MICROSTRUCTURE AND DURABILITY PERFORMANCE OF CONCRETE CONTAINING EMPTY PALM OIL FRUIT BUNCH ASH AS PARTIAL REPLACEMENT OF ORDINARY PORTLAND CEMENT

BY

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A Project Report Submitted To The Department Of Civil Engineering, Federal University Oye Ekiti, In Partial Fulfilment Of The Requirement For The Award Of The B. Eng. (Hons) In Civil Engineering.

Department Of Civil Engineering
Faculty of Engineering

2019

ABSTRACT

The production of concrete as a civil engineering material is highly dependent on the availability of its constituent materials. However, most of these materials are no more readily available. In order to solve this problem, many researches has been carried out on the use of agricultural waste as construction material, one of this material is Empty Palm Oil Fruit Bunch Ash (EPO – FBA). (EPO – FBA) is an agricultural waste material which is gotten after burning empty palm oil fruit bunch. They are generally disposed to open fields causing environmental pollution problems. Due to its abundance and pozzolanic properties, many researchers have evaluated its potential as a construction material. This research work reports the investigation carried out to determine the microstructure and durability performance of concrete containing Empty Palm Oil Fruit Bunch Ash (EPO – FBA) as partial replacement of Ordinary Portland Cement (OPC). The study employed different mix proportions which resulted in casting and testing of concrete cubes at 7, 14, 28, 60, and 90-days of curing inside which replacement of Portland cement with EPO-FBA were carried out up to 15% by weight at interval of 5%. Preliminary tests like chemical analysis, Fineness, consistency and Setting time were carried out to compare OPC and EPO – FBA. The structural parameters investigated were: workability, density and compressive strength. Slump test was used to assess the workability, while 150 x 150 x 150mm concrete cube specimens were used to assess the density and compressive strength characteristics. The microstructure of 28days crushed samples was also analysed using scanning electron microscope and in addition to this, durability performance was also checked by testing the sorptivity and water absorption of 100 x 100 x 100mm concrete cube specimen. At the end of the study, result showed that the workability of concrete specimen with EPO-FBA as partial replacement of OPC reduces with increasing quantity of EPO-FBA. The density of concrete samples with EPO-FBA falls to the class of normal weight concrete with values ranging between $2459 kg/m^3$ - $2406\ kg/m^3$ which tallies with the standard density of concrete ($2400 kg/m^3$). The morphology of concrete specimen showed that EPO-FBA produces little effect on the microstructure of concrete samples at later ages (28 days). However, the compressive strength developed by the concrete specimen at 5% replacement of OPC with EPO-FBA showed a minute and negligible difference from that of control samples. The sorptivity and water absorption properties which was used to quantify the durability of concrete containing EPO-FBA increases with increasing quantity of EPO-FBA.

AKNOWLEDGEMENT

First and foremost, I return all glory to God almighty who gave me the grace and the privilege to carry out this study in peace and not in pieces. I really appreciate my project supervisor, Dr. C.A. Fapohunda for giving me the opportunity to review the works on this topic, for his assistance, supervision, moral support and all other things I have gained and learned through him. Also, my appreciation goes to the departmental laboratory and workshop for giving me the privilege to carry out my practical works and for giving me access to all available equipment and materials. I say thank you to my Landlord, Mr. Awoyemi for giving me the chance to pack the required materials from his farmland. I will never forget to mention my project colleagues in the name of Oluwasegunota Olawale, Daramola Damilola David, Adigun Olumide, Opasina Collins and my dearest Ogunniyi Oladimeji for their support and team work in all aspect throughout the course of the study. Finally and most importantly, my sincere gratitude goes to all members of my family for their full support financially, emotionally, morally and mentally. I say thank you to all of you and God bless you.

DEDICATION

I dedicate this study to God Almighty my creator, my strong pillar, my source of wisdom, knowledge and understanding and also to my family who has always been my source of inspiration.

CERTIFICATION

This is to certify that this Project was written by BABATOLA AYOTUNDE OLUMIDE (CVE/13/1054) under my supervision and is approved for its contribution to knowledge and literary presentation in partial requirements for the award of Bachelor of Engineering (B.Eng.) degree in Civil Engineering, Federal University Oye Ekiti.. All sources of information are specifically acknowledged by means of references

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LIST OF ABBREVIATIONS

EPO-FB	Empty Palm Oil Fruit Bunch
EPO-FBA	Empty Palm Oil Fruit Bunch Ash
OPC	Ordinary Portland Cement
POFA	Palm Oil Fuel Ash

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CHAPTER ONE

INTRODUCTION

1.1 General Background

1.1.1 Concrete

Concrete is a composite material which is essentially made of a binding medium (Mixture of cement and water) within which are embedded particles of aggregate, usually a combination of fine (sand) and coarse (gravel or crushed stone) aggregate. When these ingredients are mixed together, they form a fluid mass that is easily molded into shape. Over time, the cement form a hard matrix which binds the rest of the ingredients together into a durable stone – like material with many uses.

The aim is to mix these materials in measured amounts to make concrete that is easy to: Transport, place, compact, finish and which will set, and harden, to give a strong and durable product. The amount of each material (i.e cement, water and aggregates) affects the properties of hardened concrete.

1.1.2 Composition of Concrete

A good quality concrete is essentially a homogenous mixture of cement, coarse, fine aggregate and water which consolidates into a hard mass due to chemical action between the cement and water. Concrete is mainly composed of cement, water, fine and coarse aggregate and at times some materials called admixtures which are added to concrete in order to alter its physical properties. Each of the constituent of concrete has its function which provide the end result and properties of concrete. In concrete, cement acts as "glue" that binds the concrete ingredients together and is very important for the strength of the composite. There are many different kinds of cements. But the most commonly used is Portland cement. Portland cement is an hydraulic cement which sets and hardens by chemical reaction with water and is capable of doing so under water. Coarse aggregate e.g gravel act as the main load bearer in the concrete mass. Fine aggregate e.g sand act as filler which fills up the empty pores created by the coarse aggregate in order to avoid porosity.

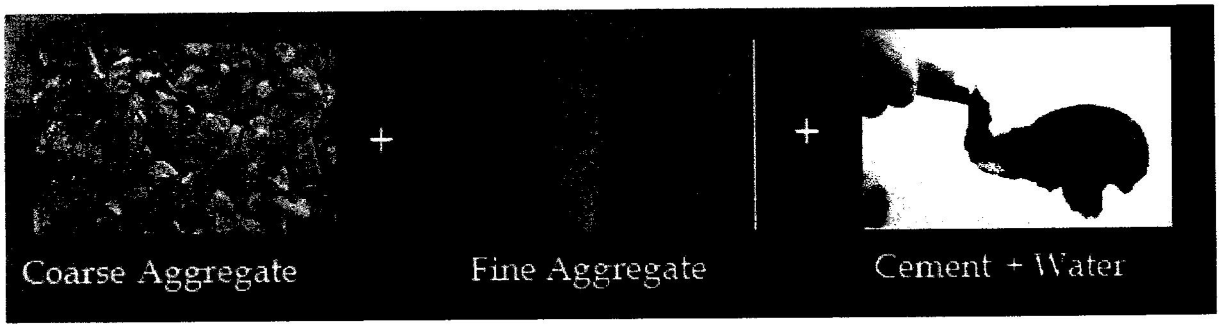

Figure 1.1: Composition of concrete

1.1.3 Types of Concrete

Over the years, progress has been made on concrete technology and therefore, a different type of concrete has been achieved;

1.0 Plain or Ordinary concrete
2.0 Air entrained concrete
3.0 Lightweight concrete
4.0 High density concrete
5.0 Reinforced concrete
6.0 Precast concrete
7.0 Pre-stressed concrete etc.

1.1.4 Production of Concrete

The stages of concrete production are: Batching or measurement of materials, Mixing, Transporting, Placing, Compacting, Curing and Finishing.

1) **Batching:** Batching is the process of measuring concrete mix ingredients either by volume or by mass and introducing them into the mixture. Traditionally, batching is done by volume but most specifications require that batching be done by mass rather than volume.
2) **Mixing:** The mixing operation consists of rotation or stirring, the objective being to coat the surface of all the aggregate particles with cement paste, and to blind all the ingredients of the concrete into a uniform mass. The mixing may be done manually or by mechanical means like batch mixer, Tilting drum mixer etc.
3) **Placing and Compacting:** The main objective is to deposit the concrete as close as possible to its final position so that segregation is avoided and the concrete can be fully compacted. The operation of placing and compaction are independent and are carried

out simultaneously. They are most important for the purpose of ensuring the requirement of strength, impermeability and durability of hardened concrete in the actual structure.

4) **Curing and Finishing:** Curing is the process of making the concrete surfaces wet for a certain time period after placing the concrete so as to promote the hardening of cement. This process consists of controlling the temperature and the movement of moisture from and into the concrete. Curing of concrete must be done as soon as possible after placement and finishing and must continue for a reasonable period of time, for the concrete to achieve its desired strength and durability. Uniform temperature should be maintained throughout the concrete depth to avoid thermal shrinkage cracks.

1.1.5 Uses of Concrete

Due to its versatility, durability and sustainability, concrete is the most widely used construction material all over the world. . It can be engineered to satisfy a wide range of performance specifications, unlike other building materials, such as natural stone or steel, which generally have to be used as they are. All this contributed to the high level of importance and use of concrete in the construction industries. It is used for various civil engineering constructions such as bridges, dams, Towers, high rise buildings, sky scrapers etc.

The high level of consumption of concrete in the construction industries is diminishing the availability of materials used in concrete production. This is making researchers to find alternatives to the materials used in concrete production. Some of this materials are either industrial or Agricultural waste used in place of fine aggregate, coarse aggregate and cement. Materials like palm kernel shell (PKS) used in place of coarse aggregate, egg shell ash (ESA), rice husk ash (RSA), Empty Palm Oil Fruit brunch ash (EPO-FBA), Palm oil Fuel Ash (POFA) e.t.c used in partial replacement of cement. In order for concrete to maintain its structural properties, some performance such as microstructure and durability performance need to be checked. Microstructure of concrete is very important due to the fact that many of its properties is originated from its internal microstructure. Also, concrete durability cannot be underestimated because it shows the ability to resist weathering actions and chemical attacks while maintaining the desired engineering properties.

1.1.6 Empty Palm Oil Fruit Brunches (EPO - FBA)

Palm oil production is on a steeply rising path and oil palm industries produce abundant of oil palm by - products after palm oil extraction process, among this by product is Empty palm oil fruit Brunches (EPO - FBA). EPO - FBA is an Agricultural residue which is obtained after removing the palm oil fruit from its brunch. According to study, EPO - FBA can be found abundantly in Asian countries like Malaysia, Indonesia, Thailand and Tropical African Countries.

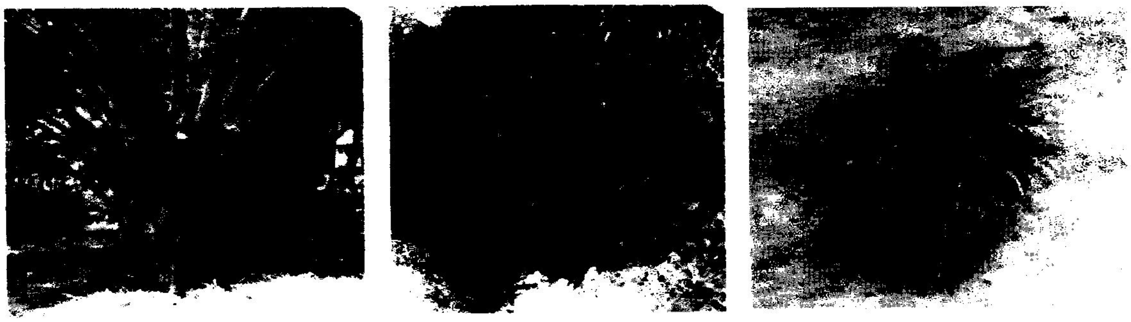

Figure 1.2 : Palm oil fruit

1.2 Statement of Problem

Concrete production is based largely on the availability of its constituent materials (Cement, sand and coarse aggregate). Due to the high level of use of concrete in construction industries, the material consumption in the usage of concrete has increased drastically. The cost of which has risen astronomically over the past few years, this led to the continuous increase in the cost of construction. Not only the construction cost has increased, but the quality of construction is also decreasing. This is one of the major problems the construction industry is facing. This problem of high rate of material consumption in the usage of concrete has necessitated research into the use of alternative materials especially those that are available locally which can replace conventional ones used in concrete production.

Due to the growth in population, the amount and type of waste materials have increased accordingly, many of the agricultural and industrial wastes have created waste management and pollution problems. However the use of these agricultural and industrial wastes to complement other traditional materials in concrete production may provide economic advantages, and foreseeable solution to the challenges of waste management.

