EVALUATION OF STRUCTURAL PERFORMANCE OF CONCRETE WITH OPC FRACTION PARTLY REPLACED BY EMPTY PALM OIL BRUNCH ASH (EPO-FBA)

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Abstract: Continuous research into the possibility of discovering new material that is fit or can be made fit for use, in structural concrete, is necessary in the quest to attain sustainability in structural concrete production and practice. The results of investigation conducted to assess the structural performance of concrete with ordinary Portland cement (OPC) fraction partly replaced by empty palm oil brunch ash (EPO-FBA) are presented in this paper. The properties assessed are: consistency, setting times of paste with EPO-FBA. Others are workability, density, compressive and tensile strength of concrete specimens containing EPO-FBA. All investigations were conducted in accordance with relevant international standards. The results showed that (i) specimens containing EPO-FBA requires higher water demand to attain standard consistency, (ii) specimens with EPO-FBA were cohesive concrete, but with low workability, (iii). Densities of samples with EPO-FBA are in the ranges meant for normal structural concrete application, (iv) though the compressive strength of concrete with EPO-FBA decrease with increasing content of EPO-FBA, usage up to 10% replacement value of ordinary Portland cement developed compressive strength comparable to the control. Expressions developed relating the splitting tensile strength to the compressive strength showed a very good correlation.

Keywords: Compressive strength, empty palm oil brunch ash, tensile strength

Introduction

It is now well-documented that concrete is one of the most widely used construction material in the world (Naik and Moriconi, 2008). In addition to the fact that it is a strong and durable material, availability of raw materials for its production, flexibility in the composition of its mix design, and ability to be formed into various shapes are some of the reasons for its primacy. However, extensive and massive use of raw non-renewable natural resources and materials, like cement, sand, gravel, etc. that go into its production is raising concerns of its sustainability. In particular, the contribution of the cement industry to the global emission of greenhouse gases, especially CO_2, is 8 - 10% (Mehta, 2002; Sudendro, 2014). The industry is also the third most energy-intensive in energy consumption (Shafigh, *et al*., 2014). All these raise serious challenges to the sustainability of built environment, that engineers are being called upon to confront and suggest possible solutions in the interest of the profession, the society and future generations (Ochsendorf, 2008).

Thus, continuous research into the possibility of discovering new material that is fit, or can be made fit for use, in the production of structural concrete, is necessary in the quest to attain sustainability in structural concrete production. Suitable materials, as alternatives to cement, have been discovered and are being discovered by researchers, especially from both industrial and agricultures wastes. Some of them are: silica fume (Yilmaz, 2010; Le *et al*., 2014), ground granulated blast furnace slag (Bleszynski *et al*., 2002; Anwar and Yamada, 2007), rice husk ash (Mehta, 1992; Foong *et al*., 2015; Swaminathen and Ravi, 2016), fly ash (Thomas, 2007), palm oil fuel ash (Abdullah *et al*., 2006), etc.

In the present work, the possibility of using empty palm oil fuel brunch ash (EPO-FBA) as supplementary cementing material (SCM) in concrete is investigated. The palm oil industry generates many wastes, of which one of them is the empty palm oil fruit brunch. This is the residue remaining, after the mesocarp and kernel of the palm fruit oil are removed (Fig. 1). Its presence presently constitutes environmental nuisance, as no disposal method has been found. Thus, making it fit for usage in concrete production will help in the protection of the environment by conserving the natural resources for cement, and also enable the civil/structural engineer affirm its commitment to sustainable practices in structural concrete.

