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RESEARCH PAPERS

Predicting the Efficiency of Using Empty Fruit Bunch of Oil-Palm Fibre in Reinforcing Structural Concrete: A Statistical Analysis

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ABSTRACT: This study evaluates the performance, curing age importance and strength increment efficiency of using Empty Fruit Bunch of Oil Palm Fibre (EFBOPF) in structural concrete through a statistical model. The prediction was carried out using some concrete structural parameters (properties) through a one-way Analysis of Variance (ANOVA) model. These parameters include density, tensile and compressive strengths, and durability. The influences of EFBOPF on concrete density, compressive strength and durability were examined using 150 × 150 × 150 mm (for density and compressive strength) and 100 × 100 × 100 mm concrete cubes (for durability). Also, the strength performance of EFBOPF in concrete against tensile splitting and cracks was determined using 150 × 300 mm cylindrical concretes. The compressive strengths were evaluated at 28 days; tensile strengths at 28, 90 and 120 days; and durability performance was assessed at 28 and 90 days. All these parameters were tested using a Universal Testing Machine, weighing balance and durability testing apparatus. The results of the experiments were modelled with ANOVA. In the process of modelling, the correlations among the percentage of EFBOPF included, curing age, and the rate of concrete's strength increment were predicted. In accordance with ANOVA's prediction, the compressive strengths of concrete were greatly enhanced at 0.2 and 0.4% of EFBOPF. In addition, the split tensile strengths and durability capacity of EFBOPF- concrete were efficiently increased at 1.0% and 0.8-1.2% of EFBOPF inclusion, accordingly. The results of the modelling proved that EFBOPF increased the concrete strengths against compressive and tensile failures efficiently. Also, it was evident that EFBOPF enhanced the durability performance of concrete greatly. Although the application of EFBOPF in concrete as well as curing have great impacts on the hydration process of the concrete and its high strength yielding capacity. However, its capacity to increase the concrete's strengths does not depend on the rate of EFBOPF included or the long curing ages of concrete but depends on the reinforcement strength of EFBOPF used.

Keywords: Concrete Structural Properties, Empty Fruit Bunch, Oil Palm Fibre, Efficiency, Analysis of Variance (ANOVA), Modelling.

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1. Introduction

Concrete is a composite material that consists of coarse and fine aggregates closely bound together with cement paste, which solidified over time. It is referred to as the second most used material in the world, especially in the construction of building structures (Hanson, 2020). The use of concrete for structural construction has been helping in providing a safe and healthy environment for the regulation of the high global population. It is the most essential material in the construction industry after water. Concrete possesses high durability capacity and good mechanical properties. Its proper production makes the concrete structures perform well under loading. From the engineering point of view, concrete is an excellent material (Carroll, 2023; Pillay et al., 2022).

Reinforced concrete is concrete made from a mixture of fine and coarse aggregates, cement, and water with steel bars embedded in it in such a way that the two are mingled together to resist the intended forces (Britannica, 2020). Concrete is said to be strong in compression but weak in tension. In several findings, most of the concrete tensile strengths were less than 10% of their compressive strengths as a result of their weak capacity against cracking and shrinkage (Mezher et al., 2020; Mack et al., 2024). Despite the application of steel bars in concrete to cater for its low tensile capacity, the issue of cracking persists.

Fibres were introduced into concrete to improve its structural properties and control flaws such as low tensile strength, cracks and shrinkage. It is defined as a reinforcing material with certain quality properties. A fibre is either flat or circular. Its aspect ratio was commonly calculated by dividing the length by its diameter. This ratio usually falls between 30 and 150 for some fibres.

Application of fibres in concrete controls some defects that are usually caused by concrete's weak properties, such as high rate of water permeability, cracking and shrinkage (Gamage et al., 2024). Also, application of natural admixtures (such as natural fibres) as a partial substitute of concrete's aggregate has really helped in reducing the high rate of Carbon Dioxide (CO_2) and Green House Gases (GHGs) emission from concrete (Kilani and Fapohunda, 2022). According to the statistical data, almost half of the waste and raw materials generated by industries were consumed in the construction industries. As estimated, up to 70 - 80% and 40% of GHGs and global energy were respectively generated from concrete industries (Sizirici et al., 2021; Miller et al., 2021).

Agricultural waste products such as Palm Oil Fuel (POFPA), Silica fume, wood ash and fly ash were rich in Silica elements for accurate binding of aggregates and performing the function of cement in concrete (Rodier et al., 2019; Thomas, 2018). Fibres from agricultural wastes (natural fibres) are currently being appreciated in the construction industries. The major reinforcement and enhancement feedback received from their application in concrete has really proved their indelible strength toward the growth of the concrete and construction industries. Some of these developments are that natural fibres are used to increase the concrete's durability, tensile, and compressive strengths. One of the outstanding reports is that most of the agro-wastes were performing better in concrete than the synthetic and metallic fibres. For instance, as reported by Shadheer et al. (2021), coconut fibres performed better than synthetic fibres in reinforcing concrete.

Also, the result of applying treated oil palm fibre ash as a partial substitute for cement in concrete, as conducted by Omoniyi (2019), proved that concrete with fibre ash decreased in compressive strength compared to that of the control after being cured for 7 to 28 days. It was observed that the treatment of oil palm fibre with sodium hydroxide caused a decrease in strength. Thus, treating oil palm fibres before applying them to the concrete is not necessary, as it does not cause a reduction in strength. On the contrary, the concrete reinforced with Empty Fruit Bunch of Oil Palm Fibre (EFBOPF) showed an increase in compressive strength up to 4.46% and 11.43% at 90 days of curing under natural weather conditions than that of the control (Lim et al., 2018). Also, as investigated by Sheng et al. (2019), the application of EFBOPF in concrete increased the concrete compressive strength by 2.07%. Therefore, the findings of Omoniyi (2019) and those of other scholars including Rao and Ramakrishna (2022) clearly showed that the application of EFBOPF in concrete could increase the concrete compressive strength up to 11.43%. Also, as experimented by Aguiar et al. (2003), up to 32% of specimens tested in the groups were unable to establish their characteristic compressive strengths.

Concrete in C20 and C25 groups had the characteristic strengths that were below the exigency, while that of C30 was above the exigency, as expected. Several existing building structures had low compressive strength, and the strength variation was very significant. The average compressive strength of buildings was in the normal distribution (Yuva, 2023). Therefore, fibres such as EFBOPF should be applied to such concrete to complement the strength capacity. In concreting, several methods of statistical analysis have been applied to evaluate the reinforcement performance of fibres in concrete. However, the analysis has not been extended to evaluate the efficiency of applying EFBOPF to the concrete and the dependency of concrete on the strength yielding capacity of EFBOPF on the hardening properties of concrete (BS EN 196-12, 2024).

This is the trust of this experimental analysis. In this experiment, one-way Analysis of Variance (ANOVA) model is used to evaluate the level of strength yielding capacity of EFBOPF in concrete, deviation, variance and variation ratio of the results obtained from the standard of concrete hardening properties (such as tensile strength, compressive strength and durability). In the analysis and modelling, the efficiency of EFBOPFs in reinforcing the concrete structural properties was determined and the optimum predicted values were noticed. These were values were evaluated based on the experimental results. Thus, this analysis focuses on the application of the statistical method in predicting the level of strength enhancement generated by incorporating EFBOPF into the concrete (BS EN 197-2, 2020) and to show the level of efficiency brought by the application of EFBOPF in reinforcing structural concrete.

This study also aimed at predicting the level of dependence of concrete strengths on the quantities of EFBOPFs applied. This aim was achieved through the following objectives: i) To determine the rate of strength increment generated through the application of EFBOPF in concrete; ii) To determine the level of efficiency achieved in reinforcing the concrete's properties with application of EFBOPF; iii) To evaluate the level of concrete's strength deviation from the standard when EFBOPF is included; iv) To determine the level of variations in strengths of concrete with EFBOPF using ANOVA model; and v) To build a standard conclusion from the statistical data obtained from experimental results as modelled by ANOVA.

2. Materials and Methods

2.1. Treatment of Materials

The empty bunches of oil palm used were collected from a dumping site of a palm oil producing mill at Asin Ekiti, Ikole, Ikole Local Government Area (LGA), Ekiti State, Nigeria. The collected bunches were split into pieces with the aid of a sharp cutlass. Before the splitting operation, the bunches were soaked in warm water at an amber temperature to kill the germs and remove some harmful chemicals. After 5 hr, the soaked bunches were removed from the water and cut into filaments. The filaments were sun-dried for two weeks to dry off all their moisture content. The dry materials were slashed into 20 mm lengths each for it to easily and perfectly mixing with other concrete aggregates. The coarse (granite) and fine (sand) aggregates used were supplied from a quarry site located at Oloko, Ikole LG. The aggregates were dried for 14 days and sieved with sieve no. 200 (75 μm) to remove the impurities and clay. The Portland cement of grade 42.5N was used for this investigation. Its production was based on BS EN 196-12 (2024) and BS EN 197-2 (2020) of British standards. Portable water was used for the mixing of the aggregates with fibre. The oil palm bunches were treated and processed into fibres by following the methods and processes as presented in Figures 1 and 2.

2.2. Chemical and Physical Properties of Oil Palm Fibre

The chemical and physical properties of fibre extracted from EFBOP were determined at the soil laboratory of the agronomy department, at the Ladoke Akintola University of Technology (LAUTECH), Ogbomosho, Oyo state, Nigeria. In the Laboratory, the diameter and length of each EFBOPF were determined with micrometer screw-gauge and meetr rule, respectively.

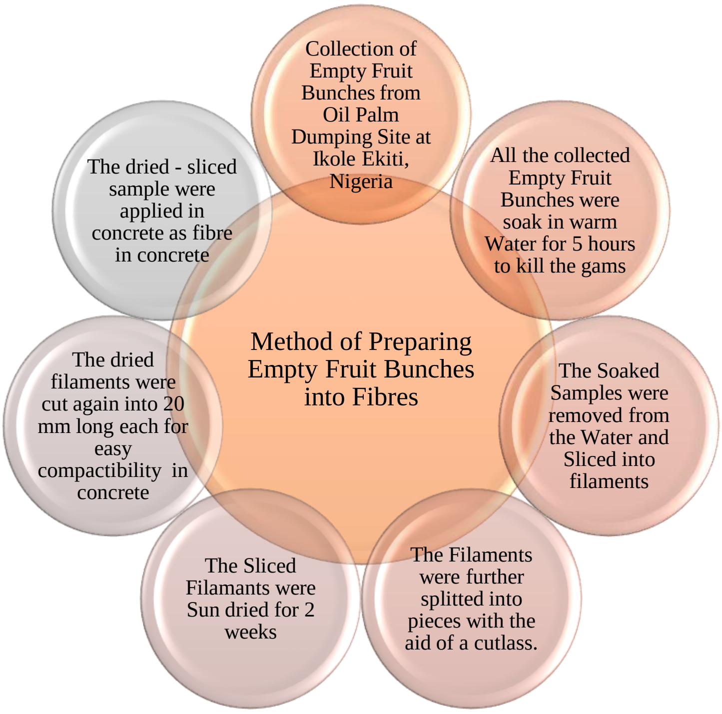


Fig. 1. Method of preparing empty fruit bunches of oil palm into fibre

(a) **(b)** **(c)** **(d)**

Fig. 2. a) An empty bunch of oil palm; b) Wet split bunches in filament form; c) Split bunches sun-dried; and d) Extracted fibres from empty bunches of oil palm, which were cut into 20 mm lengths each

Other properties of EFBOPF, like lignin, ash, hemicelluloses, cellulose and extraction, were also determined. These were done to capture the behavioural pattern of the fibre used, and its fitness for concrete operation. Cellulose possesses certain reinforcement properties required for concrete enhancement. The processes of determining the lignin, ash, hemicelluloses, cellulose and extraction content of EFBOPFs are in the order of Karunakaran et al. (2020). The ash content in EFBOPFs is determined by weighing a certain mass of dried EFBOPF on the scale as M_1.

