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Relative Density and Durability Properties of Concrete Reinforced with Treated and Untreated Fibres Obtained from Palm Oil Empty Fruit

***Fapohunda, C.A., Adebayo, H.O., Adekunle, H.B. and Olapade, V.O.**

Department of Civil Engineering, Federal University Oye-Ekiti, Nigeria.
*christopher.fapohunda@fuoye.edu.ng

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ABSTRACT

The relative properties of concrete reinforced with treated and untreated fibres obtained from Palm Oil Empty Fruit Bunch (POEFB) in concrete are reported in this paper. The criteria for comparison are density and durability characteristics. The densities were determined with the aid of 150 x 150 x 150 mm concrete cube specimens. The durability characteristics were assessed through sorptivity, coefficient of water absorption and water absorption tests. For these durability tests, 100 x 100 x 100 mm cube specimens were used. The analysis of the results showed that: (i) the densities of specimens containing POEFB fibres were higher than specimens containing the untreated fibres by as much as and 30% at both 28 and 90 days curing. and (ii) the inclusion of treated POEFB fibres improved the durability characteristics of the specimens determined through absorption, coefficient of water absorption and sorptivity tests. Absorption values for treated fibres were less than 10% at both 28 and 90 days of curing. Considering all the results as a whole, inclusion of treated POEFB fibres resulted in concrete with superior durability characteristics than specimens with untreated POEFB fibres.

1. INTRODUCTION

Non-renewable natural resources are depleted in the manufacturing process of materials used for the construction of civil infrastructures. The dangers this portend are now being acknowledged. This has prompted research efforts into finding ways of sourcing various kinds of alternatives to the constituents of structural concrete.

Non-traditional materials, like pozzolans, fibres (natural and unnatural), and other supplementary cementitious materials (SCM) are gradually finding their way as a component of concrete (Abbas et al., 2016; Arulrajah et al., 2016; Paris et al., 2016; Sua-iam et al., 2019; Fapohunda and Kilani, 2021; Fapohunda and Daramola, 2019). Agricultural wastes are particularly becoming important source of alternative or substitute materials for materials for concrete production. These wastes are available and inappropriately disposed, thus constituting serious environmental problems. Their use in concrete will help address the environmental issues occasioned by their improper disposal. More importantly, it will also help to address some of the sustainability issues of structural concrete production by bringing about a significant reduction in the usage of the non-renewable natural resources.

A particular type of fibre that is gradually forming part of the constituent of concrete is fibres obtained from Palm Oil Empty Fruit Bunch (POEFB). Results of studies conducted by many researchers on lightweight concrete and bricks showed that POEFB fibres can be used to produce suitable concrete (Ramli and Dawood 2010; Ismaila and Yacoob (2011). Identical results were also observed from the works of Lim et al. (2018) on foam concrete. Investigation conducted by Ismail and Hachim (2008), though limited in scope also showed that, within the ranges considered, application of POEFB fibres in concrete is possible in concrete. Fapohunda and Kilani (2021) did expanded investigations on the use of POEFB fibres in structural concrete. Their results, together with others, showed improved structural properties except the tensile properties of concrete. Some researchers, namely Shetty (2009) and Ozerkan et al. (2015) attributed the low tensile properties that resulted from using POEFB fibres in concrete to weak bond stress or adhesive properties between the fibres and the mortar constituent of the concrete. However, the results of works done by Izani et al. (2013) and Momoh and Osofero (2020) showed that treatment of the fibres with alkali, before using in concrete can improve the bond stress. This will no doubt improve the overall structural performance of the concrete including its durability properties and thus help address the sustainability concerns of structural production if eventually applied (Fapohunda, 2010; Fapohunda, 2016). Fapohunda et al. (2023) did an investigative comparison of structural performance of concrete containing treated and untreated POEFB. It was found out that concrete specimens reinforced with treated fibres have better structural properties than concrete specimens without fibres. Their investigation however did not consider the durability issues.

