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Comparative Examinations of Structural Responses of Concrete Reinforced with Treated Oil Palm Empty Fruit Bunch (TOPEFB) and Untreated Oil Palm Empty Fruit Bunch (OPEFB) Fibres

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ABSTRACT: The findings from the investigation conducted, to compare the structural performance of concrete containing treated (TOPEFB) and untreated Empty Oil Palm Fruit Bunch (OPEFB) fibres are presented in this paper. For the TOPEFB fibres, the dried fibres were treated with 0.2% NAOH solution following the procedures of ap-propriate authority. The structural parameters investigated were consistencies, setting times, densities, com-pressive and tensile strengths of concrete incorporating TOPEFB and OPEFB fibres in the mix. The addition of fibres was limited to 1.20% by weight of cement in the concrete. The interval of addition was 0.2%. The results showed that (i) the setting times of mortars containing TOPEFB fibres were higher than that of mortars with OPEFB fibres, (ii) concrete specimens containing TOPEFB fibres are more workable that concrete specimens with OPEFB fibres, (iii) densities of concrete specimens containing OPEFB fibres were in the range for normal concrete applications while the densities for specimens with TOPEFB developed densities that fell in the heavy weight concrete classification, (iv) concrete specimens containing TOPEFB fibres developed higher compressive strengths than specimens with OPEFB fibres and (v) tensile strengths of concrete specimens containing TOPEFB fibres were higher than specimens with OPEFB fibres by at least 59.04%. The overall conclusion from the findings of this study is that concrete specimens containing TOPEFB fibres have superior structural properties than specimens with OPEFB fibres

KEYWORDS: Compressive strength, Density, Fibres, Structural concrete, Tensile strength.

1.1 INTRODUCTION

In concrete industry, the type of concrete that consists of hydraulic cement, water, fine aggregate, coarse aggregate and discrete fibres that are discontinuous, is termed fibre-reinforced concrete (FRC) (Buttignol et al., 2018 and Marcalikovaa et al., 2020). According to Logfren (2005), fibres can be used as a substitution for reinforcing bars completely in some type of construction like foundations and walls. Fibres can also be used in combination with ordinary pre-stressed reinforcement in beams and suspended slabs. However, structurally speaking, the main reason for inserting fibres into concrete is to strengthen its fracture characteristics and structural behaviour; because of its inherent ability to bridge cracks in concrete (Logfren, 2005). The tensile responses of concrete are improved as a result. It is an established fact that concrete is weak in tension, about 10% of the compressive strength. Materials that have been used as fibres included synthetic, metallic and natural materials. Except natural fibres, other forms of fibres are very expensive, thus militating against their wide scale usage of these fibres. Natural fibres on the other hand, are readily available, very economical to produce and with positive environmental impact (Momoh and Osofero, 2019). Further, Ismail and Yacob (2011) and Lertwattanaruk (2015) listed zero-carbon footprint and healthy environment as benefits for using natural fibres in concrete. In addition, natural fibres have been recommended for use in self-compacting mortar (Khalil et al., 2012), polymer composites (Dungan et al., 2013 and reinforced concrete (Ziane et al., 2020). Some fibres used in concrete on which investigations have been carried out with encouraging results include fibres from coconut husk, sisal, sugar cane begasse, bamboo, jute, wood, akwara, elephant grass, water-reed, plantain, hemp, aluminum, and cellulose fibres (Ramli and Dawood, 2010, Sabapathy et al., 2021, Kaplan and Bayraktar, 2021). Notwithstanding the fact that natural fibres are presently applied to improve a variety of tensile-related concrete properties and its durability performance (Arslan (2016) and Kuder and Shah (2010)), there is however a growing awareness that natural fibres can be used as a construction material. Available information in the public domain documented the use of natural fibres for construction purposes in ancient times (Moses, 1984). These natural fibres were in the form of straw. Such usage in the present times on a wide scale will make the production of structural concrete sustainable. An example of natural fibre with acceptable performance for construction purposes is fibres sourced from oil palm empty fruit bunch