The measured sample is placed in a porcelain cup. The sample in the porcelain cup was heated and later burnt in the electric furnace for 5 hours at 550 ^oC until it became grey (ash). The cup was taken out of the furnace and allowed to cool. The weight of grey sample is determined as mass 2 (M_2).

The ash content of the fibre is calculated using Eq. (1).

$$\text{Ash Content (\%)} = \frac{M_1 - M_2}{M_1} \times 100\ \% \qquad (1)$$

where M_1: is the weighed mass of dried EFBOPF, and M_2: is the mass of grey sample. Also, the cellulose content of EFBOPF was determined by measured a certain quantity of Acid Detergent Fibre (ADF) on the balance noted as M_A. Then, the 72% of tetraoxosulphate (VI) acid solution was applied to the ADF sample and soaked in the solution for 3 hr. After 3 hr, the soaked sample was rinsed in a solution of acetone and hot water. The rinsed sample is then dried in the oven at 110 ^oC for 4 hours to remove all its moisture content. After 4 hours, the sample was taken from the oven, allowed to cool and weighed.

This weight was noted as M_B. The percentage of cellulose content in EFBOPF was calculated using Eq. (2).

$$\text{Cellulose Content} = \frac{M_A - M_B}{M_1} \times 100\% \qquad (2)$$

where M_A: is the weighed mass of the ADF sample, and M_B: is the weighed mass of the oven-dried sample. The percentage of hemicelluloses in EFBOPF was determined using the approach of determining the cellulose content of EFBOPF. In addition, percentage of lignin content of EFBOPF was determined by burning some weighed sample of the rinsed and oven-dried sample from cellulose test noted as M_B in a furnace at 600 ^oC. The burnt sample was weighed on the scale as Mass D (M_D). Then, the percentage of lignin content was calculated using Eq. (3).

$$\text{Lignin Content (\%)} = \frac{M_B - M_D}{M_1} \times 100\% \qquad (3)$$

where M_D: is the mass of the sample after being burnt in the furnace at 600 ^oC. The extraction content of EFBOPF was obtained after all the other contents were determined.

2.3. Aggregates (Coarse and Fine) Properties

The coarse and fine aggregates used were characterised through sieve analysis. From the gradation curve, some properties of aggregates, like moisture content, coefficient of uniformity, bulk density, and coefficient of curvature, were determined to ascertain their suitability for concreting.

2.4. Concrete Mix Proportion and Operation

The weights of aggregates (coarse and fine), cement and water used for concrete production were determined from a 1:2:4 mix proportion, and a 0.5 water/cement ratio. The addition of EFBOPF to concrete aggregates was from 0 to 1.2% by weight of cement. The percentage of fibre in concrete was increasing by 0.2% until 7 samples were produced, including a control (with 0% of EFBOPF). The above proportion was adopted to formulate a concrete mix design for cylindrical and cube specimens as presented in Table 1. Using a mix proportion of 1:2:4, concrete specimens were produced at the concrete section of civil engineering's Laboratory of Federal University, Oye Ekiti (FUOYE), Nigeria. In the batching processes, 685.8 kg/m^3 of dried sand was measured on a weighing balance and spread on a clean tray in the laboratory. The 342.8 kg/m^3 of cement was also measured on a scale and spread on dried sand. The two aggregates were thoroughly mixed with spades and trowels.

Likewise, 1371.5 kg/m^3 of coarse aggregate (granites) were added to the mixture of sand and cement. The three aggregates were mixed thoroughly for the second time. After the mixing of granite, sand and cement, 0.81-4.89 kg/m^3 of EFBOPF was spread on the mixed aggregates of granite, sand and cement per batching, and the materials were mixed properly for the third time till all the aggregates were mingled. Finally, 171.5 kg/m^3 of water was evenly applied to the mixed aggregates. The four mixed aggregates with water were thoroughly mixed again for the fourth time until the paste was formed with other composite materials. These procedures were adopted for the production of 100 × 100 × 100 mm concrete cubes, 150 × 150 × 150 mm concrete cubes, and 150 × 300 mm cylindrical concretes with the application of 0-1.2% of EFBOPF with an increase interval of 0.2%.

2.5. Determination of EFBOPF -Cement Pastes Consistency and Setting Times

The consistency of cement paste with EFBOPF was determined using BS EN 196-3 (2005) standard. At the initial stage of the experiment, the Vicat apparatus was placed in a stable place in the laboratory.

The dashpot's top of the apparatus was unscrewed to allow the plunger to be worked upon severally. 400 g of cement was weighed into an empty pan. Also, a certain volume of water was measured in a separate beaker. Moreover, through the weight of the cement used, a certain mass of EFBOPF was weighed into another container. The three: cement, EFBOPF and water were mixed thoroughly until the paste was formed. The stopwatch was set, likewise, the Vicat apparatus. The mixed cement paste with EFBOPF was placed inside the Vicat mould, and its top was levelled with a scapula to have a smooth surface. At this stage, the plunger of the Vicat device was lowered to the top*surface of the paste inside the Vicat mould. At a set time, the plunger was released quickly to penetrate the paste inside the mould. This procedure was repeated until the plunger penetrated a distance value that fall within 5-7 mm while the consistency of the paste mixed with EFBOPF was recorded. Also, the setting times of concrete's cement paste with EFBOPF were determined using BS EN 196-3 (2005) standard. In the laboratory, 400 g of 42.5N grade of cement was measured into a bowl and a certain mass of EFBOPF by the weight of cement was weighed into another bowl. A volume of water was measured using the value of fibre-cement paste consistency (0.85 P) determined earlier.

The stopwatch was set for reading. The cement, EFBOPF and water were mixed thoroughly until they form a paste. Immediately the water was added to the mixture of cement and EFBOPF, the stopwatch was started and recorded as time 1 (T_1).

The paste was placed inside the Vicat mould with the aid of trowels. The surface of the paste was levelled with a scapula to have a smooth surface. The needle was attached to the Vicat's plunger. The Vicat's plunger with needle was moved close to the top of the test block inside the Vicat mould.

Table 1. Concrete mix proportion for cylindrical and cube specimens

% of Fibre Content (%)	0.0	0.2	0.4	0.6	0.8	1.0	1.2
Granite (kg/m^3)	1371.5	1371.5	1371.5	1371.5	1371.5	1371.5	1371.5
Sand (kg/m^3)	685.8	685.8	685.8	685.8	685.8	685.8	685.8
Cement (kg/m^3)	342.8	342.8	342.8	342.8	342.8	342.8	342.8
Water (kg/m^3)	171.5	171.5	171.5	171.5	171.5	171.5	171.5
Fibre (kg/m^3)	0.00	0.81	1.63	2.44	3.26	4.07	4.89

The Vicat's plunger with needle was set and quickly released to penetrate into the testing block. The procedure was repeated after 2 min (which is a time interval) until the needle could not penetrate the test block up to 5 mm. At this stage, the paste setting time is recorded as time 2 (T_2). Instead of a needle, the plunger device was attached to the annular disc, and the procedure was repeated. The annular attachment was released to pierce the test block. The paste with EFBOPF was considered to be set finally when the application of the annular disc could not make an impact on the test block but that of the plunger needle was able to do so. The time recorded at this stage was referred to as time 3 (T_3). The initial and final setting times of concrete paste with EFBOPF were determined using Eqs. (4) and (5).

$$T_i = T_2 - T_1 \quad (4)$$

$$T_f = T_3 - T_1 \quad (5)$$

where T_1: is the recorded time when the water was first applied to the cement to form paste, T_2: is the time recorded when the penetration of the needle failed to reach between 5 and 7 mm, T_3: is the time recorded when the impression was made on the test block annular disc but the needle failed to do so, T_i: is the initial setting time of cement paste mixed with EFBOPF, and T_f: is the final setting time of cement paste mixed with EFBOPF.

2.6. Concrete Workability and Its Density

The workability of concrete can be greatly influenced by its water-cement ratio, consistency and the proportion of the aggregate used for its batching. In the investigation, the workability of concrete with EFBOPF paste was conducted using BS EN 12350-2 (2019) standard.

This was measured through the slump and compacting factor of the concrete produced. During the slump test conducted, the slump mould was held firmly after proper cleansing, and the prepared fresh concrete was placed inside the mould in four layers. Each layer was tamped with 35 strokes of blows from the tamping rod. The slump values received were recorded for analysis as shown in Figure 3.

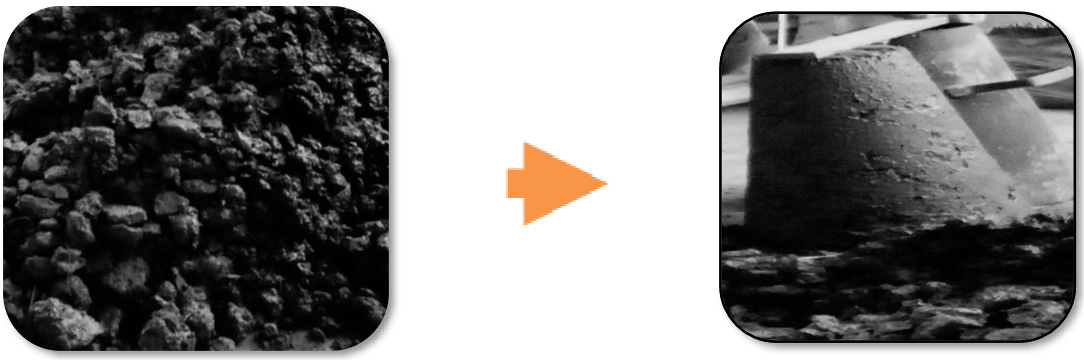
$$\text{Volume of cylindrical concrete} = \Pi r^2 h \quad (6)$$

$$\text{Concrete density} = \frac{\text{Mass of cylindrical concrete (kg)}}{\text{Volume of cylindrical concrete (m}^3\text{)}} \quad (7)$$

where r: is the radius of the circular base of the cylindrical concrete, and h: is the height of each of the cylindrical concrete.

The density of the concrete with EFBOPF was measured using the BS EN 12350-6 (2000) standard. 100 × 100 × 100 mm moulds were used to determine the density of small concrete cubes for the durability test, while the 150 × 150 × 150 mm concrete cubes were used for the compressive tests.

The volumes of cylindrical concrete specimens were calculated from the diameter of the mould (150 mm) and the height of the mould using Eq. (6). The density of the cylindrical concrete was determined using Eq. (7).



(a) (b)

Fig. 3. a) Freshly mixed concrete with EFBOPF; and b) Compacted slump concrete with its cone

2.7. Concrete Compressive and Tensile Splitting Strength of Concrete Reinforced with EFBOPF

The strengths of concrete against compression stresses were determined using 150 × 150 × 150 mm cube moulds and BS EN 12390-3 (2009) standard. During the experiment, the freshly mixed concrete with EFBOPF was placed inside the compressive moulds in four layers after a proper cleansing of the moulds. Each layer was compacted with 35 strokes of blows from the tamping rod. The top surface of the concrete in the moulds was levelled and smoothened with a trowel. The cast specimens were kept in a dry and cool place in the laboratory for 24 hr till the specimens gain enough strength. After 24 hr of casting, the specimens were removed from moulds and immersed in water for 7, 14, 28, 60, 90 and 120 days, until their crushing days. On a crushing day, the soaked specimens were removed from the water. The water on them was cleaned and allowed to air-dry for a little time, and they were positioned inside the UTM of a 1560 kW WAW-2000 B capacity model for accurate crushing. The concrete strength values gotten were recorded. The concrete cylindrical specimens were used to determine the tensile strength of concrete reinforced with EFBOPF. The specimens were formed from a 150 × 300 mm cylindrical mould.