In the current structural engineering practice, durabilities considerations are becoming as important as mechanical issues (Neville, 2011). This is because non-durable concrete will require considerable financial resources for its rectification. Thus, the aim of the present investigation is to compare the relative density and durability performance of treated and untreated POEFB fibres in concrete. Specific objectives include the comparison of the densities and water-based durability parameters of concrete reinforced with treated and untreated POEFB fibres.

2. MATERIALS AND METHODS

2.1. Materials and the Concrete Mix proportion

This study was accomplished by using the following materials namely, binder, fine aggregate, coarse aggregate, water, fibres obtained from palm oil empty fruit bunch (POEFB) and superplasticiser. The binder was Portland limestone cement conforming to the requirements of BS EN 197 (2000) and NIS (2014). The fine aggregate consisted in river sand, mined from a flowing river that is flowing close to the University where this research was carried out. The sand was treated to ensure that particle sizes were not greater than 4.75 mm and lesser than 75 um by sieving through appropriate sieve sizes were used. This was to ensure adherence with the recommendation of BS EN (2008). The coarse aggregate used for this study was obtained from the quarry at the town where the University was domiciled. In order to ensure compliance with BS 8110 (1997), the particle sizes ranged between 4.75 and 20 mm. Numerous oil palm cottage industries surrounded the University within the radius of 5 km. From the wastes generated by these industries, empty oil palm fruit brunch fibre (POEFB) were obtained; and from these bunches, the fibres used in this investigation were obtained. To extract the fibre, the empty fruit bunches were immersed in water for about 12 hours to soften them for easy extraction of the fibres (Figure 1 shows extraction process). After extraction, it was then sun-dried.

a. The bunch b. before extraction c. the fibres

Figure 1: Process of extraction of the fibres

One of the properties of fibres that affect their performance in concrete is the aspect ratio. To keep the aspect ratio, defined as in Equation 1, to between 50 and 55, for optimum performance (Kaniraj and Fung, 2018), the fibres were cut into 20 mm length.

$$\text{Aspect ratio} = \frac{Length\ of\ the\ fibre\ (mm)}{the\ diameter\ of\ the\ fibre\ (mm)} \quad (1)$$

Sodium hydroxide (NaOH) was used for the treated fibres by following the procedures suggested by Izani et al. (2013). The untreated fibres were used after sun-dried. The water that is potable and that also meet the recommendations of ASTM 1602 (2012) was used for this study. A superplasticiser with a brand name Master Glenium SKY 504 (BASF, 2014) was used to improve the workability of the concrete mix. This is because earlier works (Fapohunda and Kilani, 2021) have shown the use of the fibres resulted in concrete with significantly reduced workability. This brand of superplasticiser was capable of producing a concrete of high-quality mix with quickens strength development and prolonged workability.

2.2. Concreting Operations

For this investigation, the need to obtain a 28-day concrete grade of 20N/mm^2, as it is common practice in Nigeria led to the mix design method suggested by COREN (2017). This method recommends a mix ratio of 1: 2: 4 with water cement ratio of 0.50, as well as a slump of 25 mm. Into the concrete was added the treated and untreated fibres, which was limited to 1.20% by weight of cement, using the interval of 0.20%. The fibres were mixed randomly with the cement. The fibre addition ranged from 0 – 1.2%, which was based on findings of Kaniraj and Fung (2018). The resulting mix proportion that was obtained on the basis of this mix ratio and water/cement ratio is presented in Table 1. Concreting involved batching the ingredients by weight, and then thoroughly mixing them together. The procedure suggested by Gambhir (2013) was followed. For the density test specimens, the concrete was poured into 150 x 150 x 150 mm cube moulds, while the specimens for durability studies consisted of 100 x 100 x 100 mm cube specimens of concrete. The concrete specimens were removed from the moulds after staying for 24 hours in their respective moulds. The specimens were then arranged inside a curing tank for the process of moist-curing, which is by immersion in water until the day of testing. The specimens were tested at 7, 14, 28, 60 and 90 days of curing by water-immersion for density assessment. The specimens to be used for durability studies were tested at 28 and 90 days of curing. In all cases, the specimens without POEFB fibres were used as the control specimens. Concrete cube specimens 150 x 150 x 150 mm totaling 210 in number and 252 numbers of 100 x 100 x 100 concrete cube specimens were used in this investigation.