(OPEFB). According to Ramli and Dawood (2010), inclusion of OPEFB fibres not only resulted in concrete with higher densities but also led to increase in the compressive strength by 13.4 and flexural strength by about 16.1%. The authors further found out that the use of fibres slightly increased the density of lightweight concrete; and that the use of up to 0.8% of palm fibres led to increase in the compressive strengths by 13.4% and flexural strengths by 16.1%. Investigation conducted by Ismail and Yaacob (2011) on lateritic brick reinforced with OPEFB fibres showed improved compressive strength performance at 3% fibre content. In their own work, Kolop and Haziman (2020) used high content of OPEFB fibres (10 – 30%) in cement blocks. Their findings showed that lightweight cement blocks resulted. Fapohunda and Kilani (2021) researched into the effects of adding OPEFB fibres on structural performance of concrete. Their findings included reduced setting times and workability as well as densities ranges that were for the normal weight structural applications. Other findings from Fapohunda and Kilani (2021) were better compressive strength performance up to 0.6% inclusion of OPEFB fibres by weight of cement, but tensile strengths that were generally very low. Although tensile strengths are usually ignored in the design of structural concrete, nevertheless structural engineers may not be favorably disposed to recommend it for mass application. The low tensile strength of concrete with the fibres has been attributed to the weak bond stress (or interfacial adhesion) between the fibres and mortar matrix (Shetty, 2009 and Ozerken et al., 2015). There is however literature showing that alkali treatment of OPEFB fibres can improve the interfacial adhesion between the fibres and mortar matrix (Izani et al., 2013, Momoh and Osifero, 2020). This is a tacit suggestion that using OPEBF fibres treated with alkali in concrete could improve the tensile performance of the resulting concrete without resulting in loss of compressive strength. Thus, the thrust of this investigation is to examine the relative structural performance of concrete containing treated oil palm empty fruit bunch (TOPEFB) fibres and untreated oil palm empty fruit bunch (OPEFB) fibres. Specific objectives involved determination of fresh states properties of mortars incorporating both TOPEFB and OPEFB fibres as well as the hardened states properties of concrete containing both TOPEFB and OPEFB fibres.

2 MATERIALS AND METHODS

2.1 *Materials*

The concrete ingredients used to accomplish this research study were binder, fine aggregate, coarse aggregate, empty oil palm fruit bunch (OPEFB) fibre, treated empty palm oil fruit bunch (TOPEFB) fibre, water and superplasticizer. The binder used was grade 42.5 R Portland limestone cement. The manufacture satisfied the recommendation contained in NIS 444 (2014) and BS EN 197-1 (2000). River sand, sourced from a river that flows beside the University where this research was carried out, was used as the fine aggregate. The sand was dried in the sun and sieved so that the sand particle passing through 4.75 mm sieve size (BS sieve no 4) but retained on 75 um sieve size (BS sieve no 200) can be collected, put in a bag and stored in a normal temperature environment. This was to comply with the requirement of BS EN 12620:2002+A1 (2008**).** The coarse aggregate that was used for this study was sourced from a quarry near the University. Using the requirement of BS 8110 (1997) as it affects structural concrete as a guide, the particle sizes of the coarse aggregate varied between 4.75mm and 20 mm**.** The empty oil palm fruit brunch fibre (OPEFB) fibres were gathered from empty palm oil fruit bunches from the palm oil cottage industries in Ikole-Ekiti, Nigeria. To extract the fibre, the bunches were soaked in water, and the extracted fibres were then sun-dried (Figure 1).

a. The Bunch fibres b. Fibres before extraction

c. Fibres after extraction

Figure 1: The extracted fibres.

The fibres were cut into 20 mm length for aspect ratio at between 50 and 55 adopted for this work. Two types of fibres were used, namely TOPEFB and TOPEFB fibres. For the treated fibres, the dried fibres were treated with NAOH solution as described by Izani et al. (2013). In line with the recommendations of Izani et al. (2013), the fibres were immersed in 0.2% alkali solution for 30 minutes after which they were filtered out. The fibres were then washed with water until the NaOH is eliminated. The fibres were then allowed to dry out in the oven for 3 hrs at 600C, cooled, bagged and stored. The untreated fibres were used after sun-dried. For the investigation, potable water, satisfying the requirement of ASTM 1602 (2012) was used. A superplasticiser with a brand name Master Glenium SKY 504 (BASF, 2014) was used. The superplasticiser is capable of producing a quality concrete mix that enables accelerated strength development and good workability characteristics at the recommended dosage of 1.0 li-tre per 100kg of total cementitious material.