1.3 Justification of Study

1.3.1 Why is the study being conducted?

This study is conducted in order to determine the extent at which **EPO – FBA** would replace cement without reducing its structural competence.

1.3.2 Who is the primary target audience of the study?

The study primarily is going to target construction industries that make use of cement as the major binder in concrete production.

1.3.3 What is the result expected to contribute?

1. To provide an alternative to the constituents of concrete, cement to be precise.
2. To Increase agricultural waste product use in concrete production.
3. To reduce environmental pollution and promote sustainable development.

1.4 Aim

The aim of this project is to determine the Microstructure and durability performance of concrete containing Empty palm oil fruit Brunch Ash (EPO - FBA) as partial replacement of Ordinary Portland Cement).

1.5 Objectives

In order to achieve the stated objectives, the followings are set to be carried out.

1. Carry out preliminary investigation including chemical analysis, workability, fineness and setting time and in order to characterize the materials to be used for the research.
2. Determination of the compressive strength of concrete samples up to 28 days.
3. To conduct microstructural and morphological study using scanning electron microscope (SEM)
4. Determination of the sorptivity of specimen with EPO- FBA.
5. Determination of the water absorption of specimen with EPO - FBA.
6. To study the result and make appropriate conclusions and recommendations.

1.6 Scope of the Work

Within the context of this work which is to determine the Microstructure and durability performance of concrete containing Empty palm oil fruit Brunch Ash (EPO - FBA) as partial replacement of Ordinary Portland Cement). The investigation carried out is limited to microstructure and selected type of durability (water absorption and sorptivity) in concrete.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

Concrete is a construction material manufactured by mixing fine aggregate (sand) coarse aggregate (crushed stone and gravel), cement and water either in a designed or prescribed proportion. It is strong in compression and has good fire resisting properties, and when steel, which is strong in tension is incorporated into it, a strong and durable material which can withstand various forms of loading and can be formed into various shapes and sizes emerges. This accounts for its widespread use in civil engineering construction works such as buildings, bridges, dams, roads and so on. One drawback, however, is that its massive production exerts negative effects on the environment. Its main ingredients, that is cement and aggregate material, need to be produced and mined on massive scale and transported over considerable distances increasing energy consumption, greenhouse gas emissions and landscape mutilation (Jonkers, *et al*, 2010). According to Worrell *et al*, (2001), it is estimated that cement (Portland clinker) production alone contributes 7% to global anthropogenic CO2 emissions, what is particularly due to the sintering of limestone and clay at a temperature of 1500 C, as during this process calcium carbonate (CaCO3) is converted to calcium oxide (CaO) while releasing CO. Therefore, from the work of Gerilla *et al*, (2007), it was concluded from an environmental viewpoint that concrete does not appear to be a sustainable material. As a result, the concrete construction can make significant negative impacts over the environment. Therefore, sustainability is a key issue for the global concrete industry. Achieving sustainability has become more and more important question all over the world during the last decade. It is well known that sustain means to support or to maintain a process going, and the objective of sustainability is that life on the universe can be sustained for the projected future. Environment, economy, and society are the components of sustainability. At the present time, the environment is probably the most important component, and an engineer or architect exercises sustainability to reduce impact on the environment (Adeyemi 2014). Large amounts of low cost building materials (Portland cement concrete) is required for the construction of infrastructure due to rapidly industrializing world and this trends will be continued. The unlimited use of natural resources and huge amounts of environmental pollution is a principal caution for the preservation of the life sustaining environment on the globe. The sustainable concrete is associated with reduction of the amount of polluting and CO2 gases emitted during the concrete production, use of waste material in more efficient way, development of low-energy, long-lasting, flexible buildings and structures exploiting the thermal mass of concrete in a structure to reduce energy demand (Sustainable Concrete 2017). Two main actions that meet the needs for sustainable construction development are, A sensible use of natural resources that can be achieved by the use of by-products and reusable materials, and a lower environmental impact that will be gained through reduced carbon dioxide emission and reduced natural resources extraction from quarries (Moriconi 2007).

2.2 Review

During recent decades, many researches have been conducted on agro – waste ashes (**EPO – FBA).** Some of them are summarized below:

Amaziah and Alison (2016) in their experimental investigation on "The Effect of Palm Bunch Ash on Concrete Properties" evaluated the effect of PBA on normal Grade 20 concrete. Properties investigated include: compressive, flexural, Split Tensile strength, workability and setting times for 0%, 5%, 10%, 15%, 20% and 25% PBA replacement in concrete. Mix proportioning by weight was used with the mix design as shown on Table 2.21. The cement and dried total aggregates ratio was 1:2:4. PBA was used to replace OPC at replacement levels of 0%, 5%, 10%, 20% and 25% by weight. Ninety (90) cube specimens of 150mmx150mmx150mm each were cast. 3 cubes were cast for each replacement level and cured for 7and 28 days respectively. The average value of the compressive strength of the three cubes was obtained for each replacement level. The specimens were demoulded after 24 hours and cured in a curing tank containing water. This was done in accordance with BS EN 12390-3 Part 3; 2002. - "Testing Hardened Concrete. Compressive Strength of Test Specimen". British Standards Institute, London, United Kingdom. The workability of the concrete with various replacement level of OPC with PBA was carried out using the Concrete Slump Test. Concrete mix ratio was 1:2:4 and a water/cement ratio of 0.6. The Slump test was carried out in accordance with BS 12350-2;

2009 – "Testing of Concrete –Method for determination of Slump". British Standards Institute, London, United Kingdom. The initial and final setting times for concrete cast with the various percentages of PBA was determined in accordance with BS EN 196-3; 1995 – "Method of Testing Cement. Determination of Setting Time and Soundness". British Standards Institute. London, United Kingdom.

Table 2.21 : Mix Design for Strength Test

Mix Design	PBA Replacement	Water(Kg)	Cement (Kg)	Coarse Aggregate (Kg)	PBA(Kg)
HSCPB(A1)	0	4.73	4.12	16.47	0.00
HSCPB(A2)	5	4.73	3.91	16.47	0.21
HSCPB(A3)	10	4.73	3.71	16.47	0.41
HSCPB(A4)	15	4.73	3.50	16.47	0.62
HSCPB(A1)	20	4.73	3.30	16.47	0.82
HSCPB(A1)	25	4.73	3.09	16.47	1.03

In the investigation conducted by Fapohunda and Shittu (2017) on Some Later Ages Structural Characteristics of Concrete Containing Empty Palm Oil Fruit Brunch Ash (EPOFBA) as Partial Replacement of Ordinary Portland Cement, the latter day strengths of concrete in which the cement constituent of the mix has been partially replaced by empty palm oil fruit brunch (EPO-FBA) was assessed. The structural parameters investigated were: workability, density and compressive strength. Some physical properties and chemical analysis were conducted and results are showed on Table 2.22 and 2.23 respectively. Slump test was used to assess the workability, while 150 x 150 x 150mm concrete cube specimens were used to assess the density and compressive strength characteristics. Replacement of Portland cement with EPO-FBA were carried out up to 20% by weight at interval of 5%. The preliminary investigations performed on the ash were: fineness, specific gravity and chemical analysis. Dry sieving was used for the fineness test; specific gravity bottle was used to determine the specific gravity of ash. The chemical analysis was done at the Department of Chemistry University of Lagos. Also some investigations for the purpose of characterization were carried out on the sand and the coarse aggregates. These includes: bulk density, moisture content, water absorption capacity and the particle size distribution by using the sieve analysis text (determined in accordance with BS EN ISO 17892-1 (2014). Concrete specimens were prepared, using a mix ratio of 1:2:4 and water-cement ratio of 0.50. The Portland cement constituent of the mix was subsequently replaced by EPOFBA from 0 – 20 % at 5% interval by weight. The samples without EPOFBA served as the control. The workability was assessed through the slump test in accordance to the provisions of BS EN 12350: Part 2 (2000). The density and compressive strength tests conducted on concrete cubes 150 x 150m x 150 mm in accordance with BS 12350: Part 6 (2000) and BS EN 12390-3 (2009) respectively. The concrete specimens were moist-cured and tested after 60, 75 and 90 days. The strength characteristics of each cube were determined on WAW-2000B computerized electrohydraulic servo universal testing machine, with accuracy of ± 1% of test force.

Table 2.22 : Some physical properties of materials used

PROPERTIES	COARSE AGGREGATE	SAND
Bulk Density(kg/m3)	1789.52	1397.79
Dry Density(kg/m3)	1722.89	1505.60
Specific Gravity	2.65	2.61
Moisture Content (%)	3.87	6.07
Water Absorption (%)	3.85	3.69
Coefficient of Uniformity (Cu)	4.85	6.90
Coefficient of Curvature (Cc)	1.83	1.16
Fineness Modulus	-	2.78

Table 2.23 : Chemical composition of OPC and EPO-FBA

Compound	EPO-FBA	Portland Cement
SiO_2	0.002	19.72
Al_2O_3	0.005	4.940
Fe_2O_3	0.003	0.710
CaO	18.670	64.220
MgO	1.540	2.190
Na_2O	0.510	0.670
K_2O	0.220	0.450
SO_3	0.000	1.030
MnO	0.000	0.000
Moisture Content	0.000	0.000
LOI	61.200	0.002

Salam *et* al. (2013) investigates the topic "Microstructure of Self-Consolidating High Strength Concrete Incorporating Palm Oil Fuel Ash". This paper mainly focuses the effect of palm oil fuel ash (POFA) on the microstructure of self-consolidating high-strength concrete (SCHSC). POFA has been used as supplementary cementing material replacing ordinary Portland cement (OPC) in the range of 0-30%. SCHSC mixes were produced with the waterto-binder (W/B) ratios of 0.25-0.40to obtain high strength. The microstructure of 28 and 56 days old concretes was analyzed based on their scanning electron micrographs (SEMs) in the cases of 0 and 20% POFA contents. The influence of POFA on the 28 and 56 days compressive strength and permeable porosity was also investigated. The coarse aggregate (CA) used in this study was crushed granite stone whereas the fine aggregate (FA) used was the mining sand. The ordinary (ASTM Type I) portland cement (OPC) was used as the main cementing material. POFA was used as a supplementary cementing material substituting 0– 30% of OPC. POFA and OPC together acted as the binder (B). The mixing water (W) used was normal tap water. A polycarboxylate based high range water reducer (HRWR) was also used in the present study to achieve the self-consolidation capacity of concrete. Both CA and FA were tested to determine their specific gravity, water absorption, bulk density, moisture content, and gradation. The sieve analyses of CA and FA were conducted according to ASTM C 136-06 [15] to examine their gradation. The POFA obtained at 800–1000°C was processed through proper grinding to increase its fineness greater than that of cement. POFA and OPC were tested for their specific gravity, particle size distribution, sieve fineness, and specific surface area. The HRWR was tested for its specific gravity and solid content. The physical properties CA, FA, OPC, POFA and HRWR are given in Table 2.24. The particle characteristics of POFA and OPC were examined by a scanning electron microscope. The unground POFA particles were large, mostly spherical, and more porous whereas the particles of ground POFA were small, mostly angular, and less porous, as can be seen from Figure. 2.1.

Table 2.24 : Physical Properties of Constituent Material

Properties	CA	FA	OPC	POFA	HRWR
Specific gravity	2.62	2.69	3.16	2.48	1.05
Median particle size, d_{50} (μm)	•	•	14.6	9.5	•
% Mass passing through 45-μm sieve	•	•	91.5	96	•
Specific surface area, Blaine (m^2/kg)	•	•	351	775	•
Specific surface area, BET (m^2/kg)	•	•	3046	4103	•
Pozzolanic activity index (28 days) (%)	•	•	•	105	•
Solid content (%)	•	•	•	•	30
Absorption capacity (%)	0.55	1.32	•	•	•
Moisture content (%)	0.27	0.31	•	•	•
Fineness modulus	6.76	2.88	•	•	•
Bulk density (oven-dry) (kg/m^3)	1513	1700	•	•	•
Co-efficient of gradation	1.11	1.06	•	•	•

Table 2.25 : Paste Mix Proportion

Symbols	C/C	W/B	POFA/C
Mc	1	0.29	0
M1	1	0.29	0.1
M2	1	0.29	0.2
M3	1	0.29	0.3
M4	1	0.29	0.4
M5	1	0.29	0.5
M6	1	0.29	0.6
M7	1	0.29	0.8

In the experimental study conducted by Nurudeen *et al*. (2014), on The strength activity index of mortar and microstructural characteristics of pastes containing treated palm oil fuel ash (POFA). POFA obtained from a palm oil mill was treated via sieving, grinding and heating at temperature of 450°C for 90 minutes in order to improve the pozzolanic reactivity of the POFA. The pozzolanic reactivity of the treated POFA was evaluated by conducting strength development tests according to ASTM C311. The hydration products of hardened pastes were analyzed by means of thermogravimetric analysis (TGA), x-ray diffraction (XRD), and scanning electron microscopy (Figure 2.2) in order to quantify the influence of the treated POFA which was used at different POFA/cement ratio ranging from 0 to 0.8 (Table 2.25). After 28 days, the strength activity index of the treated POFA with ordinary Portland cement exhibited very good performance and was higher than 100%. At 90 days, the strength activity index increased to 101.72 %. Using TGA, XRD, and SEM, a significant reduction in Ca(OH)2 content was observed with increasing amount of treated POFA. The development of C-S-H gel was higher when POFA/cement ratio was raised up to 0.3.