a) A Single Empty Bunch **b) Heap of Empty Brunch**

Fig. 1: Empty palm oil fruit brunch

There is a dearth of literature on the use of EPO-FBA in concrete. Although, Fapohunda and Shittu (2017) had researched into the possible use of EPO-FBA as partial replacement of cement in concrete, their work was of limited scope, making it impossible to get a whole picture of the structural response of the use EPO-FBA in concrete. For example, only the chemical analysis of EPO-FBA and the compressive strength of mix with EPO-FBA for only the latter age curing days of 60, 75 and 90 days were considered. There is difficulty in gaining a greater knowledge of behaviour of EPO-FBA in concrete, so as to optimise its use in the concrete design. Without 28 days strength, the results seem to lack any structural value, for 28 days strength is what is used in the design of structural concrete in codes and standards (Bamforth *et al*., 2008). Thus, the aim is this work is to assess the effect of EPO-FBA on the structural performance of concrete in with the ordinary Portland cement portion had been partly replaced with EPO-FBA. Specific properties of concrete specimens with EPO-FBA to be investigated are: consistency, setting times, workability, density, compressive strength, splitting tensile strength. The ratio of tensile strength to the compressive strength as well as development of expression between them will be carried out.

Materials and Methods

Materials

The materials used for this experimental investigation are: ordinary Portland cement (OPC), empty palm oil fruit brunch ash (EPO-FBA), fine aggregate, coarse aggregate and potable water. The ordinary Portland cement used was 42.5 grade satisfying the requirement of requirements NIS 444 (2014) and BS EN 197-1 (2000). In order to obtain the empty palm oil fruit brunch ash (EPO-FBA), empty palm oil fruit brunches (Fig. 1) were collected from palm oil industries in Ikole-Ekiti, Nigeria. The brunches were sun-dried, pulverized and burnt through open burning process so as to obtain the ash, which was bagged and stored in a cooled place. The fine aggregate used was sand which was obtained from a sand deposit at a location called Oko-Ootunja, near Ikole-Ekiti, Nigeria. In order to meet the requirement of BS EN 12620:2002+A1 (2008), the sand was dried and sieved through sieve size 2.36 mm. An active quarry in Ikole-Ekiti, Nigeria, served as the source of the coarse aggregate used for this investigation. The sizes ranged from 4.75 mm to a maximum of 20 mm according to the limits of aggregate for structural concrete by BS 8110 (1997). Potable water, satisfying the requirement of ASTM 1602 (2012) was used for this investigation.

Mix proportion, design and concreting

For the purpose of this investigation, a mix proportion of 1: 2: 4 was chosen with the water cement ratio of 0.5. These values were chosen to align with practice in Nigeria. The EPO-FBA was used to replace the cement fraction of the mix up to 15% at interval of 5%. This limit was set because observations from Fapohunda and Shittu (2017) had showed that, beyond 15% replacement values, the strength development was very low. On the basis of this, the mix proportion shown in Table 1 was arrived at.

Table 1: The mix proportion used for the investigation

% EPO-FBA in the Mix	Mix Designation	Binder (kg/m^3)		Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)
		Cement	EPO-FBA			
0	M_0	11.60	0.00	23.14	46.28	5.79
5	M_5	11.02	0.58	23.14	46.28	5.79
10	M_{10}	10.44	1.16	23.14	46.28	5.79
15	M_{15}	9.86	1.74	23.14	46.28	5.79

Concrete ingredients were batched by weight, thoroughly mixed, cast into moulds (150 x 150 x 150 mm cubes for compressive test specimens and 150 x 300 mm cylinders for splitting tensile test specimens) and properly compacted. The specimens were left in the moulds for 24 hrs, de-moulded, and then placed in curing tank for curing process. The concrete specimens were moist cured, until the day of testing. The testing days were 7, 14, 28, 60 and 90 days. The specimens without EPO-FBA served as the control.

Experimental procedures

Preliminary investigations

Preliminary investigations were carried out to characterize the materials used for this investigation. This involved determination of some physical properties of the aggregates used. The properties are: specific gravity, moisture content, water absorption, dry density, bulk density and sieve analysis.