2.2 *Mix Proportion and Concreting Operations*

For the purpose of this investigation, bearing in view the need to simulate the general practice in Nigeria concrete industry, a mix cement: sand; gravel proportion of 1: 2: 4 with the water cement ratio of 0.50 and workability requirements to produce a 28-day compressive strength of 20 N/mm2 as per COREN (2017) was chosen. The TOPEFB and OPEFB fibres were incorporated into the mix up to 1.20% by weight of cement at interval of 0.20%. The fibres were randomly mixed with the cement. The range of fibre addition from 0 – 1.2% was chosen based on findings of Kaniraj and Fung (2018) for natural fibres applications in concrete. The mix proportion that was obtained on the basis of this is presented in Table 1.

Table 1: Concrete Material Proportion for the Investigation

% Fibre in the Mix	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Fibre (kg/m^3)	Water (kg/m^3)
0%	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

The ingredients for the production of concrete were batched by weight. The concrete was subsequently produced by following the approaches suggested by Gambhir (2013). For the compression test specimens, the concrete was placed into 150 x 150 x 150 mm cube moulds, while the splitting tensile strength specimens were placed into 150 x 300 mm cylinder moulds. Adequate compaction by tamping was given to the cast concrete. The concrete specimens were then left in the respective moulds for 24 hours to set. They were removed from the moulds, and then placed in curing tank filled with water for moist-curing process by immersion until the day of testing. Specimens testing were done at 7, 14, 28, 60 and 90 days of curing. The concrete specimens without OPEFB fibres served as the control.

2.3 *Experimental Procedures*

2.3.1 *Characterization of Materials*

In order to characterize the materials to be used to ascertain their fitness and suitability for use in concrete, certain preliminary tests were carried out both on the aggregates and on the fibres. The properties investigated for the aggregates were sieve analysis, specific gravity, bulk density, etc. For both the TOPEFB and OPEFB fibres, both the physical and chemical properties were determined. For the tensile properties of the fibre, an Instron Model 5590 Testing Machine was used in accordance with ASTM D 882. Fiber tests were carried out at the speed of 10mm/min. From the software attached to the equipment, the values of the tensile strength, elongation, and the modulus of elasticity.

2.3.2 *Consistency and Setting Times*

Consistency tests were performed on mortar specimens containing both TOPEFB and OPEFB fibres. These tests were conducted in accordance with the requirements of BS EN 196-3 (2005). The apparatus used were Vicat probe and the Vicat needle. This test is necessary to ascertain the quantity of water required to attain a paste of normal consistency for the samples containing both TOPEFB and OPEFB fibres. To these pastes were added fibres progressively from 0.0 % to 1.2 % at interval of 0.2%. The water demand for mortar with OPEFB fibres served as the control. This water requirement was hereafter used to evaluate the effect of both TOPEFB and OPEFB fibres on the initial and setting times of cement paste. The initial and final setting times were then investigated, using the water demand from the consistency test, for mortars containing both TOPEFB and OPEFB fibres from 0 – 1.2% at interval of 0.2%.

2.3.3 *Workability*

Determination of the effects of the inclusion of TOPEFB and OPEFB fibres in concrete on its workability was carried out using the slump test. The concrete specimens used contained fibres up to 1.20% by weight of cement at interval of 0.2%. The investigation was performed in under the guardian of the recommendations of BS EN 12350: Part 2 (2000).

2.3.4 *Density and Compression*

The densities and the compressive strengths specimens of concrete containing TOPEFB and OPEFB fibres were assessed using 150 x 150 x 150 mm cube specimens. The assessment of densities was done according to the recommendations of BS 12350: Part 6 (2000). The recommendations of BS EN 12390-3 (2009) were used as a guide for the assessment of the compressive strengths. A universal compressive testing machine model WAW-2000B with 2000KN capacity was the machine used for the assessment of the compressive strength. Three (3) specimens were weighed and tested at each of the curing age, and the average was used to compute the mean density and the compressive strength. The densities and compressive strengths were determined at curing ages of 7, 14, 28, 60 and 90 days. Both TOPEFB and OPEFB fibres were added in sequence into the concrete from 0 – 1.20 % at internal of 0.2%.

2.3.5 *Tensile Strength*

The tensile strength of concrete specimens with treated and untreated OPEFB fibres were assessed through the splitting tensile strength. The splitting tensile strength tests were carried out by using 150 x 300 mm cylinder moulds, in line with the recommendations of BS 12390: Part 6 (2009). The testing machine used for the compressive strength was also used for testing tensile specimens. However, here, the cylinder specimens were placed with their axis in horizontal position (Figure 2). The specimens were reckoned to have failed once longitudinal crack appeared as in Figure 2.