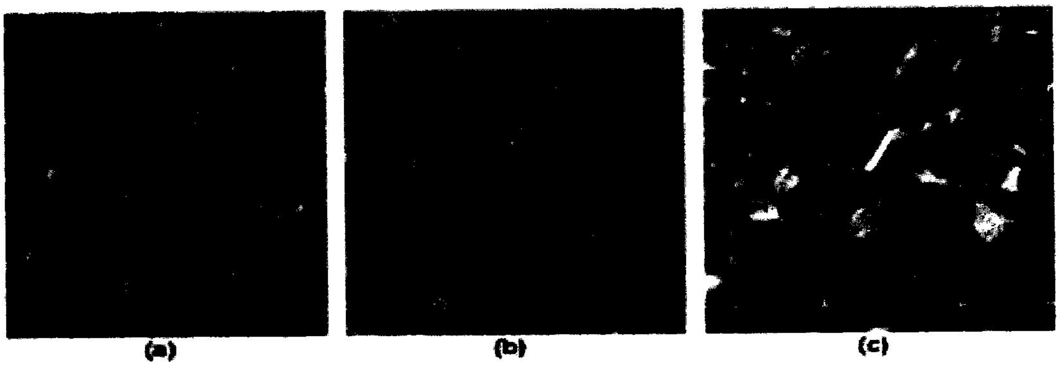

Figure 2.1 : Morphology by SEM of (a) OPC (b)unground POFA (c) Ground POFA

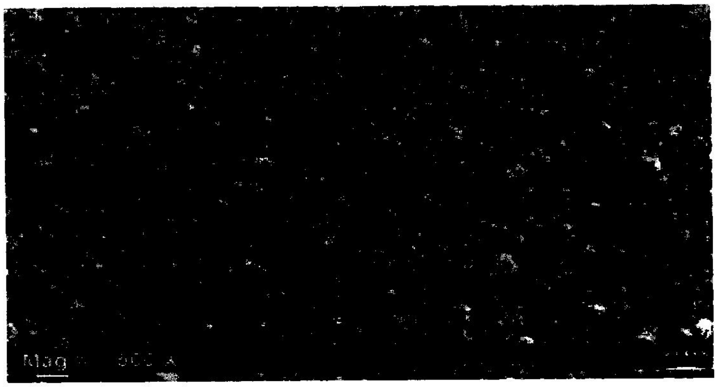

Figure 2.2 : SEM photograph of Treated POFA

Wan Bakar *et al*. (2014) in their investigation on The effect of ash from oil palm empty fruit bunch to cement properties, said Cement losses into formation could lead to zonal isolation problem. This may happen in weak formation when equivalent circulating density (ECD) of the cement exceeded formation pressure. One of the methods to avoid cement losses thus providing complete zonal isolation is by using low density cement. In the study, they investigated the effect of ashes from Oil Palm Empty Fruit Bunch (OEFB), being a material with high silicon dioxide (SiO2) content in reducing the cement density. Other important cement properties such as compressive strength should not be compromised for the density. Carboxymethyl cellulose (CMC), a standard additive to improve the compressive strength was added to the cement formulation. Result showed that 20% density reduction for standard Class G cement could be achieved with 60% OEFB ashes substitution and addition 0.2% CMC.

Hamed and Saeed (2015) in their experimental study on the Significant Characteristics of Concrete Containing Palm Oil Fuel Ash. Mixtures of concrete were selected with watertobinder (W/B) ratios of 0.5, 0.55 and 0.6 with 10% of sand"s weight filler content. This amount of filler is required to modify the standard curve of sand (Gheorghe, Saca and Radu, 2008; Jones, Zheng and Newlands, 2003). Table 2.26 shows the mixture designs for the given water to-binder ratios based on the same amounts of fine and coarse aggregate for all specimens. POFA as a percentage of cement was added to the concrete mixtures at 10%, 20%, 30% and 40%. Cylindrical specimens of 15×30 cm were used in the experiments. These cylindrical specimens were cast and installed in three steps during the filling of concrete specimens, and each step was vibrated on shaking tables. Then, the specimens were maintained in a 20 °C curing room with 98% relative humidity for 24 hours and subsequently preserved for 6 and 27 days in lime-saturated water. The ASTM code procedure (ASTM C39 / C39M – 09a) was used to test the 7-day and 28-day compressive strengths of the specimens (ASTM C39/C39M-14a, 2014). In addition, the modulus of elasticity of the specimens was tested using the ASTM C469 code procedures (ASTM C469, 2002).

Table 2.26 : Mix Design of Specimen

Cement (Kg/m^3)	**Gravel (Kg/m^3)**	**Sand (Kg/m^3)**	**W/B Ratio**
300	1150	800	0.50
300	1150	800	0.05
300	1150	800	0.60

Partial Replacement of Cement by Palm Oil Fuel Ash in Concrete (Subhashini and Krishnamoorthi, 2016) the strength properties of POFA concrete of M30 grade in different replacement level was compared with control concrete. The concrete mix is designed as per IS: 10262 –2009 and IS 456-2000 for the normal concrete. The grade of concrete adopted is M30 with a water cement ratio of 0.45. Five mixture proportions were made. First was control mix (without palm Oil Fuel Ash) and the other four mixes contained palm oil fuel ash. Cement was replaced with palm oil fuel ash by weight. The proportions of cement replaced ranged from 10% to 40% at 10% interval.

In the investigation conducted by Ranjbal N. *et al.* (2015), on Durability and mechanical properties of self-compacting concrete incorporating palm oil fuel ash, self-compacting concretes were produced by incorporation of palm oil fuel ash at 10, 15 and 20% by weight of Portland cement and their mechanical and durability potential were evaluated under normal, acid and sulfate attack conditions. Ground POFA was used as partial replacement of Type I Portland cement at proportions of 10%, 15%, and 20% of binder weight content. The mix designs of the self-consolidating concretes included 480 kg/m3 of binder and water to binder ratio of 0.35 for all specimens are specified. Sika Viscocrete-1600 superplasticizer (Sika Kimia Sdn Bhd, Malaysia) was used in the self-compacting concrete mixtures in order to obtain the fresh properties. Sika Viscocrete-1600 is an extreme water reduction which meets the requirements for superplasticizers according to ASTM C494 Type G. To obtain similar workability for the specimens, higher superplasticizer was used in mix design of higher POFA content matrices because of the agglomerated shape of POFA particles leading to the demand for more energy to roll over one another.

2.3 Results

2.3.1 Microstructure

Several researchers have performed scanning electron microscopy (SEM) and X-ray diffraction (XRD) of EPO-FBA.

In their own work, Karim *et al.*(2013) observed in the Scanning Electron Microscopy (SEM) images that the POFA got high specific surface as they show very porous and spongy surface. POFA (in the form as received from the industry) got spherical appearance with some minor amount of plerospheres and irregular shaped particles. The SEM images of POFA are shown in Figs. 2.3 and 2.4. It can be noticed that the main components of POFA are in angular and irregular form with a sizable fraction showing cellular textures. Raw POFA consists of spherical particles with a median size of about 183 μm, while the crushed medium and small POFA particles are approximately in the sizes of 15.9 and 7.4 μm respectively.

From the studies of Karim *et al.* (2013) the X-ray diffraction (XRD) of POFA indicates that it mainly consists of crystalline phases such as mullite and quartz, while some very small peaks of crystalline silica were also observed.

The work of Salih *et al.*(2017) observed dominant phase of SiO2 based on Cu radiation. Location of the highest hump (ranging from 15° to 40°) was detected in the XRD profile.

In their own work, Lim *et al.* (2015) pointed out that there was only a minimum amount of Ca(OH)2 in the XRD was because of its consumption in the pozzolanic reaction. When ultrafine POFA was used in the place of ground POFA, the amount of Ca(OH)2 has been further consumed as more amount of amorphous SiO2 was available to react with the Ca(OH)2.

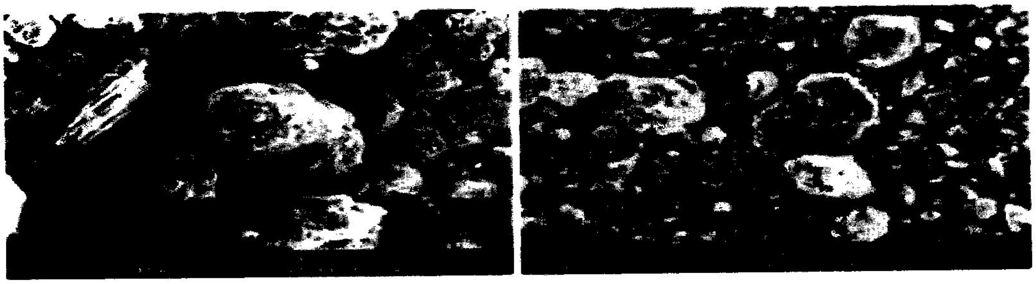

Figure 2.3 : SEM images showing (a) Original POFA and Ground POFA

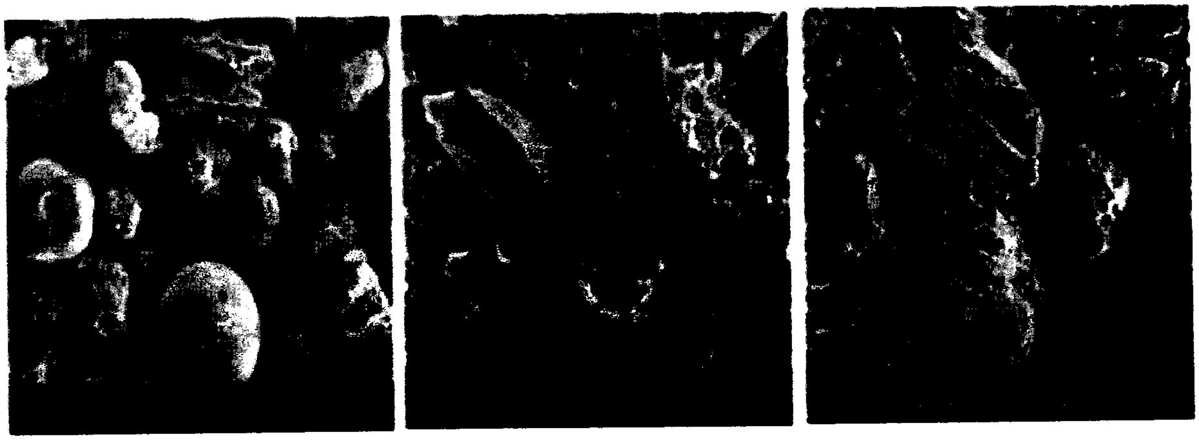

Figure 2.4 : SEM Images Showing Large, Medium and Small size POFA

2.3.2 Water Absorption

Controlling the permeability of concrete plays an important role, as the ingress and movement of ions from the environment, through the building materials are mainly responsible for the deterioration of structures.

In the investigation conducted by Tangchirapat *et al.*(2007) on The water permeability of concrete with and without POFA at 90 days of age. The permeability value of control concrete was 6.67 × 10–14 m/s, while that of the concrete containing 10%, 20% and 30% POFA were *4.17, 3.11 and 3.83 × 10–14 m/s respectively*. The pozzolanic reaction and the filler effect of the fine ash resulted in making the high strength POFA concrete more impermeable when compared to the control concrete. Similar observations were made by Tangchirapat and *Jaturapitakkul*.

In their own work, Johari *et al.* (2007) reported that the gas permeability of the high strength concrete containing 60% ultrafine POFA exhibited a 76% reduction comparing to control concrete. The water permeability coefficient for the concrete containing 20%, 40% and 60%

EPO-FBA has shown a reduction by 18%, 24% and 33% respectively when compared to control concrete.