Table 1: The proportion of concrete constituents for the study

% 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%	342	685	1371	0.00	171
0.2	342	685	1371	0.69	171
0.4	342	685	1371	1.37	171
0.6	342	685	1371	2.06	171
0.8	342	685	1371	2.74	171
1.0	342	685	1371	3.43	171
1.2	342	685	1371	4.12	171

2.3. Methodology of Investigation

2.3.1. Determination of properties of materials

Characterization of the materials to be used to ascertain their fitness and suitability for use in concrete was carried out. These were done for both the aggregate and the POEFB fibres. The properties investigated for the aggregates were sieve analysis, specific gravity, bulk density, etc. The physical and chemical properties were determined for both the treated and untreated POEFB fibres using the procedures in Fapohunda et al. (2023).

2.3.2. Density of the specimens

For determination of the densities of concrete specimens containing treated and untreated POEFB fibres, concrete cube specimens of dimensions 150 x 150 x 150 mm were used. In the determinations of densities, the provisions of BS EN 12350-6 (2000) was adhered to. The densities were assessed at curing ages of 7, 14, 28, 60 and 90 day. Both treated and untreated POEFB fibres were added in sequence into the concrete from 0 – 1.20 % at internal of 0.2%. To obtain the densities of the specimens at the date of test, the weight (W) of the concrete cube specimens were determined. These weights were then used to obtain the density (ρ) of the cube specimens of concrete with volume V (m^3) using Equation 2.

$$\rho = \frac{W}{V} \tag{2}$$

2.3.3. Water absorption test

Concrete specimens, with having the dimensions 100 x 100 x 100 mm, were used for the water absorption test. The tests were done in accordance to ASTM C642 (2006) at 28 and 90 days after moist-curing of the specimens. The concrete specimens were placed in oven maintained at the temperature of about 100 ºC until constant weight was established after weighing the samples every day. The samples were then weighed and later immerse in water for 48 hours and weighed again. The water absorption was estimated using Equation 3.

$$\text{Water absorption} = \frac{B - A}{A}\ x\ 100 \tag{3}$$

In equation 3, A = dry weight of test specimen and B = weight of test specimen after immersion in water for 48 hr. The cube specimens contained treated and untreated POEFB fibres. Samples without the fibres served as the control.

2.3.4. Coefficient of water absorption test

Concrete specimens with sizes 100 x 100 x 100 mm, containing treated and untreated POEFB fibres were used for this investigation following the recommendation of ASTM C1585 (2004). After casting the concrete cubes specimens, they were cured by immersion in water. They were then tested at 28 and 90 days of curing. Before the test day, the concrete specimens were dried in oven at the temperature of 105ºC over a period of three days until constant weight was established. The samples were put inside a sealed container for the purpose of cooling for three days. On the test day, the samples of concrete were coated in four sides with water-resisting sealant and position in such a way that flow in the vertical direction is permitted. One end of the concrete cube specimens were kept immersed in water to a height of 5 mm. The remaining parts were allowed to be exposed to the laboratory air. This is shown in Figure 2.