The splitting tensile strength (Ts) was later obtained using Equation 1.

$$T_s = \frac{2P}{\pi l d} \quad (1)$$

where: Ts = the splitting tensile strength (N/mm2), P = the maximum applied load (in Newtons) by the testing machine, l = the length of the specimen (mm), and = is the diameter of the specimen (mm).

Figure 2: The orientation and failure of the typical tensile specimens at testing

3 RESULTS AND DISCUSSION

3.1 *Characterization of Materials*

The results obtained from the investigation conducted to characterize the materials are shown in Tables 2 - 4. From Table 2, it can be observed that the value recorded specific gravity of fine aggregate is 2.62 and a value of 2.66 was obtained for the coarse aggregate. But Gambhir (2013) had shown that the average specific gravities of natural aggregate are between 2.5 and 2.8. It can thus be averred that the fine aggregate and coarse aggregate used in this study are natural aggregate. Also, the values obtained for bulk densities, water absorptions and the moisture contents of the fine aggregate and coarse aggregate were within the ranges of values permitted for normal concrete as per ACI (1999).

Table 2: Some Physical Properties of the Aggregates

Properties	Fine Aggregate	Coarse Aggregate
Specific Gravity	2.62	2.66
Bulk Density (kg/m^3)	1666.57	1642.67
Water Absorption (%)	1.99	1.98
Moisture Content (%)	0.00	0.00
Coefficient of uniformity (Cu)	2.98	4.45
Coefficient of curvature (Cc)	0.87	1.15

From Table 2, these values were 1280 to 1920 kg/m3 for density; 0 to 8% for water absorption; 0 – 2% as moisture content for fine aggregate and 0 - 10% as moisture content for coarse aggregate. Also, from Table 2, values of coefficient of uniformity (Cu = D_60/D_10) was 2.98 and coefficient of curvature or gradation (Cc = 〖D_30 x D〗_30/ 〖D_60 D〗_10) was 0.87 for fine aggregate. The values of 4.45 and 1.15 were obtained for the coarse aggregate. These were obtained from the analysis of results of sieve analysis. These values fell in the ranges allowed by ACI (1999) for fine aggregate that is to be used for the production of concrete. Thus, from Table 2, the general conclusion is that the fine aggregate and coarse aggregate materials are suitable for the production of structural concrete. The physical and mechanical properties of the fibres are presented in Table 3.

Table 3: Physical Properties of TOPEFB and (OPEFB) fibre

Physical Properties	OPEFB fibre	TOPEFB fibre
Colour	Brown	Brown
Length (single fibre) (mm)	20	20
Diameter (single fibre) (mm)	0.25 – 0.50	0.25 – 0.50
Aspect Ratio	53	53
Density (g/cm^3)	1.03	1.27
Water Absorption (%)	35.28	42.04
Pentosan (%)	21.10	18.32
Tensile Strength (GPa)	159	172.50
Young Modulus (GPa)	5.11	8.89

From Table 3, the TOPEFB fibres had density and water absorption values that were higher than the OPEFB fibres. Of significance in Table 3 was the observation that the tensile properties of TOPEFB fibres were higher than that of the OPEFB fibres ones. For example, treating the fibres increased the tensile strength by as much as 8.5% and Young's modulus by 7.4%. These results are in agreement with the findings of Izani et al. (2013). They had concluded in their investigation that alkaline treatment of fibres increases their tensile properties in relation to the untreated fibres. These relative increases in the tensile properties of treated fibres have been attributed to increased crystallinity of fibres by alkali treatment (Izani et al., 2013). Also, the results of the elemental characteristics of TOPEFB and OPEFB fibres are presented in Table 4.

Table 4: Elemental Properties of Oil Palm Empty Fruit Bunch (OPEFB) fibre

Chemical composition	OPEFB fibre	TOPEFB fibre
Hemi-cellulose (%)	11.60	14.40
Cellulose (%)	37.50	43.50
Lignin (%)	18.50	21.0
Extraction (%)	0.44	0.52
Ashes (%)	4.95	7.52

It can be seen from Table 4 that all the elemental properties of the TOPEFB fibres recorded higher values than the OPEFB fibres.