Tangchirapat *et al.* (2007) noticed that the water permeability coefficients at 28 and 90 days of control concrete as 13.3 × 10–13 m/s and 5.4 × 10–13 m/s respectively and that of recycled aggregate concrete as 64.8 × 10–13 m/s and 15 × 10–13 m/s respectively as the porosity of concrete increased. When 20% OPC was replaced with POFA, the water permeability coefficients at 28 and 90 days of recycled aggregate concrete reduced to 7.5 × 10–13 m/s and 3.6 × 10–13m/s. When the level of replacement with POFA was 35%, the water permeability coefficients at 28 and 90 days reduced to 8.6 × 10–13 m/s and 3.7 × 10–13 m/s respectively, which were much lower than the control concrete specimens. So, the incorporation of POFA at the replacement level up to 35% makes the concrete denser and resistant to water penetration.

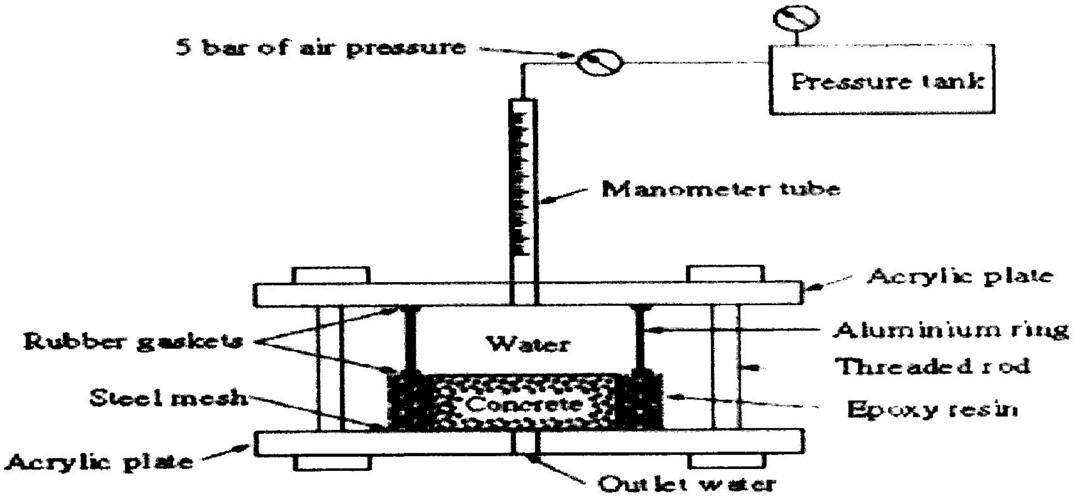

Figure 2.5 : Arrangement to Measure the Depth of Water Penetration

2.3.3 Compressive Strength

Compressive strength of concrete is the most desirable mechanical property of hardened concrete as all the other mechanical properties like flexural strength, splitting tensile strength, abrasion resistance, pull-off strength and modulus of elasticity directly depends on the compressive strength of concrete. Depending on the mix design and the curing conditions, different researchers have found different grades of strength for concrete containing POFA.

In the investigation conducted by Fapohunda and Shittu (2017), on Some Later Ages Structural Characteristics of Concrete Containing Empty Palm Oil Fruit Brunch Ash (EPOFBA) as Partial Replacement of Ordinary Portland Cement, The results of the compressive strength development for all the percent replacements of cement with EPO-FBA are presented in Figures 2.6 and 2.7. From Figure 2.6, it can be observed that the compressive strengths of all the specimens with and without EPO-FBA increased with curing age. This is to be expected, for it is already established that the strength-forming products of hydration – C-S-H gel - increased with curing ages (Fapohunda *et al.*, 2015). However, the compressive strengths of specimens with EPO-FBA reduced with increase in the cement replacement with EPO-FBA. The reduction in compressive strength can be attributed to many reasons. Firstly, it was observed that the EPO-FBA percent composition of strength-forming compounds like SiO2 and CaO is low compared to that of the ordinary Portland cement. Thus more and more cement replacement with EPO-FBA resulted in in less and less quantity of the strength forming compound, thus leading to progressive reduction in the compressive strength. Also the results of the slump test had earlier shown loss of slump with increase in EPO-FBA. This means that EPO-FBA had dehydrating effect on the concrete specimens, resulting in the loss of water that is meant for the strength-forming hydration process (Fapohunda *et al.*, 2015). Insufficient water, according to Neville (2003), will slow down the formation of the C-S-H gel known to be responsible for the strength development in concrete, and will thus result in reduced strength as the quantity of the EPO-FBA in the mix increases. In addition, the lower fineness of EPO-FBA in relation to OPC may affect its compressive strength development because of lower available specific surface area. The higher the surface area due to the fineness of the binder, the larger the area that is Iwatered for hydration process, the higher development of strength in concrete, and vice versa (Awal and Uguong, 2010). From Figure 2.7, it can be observed that the compressive strength of the specimens increased with cement replacement up to 5% at all the curing ages considered, approximately at a rate of 5.34%, and they decreased there-after with increase in the content of EPO-FBA.

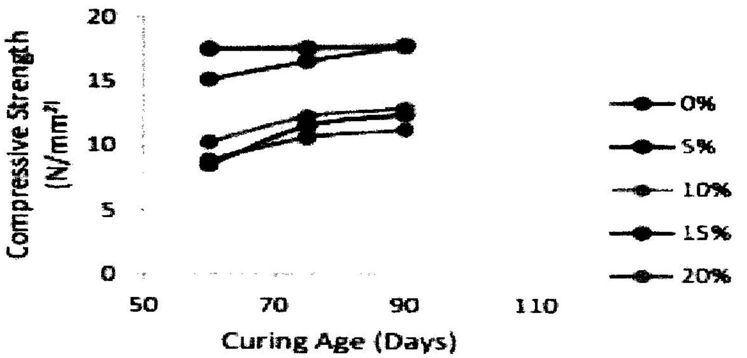

Figure 2.6. Effect of EPO-FBA on the compressive strength development of concrete specimen

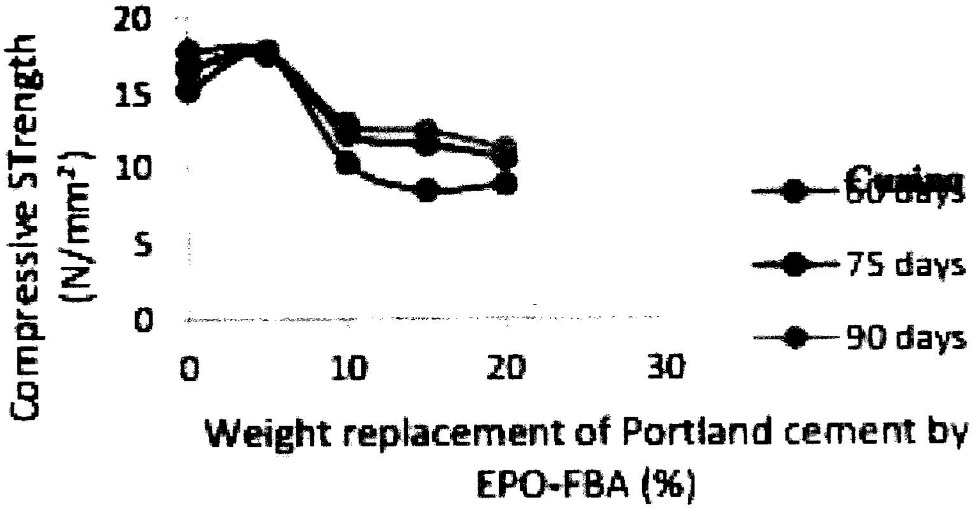

Figure 2.7 : Compressive strength development of concrete specimen with EPO-FBA

"The Effect of Palm Bunch Ash on Concrete Properties" (Amaziah and Alison, 2016) illustrates the variation of compressive strength with PBA content. The compressive strengths at 7 and 28 days, decrease as the PBA content increases as shown in Figure 2.8. This can be attributed to the fact that OPC has more bonding strength than PBA. Up to 5% PBA content, concrete can be produced by mixing 5% PBA with 95% OPC without experiencing loss of compressive strength. Between 0% and 5% PBA content, values of the compressive strength obtained compares favourably with those of Grade 20 concrete. In summary, at 7 days the compressive strength for the control mix (0% PBA) is 20.29N/mm2, while that at (5% PBA) is 19.25N/mm2, while represents a 5% decrease in strength. For the 28 days compressive strength, the strength of the control mix (0% PBA) is 24.59N/mm2, while that at (5% PBA) is 24.15N/mm2, which represents a 2% decrease.

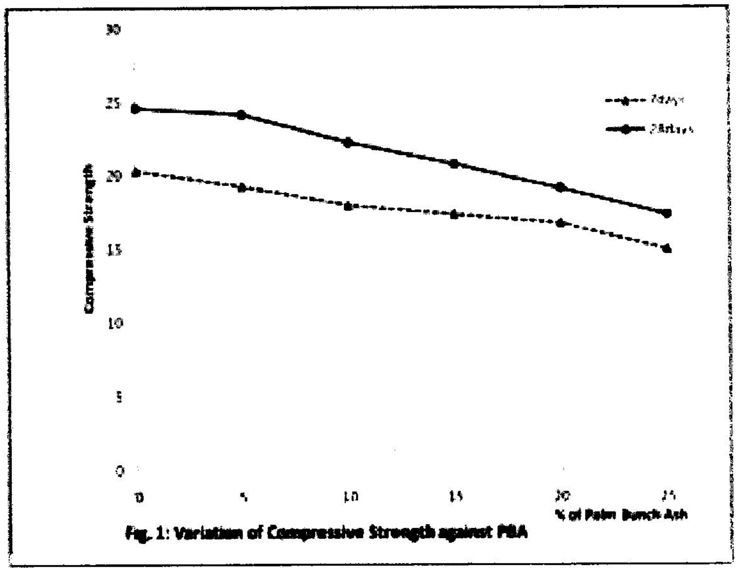

Figure 2.8 : Variation of compressive strength against PBA

Salam *et* al. (2013) investigates the topic "Microstructure of Self-Consolidating High Strength Concrete Incorporating Palm Oil Fuel Ash" compressive strength of the concretes at each testing age was the average of the strength values obtained from three Ø100×200 mm cylinder specimens. The average compressive strength of SCHSCs at 28 and 56 days are shown in Table 2.31. The 28 days compressive strength varied from 52.3 to 74.2 MPa while the 56 days compressive strength differed from 54.8 to 77.0 MPa for different SCHSCs. The POFA content influenced the compressive strength of concrete. It is obvious from Table5 that the compressive strength of concretes increased with the increase in POFA content up to a certain level. The maximum strength gain occurred at the replacement level of 20%. Beyond this replacement level, a gradual reduction in compressive strength was observed. The compressive strength of POFA concretes increased due to the pozzolanic behaviour of POFA. This can be supported based on the strength activity index of POFA. In the present study, the strength activity index of POFA was 105%, it is higher than the minimum limit of 75% for pozzolanic supplementary cementing materials, as specified in ASTM C 618- 08a. The high SiO2 content (62.3%) of the ground POFA reacted with Ca(OH)2 (liberated from cement hydration) to produce an additional calcium silicate hydrate (C-S-H), which improved the compressive strength of concrete. Furthermore, POFA had a higher surface area due to smaller particles, and therefore enhanced the pozzolanic activity and hence the compressive strength of concrete. The micro-filling ability of POFA also contributed to increase the compressive strength of SCHSC. The average particle size of POFA was lower than that of OPC. Therefore, the finer POFA particles filled in the micro-voids in cement paste, thus improving the microstructure of concrete to produce a higher compressive strength.

Table2.31 : Fresh and hardened properties of Different concrete mix

Concrete type	Slump flow (mm)	Compressive strength (MPa)		Permeable porosity (%)	
		28 days	56 days	28 days	56 days
C25P0	660	70.9	72.9	7.98	7.58
C25P10	680	72.9	75.5	7.51	7.18
C25P20	705	74.2	77.0	7.04	6.88
C25P25	710	68.2	70.8	7.97	7.60
C25P30	720	65.9	68.4	8.10	7.71
C30P0	640	67.6	69.5	8.95	8.60
C30P10	655	69.3	72.1	8.59	8.30
C30P20	670	71.3	74.1	8.21	8.10
C30P25	680	65.5	68.1	8.97	8.62
C30P30	700	63.1	65.6	9.12	8.71
C35P0	630	61.4	63.2	9.99	9.85
C35P10	640	62.8	65.5	9.70	9.42
C35P20	665	64.2	66.9	9.43	8.93
C35P25	670	58.8	61.6	9.93	9.85
C35P30	675	57.7	60.3	10.25	10.13
C40P0	605	56.2	58.0	11.16	10.96
C40P10	620	57.9	60.2	10.92	10.59
C40P20	630	58.2	60.8	10.59	10.39
C40P25	635	54.1	56.8	11.20	11.10
C40P30	645	52.3	54.8	11.50	11.25

The work of Subhashini and Krishnamoorthi (2016) on "Partial Replacement of Cement by Palm Oil Fuel Ash.in Concrete" revealed that compressive strength test on concrete specimens shows an increase in strengths up to the replacement level of 20% of Palm Oil Fuel Ash.