Main investigations

Consistency test

In order to determine the quantity of water required to achieve a paste of normal consistence, consistency test was performed in accordance with BS EN 196-3 (2005) by using the Vicat probe and the Vicat needle apparatus. The cement constituent of the mix was partially replaced by EPO-FBA up to 15% by weight at interval of 5%. The water demand for zero replacement of cement with EPO-FBA serves as the control.

Setting times

The water required to achieve the standard consistency of cement paste at zero percent EPO-FBA, as determined from the consistency test in accordance to BS EN 196-3 (2005), was used to evaluate the effect of EPO-FBA on the setting times (initial and final) of cement paste. The setting times – both initial and final – were then determined at the cement replacement value with EPO-FBA up to 15% at the interval of 5%.

Workability

Slump test was carried out to determine the ease and homogeneity with which freshly mixed concrete with EPO-FBA can be mixed, placed, consolidated and finished. This is called workability as per ACI 116R-90 (1994). The experiment was conducted in accordance with the provisions of BS EN 12350: Part 2 (2000).

Density and compressive strength

The density and the compressive strength of concrete specimens containing EPO-FBA were assessed using 150 x 150 x 150 mm cube specimens. Densities determination was done in accordance to the provisions of BS 12350: Part 6 (2000). The determination of the compressive strengths was done in accordance to the provisions of BS EN 12390-3 (2009). The compressive strength was determined with a 2000KN WAW-2000B computerized electrohydraulic servo universal testing machine with accuracy of ± 1% of test force. At each curing age, three specimens were tested, and the average used to evaluate the mean strength. Prior to testing on the testing day however, the concrete cube specimens were the weighed and the values obtained were subsequently used to calculate the density of the concrete cube specimens.

Splitting tensile strength

Concrete cylinder specimens were used to determine the strength in tension of concrete samples with EPO-FBA as partial replacement of ordinary Portland cement. The splitting tensile strength test was conducted by using cylinder moulds 150 x 300 mm. The test was done in accordance to the provision of BS 12390: Part 6 (2009) using 2000KN WAW-2000B computerized electrohydraulic servo universal testing machine with accuracy of ± 1% of test force. The splitting tensile strength (Ts) was calculated using equation 1.

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

Where: *Ts* is the splitting tensile strength (N/mm^2), P is the maximum applied load (in Newtons) by the testing machine, l is the length of the specimen (mm), and d is the diameter of the specimen (mm).

Results and Discussion

Some physical properties of aggregates used

The properties of the sand and coarse aggregates, as obtained from the preliminary investigation are presented in Table 2.

Table 2 reveals that that the values obtained for weight-based properties like: specific gravity, dry density and bulk density for coarse aggregates were respectively higher than the values obtained for sand. It can also be seen from Table 2, that the calculated values coefficient of curvature or gradation and the coefficient of uniformity using equations 2 and 3 obtained from the results of mechanical analysis were 1.72 and 4.75 for the coarse aggregates.

$$C_c = \frac{D_{30}\ x\ D_{30}}{D_{60} D_{10}} \quad \textbf{(2)}$$

$$C_u = \frac{D_{60}}{D_{10}} \quad \textbf{(3)}$$

The values recorded for sand were 1.14 and 6.70. According to Terzaghi *et al*. (1996), a well graded aggregate that will guarantee adequate compaction will have C_c value between 1 and 3, and C_u greater than 4 for coarse aggregates. For sand, the C_c will be between 1 and 3, and a C_u greater than 6. Both the sand and the coarse aggregate satisfy these conditions. In addition, the fineness modulus of the sand is 2.62. This value satisfies ASTM C 33 (1997) specifications for fine aggregates of between 2.3 and 3.1. With these properties, both the coarse aggregates and sand in this investigation are suitable for the production of structural concrete.