3.2 *Consistency and Setting Times of Mortar with TOPEFB and OPEFB fibre*

The values obtained from the investigation of the consistency and the setting times of paste with both TOPEFB and OPEFB fibres are presented in Table 5 and Figure 3. It can be observed from Table 5 that the numerical values obtained for water requirement to achieve standard consistency changed marginally with inclusion of both TOPEFB and OPEFB fibres in the mortar paste in the ranges of the percentages considered.

Table 5: Consistency of Mortars with TOPEFB and OPEFB fibres

% Fibre in the Mix	OPEFB	TOPEFB
0%	34	34
0.2	34	34.5
0.4	34	34.5
0.6	34	34.5
0.8	35	35
1.0	35	35
1.2	35	35

From Figure 3 however, it can be observed that both the initial and final setting times of mortar pastes containing TOPEFB and OPEFB fibres reduced with increase in the fibres. This suggests that progressive addition of the fibres causes the mortar to harden quickly.

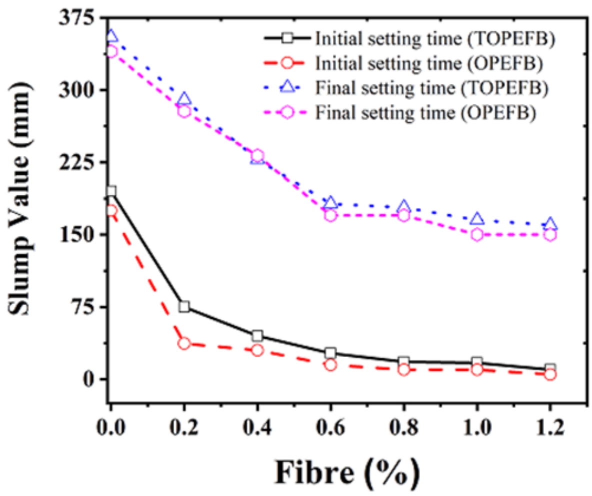

Figure 3: Effect of TOPEFB and OPEFB fibres on the Setting Times of Concrete

The general trends of decreasing setting times could be due to the fact that water is being absorbed by the fibres, thereby making the mortar set quickly (Ozerkan et al. 2015). The implication is that adequate compaction may be difficult to achieve if concrete containing OPEFB fibres treated or untreated, is to be transported over a long distance before it is placed, as the concrete may become unworkable.

Another deduction from this behavior (of reduced initial setting times) is that OPEFB fibres in concrete will act as a form of accelerator. It can also be observed from Figure 3 that both the initial and final setting times of mortar containing TOPEFB fibres were higher than that of mortar with OPEFB fibres. These results were consistent with earlier findings by Ozerkan et al. (2015). The implication is that hydration process and strength development in concrete with TOPEFB fibres may be delayed in relation to concrete with OPEFB fibres.

3.3 *Workability*

The effects of treated and untreated OPEFB fibres on concrete specimens are shown in Table 6. From Table 6, it can be noted that slump losses were recorded only for specimens with treated OPEFB fibres.

This suggested that inclusion of treated fibres in concrete resulted in a workable concrete when compared with concrete with untreated fibres. These results are consistent with the results obtained for the setting times in Figure 3. Nevertheless, concrete specimens with both treated and untreated fibres exhibited true slump suggesting that the fibres were able to provide sufficient cohesive forces in the mix which prevented shear or collapse slump. Based on the magnitude of the slump, concrete specimens with untreated OPEFB fibres had stiff consistency and with zero slump, can thus be described as no-slump concrete in relation to workability (Neville, 2011). On the other hand, however, concrete specimens containing treated

OPEFB fibres have workability that range from low medium to very low.

3.4 *Density of Concrete specimens with treated and untreated OPEFB fibres*

According to Fapohunda and Daramola (2019), to apply concrete effectively in reinforced concrete design to BS 8110 (1997), accurate knowledge of relevant ranges of its densities is essential. In this regard, both the qualitative and quantitative descriptions are essential. The general pattern of densities obtained showed that concrete specimens with TOPEFB fibres have higher densities than specimens with OPEFB fbres. A plot of 28-day densities of the specimens, as an example of general pattern of the results, and being a day that is structurally significant in concrete design, is shown in Figure 4 for observation.