In the experimental study conducted by (Tejendra and Danish 2016) on the Strength of concrete with palm oil fuel ash as cement replacement, result showed that the concrete with palm oil fuel ash shows increase in both 7 days and 28 days compressive strength which is due to pozzolanic action of palm oil fuel ash. The strength of concrete is found to increase uniformly with increase in amount of palm oil fuel ash. The compressive strength test results of palm oil fuel ash is shown in Table 2.32 and Figure 2.9

Table 2.32: Compressive Strength Test Result

Concrete Composition with POFA replacement	Average Compressive Strength (N/mm2)		
	7 DAYS	14DAYS	28DAYS
0%	24.07	32	36.89
10%	28.89	33.33	33.33
20%	29.78	33.78	36.44
30%	25.78	28.89	29.33
40%	20	24	26.22

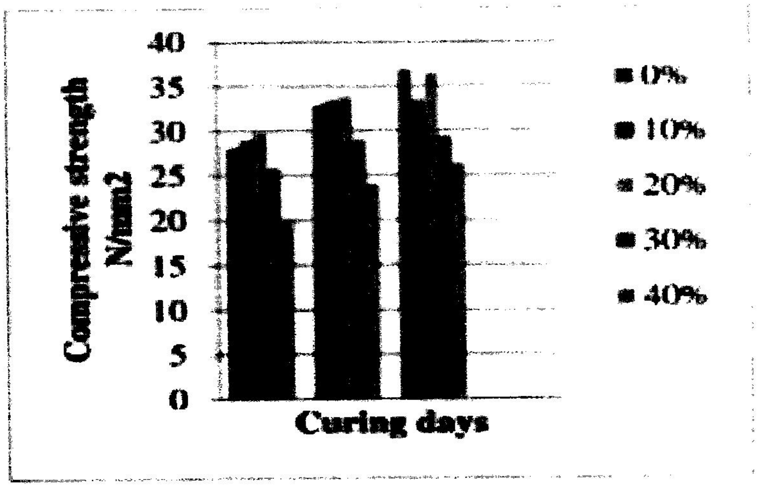

Figure 2.9: Variation Of Compressive Strength

2.3.4 Workability: Fresh concrete is defined as workable when the concrete can be transported, placed, compacted and finished easily and without segregation, Workability of concrete can be defined as the ease with which it can be mixed, handled and compacted. In the investigation conducted by (Fapohunda and Shittu, 2017) on Some Later Ages Structural Characteristics of Concrete Containing Empty Palm Oil Fruit Brunch Ash (EPOFBA) as Partial Replacement of Ordinary Portland Cement, results of the workability (Figure 2.10) to assess the ease with which freshly prepared concrete containing EPO-FBA can be transported and placed for the job and compacted to a dense mass without segregation and bleeding showed low slump values. The slump values were 50, 45, 40, 40, and 30 mm respectively for 0, 5, 10, 15, and 20% cement replacement with EPO-FBA. This is an indication that harsher or lean mix progressively resulted with increase in the level of EPO-FBA in the mix. This can be attributed to the fact that EPO-FBA is lighter than cement (as previously discussed in Section 3.1), and this means a larger volume is required for a unit weight replacement. The larger volume means a larger surface areas are exposed for water to wet, making the water to become less sufficient as the EPO-FBA content is increased. The effect is that harsher mix resulted as the EPO-FBA in the mix increased. This is the reason for reduction in slump as the content of EPO-FBA in the mix increased. According to Neville (2003), these values translate to concrete with low workability. All the specimens however displayed true slump. The true slump displayed by the samples was an indication of cohesiveness of the mix and absence of segregation characteristics (Shetty, 2009). In order words, there was no disruption to cohesiveness of the materials at higher EPO-FBA content. The practical implication of the low workability of concrete with EPO-FBA is that such concrete can only be used in lightly reinforced sections (in slabs, beams, walls, and column), strip footings with substructure walls, hand placed pavement and for mass concrete (Gambhir, 2013).

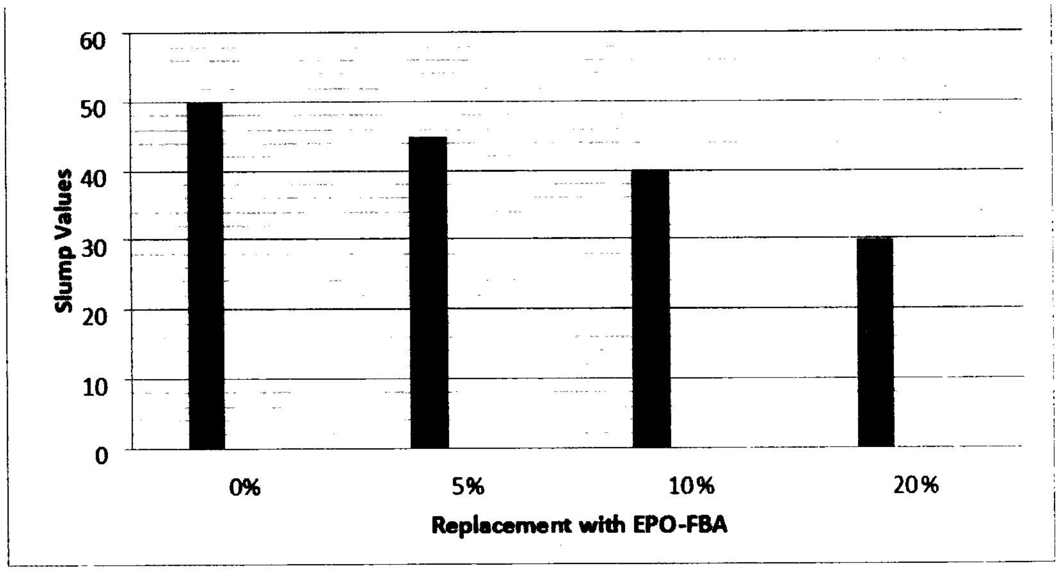

Figure 2.10 : Workability of Specimen with EPO-FBA

Amaziah and Alison (2016) in their experimental investigation on "The Effect Of Palm Bunch Ash On Concrete Properties Fig. 2.11 shows the variation of the workability of concrete mixed with various percentages of PBA. The slump test result shows that that the workability decreases as the content of PBA is increased explained that this is due to the fact that a lesser amount of free water is available in the presence of PKSA. The PKSA particles according to their findings were more porous and possessed a greater specific surface than cement.

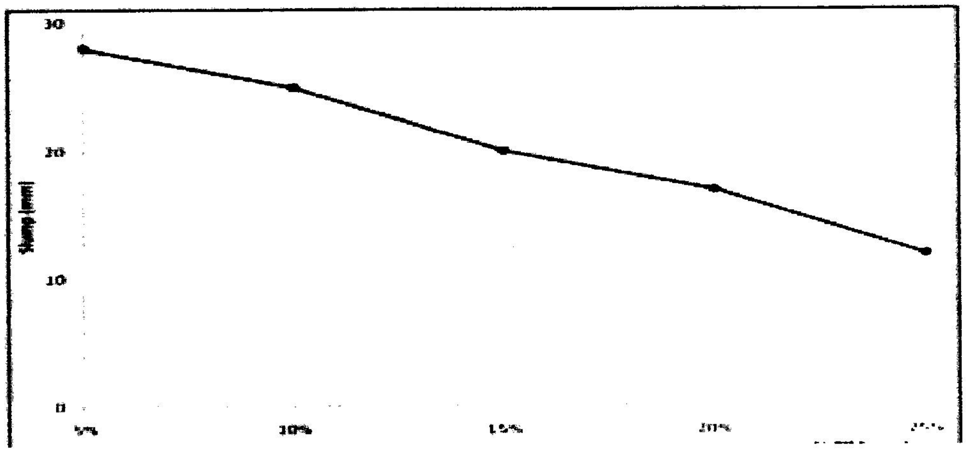

Figure 2.11 : Variation of Slump against EPO-FBA content

In the experimental study conducted by (Tejendra and Danish 2016) on the Strength of concrete with palm oil fuel ash as cement replacement, result showed that the slump value increase uniformly as amount of POFA is increased. It is due to the fine particles of fuel ash which contribute to enhancement in workability of concrete. The slump value in all three mixes i.e. M20, M25, M30 is observed to increase by 10% for every 5% replacement of cement with fuel ash.

Ranjbar *et al.*, (2016) in their work, "Durability and mechanical properties of self-compacting concrete incorporating palm oil fuel ash" studied the properties of self-compacting concrete containing POFA and inferred that it is possible to replace up to 20% of cement with POFA without any adverse effect on the fresh properties of self-compacting concrete (SCC). Higher content of POFA can lead to the improved viscosity of concrete and decrease the slump flow, L-box and J-ring, while increasing the V-funnel flow time, T50 and segregation index. All the test mixtures fulfil the requirements of passing ability and segregation resistance as per the limitations in EFNARC, 2002.The slump flows of the mixes were determined using an Abrams slump cone according to EFNARC guidelines 2002. All mixes were designed for a slump flow of average diameter of 710 ± 20 mm. For all the mixes, the slump flow was in the range of 700–730 mm, which is in agreement with the EFNARC standard. As shown in Figure 3, it can be seen that the mixes incorporating the treated POFA could enhance the slump flow. Figure 4 shows the flow of the mix containing 50% treated POFA. As can be seen in this Figure, this mix has a good flow and cohesive mix compositions. No bleeding or segregation can be observed. The improvement of the fresh properties can be attributed to the reduction of the unburned carbon content of the treated POFA. In addition, the improvement of the fresh properties of SCHSC

2.3.5 Density

In the investigation conducted by (Fapohunda and Shittu, 2017) on Some Later Ages Structural Characteristics of Concrete Containing Empty Palm Oil Fruit Brunch Ash (EPOFBA) as Partial Replacement of Ordinary Portland Cement, results of the density for the concrete specimens with EPO-FBA as partial replacement of Portland cement are presented in Table 2.33. The standard deviations are in the parenthesis. Table 2.33: Density development of Concrete Specimen with EPO-FBA Efficient application of concrete requires a knowledge of its densities against the background that there exist three classes of concrete on the basis of weight namely, lightweight concrete, normal weight concrete and heavy weight concrete with densities 300 – 1,920 kg/m3, of 2,240 –2,480 kg/m3, and greater than 2,500 kg/m3 respectively (Falade *et al.*, 2011). From Table 2.33, it can be observed that all the densities fell within the range for normal weight concrete at all the replacement values of cement with

EPOFBA. In the light of this, it can be reasoned that concrete produced by inclusion of EPO-FBA at replacement level up to 20% can be used for normal weight concrete applications

Table 2.33 Density Development of Concrete Specimen with EPO-FBA

EPO-FBA in Mix (%)	**Density (kg/m^3) of concrete specimens with curing ages**		
	65 DAYS	**75 DAYS**	**90 DAYS**
0	2301.23±35.90	2320.99±45.20	2311.11±30.70
5	2330.86±28.56	2301.23±40.34	2320.99±33.56
10	2350.62±45.45	2241.97±39.25	2291.36±38.89
15	2301.23±42.56	2281.48±38.45	2330.86±43.45
20	2340.74±39.32	2400.01±40.23	2355.56±42.69

2.3.6 Setting Times

Amaziah and Alison (2016) in their experimental investigation on "The Effect Of Palm Bunch Ash On Concrete Properties Fig. 2.12 shows the variation of the initial and final setting times with the PBA content. Between (0-5% PBA), the initial and final setting times increased as the PBA content was increased. Between (5% - 15% PBA) there is no increase in the initial and final setting times. Between (20-25% PBA), the initial and final setting times increase as the PBA is increased. This is as result of the fact that the rate of hydration reduces as the content of the PBA is increased due to the increase in the amount of silica from the PBA

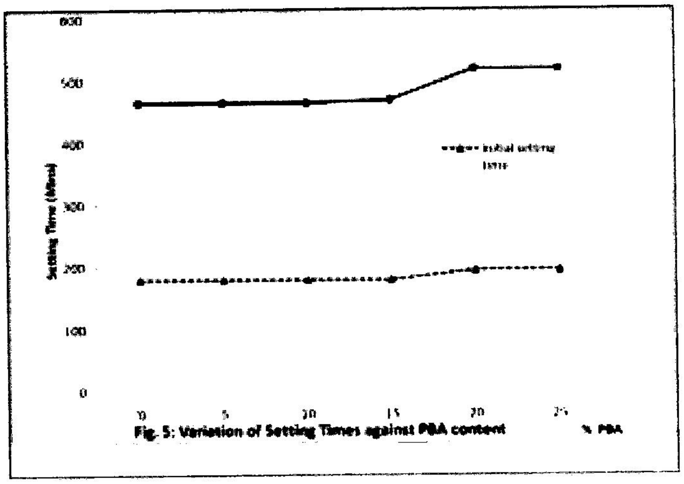

Figure 2.12: Variation of setting times against EPO-FB

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 Theoretical Background

The production of concrete involves the mixing of various materials including cement, aggregates (fine and coarse), water and any other additives. These materials are very important in the production of concrete because they have their individual functions. The function of cement is to serve as a gum which binds all other materials together, fine aggregate serves as filler which fills the pores created in between coarse aggregates while coarse aggregate serve as the major load bearer. In order for concrete to fully perform its intended functions, then some properties has to be considered. Some of these properties involve freshly mixed concrete properties (workability, consistency, setting times etc.) Mechanical properties (compressive strength, tensile strength, flexural strength, abrasion etc.) and Durability properties (sorptivity, water absorption, fire resistance etc.). To quantify these aforementioned properties, various test are carried out and different methods are employed. In this chapter, discussion will be based on materials (sand, granite, cement and water) used for the concrete production including the material used in replacing OPC. In addition to this, various test and their methodology will be discussed.