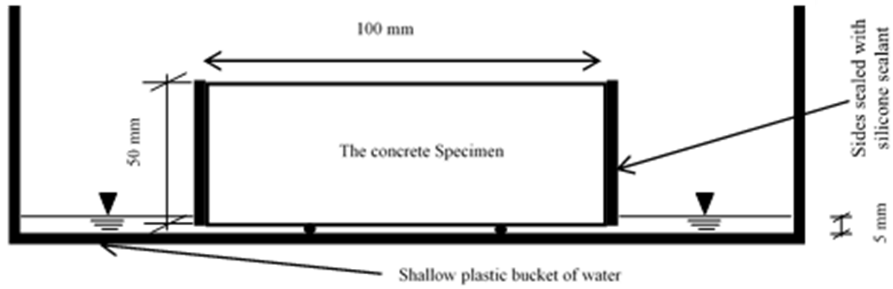

Figure 2: Configuration for Coefficient of Absorption and Sorptivity Tests (ASTM C 1585 2004; Ganesan et al., 2008; Fapohunda et al., 2021)

During the first 60 minutes, the quantity of water absorbed by the concrete samples with EPOFB fibres (in both treated and untreated conditions) was estimated using Equation 4.

$$\text{Ka} = [\frac{Q}{A}]^2 \text{ x } \frac{1}{t} \quad (4)$$

In Equation 4, Ka = the coefficient of water absorption (m^2/s), Q = the quantity of water absorbed (m^3) by the oven dry specimen in time (t), t = 3600 s and A = the surface area (m^2) of concrete specimen through which water permeated.

2.3.5. Sorptivity test

The instrumentation for the assessment of the sorptivity characteristics of the concrete cube specimens, as well as specimen preparation used for the tests were similar to that used for coefficient of absorption as shown in Figure 2. However, in the sorptivity investigation, the tests were conducted at some selected times. The selected times were 0, 2, 4, 8, 10, 20, 30, 60, 90 and 120 minutes. At each of the selected times, the concrete samples were taken out of the water, and the excess water on the surface was cleaned with a paper towel. The samples are then weighed. This process was carried out for each of the selected time periods and water absorption was determined by using Equation 5.

$$\text{I} = \frac{m_t}{a.d} \quad (5)$$

In Equation 5, represents absorption (mm), m_t represents specimen mass in grams at time t (g), a represents exposed area of the sample (mm^2), d represents density of water in g/mm^3 ($0.001 \ g/mm^3$). Then the water absorption was plotted versus the square root of the time that elapsed. The sorptivity value of the concrete sample was taken to be the gradient of the line of best fit of these points, and as expressed in Equation 6.

$$I = St^{\frac{1}{2}} \quad (6)$$

In Equation 6, where *I* represent 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).

3. RESULTS AND DISCUSSION

3.1. Characterization of Materials

In Tables 2 – 4 are presented the results of the characterization of materials. Looking at Table 2, it is observable that the specific gravity of fine aggregate was 2.61 and that of coarse aggregate was 2.65. Against the background of the fact that the average specific gravities of majority of natural aggregate is between 2.5 and 2.8 (Gambhir, 2013), it can be concluded that the fine aggregate and coarse aggregate used in this study are natural aggregate. In the same vein, the bulk densities, water absorptions and the moisture contents of both the fine aggregate and coarse aggregate were within the ranges recommended for normal concrete ACI (1999).

Table 2: Physical properties of the fine and coarse aggregates

Properties	Fine aggregate	Coarse aggregate
Specific gravity	2.61	2.65
Bulk density (kg/m^3)	1666.56	1642.57
Water absorption (%)	1.98	1.97
Moisture content (%)	0.00	0.00
Coefficient of uniformity (Cu)	2.98	4.45
Coefficient of curvature (Cc)	0.87	1.15