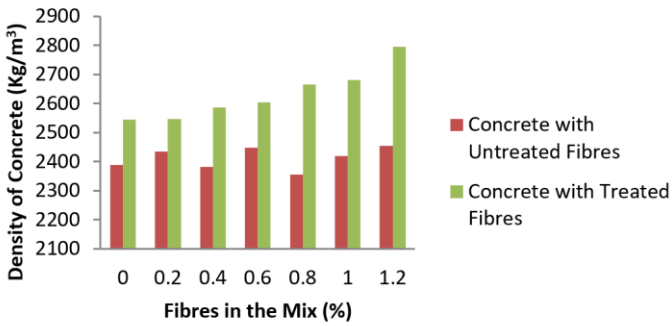

Figure 4: 28-day Densities of Concrete specimens with TOPEFB and OPEFB fibres

The behaviour TOPEFB fibres in relation to OPEFB fibres cannot be unconnected with the densities obtained for both fibers that were previously shown in Table 3. In Table 3, it can be observed that treated TOPEFB fibres have higher density than the OPEFB fibres. Thus, higher densities displayed by specimens with TOPEFB fibres should be expected. The fact that OPEFB fibres have the tendency to increase the density of concrete products was also established in the work of Ramli and Dawood (2010). Looking at the observed 28-day densities numerically, it can be deducted in Figure 4 that the range of densities for the specimens with OPEFB fibres was approximately between 2350 and about 2450 kg/m^3. On the other hand, the densities obtained for specimens with TOPEFB fibres were generally in excess of 2500 kg/m^3. Thus, taking into consideration the classifications by ACI (2003) and Falade et al. (2011), concrete specimens with OPEFB fibres can be classified as normal weight concrete, while specimens with TOPEFB fibres can be classified as heavyweight concrete. The implication of this behaviour is that concrete with OPEFB fibres can be employed in the design of structural concrete as normal concrete according to BS 8110 (1997). On the other hand, if applications requiring heavy weight concrete like for biological shields and where protection against gamma rays or nuclear shielding are necessary, concrete specimens containing TOPEFB fibre could be considered (Neville, 2011 and Gambhir, 2013)

3.5 *Compressive Strength of concrete specimens with TOPEFB and OPEFB fibres*

The general pattern of compressive strengths development for concrete specimens with both treated and untreated OPEFB fibre was that the compressive strength increased with increase in OPEFB fibre content, and then followed by decrease. A typical plot, which is for 28-day compressive strength at the various additions of OPEFB fibres, is shown in Figure 5.

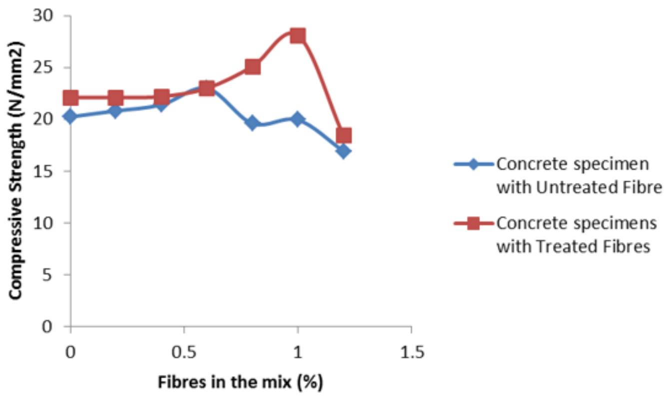

Figure 5: Effect of TOPEFB and OPEFB fibres on the 28-day compressive strengths of specimens

However, while the descent started after 0.6% addition for untreated fibres, the descent started after 1.0% addition for treated fibres. At all the curing ages and at all the percentage addition of fibres, specimens with TOPEFB fibres performed better in compressive strength development than specimens with OPEFB fibres. A picture of relative performance of concrete specimens containing treated and untreated OPEFB fibres, expressing increase or de-crease as percentage of untreated specimens is presented in Figure 6.