3.2 Material Design and Preparation

The following materials were used for the experimental work: OPC (Ordinary Portland Cement), Empty Palm Oil Fruit Brunch Ash (**EPO – FBA)** sand (Fine aggregate), granite (Coarse aggregate) and water.

3.2.1 Cement

Ordinary Portland Cement (OPC) was used. The OPC used was a product of DANGOTE INDUSTRIES PLC, Nigeria as shown in Plate 3.1. It was obtained from one of the local markets in Ikole Ekiti. The cement properties conformed to BS 12; 1996 – Specification for Portland cement. British Standards Institute, London, United Kingdom. And BS 4450-3; 1978 – “Methods of Testing Cement. Physical Test”. British Standards Institute, London, United Kingdom.

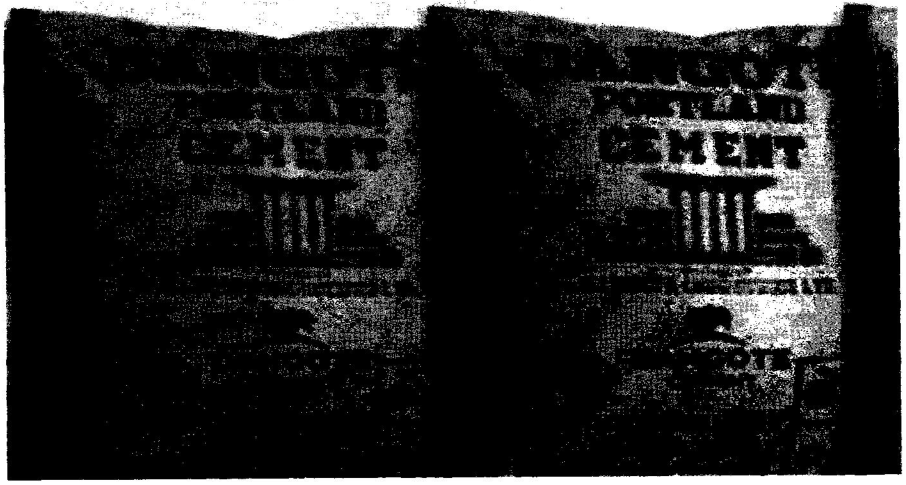

Plate 3.1: Ordinary Portland cement (Dangote Product)

3.2.2 Fine Aggregate

The Fine aggregate used in this study for the production of concrete is clean river sand as shown in Plate 3.2 with maximum size of 4.75mm and specific gravity of 2.80. The sand was obtained from an on-going construction work located inside the school.

Plate 3.2 : Fine aggregate (River sand)

3.2.3 Coarse Aggregate

For the coarse aggregates, granite chippings of sizes ranging from 4.75mm to 20mm as shown in Plate 3.3 was used. The granite was also obtained from an on – going construction work located inside the school.

Plate 3.3: Coarse aggregate (granite)

3.2.4 Water

The water used for the experiment was potable tap water, free from any dissolved metal or ions that might inhibit the setting and hydration process of the foamed concrete.

3.2.5 Empty Palm Oil Fruit Bunch Ash (EPO – FBA)

Empty palm oil fruit bunch ash was produced by burning empty palm oil fruit bunch into ashes. Empty palm oil fruit bunch was gotten by removing palm oil fruit from its bunch. The empty palm oil fruit bunch was collected from local palm oil industries (as shown in Plate 3.4) located around Ikole Campus of the Federal University Oye- Ekiti, where this research took place. They were then sun-dried and cut into smaller pieces with the aid of cutlass as shown in Plate 3.5. The empty palm oil fruit brunch pieces were then burned into ashes using close burning method at temperature 650°C as shown in Plate 3.6. The ashes (EPO-FBA) as shown in Plate 3.7 were bagged using empty cement bags, and then stored in a cool and dry place. The technological processes employed were within the means and ability of the environment to ensure practicability of the process.

Plate 3.4 : Collection of EPO-FB from Local Oil Industry

Plate 3.5: Sun drying EPO-FB

Plate 3.6 Burning EPO – FB.

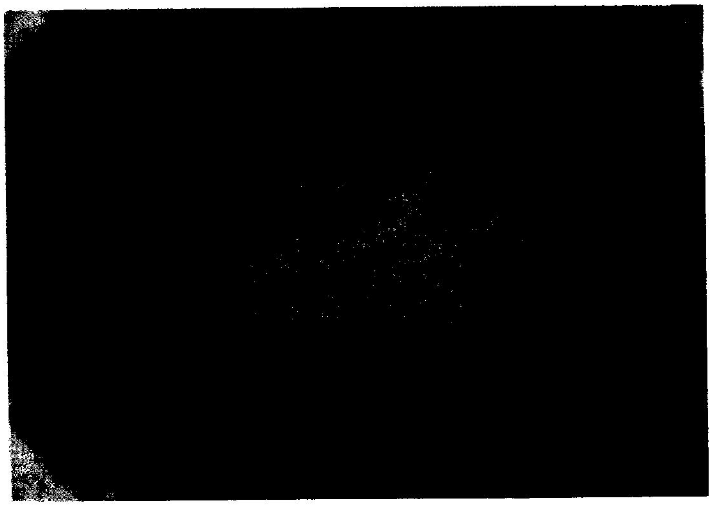

Plate 3.7: EPO-FBA

3.2.6 Preparation of Test Specimen (Concrete Cubes)

Three samples each of Concrete cube specimen of sizes 150mm and 100mm were casted to test for compressive strength and durability respectively. The batching was done by weight (as shown in Plate 3.8 and 3.9) using mix ratio 1:2:4, with partial replacement of Ordinary Portland Cement with EPO-FBA at 0%, 5%, 10% and 15%. Also the w/c ratio used was 0.5. The concrete cube moulds were cleaned and lubricated before concrete was placed inside them so as to avoid the concrete paste from sticking on the moulds which might in turn leads to difficulty during the removal of hardened concrete. The mould was filled with freshly mixed concrete (as shown in Plate 3.10) in three layers and was compacted using a compacting rod (each layer not compacted less than 35 strokes) to ensure minimum amount of voids. After compaction, the top of the concrete was levelled to obtain a smooth surface, each set of specimens were labelled for easy identification.

Plate 3.8: batching process (by weight)

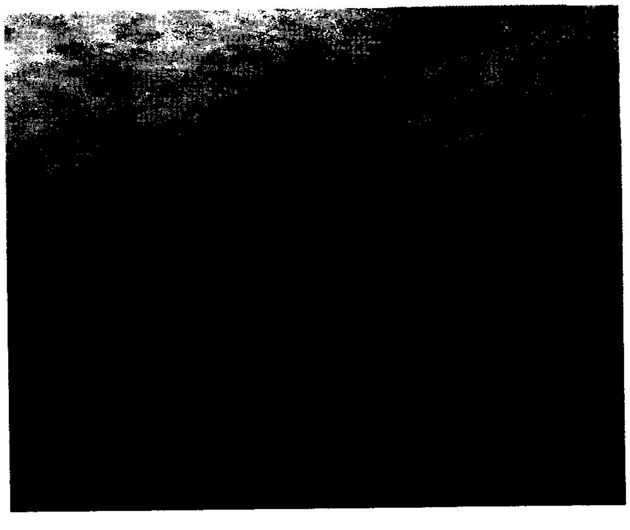

Plate 3.9 : Concrete mix Process

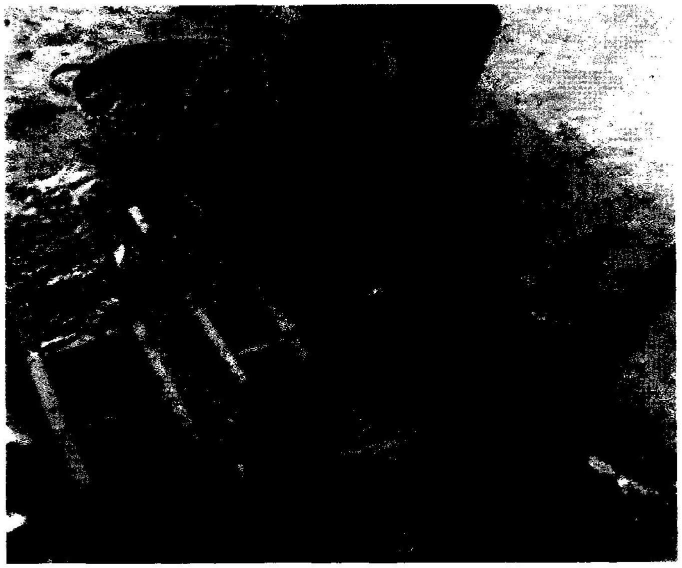

Plate 3.10: pouring and compaction process

Concrete Mix Design

This mix ratio adopted for this investigation is 1:2:4 with water/cement ratio of 0.5. This mix design was adopted in line with common field practice in Nigeria. Table 3.1 and 3.2 show the mix design for 150mm and 100mm cube respectively.

Density of Concrete = 2400kg/m3

Volume of 150mm cube of concrete = 0.15m x 0.15m x 0.15m = 0.003375m3

Volume of 100mm cube of concrete = 0.1 x 0.1 x 0.1 = 0.01m3

Mass of 150mm cube of concrete = Density x Volume = 2400 x 0.003375 = 8.1Kg

Mass of 100mm cube of concrete = 2400 x 0.001 = 2.4Kg

Mass of 3 samples (150mm cubes) = 8.1 x 3 = 24.3kg

Mix Ratio = 1:2:4

Weight of cement = 1/7 x 24.3 = 3.47Kg

Weight of fine aggregate = 2/7 x 24.3 = 6.94Kg

Weight of coarse aggregate = 4/7 x 24.3 = 13.88Kg

Weight of water = 0.5 x 3.47 = 1.74Kg

Table 3.1 : Mix Design for a Batch of Casting for 150mm cubes

MIX	CEMENT(Kg)	EPO-FBA(Kg)	SAND(Kg)	GRANITE(Kg)	WATER(Kg)
0%	3.47	0	6.94	13.88	1.74
5%	3.29	0.18	6.94	13.88	1.74
10%	3.12	0.35	6.94	13.88	1.74
15%	2.95	0.52	6.94	13.88	1.74

Mass of 3 samples (100mm cubes) = 2.4 x 3 = 7.2kg

Mix Ratio = 1:2:4

Weight of cement = 1/7 x 7.2 = 1.03Kg

Weight of fine aggregate = 2/7 x 7.2 = 2.06Kg

Weight of coarse aggregate = 4/7 x 7.2 = 4.12Kg

Weight of water = 0.5 x 1.03 = 0.52Kg

Table 3.2 : Mix Design for a Batch of Casting for 100mm cubes

MIX	CEMENT(Kg)	EPO-FBA(Kg)	SAND(Kg)	GRANITE(Kg)	WATER(Kg)
0%	1.03	0	2.06	4.12	0.52
5%	0.98	0.05	2.06	4.12	0.52
10%	0.93	0.10	2.06	4.12	0.52
15%	0.87	0.16	2.06	4.12	0.52

3.2.7 Curing Of Concrete Cube Specimen

After 24 hours of casting, Specimen were de-moulded and totally immersed in fresh water in a curing tank (as shown in Plate 3.11) to ensure complete hydration. The number of days each concrete spent in the curing tank was based on the individual target strength. In this study, concrete cube specimens were cured for 7, 14, 28, and 90 days.