Table 2: Some physical properties of aggregates used

Properties	Coarse Aggregates	Sand
Bulk Density (kg/m^3)	1779.02	1387.79
Dry Density (kg/m^3)	1702.89	1501.60
Specific Gravity	2.64	2.60
Moisture Content (%)	3.87	6.07
Water Absorption Capacity (%)	3.75	3.59
Coefficient of Curvature (C_c)	1.72	1.14
Coefficient of Uniformity (C_u)	4.75	6.70
Fineness Modulus	-	2.62

Table 3: Oxide composition of empty palm oil fruit brunch ash (EPO-FBA)

Oxide	EPO-FBA	OPC
CaO (%)	19.01	64.37
SiO_2 (%)	6.42	20.68
Fe_2O_3 (%)	6.64	3.62
MgO (%)	4.10	1.81
Al_2O_3 (%)	12.70	5.41
SO_3 (%)	1.42	1.03
Na_2O (%)	7.25	0.51
K_2O (%)	1.86	0.47
LOI (%)	40.60	0.39

Chemical composition

Table 3 contains the oxides composition of EPO-FBA, in relation to that of ordinary Portland cement, from the results of chemical analysis.

From Table 3, it can be observed that the total sum of SiO_2+Al_2O_3+Fe_2O_3 is not up to the value that could permit classification into the categories of fly ash as per ASTM C 618 (2005). Also, the loss of ignition (LOI) present in the EPO-FBA is far greater than the LOI present in the cement. The loss on ignition, a measure of the extent of carbonation and hydration of free lime and free magnesia due to atmospheric exposure (Neville, 2011), of EPO-FBA is 40.60%. This value is far greater than the limits of 5.0% set by BS EN 197-1:2000. The loss on ignition is high, as it could not prevent EPO-FBA from being hydraulic. For example, the work of Day (1990) contained a list of about 538 pozzolans. Many of them had LOI as high as EPO-FBA and had the sum of SiO_2+Al_2O_3+Fe_2O_3 that did not fall into ASTM C 618 (2005). Yet they were classified as pozzolans because of performance-based cementitious properties. It is also worthy of note that lime stone powder (LSP) was found to have high LOI by Le *et al*. (2014), yet it still performed satisfactorily. This is because of the fact that hydrated free lime is innocuous, for a given free lime content of cement; a greater loss on ignition is really advantageous (Neville, 2011). The high alkali (K_2O and Na_2O) value (9.11%) raises concerns about possible alkali-aggregate reaction if used in concrete without mitigating measures.

Consistency and setting times

Table 4 is the summary of the results of tests on the standard consistence and setting times of EPO-FBA. The consistency of the ordinary Portland cement was determined to be 27%, and thus falls within the usual range of values being between 26 and 33 per cent (Neville, 2011).

However, the water content that will produce the desired consistency of paste containing EPO-FBA increased with increase in the EPO-FBA content. These results indicated that more water will be required to obtain consistence mix, when used in concrete. Unless high water cement-ratio is used, mix containing EPO-FBA may lead to harsh mix and hydration process may stop prematurely leading to reduced strength. Table 4 also shows both the initial and final setting times of paste with and without EPO-FBA. The specimens met the minimum initial setting times of 60 minutes prescribed by BS EN 197-1 (2000) for cement with strength 42.5MPa. Although, limits on the final setting time no longer appear in the European or ASTM standards (Neville, 2011), the final setting times determine agreed with the values obtained using expression developed by Americans for determining the final setting time in equation 4.

$$\text{Final setting time (min)} = 90 + 1.2 \times \text{initial setting time (min)} \quad (4)$$

The numerical difference of less than 10% between the obtained values and the one obtained using equation 4 suggest a close agreement.