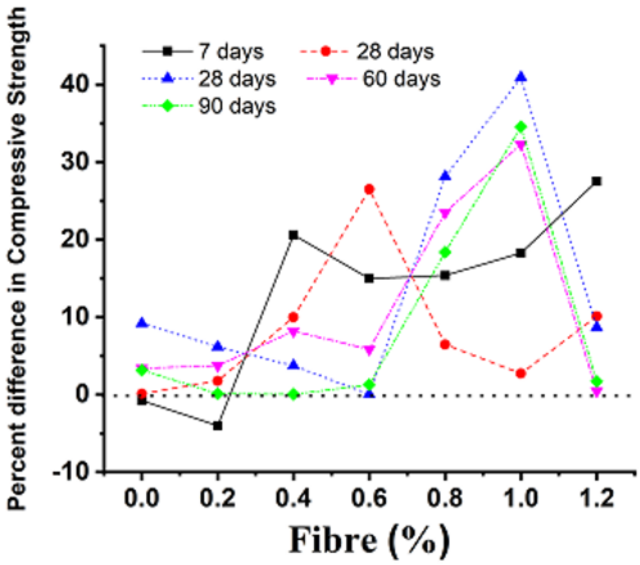

Figure 6: Compressive performance of concrete with TOPEFB fibres relative to OPEFB fibres (in percent)

With the exception of specimens at 7-day curing for control and 0.2 % addition specimens, all the specimens containing TOPEFB had percent increase in compressive strength over the specimens of OPEFB fibres. The higher percentages of cellulose and hemicellulose recorded for treated OPEFB fibres in Table 4 may have been responsible for the improved strength performance relative to the OPEFB fibres. This observation is in agreement with the findings of (Mazlan et al., 2020) who concluded that cellulose and hemi-cellulose that formed part of the constituents of palm oil empty fruit bunch waste increase the compressive and tensile strength of mortars.

3.6 *Tensile Strength*

The values obtained for the splitting tensile strength development of concrete specimens containing TOPEFB and OPEFB fibres are presented in Figure 7. From Figure 7 the following observations are obvious. The tensile strengths increased with fibre content for specimens containing treated and untreated OPEFB fibres. With the exception of specimens at 7-day curing age, where there were decrease in tensile strength values beyond 0.6% addition of fibre, TOPEFB specimens developed tensile strength with addition of fibres up to 1.0% at curing ages of 14, 28, 60 and 90 days.

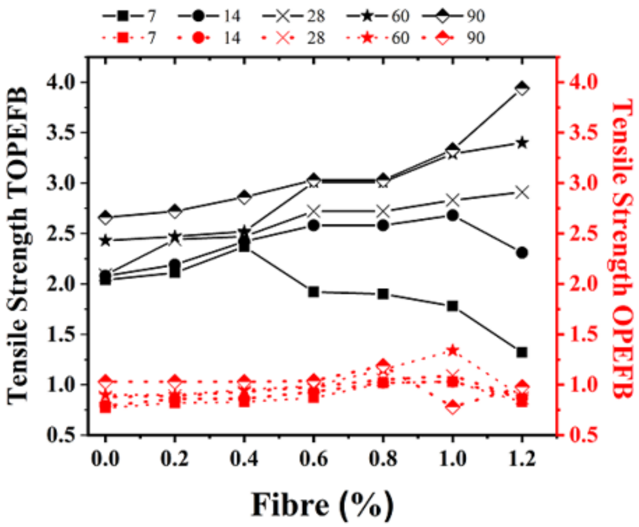

Figure 7: The Tensile Strength of specimens with TOPEFB and OPEFB fibres

Also, from the figure, it can be observed that TOPEFB specimens developed higher tensile strengths than specimens with OPEFB fibres at all the fibre addition levels, and at all the curing ages. These showed beneficial tensile performance of OPEFB fibres. Figure 8 gives the relative tensile performance of specimens containing TOPEFB and OPEFB fibres by expressing increase or decrease as percentage of untreated specimens. The picture portrays in Figure 8, using 28-day curing specimens is that the tensile strength developed by specimens containing TOPEFB fibres were higher than specimens with untreated OPEFB fibres by approximately 140%, 170. %, 160%, 170%, 150%, 150% and 200% respectively at 0.0, 0.2, 0.4, 0.6, 0.8, 1.0, and 1.2% fibres content.