The recommended values by ACI (1999) for densities are between 1280 and 1920 kg/m^3; for water absorption they are between 0 and 8%, and for moisture content: it is 0 – 2% for fine aggregate and 0 - 10% for coarse aggregate. It can also be observed in Table 2 that values of coefficient of uniformity ($C_u = \frac{D_{60}}{D_{10}}$) and coefficient of curvature or gradation ($C_c = \frac{D_{30}\ x\ D_{30}}{D_{60} D_{10}}$), which were obtained from the results of mechanical analysis, were 2.98 and 0.87 for fine aggregate; and 4.45 and 1.15 for the coarse aggregate. ACI (1999) permitted the use of these ranges of values for fine aggregates intended to be used in concrete. Thus, from Table 2, it can be concluded that the aggregate (the fine aggregate and coarse aggregate) used for this investigation are suitable for concrete production. Presented in Table 3 are the obtained values for physical and mechanical properties of palm oil empty fruit bunch (POEFB) fibres. From Table 3, it can be seen that the treated POEFB fibres had density and water absorption values that were higher than of the untreated POEFB fibres. Of importance in Table 3 was the observation that the tensile responses of treated POEFB fibres were higher than that of the untreated POEFB fibres. For example, treating the fibres increased the tensile strength by as much as 8.5% and Young's modulus by 7.4%. These results agreed with the findings of Izani et al. (2013). The increases in the tensile properties of treated fibres have been attributed to increased crystallinity of fibres alkali treatment Izani et al. (2013). In Table 4 are presented the results of the elemental properties of treated and untreated POEFB fibres. From Table 4, it is obvious that all the elemental properties of the treated fibres recorded higher values than the untreated fibres

Table 3: Physical properties of palm oil empty fruit bunch fibre

Physical properties	Untreated fibre	Treated fibre
Color	Brown	Brown
Length (single fibre) (mm)	20	20
Diameter (single fibre) (mm)	0.25 – 0.50	0.25 – 0.50
Aspect ratio	52.50	52.50
Density (g/cm^3)	1.13	1.37
Water absorption (%)	35.17	42.13
Pentosan (%)	20.91	18.25
Tensile strength (GPa)	160.67	175.49
Young modulus (GPa)	5.07	9.09

Table 4: Elemental properties of palm oil empty fruit bunch fibre

Chemical composition	Untreated POEFB fibre	Treated POEFB fibre
Hemi-cellulose (%)	11.59	14.50
Cellulose (%)	37.51	44.50
Lignin (%)	18.40	21.10
Extraction (%)	0.44	0.52
Ashes (%)	4.95	7.52

3.2. Density of Specimens with Treated and Untreated POEFB Fibres

The results of the densities pattern for both treated and treated POEFB fibres concrete specimens are shown in Tables 5 and 6. The figures in the parenthesis represent the standard deviations. With the exception of concrete samples containing treated POEFB fibres up to 0.4% at 7 day curing days, the densities of samples containing treated POEFB fibres were higher than the samples containing the untreated fibres. The reason for this can be observed in Table 3, where it can be observed that the density of treated fibres (1.27 (g/cm^3) was higher than the untreated fibres (1.03 (g/cm^3). Also, looking from another perspective, the range of densities for the specimens with untreated fibres was approximately between 2200 and 2500 kg/m^3. This is the density ranges for concrete classified as normal weight concrete according to ACI 213R-03, (2013) and Falade et al. (2011). The ranges of densities for concrete specimens with treated fibres were in excess of 2500 kg/m^3 (with the exception of specimens up to 0.4% fibres content at 7-day curing). Thus, the density ranges of treated specimens fell into heavy weight concrete classification (ACI 213R-03 (2013) and Falade et al. (2011)). This will make the concrete with treated POEFB fibres suitable for protective application as biological shields and shelter against gamma rays or nuclear shielding (Neville, 2011; Gambhir, 2013)

Table 5: Density (in kg/m^3) of Concrete specimens with treated fibres

% fibre in the mix	Curing age (days)				
	7	14	28	60	90
0	2395.49 (± 32.10)	2514.79 (± 27.26)	2544.38 (± 23.46)	2544.38 (± 31.00)	2573.85 (± 27.22)
0.2	2423.96 (± 24.06)	2532.10 (± 26.64)	2565.34 (± 23.32)	2571.54 (± 21.91)	2585.01 (± 27.54)
0.4	2448.10 (± 21.32)	2547.54 (± 25.36)	2585.79 (± 27.63)	2589.20 (± 22.72)	2603.65 (± 26.68)
0.6	2511.58 (± 22.78)	2573.96 (± 28.10)	2603.65 (± 28.20)	2611.11 (± 24.60)	2633.14 (± 25.79)
0.8	2529.99 (± 24.26)	2611.44 (± 28.26)	2665.68 (± 29.00)	2665.98 (± 24.82)	2669.16 (± 26.71)
1.0	2532.96 (± 29.10)	2630.18 (± 31.26)	2680.47 (± 28.24)	2697.54 (± 26.64)	2689.23 (± 27.00)
1.2	2559.59 (± 31.11)	2630.18 (± 30.01)	2795.86 (± 29.10)	2781.45 (± 27.53)	2782.67 (± 28.71)