This test was conducted in the laboratory using BS EN 12390-6 (2023) standards. After the proper preparation of the mould, the concrete with EFBOPF freshly prepared was placed inside the mould and compacted with 35 strokes of tamping from the rod, each in four layers. The top of the specimen was smoothened and levelled with a hand trowel. After a few hours, when the concrete started to be hardened, the specimens were labelled for identification.

After the labelling, the cast specimens were de-moulded and soaked in clean water for 7, 14, 28, 60, 90 and 120 days until their crushing day. The cured specimens were crushed using UTM of a 1560KN WAW-2000 B capacity. The crushed values on the machine were recorded. The splitting strength of the crushed concrete was determined using Eq. (8).

$$\text{Concrete's tensile splitting strenght}\left(\frac{\mathrm{N}}{\mathrm{mm}^2}\right) = \frac{2P}{\pi LD} \quad (8)$$

where T: is the tensile strength of cylindrical concrete, P: is the maximum indicated load when applied by machine (N), D: is the specimen's diameter (mm), L: is the specimen's length, and Π: Pi.

2.8. Durability of Concrete: Coefficient of Water Absorption

The concrete's coefficient of water absorption test was conducted to determine the rate of water permeability into the concrete with EFBOPF. This was ascertained by determining the speed at which water is being taken up into the dried concrete. The specimens were prepared using 100 × 100 × 100 mm concrete cubes with the application of ASTM C1585-13 standard for the experiment. The concrete was prepared according to the prescription in the concrete mix design. After the concrete casting, the de-moulded concrete cubes were immersed in water for 28 and 90 days to complete the cement-water hydration process in concrete until their testing time. Before the testing, after the concrete was removed from the water, the concrete specimens were prepositioned inside the oven for 7 days to dry off all their moisture at a temperature of 60 ˚C. On the 7th day, the dried specimens were weighed on a scale balance until a constant weight was observed. Then, the dried specimens were allowed to cool for 3 days in a sealed container. After all, each specimen's edge was coated with transparent epoxy to allow the flow of water in one direction.

Big and thick white bowls were filled with water up to 7 mm. The coated specimens were placed inside the bowls with their base at a 5 mm level of the water in the bowls, as presented in Figure 4. The data gotten from the experiment were analysed using Eq. (9).

$$K_a = \left\{\frac{Q}{A}\right\} \times \frac{1}{t} \quad (9)$$

where K_a: is the water absorption coefficient (m^2/s), Q: is the quantity of water absorbed, t: is the time taken to perform the experiment (3600 s), and A: is the penetration area of the concrete cube in water (m^2).

2.9. Predictions of the Rate of Strength Yielding Capacity

One-way AVONA is one of the statistical analysis methods that are good in predicting the efficiency of a material in application. The use of ANOVA in concrete will help in predicting the rate of strength development in concrete with the inclusion of EFBOPF.

The prediction was based on the analysis of experimental data obtained through the results of EFBOPF -concrete properties tested, such as compressive strength, density, tensile strength and durability.

Also, ANOVA in predicting the percentage of strength increment yielded by EFBOPF in concrete. For effective modelling of EFBOPF -concrete's experimental results with ANOVA, some essential parameters were firstly determined such as Sum of the Squares (*SS*), Degree of Freedom (*DF*), Correlation factor (*C*), sum of square of treatment, a Ground Total (*GT*) of the data, number of replicates by treatment (n), number of treatment (k), the standard deviation (S), variance (S^2) and variance ratio. With these parameters, the rate of strength deviation and variation in EFBOPF -concrete were determined.

2.9.1. Determination of Standard Deviation and Variance of Concrete's Strengths from Experimental Data of Concrete Reinforced with EFBOP Fibre

All the values of the sample analysed in the experiment were grouped and represented by X_n vertically downward in the group, where n is the number of data presented in the group.

The addition of all the data in each group was done using $\sum X_n$. The means of the group data were determined using Eq. (10).

$$\text{Mean of the group data } (\ddot{X}_n) = \frac{(\sum X_n)}{N} \quad (10)$$

where N: is the total number of data in the group, and n: is the number of data in the group. The group explains the number of observing data in each of concrete properties, such as compressive and tensile strengths data, durability data, and density data.

(a) **(b)**

Fig. 4. 100 × 100 × 100 mm concrete cubes coated with transparent epoxy partially immersed to a depth of 5 mm at one end for varieties of time intervals: a) 7 concrete cubes immersed in water, first part; and b) 7 concrete cubes immersed in water, second part

The difference between each of the data in a group and the mean of each group is determined using $X_n - \ddot{X}_n$. The values gotten from $X_n - \ddot{X}_n$ were squared. Then, the rate of deviation in concrete strength when EFBOPF was applied to the concrete was calculated using Eq. (11). *N* and *n* have been defined earlier.

$$\text{Standard deviation of concrete's strength } (S) = \sqrt{\left[\frac{\sum(X_n - \ddot{X}_n)^2}{N-1}\right]} \quad (11)$$

The variances in concrete strengths' deviations after being reinforced with EFBOPF were predicted using Eq. (12). *N* and *n* in the equation have been defined earlier with other parameters.

$$\text{Variance in concrete strengths' deviation} = \left[\frac{\sum(X_n - \ddot{X}_n)^2}{N-1}\right] \quad (12)$$

2.9.2. Determination of Concrete Strength Variation Ratio from Experimental Data

To predict the rate of strengths yielded by EFBOPF in concrete and the rate of dependence of concrete on the strength increment yielded by EFBOPF in concrete, two hypotheses theories were formulated: 1) Null hypothesis (H_0); and 2) Alternate hypothesis (H_a) using $\alpha = 0.05$ as the level of significant for the hypothesis.

The Null hypothesis (H_0) states that the rate of strength increment in concrete reinforced with EFBOPF does not depend on the depth of increasing the percentage of EFBOPF included, while the Alternate Hypothesis (H_a) states that the rate of increase in concrete strengths depends on the increase in the percentage of EFBOPF included. After a careful consideration of the obtained experimental results, the null hypothesis theorem was adopted for this prediction. This is because the null hypothesis adopted was based on the 99.95% assurance of the experimental data with a 0.05 level of uncertainty (α). The analyses of data for the right prediction of the certainties were conducted using the equations and formulas below. First of all, the degree of freedom of statistical group data was determined using Eq. (13).

$$\text{Degree of concrete strengths' freedom } (DF) = (R-1) \times (C-1) \quad (13)$$

where *R*: is the number of rows, and *C*: is the number of columns. Secondly, the *GT* of the concrete strengths was determined from Eq. (14). The correlation within the concrete samples analyzed was determined using Eq. (15).

$$\text{Concrete strengths' ground total } (GT) = \sum X_1 + \sum X_2 + \sum X_3 + \cdots . + \sum X_n \quad (14)$$

$$\text{Correlation factor } (C) = \frac{(GT)^2}{K \times n} \quad (15)$$

where *K*: is the number of columns, and *n*: is the number of rows. Then, the sum of squares of experimental strengths obtained (*SS*) and its Sum of Squares of Treatment (*SST*) were calculated using Eqs. (16) and (17).

$$\text{Total sum of square } (SS) = \left[\sum X_n{}^2 - C\right] = \left[\sum X_1{}^2 + \sum X_2{}^2 + \sum X_3{}^2 + \cdots + \sum X_n{}^2\right] - C \quad (16)$$

where *n*: is the number of samples, *C*: is the concrete strengths' correlation factor, and *X*: is resulted from experimental data.

$$\text{Sum of square of treatment } (SST) = (\sum X_n)^2/(N) - C = [(\sum X_1)^2 + (\sum X_2)^2 + (\sum X_3)^2 + \cdots . + (\sum X_n)^2]/N - C \quad (17)$$

where *N*: is the number of data presented in a group column. Likewise, the standard rate of concrete strengths' deviation and its strengths variance were predicted using Eqs. (18) and (19).

$$\text{Standard deviation of concrete}' \text{ strengths } (S) = \sqrt{\left[\frac{\sum (X_n - \ddot{X}_n)^2}{N-1}\right]} \quad (18)$$

$$\text{Variance of concrete}' \text{ strengths } (S^2) = \left[\frac{\sum (X_n - \ddot{X}_n)^2}{N-1}\right] \quad (19)$$

where N: is the number of rows, and n: is the number of samples. Having determined the values of the above parameters using Eqs. (13) to (19), the actual variation ratio of concrete strength calculated ($F_{cal.}$) was determined from the computed values as shown in Table 2. The statistical values gotten from Table 3 were used to determine the value of the Sum of Square Error (SSE) of concrete strengths using Eq. (20).

$$\text{Sum of square error } (SSE) \text{ of concrete}'s \text{ strengths } = SS - SST \quad (20)$$

where SS: is sum of square, and SST: is sum of square treatment.

3. Results and Discussions

The 20 mm length of each EFBOPF used, as shown in Table 3, was adopted for the smooth mingle of EFBOPFs with other aggregates during concrete mixing. As investigated, the adopted length (20 mm) of EFBOPF used was similar to that of Omoniyi (2019) and Ekelene et al. (2021) and falls within the range of 15-25 mm.

This proves that the 20 mm length of EFBOPF used is suitable for concrete enhancement. The Young Modulus (5.21 GPa), tensile strength (172.50 GPa), and Pentosan (21.50%) values of EFBOPF determined are all in line with the specified standard, which is good for the production of workable concrete according to ACI (1990). Also, with 35.78% water absorption of EFBOPF, up to 36% of the water required for concrete mixing might have been absorbed by the dried fibre, leading to the production of stiff concrete.

Therefore, it is advisable to soak the dried fibre (EFBOP) in water for some minutes to avoid unexpected water absorption within the concrete aggregate's mixing, thus, reducing the cement-water hydration process in concrete. As shown in Table 3, the 1.07 g/cm^3 density of EFBOPF and its aspect ratio of 53 shows that EFBOPF is suitable for the production of light-weight concrete. From another perspective, the results of the chemical composition of EFBOPF also contributed to the best performance of EFBOPF in concrete. As shown in Table 3, EFBOPF is made up of 38.50% cellulose, which is the firm component of plants required for high-strength yielding in concrete (Kilani et al., 2022a,b). From deep observation of the results presented in Table 3, the three main chemical properties of EFBOPF (Lignin-19%, Hemi-cellulose-12.6%, and cellulose-38.5%) needed for the enhancement of concrete properties were summed up to 70.1% which is a good result for the reinforcement of concrete structural properties. This percentage (70.1%) equates to the specified standard stated by ACI 232.1R (2012) for a good pozzolanic material to be used for concrete production (70%).

This also supports that the EFBOPF is fit for concrete reinforcement according to the physical characterisation tests' results obtained. Also, the moisture content of EFBOPF (0.014%) observed in Table 3 signified that EFBOPF will absorb a large quantity of water required for concrete cement-water hydration due to its high dried quantity. The 0.45% value of extraction of the fibre shows that the percentage of impurity in EFBOPF is minimal, less than 0.5%. It means, no dangerous material was found in the fibre, and it is chemical-free of toxic substances that are harmful to human health. The chemical and physical fitness of using EFBOPF in concrete is high compared to that of Ekelene et al. (2021) and Omoniyi (2019)'s findings. The properties of concrete's coarse and fine aggregates as analyzed through sieve analysis were presented as shown in Table 4. Considering the results in Table 4, it was observed that both coarse and fine aggregates have good uniformity for concrete operation. Also, as presented in the gradation curve in Figure 5, the values of the aggregates' coefficient of curvature were less than 1.00.