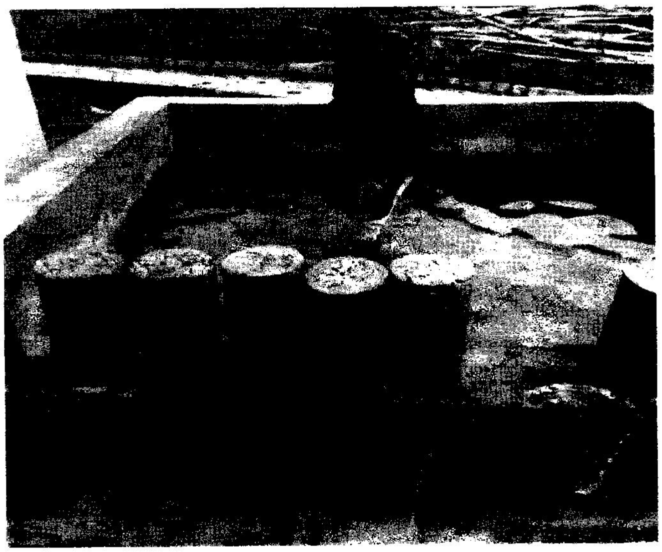

Plate 3.11 : Curing of Concrete specimens

3.3 Preliminary Investigation

The preliminary investigations performed on the ash were: Chemical analysis, fineness, specific gravity, Consistency and Setting Times.

3.3.1 Chemical Analysis

The aim of this Test was to analyze and compare both **OPC** and **EPO – FBA** for the amount of Silicon dioxide, Aluminium oxide, Ferric oxide, Calcium oxide, Magnessium oxide, Sulfur trioxide, Sodium oxide, Potassium oxide, Titaniun oxide, Phosphorus pentoxide, Zinc oxide and Manganic oxide. In order to carry out this test, X-ray fluorescence machine was used.

3.3.2 Fineness

The aim of this test is to determine how suitable a cement is for concrete production. Fineness of cement is measured by sieving it on a standard sieve ($90\mu m$). The proportion of cement of which the grain sizes are larger than the specified mesh size is thus determined. Fineness test is carried out on both the OPC and EPO-FBA using dry sieving method in accordance with BS 1377. Apparatus used in carrying out the test were; Weigh balance, $90\mu m$ sieve with receiver, Scoop and Hand Trowel.

Approximately 10g of Cement/ EPO-FBA was weighed to the nearest 0.01g using the weigh balance and then placed on the $90\mu m$ sieve covered with its lid. The cement was agitated by shaking the sieve in a planetary and linear movements, until no more fine material passes through it. The residue that passed through the sieve was then weighed and express its mass as a percentage R1, of the quantity first placed on the sieve to the nearest 0.1 percent. Gently the fine materials was brushed off the base of the sieve. The whole procedure was repeated using another fresh 10g sample to obtain R2. Then R was calculated as the mean of R1 and R2 as a percentage, expressed to the nearest 0.1 percent which was the fineness of the material. The process of the fineness test is as shown in Plate 3.12.

Plate 3.12 :Fineness of Materials Test

3.3.4 Consistency

This test is carried out to determine the percentage of water for consistency of a given sample of cement.

Cement paste of normal consistency is defined as percentage of water by mass of cement to produce a consistency, which permits a plunger of 10mm diameter to penetrate up to a depth of 5 to 7mm above the bottom of a Vicat"s mould. It is necessary to determine the quantity of water to be mixed to prepare a cement paste of standard consistency for performing the tests for setting times, compressive strength and soundness. The quantity of the water to be added in each of the above mentioned experiments bear a definite relation with the percentage of water for normal.

Apparatus used for this test were Vicat's apparatus with plunger 10mm diameter and 50mm length weighing 300g and Vicat's mould with non – porous plate. Weigh balance with 1kg mass, graduated measuring cylinder, Hand trowel, enamelled trays, standard spatula, thermometer and stopwatch.

300g of material was accurately weighed and placed on the enamelled tray. To start with, about 25% of clean water was added and mixed by using spatula. The mould was then placed together with the non -porous glass plate under the plunger of the Vicat"s apparatus. The indicator was adjusted to show the zero reading when the plunger touches the bottom surface of the test mould. The plunger assemble was then fixed near its top position.

The Vicat"s mould was then filled with the already prepared paste while the mould is resting on a non-porous plate. Using hand trowel, the surface of the paste was levelled with the top of the mould. The mould was slightly shaken in order to expel air. The filled mould was then placed under the plunger with the surface of the paste just in contact with the plunger bottom.

The plunger was quickly released allowing it to sink into the paste. After these, new trial was prepared with varying percentage of water and was tested as describe above until the plunger penetrates 5 to 7mm above the bottom of the mould. The amount of water that gave this result was expressed as the percentage by weight of the dry material.

Using the result above, the percentage of water P require to prepare a cement paste of standard consistency was calculated

$$P = \frac{W}{C} \times 100$$

P = Percentage of Water content for standard consistency

W = Quantity of water for 5-7mm penetration

C = weight of binder (OPC and EPO-FBA)

3.3.5 Setting Times

The term "setting"" is used to describe the stiffening of the paste which begins to occur sometimes after the water is added to the cement i.e. The change from a fluid to a rigid state (loss of Plasticity). When water is mixed with cement to form a paste, hydration reaction starts. Out of the three active compounds: C3, AC3, C, C2. C react quickly with water to produce a jelly like compound which starts solidifying. This point of starting the process of solidifying is termed as initial setting time and is arbitrarily judged by needle (1 mm^2 cross section) when it penetrates in test block up 5 to 7mm from the base. Final setting is assumed to have occurred when the annular ring fails to make the impression on the surface of the test block.

The apparatus used for this experiments are ; Vicat apparatus with mould and non-porous plate. Needle 1 mm^2 and needle with annular cap. Weight balance with capacity of 1kg. Graduated measuring cylinder 100ml. trowel of about 210gm weight, enamel trays, standard spatulas. Stop watch and thermometer.

Initial setting time.

300g of material was weighed and prepared by mixing with 0.85 times the percentage of water required for standard consistency. The stop watch was started immediately the water was added to the material. The Vicat"s mould resting on a non-porous plate was then filled with the prepared paste. Ganging time was less than 4plus or minus 15m. The mould was completely filled and smoothen off the surface of the paste making it level with the top of the mould. The filled mould was placed under the Vicat"s rod bearing $1mm^2$ needle.

The needle was then lowered gently till it comes in contact with the surface of the test block and then it was quickly released, allowing it to penetrate into the test block, the penetration was noted after every two minutes. The whole procedure was repeated until the needle fails to pierce the block for about 5 to 7mm measured from the bottom of the mould. The time at which this was attained was noted which is the Initial setting time.

Final Setting Time

For the final setting time, the Vicat"s needle was replaced with needle having an annular attachment. The replacement was done until the needle point makes an impression there on the surface, while the attachment fails to do so. The time that elapse from the time water was added to the material till the time the needle only makes an impression is known as the final setting time for the material under test.

Plate 3.13: Consistency and setting time test

3.4 Main Investigation

Main investigations carried out were: Workability, Density, Compressive Strength, Durability and Microstructure. Concrete specimens were prepared using a mix ratio of 1:2:4 and water-cement ratio of 0.50. The Portland cement constituent of the mix was subsequently replaced with EPO-FBA from 0 – 15% at 5% interval by weight. Samples without EPO-FBA served as control samples.

3.4.1 Workability

Workability of concrete defined by ACI standard 116R-90 (ACI 1990b) as that property of freshly mixed concrete which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished to a homogenous condition. The slump test was carried out in accordance with (BS 1881: Part 102 1983) using apparatus which consist of slump cone, hand trowel, weigh balance and tamping rod. The concrete was batched by weight following the mix ratio, it was then mixed with water in order to prepare the required paste. It was ensured that the internal surface of the mould was clean and damp and also free from superfluous moisture before the test commenced. The mould was placed on a smooth, horizontal, rigid and non-absorbent surface free from vibration and shock. The mould was held firmly against the surface, whilst it was filled in three layers, each approximately one-third of the height of the mould when tamped. Each layer was tampered with 25 strokes of the tamping rod, the strokes being distributed uniformly over the cross-section of the layer. Each layer was tampered to its full depth, ensuring that the tamping rod did not forcibly strike the surface below when the first layer was tampered and just passed through the second and top layers into the layers immediately below. The concrete was heaped above the mould before the top layer was tamped. Concrete was further added to maintain an excess, above the top of the mould throughout the tamping operation. With the mould still held down, concrete from the surface below which may have fallen onto or leaked from the lower edge of the mould was cleaned. The mould was removed from the concrete by raising it vertically, slowly and carefully, in 5 s to 10 s, in such a manner that there was minimum lateral or torsional movement to the concrete. The entire operation from the start of filling to the removal of the mould was carried out without interruption and was completed within 150 s. Immediately after the mould was removed, the slump was measured to the nearest 5 mm, using the rule to determine the difference between the height of the mould and of the highest point of the specimen under test. The process is as shown in Plate 3.14.

Plate 3.14: Workability test using slump cone

3.4.2 Density

The weight of concrete per unit volume was determined using the concrete cube samples of 150mm x 150mm x 150mm size prepared for the compressive strength test. Mass of concrete samples were measured using weigh balance.

3.4.3 Compressive Strength

Compressive strength of concrete can be defined as the maximum compressive force it can withstand without fracture. It is the maximum compressive load the concrete can carry per unit area. Compressive strength of concrete is the most desirable mechanical property of hardened concrete as all the other mechanical properties like flexural strength, splitting tensile strength, abrasion resistance, pull-off strength and modulus of elasticity directly depends on the compressive strength of concrete.

In this study, Concrete cube specimens of 150mm x 150mm x 150mm were casted in order to quantify the compressive strength of specimens. 3 cubes were casted for each replacement level and cured for 7, 14, and 28 days. The compressive strength of concrete cubes was tested using compressive strength testing machine with maximum load capacity of 1000kN. The bearing surfaces of the machine were wiped clean. Also, the surface of concrete specimen was wiped clean in order to remove any loose grit or other extraneous material from the surface of the specimen. On the lower platen of the machine, the concrete cube was centrally placed (as shown in Plate 3.15) in order for the load to be applied on the two opposite faces of the cube. The concrete cube was subjected to load from the machine until a crack pattern surfaced as shown in Plate 3.16. The load that produced the crack was then recorded. The compressive strength of concrete was calculated by dividing the crushing load by the cross sectional area of the cube. The average value of the compressive strength of the three cubes were obtained for each replacement level.

Plate 3.15: Concrete specimen under compressive strength test

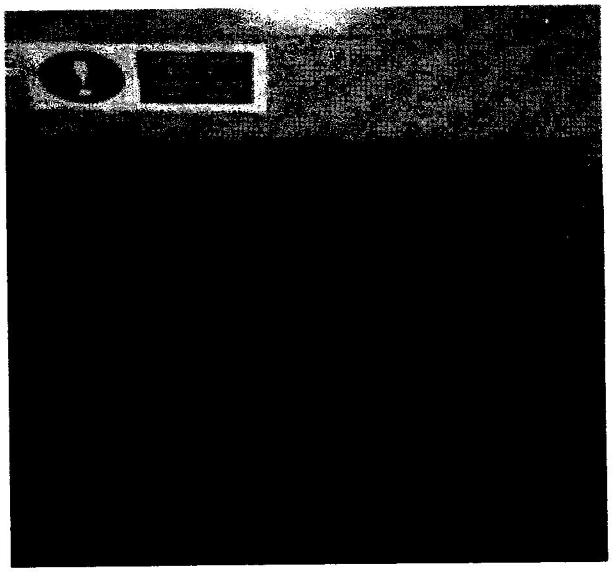

Plate 3.16: concrete specimen after failure

3.4.4 Durability

Durability is defined as the capability of concrete to resist weathering action, chemical attack and abrasion while maintaining its desired engineering properties. It normally refers to the duration or life span of trouble-free performance. Different concretes require different degrees of durability depending on the exposure environment and properties desired. For example, concrete exposed to tidal seawater will have different requirements than indoor concrete. In this study, concrete specimens containing EPO-FBA were tested under durability properties consisting sorptivity and water absorption. Concrete specimens of size 100mm x 100mm x 100mm were used.

Coefficient of Water Absorption

Coefficient of water absorption is suggested as a measure of permeability of water. This is measured by the rate of uptake of water by dry concrete in a period of 60m.