Table 4: Consistency and Setting Times of EPO-FBA

Mix Designation	Consistency (%)	Setting Times (min)		Equation 2	% Difference
		Initial	Final		
M_0	27	80	180	186	+ 3. 23
M_5	32	80	190	186	- 2.15
M_{10}	34	70	165	174	+ 5.17
M_{15}	39	70	160	174	+ 8.05

Table 5: Effect of EPO-FBA on the Workability of Concrete Specimens

Mix Designation	Slump	Type	Workability
M_0	30	TRUE	Low
M_5	20	TRUE	Low
M_{10}	20	TRUE	Low
M_{15}	20	TRUE	Low

Workability

The results of the slump test conducted to determine the ease and homogeneity with which freshly mixed concrete with EPO-FBA can be mixed, placed, consolidated and finished, as per ACI 116R-90 (1994), the phenomenon described as workability are presented in Table 5.

It can be observed in Table 5 that the slump value decreased in relation to the control but remain constant at 20 mm, at all the replacement values of content with EPO-FBA. Similar low slump values were reported by earlier work of Fapohunda and Shittu (2017). The numerical slump value of 20 mm, according to Neville (2011) translates to concrete with low workability. Despite the harshness of the mix occasioned by low workability, all the specimens displayed true slump. True slump of the specimens, according to Shetty (2009), means that the cohesiveness of the mix was not disrupted and without segregation (Shetty, 2009). Gambhir (2013) suggested that concrete with low workabilities, in the manner displayed by concrete specimens with EPO-FBA, can be employed in lightly reinforced structural concrete sections of slabs, beams, walls, column, strip footings with substructure walls, hand placed pavement and for mass concrete.

Density

How a material affects the density of concrete in which it is used will give a direction on how it is to be applied in practical terms. In the design of structural concrete, three categories of densities are recognized (ACI 213, 2003; Falade *et al*., 2011), namely: (i) lightweight concrete with densities less than 2200 kg/m^3, (ii) normal weight concrete with densities ranging between 2200 – 2550 kg/m^3 and (iii) heavy weight concrete have densities greater than 2550 kg/m^3. From the results of densities of the concrete specimens presented in Table 6, it can be observed that the densities are between 2406 and 2510 kg/m^3.

Table 6: Effect of EPO-FBA on densities of concrete specimens

Mix Designation	Curing Age (days)				
	7	14	28	60	90
M_0	2442 (± 30.54)	2483 (± 28.76)	2489 (± 21.22)	2510 (± 25.22	2486 (± 30.76)
M_5	2418 (± 29.11)	2483 ± 29.12)	2483 (± 30.33)	2501 (± 27.45)	2492(± 30.11)
M_{10}	2415 (± 30.01)	2433 (± 31.17)	2474 (± 32.13)	2462 (± 28.67)	2483(± 29.34)
M_{15}	2406 (± 29.01)	2424 (± 32.11)	2474 (± 31.78)	2456 (± 30.11)	2489 (± 28.89)

What this suggests is that concrete containing EPO-FBA can be used for normal structural concrete applications.

Compressive strength

The effects of EPO-FBA on the compressive strength development of concrete specimens are shown in Fig. 2. From the Figure, two observations can be made.

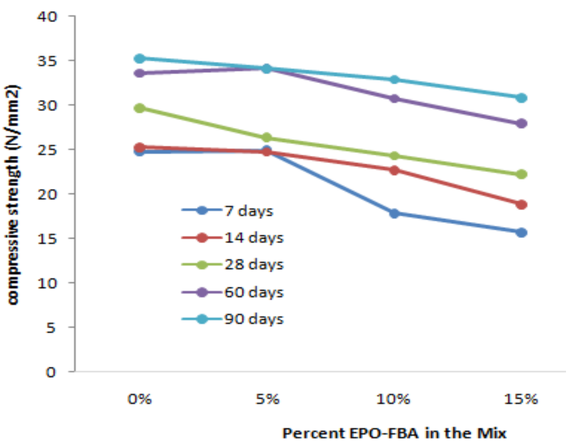


Fig. 2: Effect of EPO-FBA on the compressive strength of concrete specimens

First, the compressive strength increased with curing days. This is a well-established pattern in concrete technology, if hydration process is undisturbed. Continue hydration means that the production of the strength forming C-S-H gel, which is the product of hydration, is undisturbed, leading to progressively higher strength. Secondly the compressive strength decreased with increase in the percent replacement of cement with EPO-FBA. Slow strength development, in relation to the control samples, is typical of pozzolanic materials (Thomas, 2007). This is because of the fact that hydration of cement has to come first to produce $Ca(OH)_2$ as a by-product before pozzolanic action can be initiated as per equation 5.