Table 2. Determination of the concrete strengths' variation ratio from calculated data ($F_{cal.}$)

Source of variation	Sum of squares	Degree of freedom	Mean squares	$F_{cal.}$
Treatment	*SST*	*k*-1	*MST* = *SST* / (*k*-1)	*MST* / *MSE*
Error	*SSE*	*k*(*n*-1)	*MSE* = *SSE* / *k*(*n*-1)	
Total	*SS*	(*kn*-1)		

Table 3. Physical and chemical properties of EFBOPF

Physical properties	Value	Chemical properties	Value
Young modulus (GPa)	5.21	Ashes (%)	5.25
Tensile strength (GPa)	172.50	Extraction (%)	0.45
Pentosan (%)	21.50	Lignin (%)	19.00
Water absorption (%)	35.78	Cellulose (%)	38.50
Density (g/cm^3)	1.07	Hemi-cellulose (%)	12.60
Aspect ratio	53	Moisture content (%)	0.014
Diameter (single fibre) (mm)	0.25-0.50		
Length (single fibre) (mm)	20		
Colour	Brown		

Table 4. Properties of coarse and fine aggregates

Properties	Value(s)	
	Coarse	Fine
Coefficient of uniformity (*Cu*)	2.43	3.00
Coefficient of curvature (*Cc*)	0.98	0.88
Moisture content (%)	0.00	0.00
Water absorption (%)	2.00	2.00
Bulk density (kg/m^3)	1641.67	1666.67
Specific gravity	2.67	2.63

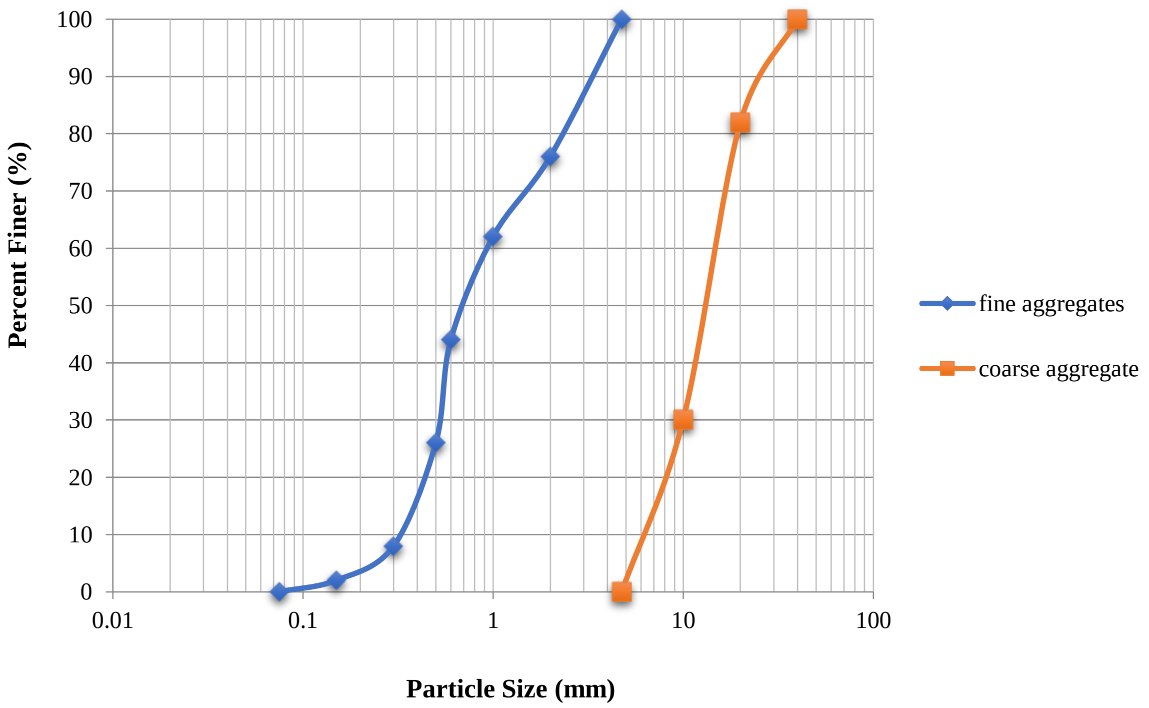


Fig. 5. Particle size distribution (gradation) curve

As estimated, the values of the coefficient observed were 67% better than expected. This proves their suitability for concrete production. As investigated, the percentage of moisture content and water absorption of coarse and fine aggregates were observed to be 0.00% and 2.00%, respectively. This indicated that both aggregates used are very dry; their application in concrete cannot increase the percentage of the water required for workable concrete production. The 2% of water absorption observed in both the coarse and fine aggregates was low compared to that of the specified limit allowable for concrete water absorption for good concreting (0-8%) as specified by ACI 318R (1999). Also, according to the ACI 318R (1999) standard, the aggregates' bulk density should be within the range of 1280-1920 kg/m^3 before it can be adopted for concrete production. The bulk density of the aggregates (coarse and fine) observed in this experiment was recorded as 1641.67 and 1666.67 kg/m^3, respectively (Table 4).

These values (1641.67 and 1666.67 kg/m^3) are in agreement with the ACI 318R (1999) specified limit (1280-1920 kg/m^3). The aggregates' coefficient of uniformity (*Cu*) observed from the analysis (2.43 and 3.0 for coarse and fine aggregates, respectively) is 4.0, which is also in line with the ACI 318R (1999) standard. Likewise, the specific gravity of both aggregates (2.67 for coarse and 2.63 for fine) are within the limit (2.6-2.8) specified by ACI 318R (1999) as good material for concrete production. With these low specific gravities of both aggregates (2.67 and 2.63), it shows that both aggregates possess low surface areas for perfect compatibility and stability of concrete aggregates. In addition, the water-absorbing capacity of both aggregates is limited. This will assist in producing the workable concrete without segregation. With the critical observation of the presented results, both coarse and fine aggregates have good properties that fit into the ACI 318R (1999) specification; thus, the aggregates have good properties for concrete production, most importantly for research work.

3.1. Results of EFBOP Fibre-Cement Paste Consistency and Setting Times

As shown in Figure 6, the concrete consistency increased by 2.94% up to 0.8% inclusion of EFBOPF when compared with that of the control. The increase in consistency up to 1.2% EFBOPF inclusion with the increase percentage of 5.88%. The increase in concrete's paste consistency required more volume of water to attain the standard consistency of concrete's paste at the inclusion of EFBOPF in concrete production. Therefore, it is advisable to use a higher water-cement ratio for the production of concrete with EFBOPF to achieve the standard consistency of EFBOP fibre-cement paste concrete.

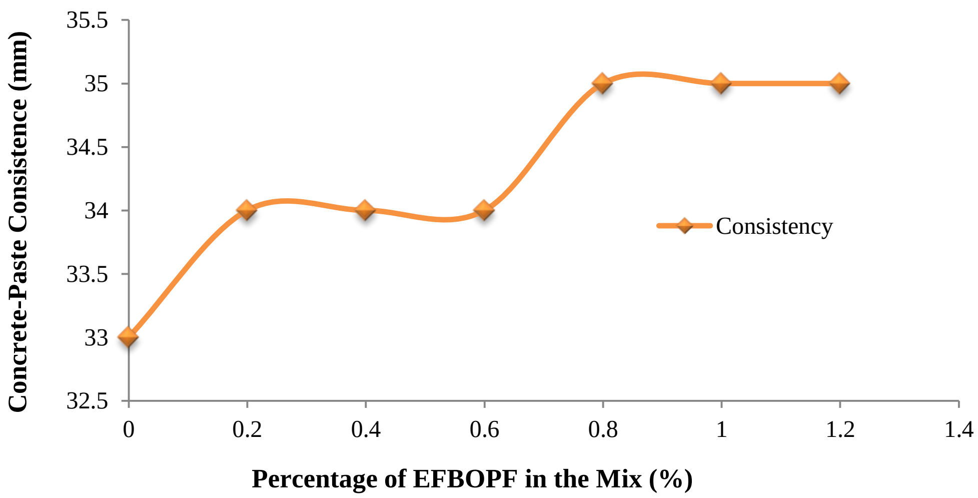


Fig. 6. Concrete's EFBOP fibre-cement paste consistency

Also, in Figure 7, the initial setting time of the EFBOP fibre-cement paste reduced from 175 to 5 minutes with the application of EFBOPF. As estimated, this time reduction is up to 97.1%. This result shows that EFBOPF is an accelerator of cement paste setting up to 97% at the early stage of the paste's setting. With this setting style of EFBOP fibre-cement's paste, the workable concrete might not be produced; thus, much water is required for hydration in concrete to take place.

To achieve the perfect setting of EFBOP fibre–cement paste, it is advisable to soak EFBOPF in water for a few minutes before using it for concrete production. Likewise, the final setting time of paste with EFBOPF shows a time reduction of about 55.88% compared with that of the control, as shown in Figure 7. The reduction in time of setting EFBOP fibre-cement paste from 340 min (for control) to 150 min (for paste with 1.2% of EFBOPF) might be a result of the hydration process within the paste. Though, the setting times observed in the experiment, 150 min (initial) - 340 min (final), are within the specified range of ACI (1990), that is, most importantly, the final cement paste setting time, which is 600 min, yet; the final set of the concrete was too accelerated by 55.88% which can cause the production of unworkable concrete. The use of a higher water-cement ratio and pre-soak of the dry EFBOPF in concrete will control this effect.

3.2. Result of Workability of Concrete Reinforced with EFBOPF F

The concrete reinforced with 0.2-1.2% of EFBOPF developed no slump loss after casting (Table 5). On the other hand, concrete without EFBOPF, that is, concrete with 0% of EFBOPF developed a 20 mm slump fall, which is known as true slump. All the concrete produced with the inclusion of 0.2-1.2% of EFBOPF are too stiff, and not workable. Application of chemical admixture, such super-plasticizer, and the use of high-water cement ratio for its production will increase its workability.

