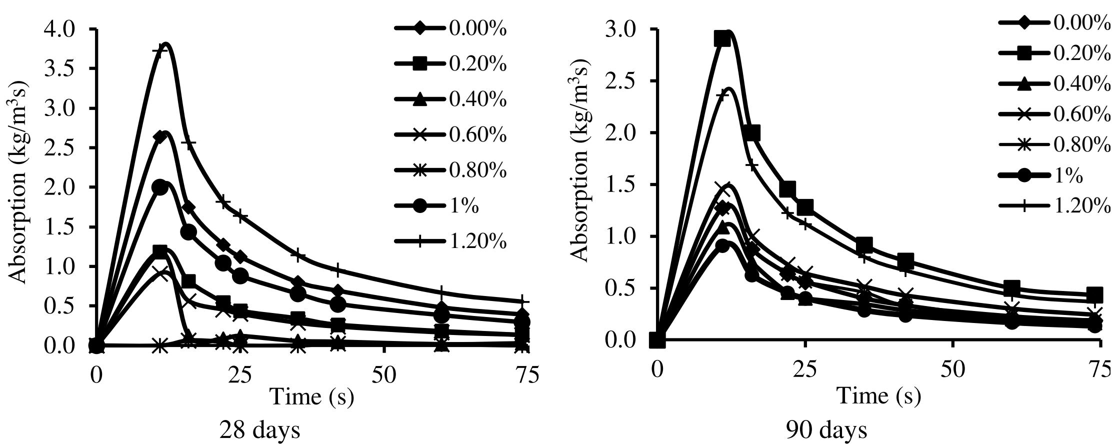

Figure 4: Sorptivity of the concrete samples at 28 and 90 days

To be permeable, pores have to be interconnected. When pores are interconnected, water can flow more easily through the specimens, thus aiding the agents of disintegration. That the values obtained is less than 10% was indication that the concrete sample were impervious to migration of water. The inclusion of OPEFB fibres in the concrete discouraged the development of porous internal concrete matrixes. Furthermore, the sorptivity test measures the water flow in unsaturated porous materials due to pressure differences caused by capillary and gravitational forces. Capillary potential is highly dependent on the volume of empty pores which are able to absorb fluid (Mohammad, 2013). The low values of sorptivity obtained from this investigation (Figure 4), in concrete specimens with OPEFB fibres indicated either discouragement of formation of pores or filled empty pores, thereby reducing the capillary potential. Thus, considering all these together, inclusion of OPEFB fibres in concrete will produce a durable concrete.

3.3. Microstructure

The SEM micrograph showing the morphological structures of concrete specimens with OPEFB fibres up to 1.0% by weight of cement, are shown in Figures 5. It is known that the addition of fibers in the concrete matrix increases the difficulty of studying the mixture properties as fibers are randomly distributed inside the concrete (Ghanem, 2020). However, microstructural examinations are to determine to what extent does the inclusion of OPEFB fibres in the concrete provide a crack arrest mechanism and inhibit cracking formation. Careful study of Figure 5 shows that the SEM images of control samples and samples with 0.8 and 1.0% of OPEFB fibres were similar. The similarity is within the context of seeming prevalence of microcracks and large pores (Mehta and Monteiro, 2014).