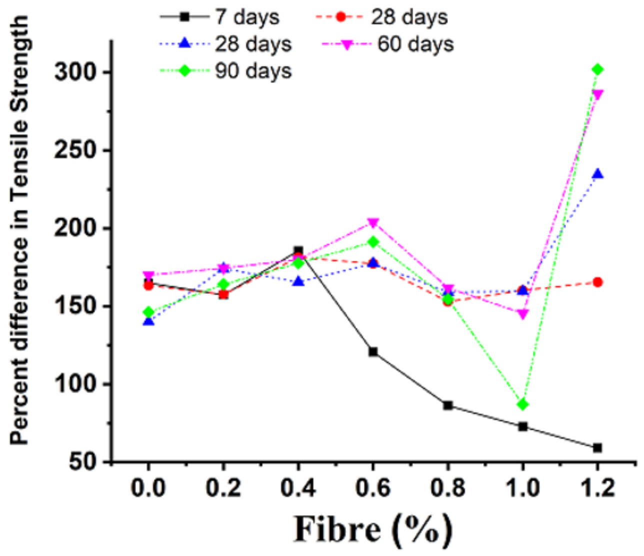

Figure 8: Tensile performance of concrete with TOPEFB fibres relative to OPEFB fibres (in percent)

Similarly, at 90-day, the developed tensile strengths for samples with TOPEFB fibres were approximately 15%, 160%, 170%, 190%, 150%, 80% and 300% higher than samples with OPEFB fibres. This was the pattern at all the curing ages for all the fibres addition considered. The reasons for the improved tensile performance of OPEFB fibres cannot be far-fetched looking at Tables 3 and 4. Form Table 3, it can be seen that the tensile properties (tensile strength and young's modulus of elasticity) of TOPEFB fibres recorded higher values than untreated fibres. Similarly, in Table 4, properties like cellulose and hemi-cellulose were higher in values for the TOPEFB fibres than for the OPEFB fibres. According to Mazlan et al. (2020), the presence of cellulose and hemi-cellulose in palm oil empty fruit bunch waste increases the compressive and tensile strength of mortars. Thus, the overall effects of the higher values of tensile properties obtained for the TOPEFB fibres are improved tensile strength development.

3.7 *Implication of Usage of Fibres in Concrete*

Implementation of TOPEFB fibres for concreting will require adjustment to the mix design and little additional working space for the production of concrete. The latter involves treating the fibres as one of the ingredients to be batched into the concrete mixer, just like cement, aggregates and water, as in the normal concrete production practice. This leads to the second consideration, which is the production of the fibres at a location, either on the construction site, or at the oil palm industry where it is regarded as waste. Wherever the location is, space for the following processes is required. These processes are: (i) extraction of fibres and cutting into appropriate length, (ii) alkaline treatment of fibres. This will require the erection of a treatment bath (akin to curing tank for concrete specimens used for quality controls on site) of suitable size for alkali treatment of the fibres. The curing tank can even be used for this purpose prior to casting and curing concrete specimens through careful planning. This will require that the curing bath be washed with water to remove the alkali; (iii) drying of the wet fibre, and (iv) storage of dried treated fibres and ready to be batched with other ingredients for concrete production into the concrete mixer. All these four stages can be established easily and at minimal cost, without high level technology. Practical implementation of scheme involving TOPEFB will also be beneficial to the society in relation to: (i) helping to generate a clean and wholesome environment (ii) enhancing sustainability in concrete production by reduction in the aggregate volume of the materials consumed and (ii) helping to release the land previously used as dump site for other economic and developmental purposes; amongst others.

4 CONCLUSIONS

Considering the analysis that was carried out on the results of this investigation, the followings conclusions can be made.

1. Alkaline treatment OPEFB fibres increased their tensile properties by approximately 8%.
2. The setting times of mortars containing TOPEFB fibres were higher than that of mortars with untreated fibres.
3. Concrete specimens with TOPEFB fibres are more workable than concrete specimens with OPEFB fibres
4. The densities of concrete specimens containing OPEFB fibres were in the range for normal concrete applications (2350 to 2450 kg/m^3) while the densities for specimens with TOPEFB fibres developed densities that fell in the heavy weight concrete classification (> 2500kg/m^3).
5. Concrete specimens containing TOPEFB fibres developed better compressive strength development than specimens with OPEFB fibres.
6. Tensile strengths of concrete specimens containing TOPEFB fibres were at least 15% higher than specimens with OPEFB fibres.

Although, findings from this investigation *prima facie* supported the fact of improved structural performance of concrete specimens containing TOPEFB fibres over the specimens with the OPEFB ones, there are still other important properties that are necessary to be investigated so as to understand its whole structural performance. For example, bending and shear responses as well as durability performance of treated fibres of concrete specimens with TOPEFB fibres are some of the properties that ought to be investigated. These are thus recommended for further investigations.

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