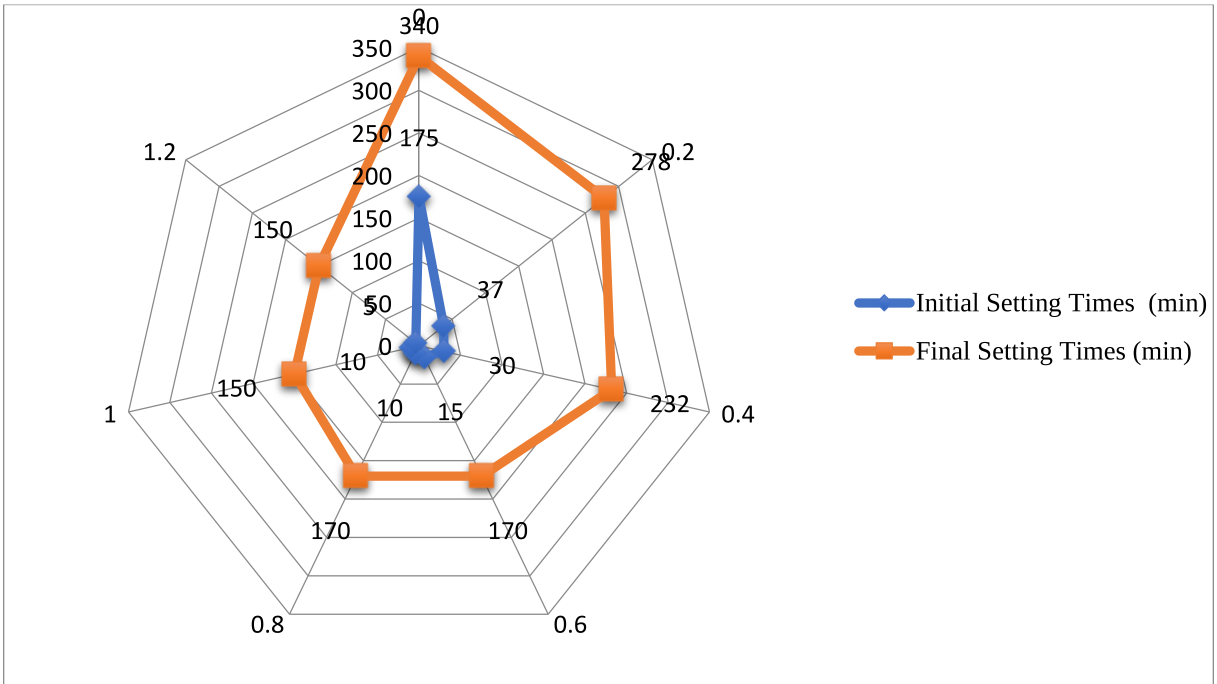


Fig. 7. Initial and final setting times of cement paste with EFBOPF

Table 5. Result of concrete slump tests

% of EFBOPF added	0.0	0.2	0.4	0.6	0.8	1.0	1.2
Slump loss developed (mm)	20	0	0	0	0	0	0
Type of slump	True	True	True	True	True	True	True
Workability	Very low	Very low	Very low	Very low	Very low	Very low	Very low

3.3. Result of Concrete Density Reinforced with EFBOPF

The density values of concrete with 0% to 1.2% of EFBOPF with a fibre increment interval of 0.2% are presented as shown in Figure 8. The density values of EFBOP fibre-concrete obtained after 7, 14, 28, 60, 90 and 120 days of curing range from 2330.9 kg/m^3 to 2500.7 kg/m^3. The values fall within the specified range (2200-2550 kg/m^3) stated by ACI 318R (1999) for the density of normal concrete. Thus, EFBOPF is good for the production of lightweight and normal-weight concrete.

3.4. Concrete Compressive Strengths with EFBOPF

As shown in Figure 9, the compressive strength of concrete with EFBOPF developed increases in strength up to 0.6% of EFBOPF inclusion at 28 and 60 days of curing.

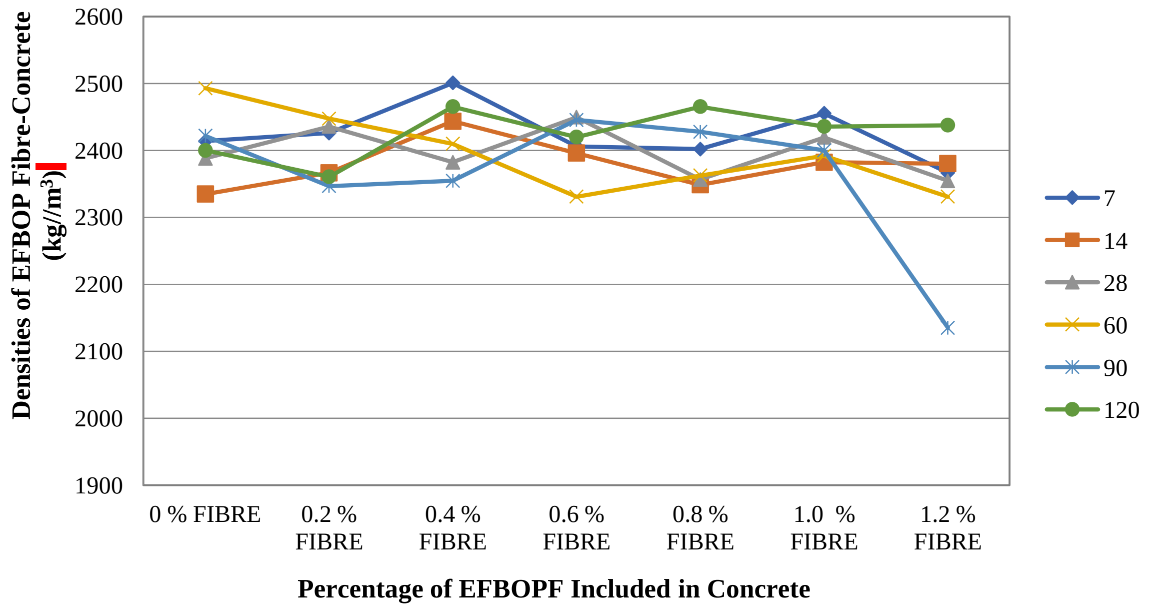


Fig. 8. Densities of EFBOP fibre-concrete with their curing ages

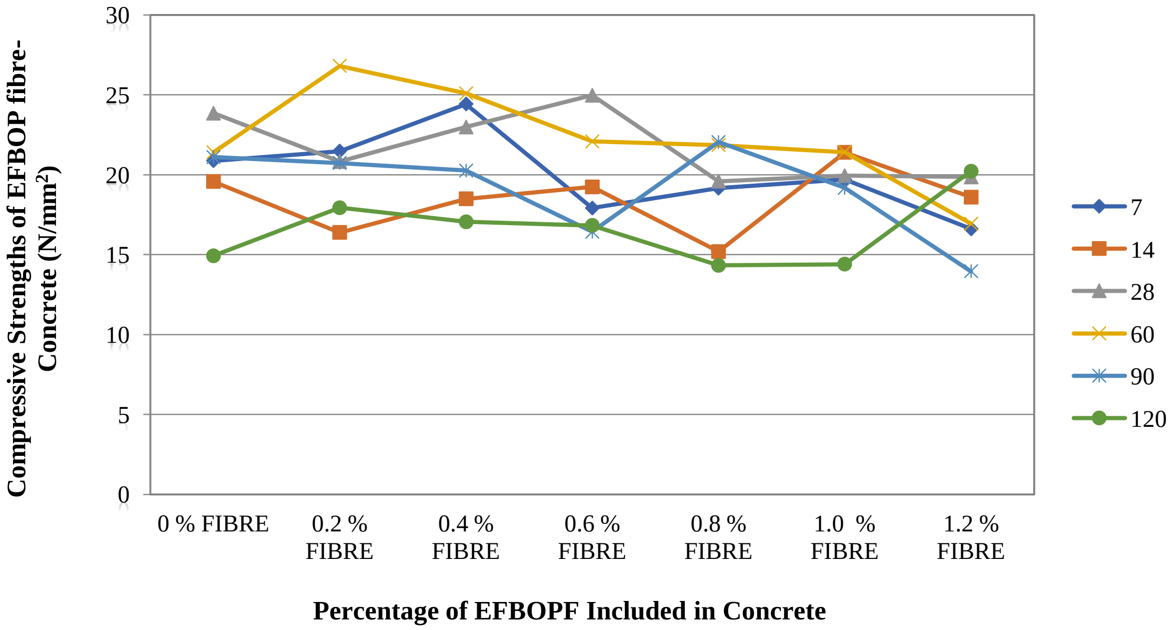


Fig. 9. Compressive strengths of EFBOP fibre-concrete with curing ages

At the 28th day of curing, the concrete compressive strength increased by 3.8% with 0.6% of EFBOPF as a percentage of optimum strength increment. Also, after 60 days of curing, the concrete compressive strength increased from 21.40 to 26.81 N/mm^2 (25.3% increment) with 0.2% of EFBOPF as a percentage for optimum strength increment. The output showed that up to 25.3% of strength increment was yielded by applying EFBOPF to concrete. This result is similar to the finding of Sheng et al. (2019), who reported that the application of EFBOPF in concrete increased the concrete's compressive strength by 33.8% (from 20.6 MPa to 31.13 MPa), after 28 days of curing. Contrary to the finding of Sheng et al. (2019), the report of Omoniyi (2019) shows that the application of EFBOPF in concrete reduced the concrete's compressive strength up to 62.5% with a substitution percentage of 0 to 30% replacement of cement. The results of this experiment prove that the application of EFBOPF in concrete increases its strength and toughness properties, which is in line with Rao and Ramakrishna (2022) report.

For maximum strength increment, the inclusion of EFBOPF in concrete should not exceed 0.2% and the curing age should be limited to 60 days.

3.5. Result of Concrete Tensile Strength

The EFBOPF possesses great potential for concrete reinforcement against cracking and splitting stresses. As presented in Figure 10, the concrete tensile strength increased from 0.994 N/mm^2 to 1.099 N/mm^2 after 7 days of curing with 0.2% of EFBOPF as a percentage of optimum strength increment. With the trend of strength increment after 7 days of curing, the tensile strength of the concrete increased to 1.024 N/mm^2 from 0.854 N/mm^2 after 14 days of curing, with 0.6% as a percentage of the optimum strength increment yielded by EFBOPF in concrete. The observed optimum strength of concrete with EFBOPF was after 28 days of curing with 0.4% EFBOPF as a percentage of optimum strength increment (Figure 10). From 28 days' result, it was observed that about 33.6% of the strength increment was yielded with the application of 0.2% of EFBOPF in concrete. The result proves that 0.2% of EFBOPF is the best percentage for optimum strength increment in concrete.

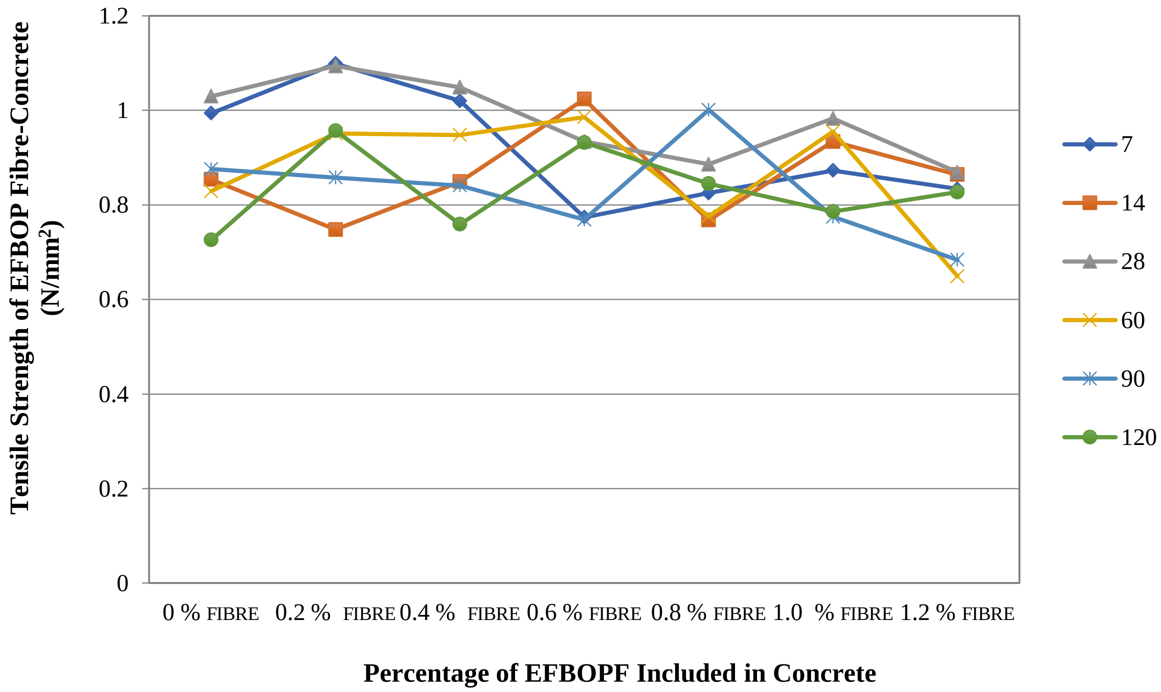


Fig. 10. Concrete tensile splitting strength reinforced with EFBOPF

In comparison, the percentage of strength generated by including EFBOPF in concrete was 13.3% more than that of compressive strength. The strength-yielding quality of the EFBOPF can be improved when it is treated with chemicals like sodium hydroxide (NaOH) to increase its bonding matrix to increase the toughness of concrete against cracking and splitting.