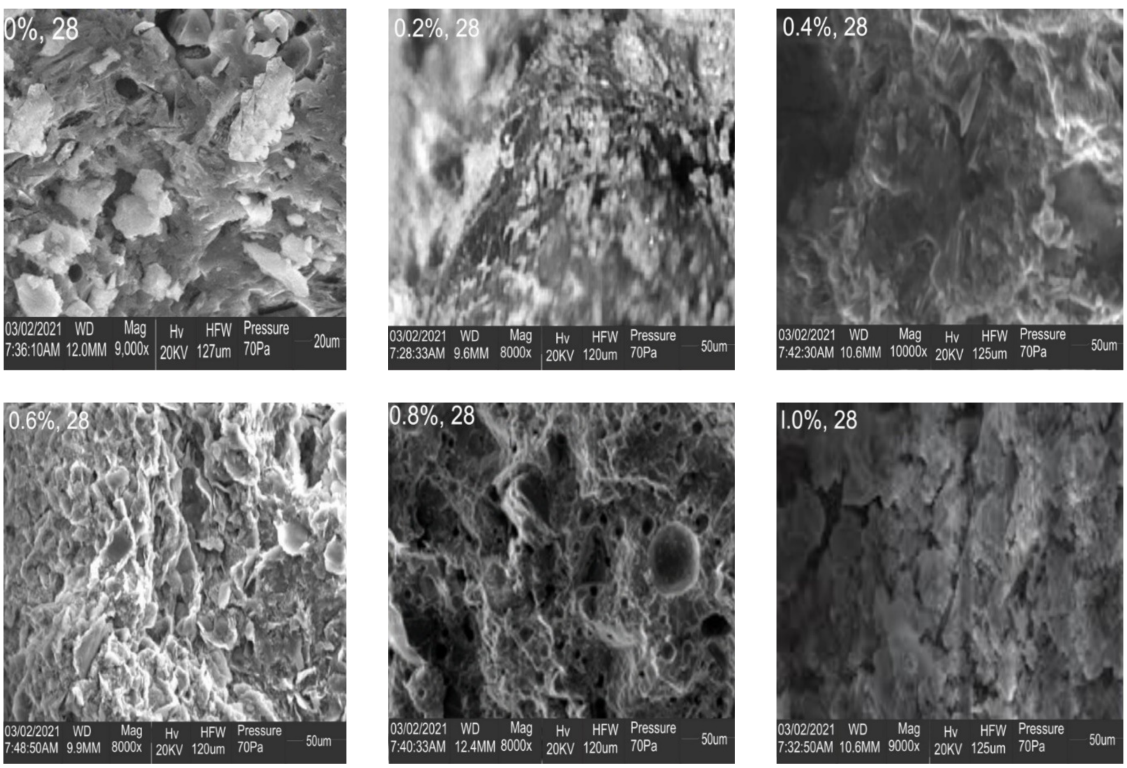

Figure 5: SEM images of concrete specimens with OPEFB fibres

On the other hand, samples with 0.2, 0.4, and 0.6% OPEFB fibres seemed to have less of these cracks. Thus, the samples with 0.2, 0.4, and 0.6% OPEFB fibres appeared to be less porous and of denser microstructure than the control. This suggested improvement in durability characteristics of the samples, in relation to the control, up to 0.6% of OPEFB fibres. However, samples with 0.8 and 1.0% of OPEFB fibres appeared to be porous, suggesting deteriorating durability features of samples beyond 0.6% of OPEFB fibres. The possible reason of this behaviour can be attributed to the fact that, at higher OPEFB fibres, development of strong bonding between fibres and cement matrix became difficult, resulting in porous matrix. (Ghanem, 2020). This behaviour correlate with the results of the compressive strength development of specimens with OPEFB fibres, as obtained by Fapohunda and Kilani (2020). According to the Fapohunda and Kilani (2020), specimens with OPEFB fibres developed compressive strengths that are better than the control specimens up to 0.6% by weight of cement. This confirms that the principle that the properties of a material originate from its internal structure (Mehta and Monteiro, 2014), and also that the microstructure has a significant effect on strength and durability properties of concrete (Hilal, 2016). Thus, considering the results of the compressive strength with observations from the microstructural investigations, it appears that inclusion of OPEFB fibre in the concrete up to 0.6% by weight of cement will result in durable concrete.

4. CONCLUSION

This investigation was carried out to assess the durability and examine the microstructure of concrete specimens containing OPEFB fibres. From the analysis of the results, the following conclusions can be made:

1. The durability properties of concrete specimens with OPEFBF measured through water absorption, coefficient of water absorption and sorptivity tests recorded values that are less than 10%, indicating good concrete, and thus can be considered as good
2. The SEM morphological images of concrete with OPEFBF at 28 days of curing shows denser and less porous microstructure up to 0.60% of OPEFBF

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

ACI (1999). Aggregates for Concrete. ACI Education Bulletin – E1-99, American Concrete Institute, American Concrete Institute, Farmington Hills, Michigan.

ASTM (2006). ASTM Standard C642. Standard Test Method for Density, Absorption, and Voids in Hardened Concrete. ASTM International, West Conshohocken, PA.

ASTM (2004). ASTM Standard C1585. Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes. ASTM International, West Conshohocken, PA.

Bastidas-Arteaga E. and Schoefs F., (2015). Sustainable Maintenance and Repair of RC Coastal Structures. Proceedings of the Institution of Civil Engineers: Maritime Engineering.