$$\text{Pozzolans} + Ca(OH)_2 \rightarrow \text{C-S-H gel} \qquad (5)$$

However, considering the performance criterium, through strength activation index (SAI), as a way to determine the pozzolanicity of EPO-FBA, the results are shown in Table 7. According to ASTM C 618-08 (2008), a material is pozzolanic if the compressive strength of the blended concrete sample at 7-day or/and 28-day is not less than 75% of the compressive strength of the control specimens.

Table 7: Potential of EPO-FBA as pozzolanic potentials of the samples

Mix Designation	Compressive strength, CS (N/mm^2) and strength activation index, SAI									
	Curing Age (days)									
	7		14		28		60		90	
	CS	SAI (%)	CS	SAI (%)	CS	SAI (%)	CS	SAI (%)	CS	SAI
M_0	24.84	100.00	25.34	100.00	29.78	100.00	33.61	100.00	35.28	100.00
M_5	24.96	100.48	24.82	97.95	26.42	88.72	34.12	101.52	34.11	96.68
M_{10}	19.82	**79.79**	22.71	89.62	24.38	**81.87**	30.75	91.49	32.90	93.25
M_{15}	15.82	63.69	18.85	74.39	22.24	74.68	27.51	81.85	30.84	87.42

It can be observed in Table 7 that the compressive strength at 10% cement replacement with EPO-FBA, the strength development was at least 75% of the control, at both 7 and 28 days. At higher curing ages of 60 and 90 days, all the specimens developed strength greater that 75% of the control. The long-term improvement in the strength development of the specimens is characteristic of pozzolans. Pozzolanic action is a process that consumes $Ca(OH)_2$ from cement hydration. Thus, it will not commence without cement hydration, and it continues as long as $Ca(OH)_2$ is available to be consumed. As can be seen in Figure 3, there is progressively improvement in strength development with age. This is in agreement with Thomas (2007), that long-term strength development is improved, when pozzolans is used, and at some age the strength of the concrete specimens with pozzolans will equal that of the control concrete specimens so long as sufficient curing is provided. It can however be concluded that, the optimum use of EPO-FBA is at 10% replacement level.

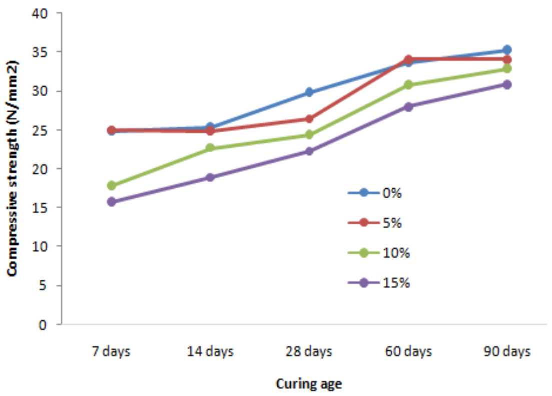


Fig. 3: Effect of curing age on strength development of samples with EPO-FBA

Tensile strength

The effect of EPO-FBA on the strength of concrete samples in tensile, assessed through splitting tensile strength, at 28 and 90 days of curing, is presented in Fig. 4. According to Bamforth *et al*. (2008), the knowledge of tensile strength is necessary in the design of structural concrete for both serviceability and ultimate limit state calculations, in the following situations: (i) considerations of cracking, shear, punching shear, bond and anchorage, (ii) the design of reinforcement to control crack width and spacing resulting from restrained, in (iii) deflection calculations, etc.