The finding of Futami et al. (2021) is in support of the result of the concrete tensile strength increment observed in this study with the inclusion of EFBOPF. According to the author, the enhancement of concrete properties with EFBOPF had increased the concrete tensile strength up to 70%.

With high strength yielding capacity of EFBOPF in concrete (most especially from 33.6 to 70%), it proves that application of EFBOPF in concrete will control the high effect of sudden splitting and cracks in concrete. In support of the above result, the experimental report of Mazlan and Abdul (2012) also proved that the application of EFBOPF in concrete has a high capacity of increasing the concrete's tensile strength. Considering the agreement between the findings of Futami et al. (2021) and Mazlan and Abdul (2012) and that of this experimental result, it could be deduced that, achievement of high tensile strength in concrete with the application of EFBOPF should not exceed 3% to prevent strength yielding reduction. This suggestion is in correlation with the percentage of EFBOPF observed for optimum tensile strength increment (0.2%) in concrete, which is equivalent to 33.6%.

3.6. Result of Concrete Coefficient of Water Absorption

The inability of permitting the penetration of water into the dried concrete is one of the properties that prolongs the life span of a concrete structure. The penetration of water or liquid into the concrete has been causing a lot of damage to concrete toughness through weakening of the concrete's strength. As observed in this study, after 28 days of curing, the concrete coefficient of water absorption rate increased from 0.05 to 0.06 at the inclusion of 0.6% of EFBOPF (Figure 11). This result proved that concrete with dried EFBOPF (most especially, with 0.6% of EFBOPF) tends to absorb more water meant for the hydration process in concrete, and this can accelerate its initial setting time, thus, cause production of poor strength concrete.

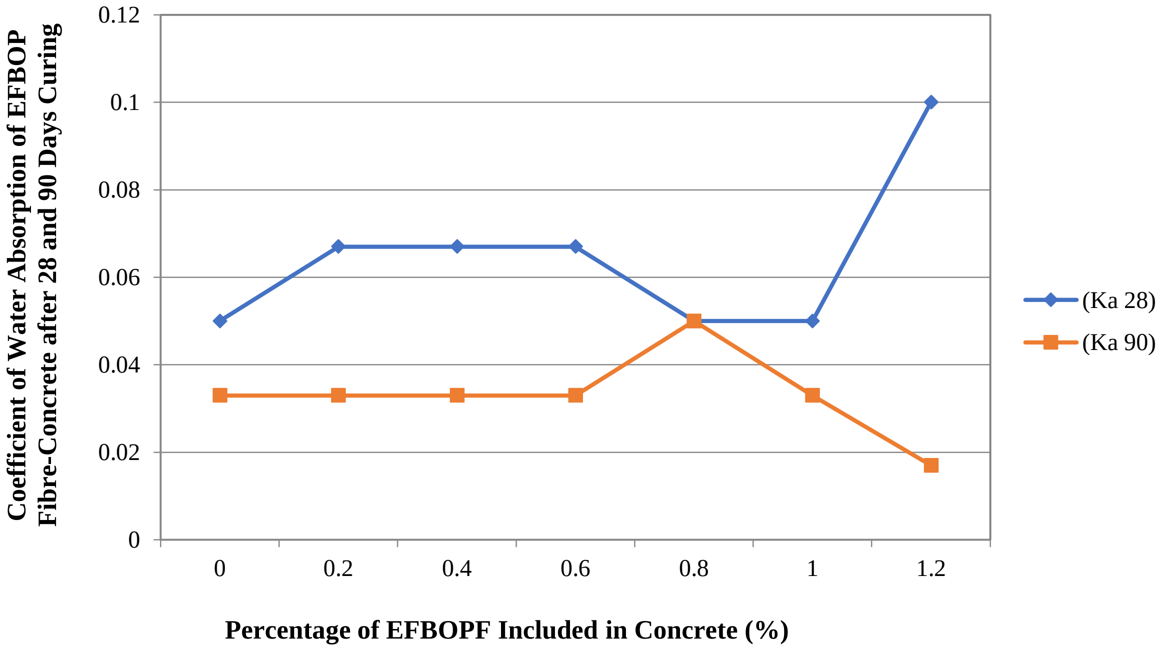


Fig. 11. Coefficient of water absorption of EFBOP fibre-concrete (*Ka*) after 28 and 90 days of curing

On the other hand, the application of 0.1% of EFBOPF in concrete has reduced its coefficient of water absorption by 48.5% after 90 days of curing (Figure 11). This might be a result of the long hydration process of EFBOP fibre-concrete. This might have developed the concrete properties against porosity, pores and holes formation within the concrete’s aggregates.

As shown in Figure 10, application of 0.8% of EFBOPF in concrete will reduce the high rate of water penetration in concrete after 28 days of curing, while the application of 1.2% of EFBOPF in concrete will improve its durability strength against capillarity of water if its curing age is prolonged till 90 days. On the high rate of water absorption in concrete after 28 days of curing, the experimental report of Basiran and Ja’afar (2022), and Futami et al. (2021) support the fact that an increase in the percentage of EFBOPF included in concrete can influence its high rate of water absorption. Based on this observation, it could be deduced that EFBOPF has absorbed a large percentage of water meant for the hydration process in concrete. It was suggested that the percentage of EFBOPF in concrete should be limited to prevent the production of harsh concrete, which is bad for construction purposes.

3.7. Prediction of Concrete Strength Yielding Capacity of EFBOPF in the Concrete

3.7.1. Standard Deviation of Concrete’s Compressive Strength Reinforced with EFBOPF

The results of deviation in EFBOP fibre-concrete strength from the specified standard were presented as shown in Figure 12. As predicted by ANOVA, the trend of EFBOP fibre-concrete strength yielding deviated from 0.120 to 3.227 on the 7th day of curing after being immersed in water at 0.4% of fibre inclusion in concrete. The optimum deviation in concrete’s compressive strength was observed at 7 days of concrete’s curing according to the prediction from ANOVA. This deviation occurred at the inclusion of 0.4% of EFBOPF. The strength deviation observed was by 96.3% out of the specified standard. This gap is too wide. This deviation in strength might have occurred because concrete has not yet attained its full hydration process at the 7th day of curing. At the point that curing of concrete reached 14 days, its deviation in strength ranges from 0.224 to 1.728, which is about 87.04%. It could be deduced that the increase in concrete curing age influenced the deviation in its strength. This was observed by considering the 7-14 days curing deviation difference (96.3% to 87.04%, respectively). According to the strength development trend in concrete, it was expected that at the 28th day of curing, up to 99% of concrete strength would have been developed during the hydration process. At this point, there should be a reduction in the strength deviation of the concrete. As predicted by ANOVA, concrete compressive strength deviation at 28th day of curing ranges from 0.756 to 1.760, which is about 57.04%. The trend of deviation here doubled the initial one, and this was recorded at the inclusion of 0.6% of EFBOPF. Likewise, the inclusion of 0.6% of EFBOPF in concrete also contributed to this deviation in the strength trend. Considering the results of applying 0.2% and 0.4% of EFBOPF in concrete with 28 days curing, the strength deviation observed was almost zero (0.0182 and 0.0723), compared with that of concrete with 0% of EFBOPF (0.756) as predicted by ANOVA. Therefore, it is suggested that the application of EFBOPF in concrete should be limited to 0.2% and 0.4% to prevent unexpected deviation in concrete compressive strength according to ANOVA’s prediction. Also, its curing age should be limited to 28 days. The strength deviation observed at 60 and 90 days of curing concrete with EFBOPF is from 0.115 (control) to 4.68; and from 0.667 (control) to 4.400, which have 85.7% and 84.8% strength deviation differences, respectively.

Also, the maximum percentage in EFBOP fibre concrete's compressive strength deviation after 120 days of concrete curing is 81.2%. Critically considering the results obtained from the application of 0.2-1.2% of EFBOPF to concrete with their curing ages, which ranged from 7 to 120 days (Figure 12), it was observed that the application of 0.6% of EFBOPF in concrete developed no strength deviation for all the concrete specimens cured and tested. Therefore, the application of EFBOPF in concrete should be limited to 0.6% for maximum compressive strength enhancement.

3.7.2. Standard Deviation of Concrete's Tensile Strength Reinforced with EFBOPF

The standard deviation observed as predicted by ANOVA within the tensile strengths of concrete reinforced with EFBOPF are presented in Figure 13.