BS (1997). BS 8110. Structural use of Concrete – Part I. British Standard Institution, London.

BS EN 197-1 (2000). Cement, Composition, Specification and Conformity Criteria for Common Cements. British Standard Institution, London.

BS (2008). BS EN 12620:2002+A1. Specification for Aggregates from Natural Sources for Concrete. British Standards Institution, London.

Fapohunda, C. A. and Kilani, J. A. (2020). Some Structural Performance Evaluation of Concrete reinforced with Empty Palm Oil Fruit Brunch (OPE-FBF). Proceeding, 3rd College of Engineering International Conference of the Federal University of Agriculture, Abeokuta.

Foong, K. Y., Alengaram, U. J., Jumaat, M. Z. Mo, K.H. (2015) Enhancement of the mechanical properties of lightweight oil palm shell concrete using rice husk ash and manufactured sand. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 16(1), pp. 59 – 69.

Gambhir, M. L. (2013). *Concrete Technology – Theory and Practice*. 5th Ed., McGraw Hill Education Private Limited, New Delhi, India, pp. 149 – 161.

Ganesan, K., Rajagopal, K., & Thangavel, K., (2008). "Rice husk ash blended cement: assessment of optimal level of replacement for strength and permeability properties of concrete". *Construction and Building Materials,* Vol. *22, Nos.* 8, pp. 1675–1683.

Ghanem, S. Y. (2020). Three-Dimensional Microstructure Model for Discontinuously Fiber Reinforced Concrete. *International Journal of Civil Infrastructure (IJCI*), 3, pp. 15 – 23.

Hall C. (1989). Water sorptivity of mortars and concretes: a review. Magazine of Concrete Research, 41(14), pp. 51 – 61

Hilal, A. A. (2016). Microstructure of Concrete. Intech Open.

Hwang, C. L. and Chandra, S. (2016). *The Use of Rice Husk Ash in Concrete*.

https://3cl1105uvd.files.wordpress.com/2013/06/book-by-satish-chandra-220504.pdf (assessed 27 - 4- 2016).

Hwang, C. L., Bui, L. A. and Chun-Tsum, C. (2011). Effect of rice husk ash on the strength and durability characteristics of Concrete. *Construction and Building Materials,* 25(9), pp. 3768-3772.

ICE (2019). The role of water in structural failure. https://www.icevirtuallibrary.com/page/ice-news/cfp-foen-01-2020?_ccCt=io22p%7ed6Je74GotI1lueJ1iai_Rm0uWXciCBOAMVWC0ixD04aXXPv4BLdDPXGoSX (accessed 12 – 12 – 2019)

Jahangiri, N, Koseoglu, K, Cengizler, H. (2017). Concrete with by-products and waste materials as aggregate or cement. *Dicle University Institute of Natural and Applied Science Journal*, 6(1), pp. 29-38.

Le, H. T., Müller, M., Siewert, K. and Ludwig, H. (2015). The mix design for self-compacting

high-performance concrete containing various mineral admixtures. *Materials and Design*, 72, pp. 51 - 62

Mehta, P. K. and Monteiro, P. J. M. (2014). *Concrete: Microstructure, Properties and Materials*. 4th Ed., McGraw-Hill Education

Mohammad, B. (2013). Development of Concrete Water Absorption Testing for Quality Control. MSc. Thesis, Department of Building, Civil, and Environmental Engineering, Concordia University Montréal, Québec, Canada.

Neville, A. M. (2011). *Properties of Concrete*. 5th Ed., Pearson International, London, UK.

NIS (2014). NIS 444-1. Cement – Part I: Composition and Conformity Criteria for Common Cements. Standard Organisation of Nigeria, Abuja Nigeria.

Powers, T. C. (1968). *Properties of fresh concrete*. John Wiley and Sons, New York.

Prusty, J. K, Patro, S. K. and Basarkar, S. S. (2016). Concrete using agro-waste as fine aggregate for sustainable built environment – A review. *International Journal of Sustainable Built Environment*, 5, pp. 312 – 333.

Sahafnia, M. (2018). Concrete Structures Durability and Repair. MSc. Thesis, Department of Civil Engineering, Kansas State University.

Stanish, K. D., Hooton, R. D. and Thomas, M. D. A. (1997). Testing the chloride penetration resistance of concrete: a literature review, FHWA contract DTFH61 1997. Department of civil engineering, University of Toronto, Toronto, pp. 19 – 22.