Table 6: Density (in kg/m^3) of Concrete specimens with untreated fibres

% fibre in the mix	Curing Duration (days)				
	7	14	28	60	90
0	2413.81 (± 31.26)	2334.80 (± 30.71)	2388.11 (± 22.40)	2492.80 (± 28.61)	2421.70 (± 31.16)
0.2	2425.71 (± 22.60)	2366.42 (± 29.24)	2435.62 (± 29.51)	2447.42 (± 32.76)	2346.71 (± 30.24)
0.4	2500.73 (± 30.67)	2443.46 (± 28.22)	2382.22 (± 27.11)	2409.96 (± 31.13)	2354.61 (± 32.11)
0.6	2405.90 (± 31.16)	2395.80 (± 27.43)	2449.40 (± 30.22)	2330.91 (± 30.62)	2445.42 (± 34.14)
0.8	2402.00 (± 30.24)	2348.64 (± 24.51)	2356.55 (± 31.31)	2362.56 (± 28.74)	2427.72 (± 33.86)
1.0	2455.39 (± 30.22)	2382.22 (± 25.32)	2419.44 (± 31.95	2392.11 (± 30.90)	2400.00 (± 29.19)
1.2	2366.42 (± 31.34)	2380.25 (± 24.36)	2354.53 (± 28.64)	2330.90 (± 31.30)	2135.11 (± 31.44)

3.3. Durability - Water Absorption

The results obtained from the water absorption tests, for the concrete specimens reinforced with treated and untreated POEFB fibres at 28 and 90 day curing are presented in Figures 3 and 4. Within the context of definition of absorption as the tendency of an unsaturated porous material to employ capillary suction to absorb fluids Castro et al. (2011), it can be seen from the figures that samples with treated POEFB fibres absorb less water than the untreated OPFB fibres at both 28 and 90 day of curing irrespective of the quantity of the fibres in the mix. As absorption test method gives the total tendency to absorb water and volume of permeable voids Mohammadi (2013). What this suggests is that treatment of POEFB fibres before use reduced its tendency to absorb water and reduction in volume of permeable voids. The high absorption of untreated fibres can also be viewed from the perspective of the fact that its water absorption is low relative to the treated fibre (Table 3). What this indicates is that it has the tendency to absorb more water due to hydrostatic pressure differential. At 28 and 90 days of curing the values of absorption of treated fibres are less than 10%. Neville (2011) described concrete with absorption values less than 10% as good concrete.