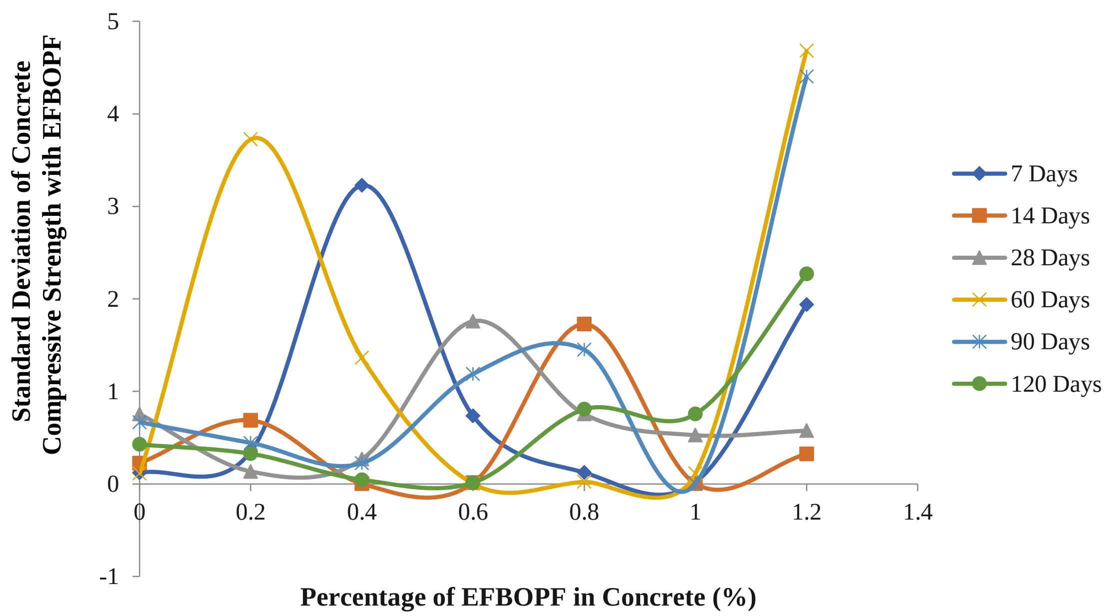


Fig. 12. Standard deviation of concrete compressive strength with EFBOPF

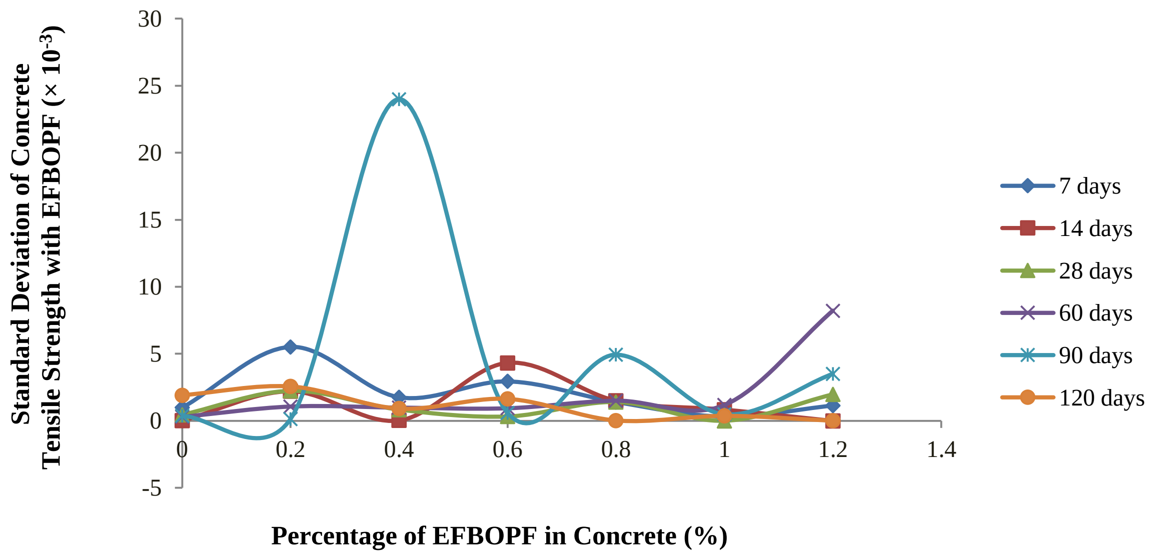


Fig. 13. Standard deviation of concrete tensile strength reinforced with EFBOPF

Generally, the deviation in concrete tensile strength was minimal compared to that of the compressive strength. Almost all the deviations observed from the prediction of ANOVA, as shown in Figure 13, are zero (0-0.025). It is therefore observed that concrete tensile strength increases with no deviation in strength at the application of 0.2-1.2% of EFBOPF despite its long curing ages of 7-120 days. As presented in Figure 13, the maximum strength deviation observed at the concrete tensile zones for 7 to 120 days of curing were 1.1482×10^{-3} for 7 days, 1.5042×10^{-3} for 14 days, 1.41067×10^{-3} for 28 days, 1.067×10^{-3} for 60 days, 0.024 for 90 days and 1.6335×10^{-3} for 120 days at 1.2, 0.8, 0.8, 0.2, 0.4, and 0.6% of EFBOPF inclusion, respectively. All are almost zero. For the control, only the concrete sample cured for 120 days was observed to have a maximum deviation in strength (1.9082×10^{-3}). Others were minimal and they are approximately zero.

As predicted by ANOVA, the application of EFBOPF has a great potential for increasing the concrete's toughness, delaying expansion in concrete that could lead to cracks, increasing the concrete's tensile strength, and blocking pores that can cause absorption of water into the concrete, which can reduce its durability, strength and also initiate cracks. Though the concrete tensile strength increases with the inclusion of different percentages of EFBOPF, its enhancement capacity does not depend on the high percentages of EFBOPF included. According to Figure 13, the ANOVA prediction proved that application of EFBOPF in concrete will develop no deviation in strength, most especially, when concrete with 0.2% of EFBOPF is cured in water for 7 days, and that of 0.4%, 0.6%, 0.8%, 1.0% and 1.2% for 14, 28, 120, 28 and 120 days, respectively. Having observed the above results, 1.0% of EFBOPF is suggested as the best percentage for concrete tensile reinforcement and 120 days for curing duration.

3.7.3. Deviation in Concrete Durability's Strength with EFBOPF

The results of statistical analysis conducted on concrete durability data obtained from the laboratory experimental results were presented as shown in Figure 14. As predicted by ANOVA, the deviation in concrete's strength with the coefficient of water absorption at 28 and 90 days of curing were observed to be minimal. According to Figure 14, the maximum strength deviation values obtained were recorded as 3.267×10^{-5} and 3.267×10^{-9} for 28 and 90 days of curing, respectively.

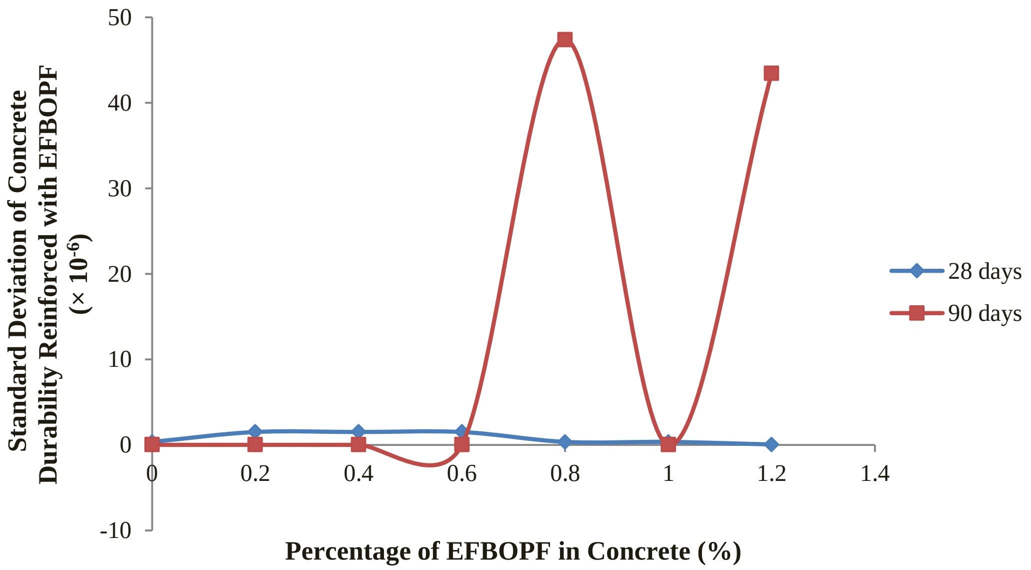


Fig. 14. Deviation of EFBOP fibre-concrete durability

These values are very minimal, approximately zero, even compared to that of controls (3.267×10^{-5} and 3.267×10^{-9} for 28 and 90 days curing, respectively). With these results, it could be observed that application of EFBOPF in concrete is effective in blocking holes and pores developed within the concrete composites, which might result into the permeability of water into concrete. Also, the inclusion of EFBOPF in concrete has improved its toughness property against deformation and developed its thickness against cracks. Thus, EFBOPF has great potential for the reinforcement of concrete durability properties for its more sustainability and durability. As predicted by ANOVA, it could be inferred that, application of EFBOPF in concrete should be limited to 0.8 and 1.2% for 28 days curing, and 0.2, 0.4, 0.6 and 1.0% for 90 days curing to attain maximum concrete's reinforcement.

3.7.4. Variances of Concrete Compressive Strength Reinforced with EFBOPF

The variations in concrete's compressive strength with the application of 0.2 to 1.2% of EFBOPF were observed in this section. As shown in Figure 15, the curing of 0.2 to 1.2% of EFBOP fibre-concrete was carried out as stipulated for 7 to 120 days. On the 7th day of curing, the concrete compressive strength has a variation in strength ranged from 0.0145 (control) to 10.4113, most especially, at the application of 0.4% of EFBOPF to concrete. The strength variation observed was about 99.9% which is very high. This might have occurred as a result of improper mixing of concrete aggregates with EFBOPF.

Also, it might be a result of the poor concrete's aggregate compaction rate. Or it might be a result of irregularity in concrete strength's development. At this stage of curing (7th day), less than 50% of the concrete strength might has not been formed. After 14th day of curing, the variation in concrete's compressive strength reduced from 10.4113 (that of 7th day) to 2.9862 (that of 14th day with 0.8% of EFBOPF). This is about 71.3% in strength variation. The in-uniformity among the compressive strengths of concrete is too wide (from 71.3% to 99.9%).

More efficient method is required for the application of EFBOPF in concrete. The concrete mixing method also needs improvement to give room for uniformity in concrete strengths produced after curing and crushing. As shown in Figure 15, the concrete compressive strength variation observed at 28th day was about 67.7%. The strength variation here is still high. Though, the increase in concrete's curing age leads to a decrease in concrete compressive strength variation, still, there was strength increment at the concrete compression zone.

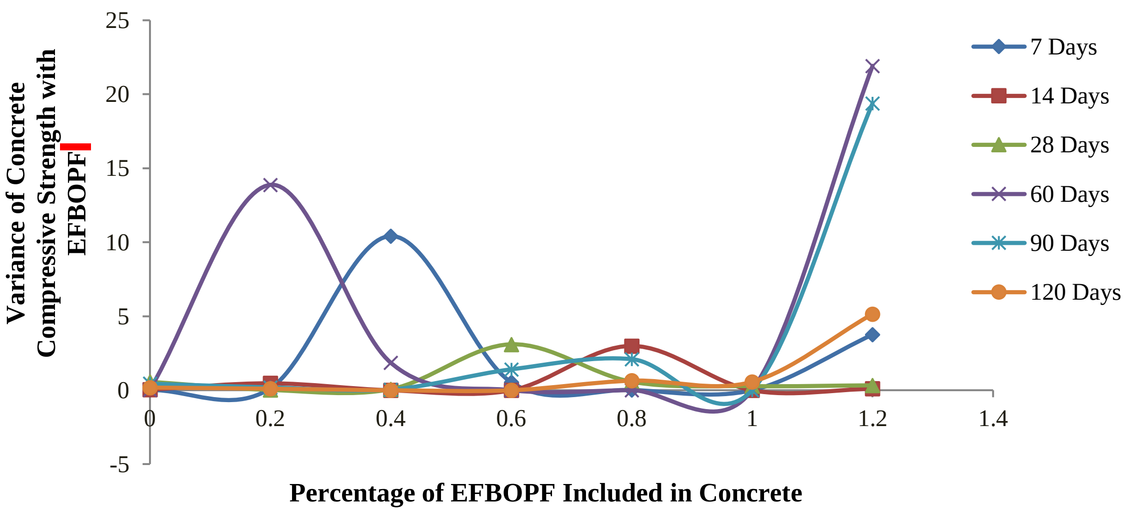


Fig. 15. Variance of concrete compressive strength with EFBOPF

At the 60, 90 and 120 days of concrete curing, the strength variations observed were 21.9180, 19.3888, and 5.1500, respectively. Compared to that of controls, the level of strengths' variation observed were 99.93%, 97.71% and 96.47% at 60, 90 and 120 days of curing, respectively. With all the above high strengths variation values observed at concrete's compression zones, it could be suggested that concrete with EFBOPF should be properly mixed and produced for uniformity in high quality. As predicted by ANOVA (Figure 15), to obtain uniformity in concrete compressive strength, application of EFBOPF in concrete should be from 0.2-0.6% for 120 days curing, while that of 0.8%, 1.0% and 1.2% of EFBOPF should be for 90-, 14- and 28 days curing, respectively. Any alteration of prediction can result in concrete strengths' variations, which can affect the effectiveness of concrete in service.

3.7.5. Variances of Concrete Tensile Strength Reinforced with EFBOPF

The tensile strengths' variation among the samples of concrete reinforced with EFBOPF as predicted by ANOVA are very minimal, approximately zero. As shown in Figure 16, the tensile splitting results of concrete with 0.2%-1.2% of EFBOPFs produced the following variations, that is, 9.76×10^{-7} to 1.318×10^{-6} for 7 days curing; 1.823×10^{-10} to 2.779×10^{-14} for 14 days curing; 2.031×10^{-7} to 1.736×10^{-11} for 28 days curing; 8.643×10^{-8} to 8.789×10^{-7} for 60 days curing; 1.355×10^{-7} to 1.965×10^{-8} for 90 days curing, and 3.642×10^{-6} to 3.6×10^{-11} for 120 days curing. All the concrete tensile strength variations observed are zero, except that of the 7 days curing value with a small variation. With this outstanding performance of concrete tensile strength with EFBOPF, the application of EFBOPF in concrete will really have a better enhancement on concrete's tensile strength against splitting, cracks and deflections. For better strength increment, the application of 0.2%-1.2% of EFBOPF in concrete should undergo long curing ages, that is, from 7 to 120 days, so as to improve its toughness properties against splitting without strength variation.