It can be observed in Fig. 4 that the splitting tensile strength followed the pattern of the compressive strength in that it reduced as the percent replacement of cement with EPO-FBA was increased.

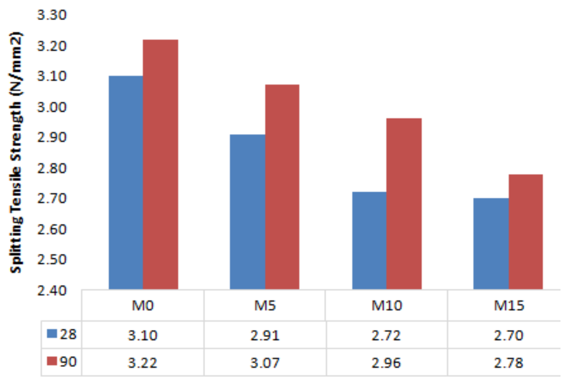


Fig. 4: Effect of EPO-FBA on the tensile strength of concrete specimens

Table 8: Effect of EPO-FBA on strength ratios of the samples

Mix Designation	28-day (N/mm^2)		90-day (N/mm^2)		Ratio $\kappa = \frac{f_t}{f_c}$	
	f_t	f_c	f_t	f_c	28-day	90-day
M_0	3.10	29.78	3.22	35.28	0.104	0.091
M_5	2.91	26.42	3.07	34.11	0.110	0.090
M_{10}	2.72	24.38	2.96	32.90	0.112	0.090
M_{15}	2.70	22.24	2.78	30.84	0.122	0.090

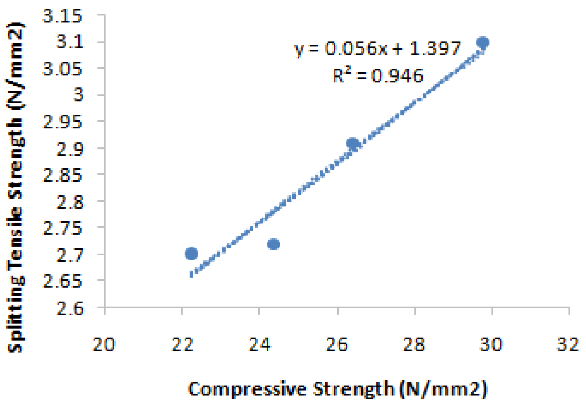
Relationship between compressive strength and splitting tensile strength

According to Bamforth *et al*. (2008), relationship information between tensile and compressive strength for a particular concrete for comparison with that given in BS EN 1992-1-1 (2004) is necessary in the design of structural concrete. The effect of EPO-FBA on the ratio (**κ**) of splitting tensile strength to the compressive strength is shown in Table 8.

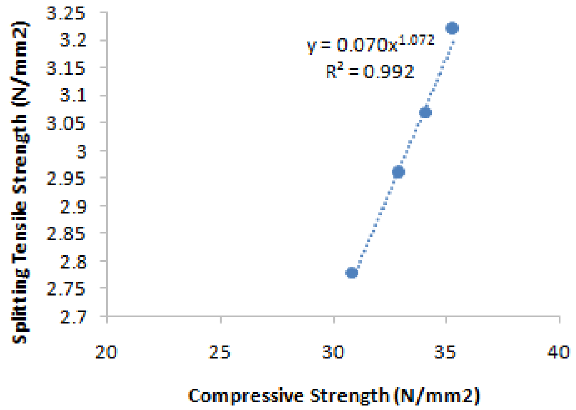
At 28 days of curing the BS EN 1992-1-1 (2004) expects a splitting tensile strength of 2.5 – 2.8 N/mm^2 consistent with the compressive strength developed. From Table 8, the minimum value obtained at 15% replacement cement with EPO-FBA was 2.70 N/mm^2. According to Bamforth *et al*. (2008), the higher splitting tensile strength may require increase in the minimum steel ratio to accommodate the higher stress transferred to the steel when a crack occurs and a higher binder content and hence higher temperature rise and thermal strain. It can also be seen that the strength ratio increased with EPO-FBA at 28 days of curing but decreased to a constant value at 90 days. This can only suggest that splitting tensile strength increases at a decreasing, in relation to the compressive strength, rate at higher curing ages. For the purpose of quality control in structural concrete, since compressive strength can be measured easily than tensile strength in the field (Neville, 2011), it is usual to develop expression relating the tensile strength to the compressive strength. This will make estimation of field tensile strength possible. In order to obtain relationship between the splitting and compressive strengths of mix with EPO-FBA, the strengths results were plotted in scattered diagrams (Figure 5) and analysed statistically by performing regression analysis. In other to obtain numerical relationships between: (i) the splitting tensile strength and compressive strength a statistical model of the form in the equation 6 was adopted:

$$f_t = A f_c B, \qquad (6)$$

Where: ft is the tensile strength, fc is the compressive strength, while A and B are non-dimensional coefficients. The adoption of the power equation of the form of the equation 6 is because expressions relating tensile strength to compressive strength in concrete industry are usually expressed in the similar form (Oluokun, 1999; Arıoglu *et al*., 2006; Mhaiskar and Naik, 2012).



(a) 28-day (Linear)



(b) 90-day (Power)

Fig. 5: Relationship between splitting and compressive strengths of concrete samples with EPO-FBA

The regression analysis showed that at 28-day curing, the relationship between the splitting tensile strength and the compressive strength will best be represented by a line expression given by:

$$f_t = 0.06 f_c + 1.4 \qquad R^2 = 0.9460 \qquad \textbf{(7)}$$

For the mix at 90-day however, the regression analysis showed that the expression can better be represented by a power expression given by:

$$f_t = 0.07 f_c^{1.07} \qquad R^2 = 0.9923 \qquad \textbf{(8)}$$

Where f_t = splitting tensile strength and f_c = cube compressive strength.

The respective form of the equations showed a high correlation coefficient. For example, at 28-day, about 95% of the test data correlated to the regression equation (equation 7), while at the 90-day, it was 99% (equation 8).

Conclusion and Recommendation

From the analysis of the results of this investigation, the followings conclusions can be made:

1. Specimens containing EPO-FBA requires higher water demand to attain standard consistency.
2. The use of EPO-FBA resulted in cohesive concrete, but with low workability.
3. The densities of samples with EPO-FBA are in the ranges meant for normal structural concrete application
4. The compressive strength of concrete with EPO-FBA decrease with increasing content of EPO-FBA. However, optimum usage is at 10% replacement value of ordinary Portland cement
5. The tensile strength of concrete specimens with EPO-FBA decreased with increase in the percent replacement of cement with EPO-FBA.
6. The developed relationship between the splitting tensile strength and the compressive strength showed a very good correlation, and thus can be used as a form of quality control on the site where EPO-FBA is used in the concrete mix.

From the perspective of the objectives set out to accomplish, as stated in the concluding part of the Introduction, there is no doubt that a better understanding of the fundamental structural behavior of EPO-FBA can be observed in this investigation. Not only that, this investigation reveals that EPO-FBA can be used as partial replacement of ordinary Portland cement up 10% in the production of structural concrete without suffering loss of structural integrity. This is a positive preliminary investigation to encourage researches into other areas not yet covered, but very relevant to structural concrete. This includes, but not limited to, the flexural characteristics and associated properties like crack (initiation, propagation, widths, etc.), stiffness; bond performance; shear properties; etc. In the design of structural concrete, especially according to the limit state method, the standards (BS 8110 and Eurocode), place same emphasize on both the strength and serviceability issues, especially the durability of structural concrete during the service life in the domiciled area. All these are therefore recommended for further investigation.

Acknowledgement

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Conflict of Interest

The authors declare that there is no conflict of interest related to this study.

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