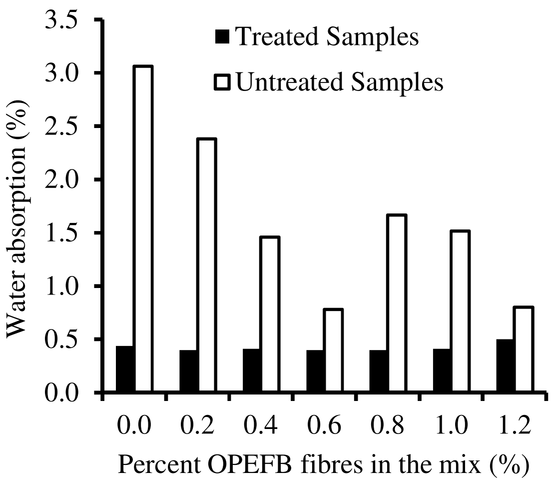

Figure 3: 28-day water absorption for the concrete specimens

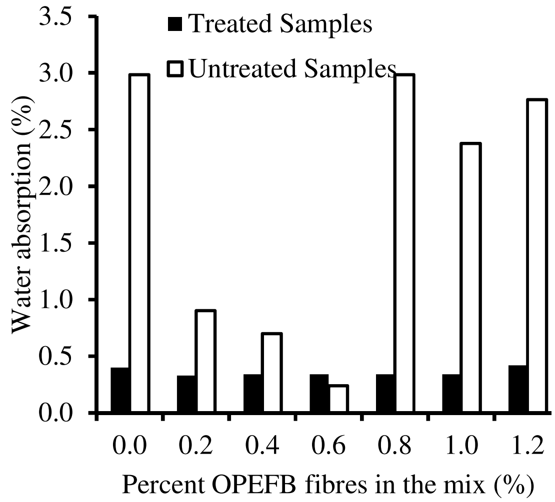

Figure 4: 90-day water absorption for the concrete specimens

3.4. Durability - Coefficient of Water Absorption

The patterns of the results obtained for coefficient of water absorption are presented in Figures 5 and 6. From the figures, it is obvious that samples with treated POEFB fibres recorded lower values than samples with untreated POEFB fibres. According to Mohammadi (2013), the coefficient of water absorption measures the permeability of water; which in turn is a measured of interconnectivity of pores in the specimens. What these results indicate was that the use of treated POEFB fibres produces a less permeable concrete than the specimens with untreated POEFB fibres. That is, treated fibres likely discourage the formation interconnectivity of pores in the concrete matrix. Presence of unconnected pores inhibits ingress of water and thus reduced permeability. The conclusion that can be drawn is that concrete with treated POEFB fibres will produce a more durable concrete, since concrete water absorption test have been observed to be a potentially fast and practical tests for durability evaluation Mohammadi (2013).

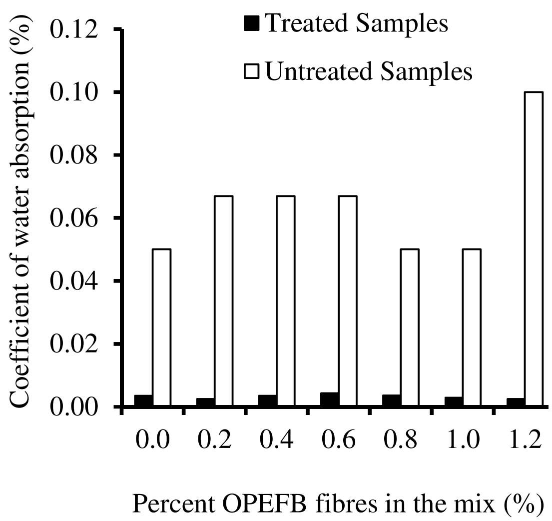

Figure 5: 28-day coefficient of water absorption for the specimens

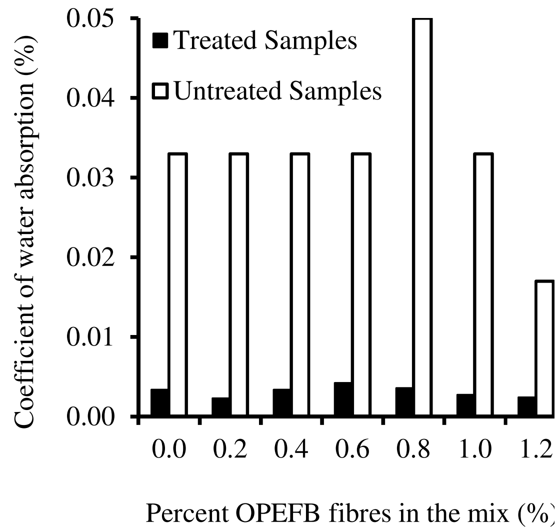

Figure 6: 90-day coefficient of water absorption for the specimens

3.5. Durability – Sorptivity

The pattern of the results of the sorptivity values obtained for specimens with treated and untreated POEFB fibres at 28 and 90 days of curing in water is shown in Figures 7 and 8. From the figures, the specimens with treated POEFB fibres recorded lower values. Since sorptivity test measures the rate of water absorbed by concrete samples due to capillary forces when in unsaturated conditions Mohammadi (2013), it can be deducted that the presence of treated POEFB fibres in concrete inhibit the water absorption rate in concrete. Thus, the reduced rate of penetration of water in treated specimens, if used in concrete, will likely arrest the quick-spread of water-based agent of deterioration.