3.7.6. Variances of Concrete Durability Strength After Being Reinforced with EFBOPF

The strength variations of concrete durability as predicted by ANOVA for 28 and 90 days curing were presented as shown in Figure 17.

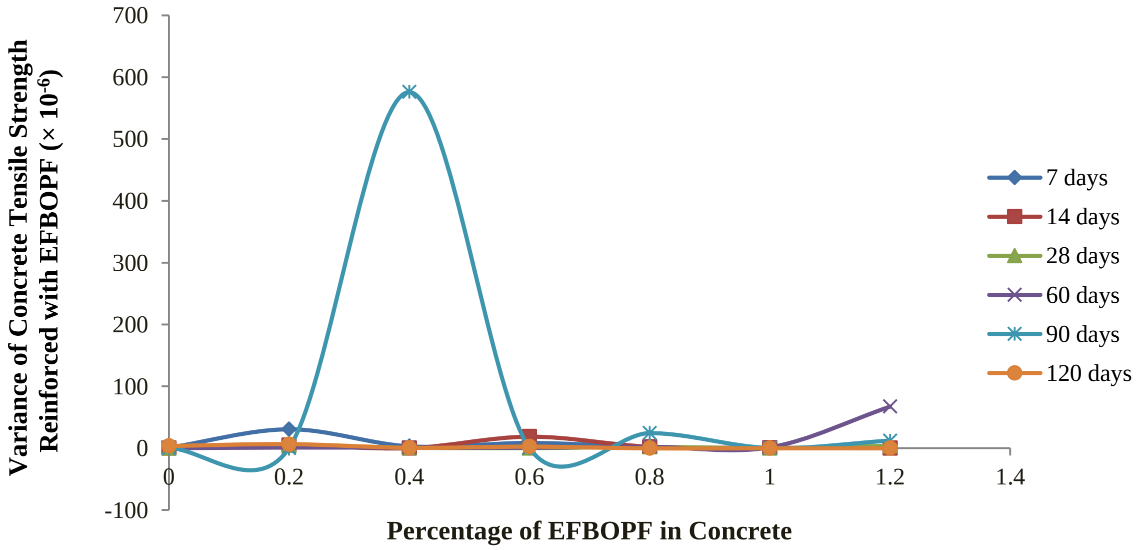


Fig. 16. Variance of concrete tensile strength with EFBOPF

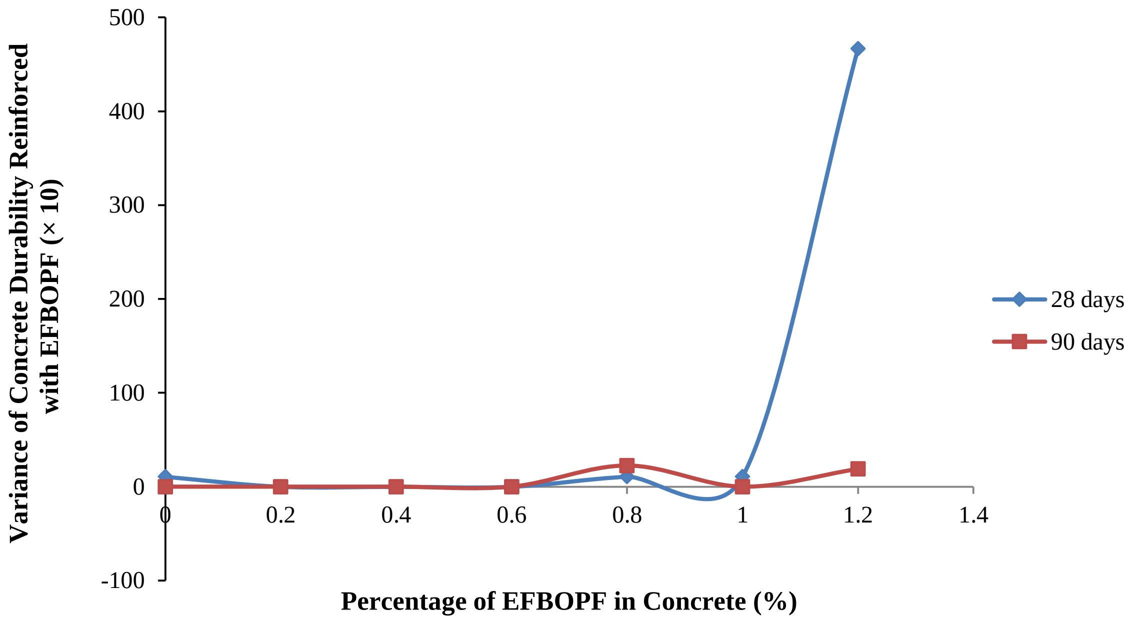


Fig. 17. Variance of concrete durability reinforced with EFBOPF

As observed, the variation in concrete's durability strengths with the inclusion of EFBOPF were from 1.067 × 10^{-9} to 2.25 × 10^{-12} for 28 days, and from 1.0673 × 10^{-17} to 1.0673 × 10^{-17} for 90 days of curing. The variation here is approximately zero. Thus, the inclusion of EFBOPF in concrete prevented the penetration of water into the concrete significantly and thus increased its durable properties. For excellent durability results, the addition of EFBOPF in concrete should be adopted but limited to 0.2%, 0.4%, 0.6% and 1.0% for 28 to 90 days of curing.

3.7.7. Variation Ratio (*F*) of Concrete Compressive Strength with EFBOPF

From the experimental and analysis results of concrete compressive strength, the maximum variation ratio (*Fmax*) of concrete strength observed was 5.5852. While the result of the concrete variation ratio (*F*) from the group data of its compressive strength, as presented in Table 6, with 99.95% (α = 0.05%) level of strength certainty was 5.3288. Also, from the experimental results, the maximum variation ratio (*Fmax*) of concrete tensile strength was calculated to be 54.6393. The variation ratio (*F*) from the group data of concrete tensile strength is 2.132, as shown in Table 7. As shown in Tables 6 and 7, since $F = 5.3288 < Fmax = 5.5852$ for concrete compressive strength, and $F = 2.132 < Fmax = 54.6393$ for concrete's tensile strength, then, the null hypothesis (H_0) which stated that, the rate of increase in EFBOP fibre-concrete strengths does not depend on the increase in the percentage of EFBOPF included, is accepted.

Table 6. Variation ratio (*F*) of concrete EFBOP fibre - compressive strength

Source of variation	Sum of squares	Degree of freedom	Mean squares	*F*
Treatment	170.3149	5	34.0630	5.3288
Error	230.1202	36	6.3922	
Total	400.4351	41		

Table 7. Variation ratio (*F*) of EFBOP fibre - concrete tensile strength

Source of variation	Sum of squares	Degree of freedom	Mean squares	*F*
Treatment	0.113	5	0.0226	2.132
Error	0.382	36	0.0106	
Total	0.495	41		

The statistical result clearly shows that the concrete compressive strength increment does not depend on the large percentage EFBOPF included and also, it does not depend on the long curing age of concrete for strength increment but still contributed solely to stability, durability and sustainability of concrete. These results negate the finding of Musa et al. (2017), who said, an increase in concrete curing days brought about a steady increment in concrete compressive strength. Likewise, the results of Okonkwo and Nwokike (2015) also support this fact that concrete compressive strength varies with variation in curing methods.

4. Conclusions and Recommendations

Concrete is a good construction material that is commonly used for the construction of major infrastructures. It is globally acceptable because of its good structural properties, such as high compressive and flexural strengths, good durability, and high sustainability capacity. One of the major challenges in concreting is its weak ability to resist tensile stress, and this has been developed into a lot of deficiencies, such as cracks and shrinkage. Despite the application of steel bars to concrete to reinforce its weak tensile properties, its crack problem is still unsolved. From the research point of view, the application of natural fibre in concrete is one of the best solutions to these problems of cracks and deformation. Empty Fruit Bunch of Oil Palm Fibre (EFBOPF) is one of the natural fibres that possess good properties for structural concrete enhancement. In this study, EFBOPF is used as a concrete properties' enhancement material to improve its performance in service. As investigated in this experiment, the influence of EFBOPF on concrete's structural properties has been carefully evaluated using an ANOVA model. From ANOVA prediction, it was deduced that the application of EFBOPF in concrete influenced its structural properties positively; however, its structural influence does not depend on a high percentage of EFBOPF included for sequential strength increment.

From the experimental point of view, EFBOPF is good for the production of lightweight and normal-weight concrete. This fact is in agreement with the value of EFBOP fibre-concrete densities observed from the experimental results. Likewise, the experimental result of EFBOP fibre-concrete's mechanical properties, such as compressive and tensile strengths, and durability increased in strengths with the inclusion of EFBOPF. The increase in the percentage of EFBOPF included in concrete is not the determinant factor for strength increment in concrete. Thus, the application of fibres such as EFBOPF in concrete could increase or decrease the strength of concrete. Also, the curing of EFBOP fibre-concrete beyond 30 days does not determine that its strength increment will be progressive with the increase in curing age.

From the experimental results, it was observed that the application of EFBOPF in concrete improved its toughness properties, and blocked pores and holes that normally cause cracking due to applied tensile force or thermal expansion. Also, it increases the concrete strength against deflection, compression and shrinkage, but the rate of strength increment yielding does not depend on a high percentage of EFBOPF included. Considering the results of analysis obtained from ANOVA, since the values of F are less than those of $Fmax$ from the variation ratio results, therefore, the null hypothesis (H_0), which states that the rate of strength increment in concrete reinforced with EFBOPF does not depend on the depth of increasing the percentage of EFBOPF included is accepted. It can be concluded that only a certain percentage of EFBOPF influence the concrete's strength increment, and the increase in EFBOP fibre-concrete's curing ages does not guarantee its progressive strength increment. According to AVOVA prediction, for maximum strength increment, the inclusion of

EFBOPF in concrete should not exceed 0.2% and the curing age should be limited to 60 days. For high concrete tensile strength, the percentage of EFBOPF in concrete should not exceed 3%. From the experimental result, it was observed that the EFBOPF absorbed a large percentage of water meant for the hydration process in concrete. Thus, the percentage of EFBOPF applied to concrete should be limited, to prevent the production of harsh concrete.

Likewise, the application of EFBOPF for concrete compressive strength increment after 28 days of curing should be limited to 0.2% and 0.4% which gave a zero deviation in strength as predicted by ANOVA. Also, 1.0% of EFBOPF was suggested as the best percentage for concrete's tensile increment and 120 days as its good curing age. As predicted by ANOVA, the application of EFBOPF in concrete should be limited to 0.8 and 1.2% for 28 days curing, and 0.2, 0.4, 0.6, and 1.0% for 90 days curing for optimum strength increment, and to prevent concrete's strength deviation. 1.0% of EFBOPF is suggested for the reinforcement of concrete compressive strength for optimum strength yielding at 7, 14, 28, 60, 90 and 120 days of curing with no strength variation. The inclusion of EFBOPF in concrete for its tensile strength reinforcement should be limited to 0.4% and 1.0%, and 7 to 120 days for curing ages, in order to have optimum tensile strength increment without any variation in strength. The application of EFBOPF in concrete improved its strength against water weakening, thus, making it more durable than the ordinary concrete. It was recommended that, application of EFBOPF in concrete should be limited to 0.2%, 0.4% and 0.6% and that of curing age should be limited to 28 and 90 days for concrete's better durability.

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