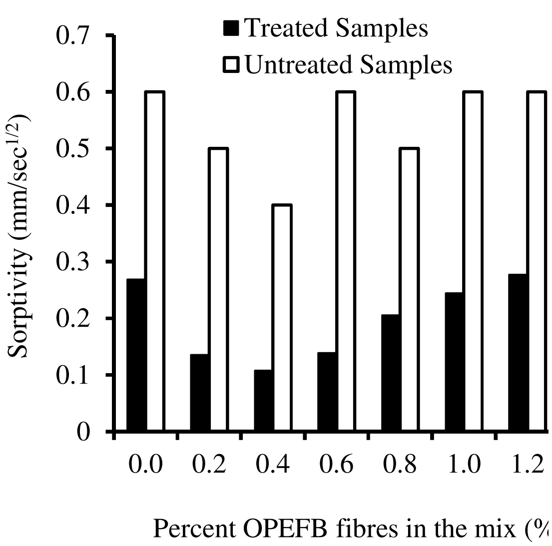

Figure 7: Sorptivity of the specimens at 28-day curing

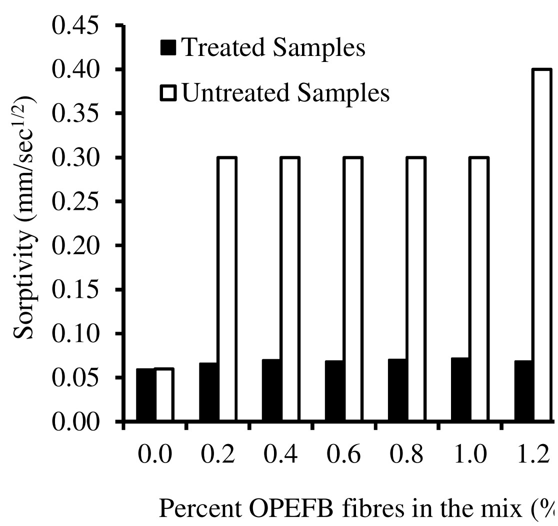

Figure 8: Sorptivity of the concrete specimens at 90-day

3.6. Correlation Between the Density and the Durability Results

From consideration of the results the durabilities studies measured through water absorption, coefficient of water absorption and sorptivity, it is noticeable that the treated samples displayed superior durability properties in each of the test measures. From these results, it can be deducted that the use of treated fibres produced a denser concrete matrix than specimens with untreated fibres. The fact that the densities of specimens with treated fibres were found to be higher than that of the specimens with untreated fibres is a confirmation of this deduction. Higher densities mean the fibres aid the packing of the matrix by serving as a lubricant.

4. CONCLUSION

Findings from the analysis of the results obtained from this investigation showed that the densities of specimens reinforced with POEFB fibres were higher than specimens containing the untreated fibres by as much as 30%. Also, the inclusion of treated POEFB fibres improved the durability characteristics of the specimens determined through absorption, coefficient of water absorption and sorptivity tests. Finally, improved durability performance of specimens with treated fibres over specimens with untreated fibres was consistent with the pattern of higher densities of treated fibres over specimens with untreated fibres. This investigation covers only water-based durability issues of concrete. There are other agents of deterioration that can affect the durability of concrete, especially in an aggresive enviroment, like sulphate, chlorides, and so on. Investigation of the effects of these on the durability characteristics of concrete containing treated and untreated POEFB is thus recommended.

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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