In this study, water absorption and sorptivity test were done in accordance with (ASTM C 1585 2004) Concrete specimens were heated in an oven at temperature 90°C – 100°C until constant weight is achieved. The concrete was then cooled at room temperature for 24hr. To ensure unidirectional flow through the concrete specimen without any influence of wicking actions, four sides of the concrete specimen was then coated with silicone sealant to a height of 50mm after which the mass was measured. The sealed concrete specimen was then immersed in water in a shallow span to a depth of 10mm. After 60m, the concrete specimen was removed. Excess surface water was wiped out and the concrete was then reweighed. At the end of the test, the coefficient of water absorption was calculated using the formulae below.

$$ka = \left(\frac{Q}{A}\right)^2 \times \frac{1}{t}$$

Ka = coefficient of water absorption (m^2/s)
Q = the amount of water absorbed by the concrete specimen (m^3)
A = the cross sectional area of concrete specimen in contact with water (m^2)
t = time (s)

Sorptivity

Sorptivity is a measure of the capillary forces exerted by the pore structure causing fluids to be drawn into the body of the material. The same procedure as that of water absorption was followed but the time at which the concrete specimen was taken out of the water differs. The concrete specimen was removed at selected times 4, 8, 10, 20, 30, 60, 90 and 120m. For sorptivity test, the cumulative absorbed volume of water per unit area of inflow surface (i) was calculated using the formulae below;

$$i = \frac{\Delta w}{Ad}$$

I = the cumulative absorbed volume of water per unit area of inflow surface (mm)

Δw = change in weight of concrete specimen = w2 – w1

W1 = oven dry weight of concrete cube in grams

W2 = weight of concrete after capillary suction of water in grams

A = surface area of the specimen through which water penetrated.

D = density of water

In order to get the sorptivity value of concrete samples, the cumulative absorbed volume of water per unit area of inflow surface (i) was related with the square root of the elapsed time ($t^{0.5}$) by plotting the graph of (i) against $t^{0.5}$. The relationship between these two values is shown below;

$i = S \times t^{0.5}$ (the slope of the line of best fit of these points was taken as the sorptivity value)

The experimental setup and process for water absorption and sorptivity test is as shown in plate 3.17 and 3.18 below and represented in Figure 3.1.

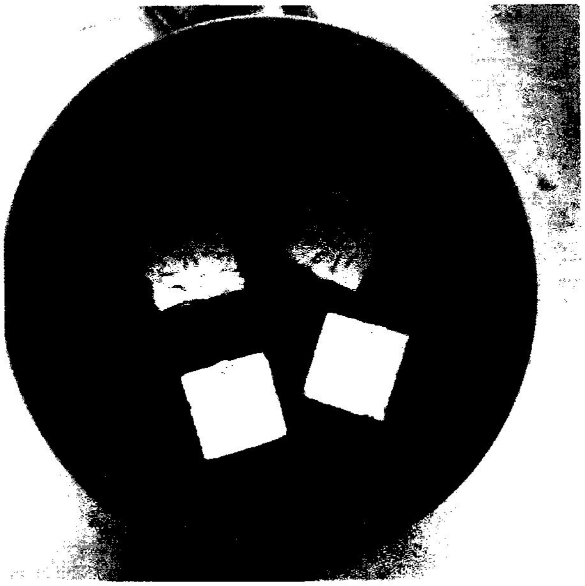

Plate 3.17: 100mm concrete cubes with 10mm depth in Water to test for sorptivity and water Absorption

Plate 3.18: Water absorption and sorptivity test experimental setup

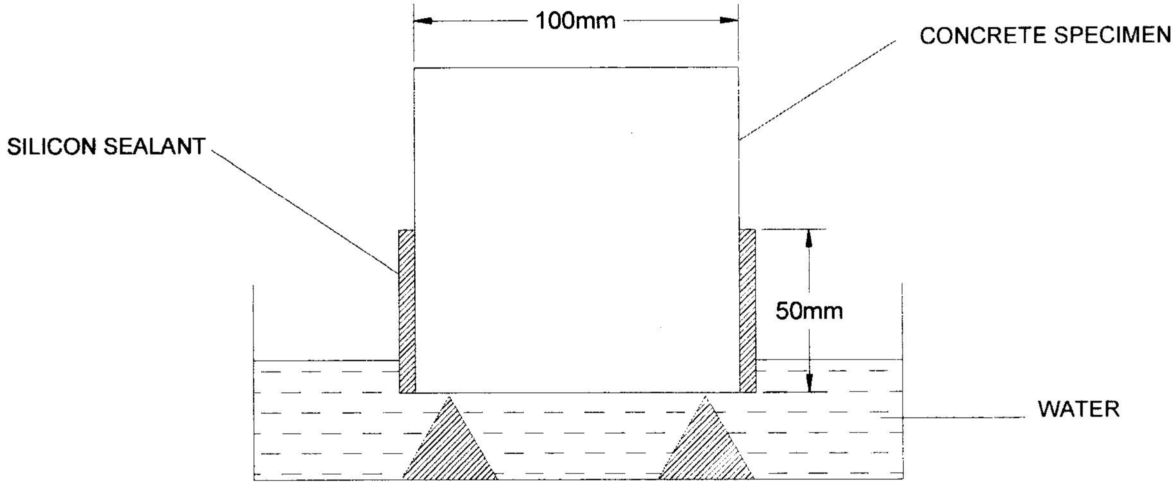

Figure 3.1 : Schematic diagram of durability test (sorptivity and water absorption)

3.4.5 Microstructure

Concrete has a heterogeneous microstructure, which consists of three components namely, cement paste, pore structure, and interfacial transition zone between the cement paste and aggregates. Improving these three components leads to enhance mechanical strength and durability of concrete.

In this study, Microstructural test was carried out on broken samples of 28 days concrete specimen of EPO – FBA Concrete. Scanning electron microscope machine (as shown in Plate 3.19) was used to examine the morphological structures of the specimens. This involve the characterization of the cement paste and the paste/aggregate interface. The equipment model JEOL JSM-7600 scanning electron microscopy (SEM) comes with energy dispersive spectrometer (EDS) and it allows high resolution identification of elements and compounds present in prepared 2-D cross sections of aggregate samples to be obtained.

All samples must be of an appropriate size to fit in the specimen chamber and are generally mounted rigidly on a specimen holder called a specimen stub. Several models of SEM can examine any part of a 6-inch (15 cm) semiconductor wafer, and some can tilt an object of that size to 45^0.

Samples are coated with platinum coating of electrically conducting material, deposited on the sample either by low-vacuum sputter coating or by high-vacuum evaporation. SEM instruments place the specimen in a relative high-pressure chamber where the working distance is short and the electron optical column is differentially pumped to keep vacuum adequately low at the electron gun. The high-pressure region around the sample in the ESEM neutralizes charge and provides an amplification of the secondary electron signal. Low-voltage SEM is typically conducted in an FEG-

SEM because the field emission guns (FEG) is capable of producing high primary electron brightness and small spot size even at low accelerating potentials.

Embedding in a resin with further polishing to a mirror-like finish can be used for both biological and materials specimens when imaging in backscattered electrons or when doing quantitative X-rays microanalysis.

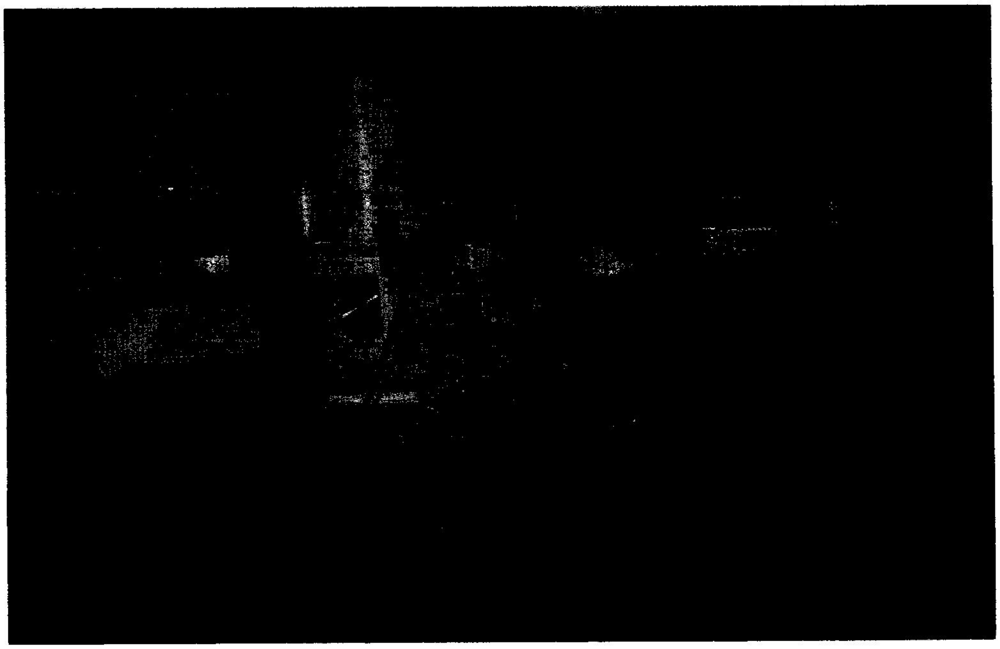

Plate 3.19 : Scanning Electron Microscope Machine and its experimental setup

3.4.6 Tensile Strength

Tensile strength of a material is the maximum amount of tensile stress that it can take before failure, for example breaking. Concrete specimen of 150 x 300mm cylinder mould was casted and cured for 28 and 90 days before testing the tensile strength as shown in Plate 3.20.

Plate 3.20: Tensile strength test

CHAPTER FOUR

RESULT AND DISCUSSION

4.0 Background

The various aspects studied are grouped into two part, number one is the preliminary test including comparison of EPO-FBA and OPC using chemical analysis, fineness test, consistency test and setting time. The second part which is the Major test include the effect on Workability, Compressive Strength, Density, Durability and Microstructure using EPO – FBA in varying percentages as partial replacement of cement. The results are given below:

4.1 Preliminary Test

4.1.1 Chemical Analysis

The result of chemical analysis which was carried out in order to compare the chemical contents present in EPO – FBA and OPC is as shown in Table 4.1 below. From the Table, it can be observed that, compared to OPC, EPO-FBA is low in the amount of Silicate (**SiO_2**) and Carbonate (**CaO**). **SiO_2** and **CaO** content of EPO-FBA is 6.42% and 7.03% respectively while that of OPC is 20.68% and 64.37% respectively. **Al_2O_3** of EPO-FBA was found to be 12.73% which is higher than that of OPC (5.41%). According to the ASTM C618, the value of SiO2 + Al2O3 + Fe2O3 of EPO-FBA that is 25.78% is less than the required minimum of 70 % of pozzolans.

The other chemical contents including, **K_2O, Fe_2O_3, Mn_2O_3, MgO, P_2O_3** and **SO_3** showed insignificant differences between OPC and EPO – FBA. Moreover, the percentage loss of ignition (LOI) in EPO – FBA is far greater than that of OPC with the value 44.62%. The higher percentage of LOI which is the measure of the carbonation and hydration extent of free lime and free magnesia due to atmospheric exposure can be connected to the absence of processing energy during the preparation of EPO-FBA (Fapohunda *et al.*, 2017). In the other hand, EPO-FBA can still perform satisfactorily based on the work of Day (1990). In the work of Day (1990), 120 pozzolanic materials was surveyed from different countries, it was discovered that materials with higher LOI compared to the lower amount of **SiO_2**, **Al_2O_3**, **Fe_2O_3** were still classified as pozzolans because of their proven cementious property. In addition to this, the work of (Lee *et al.* , 2014) showed that limestone powder gave a promising result even though its LOI is very high. Finally, the alkali content which took a combined value of 9.12% is negligible based on BS 12(1996), therefore, according to (Neville 2003), the possibility of destructive alkali aggregate reaction is very low in concrete containing EPO - FBA

Table 4.1 : Chemical Composition of EPO-FBA and OPC

PARAMERTERS (%)	EPOFBA	OPC
SiO_2	6.42	20.68
Na_2O	7.23	0.51
CaO	7.03	64.37
K_2O	1.89	0.47
Al_2O_3	12.75	5.41
Fe_2O_3	6.61	3.62
Mn_2O_3	2.64	3.25
MgO	4.10	1.81
P_2O_3	0.60	5.65
SO_3	1.49	1.03
LOI	44.62	0

4.1.2 Fineness Test

The result of fineness test carried out in order to compare EPO-FBA and OPC is as represented in Table 4.2 and Figure 4.1. The percentage residue remained on the 90micrometer sieve was found to be 9% for OPC while that of EPO – FBA is 31%. The reason for the high percentage of EPO – FBA residue can be because of the presence of impurities due to the burning method that was employed. This can also be attached to the fact that EPO-FBA has coarser particle size.

Table 4.2 : Fineness of Materials (EPO-FBA and OPC)

OPC (%)	EPO-FBA (%)
91	69

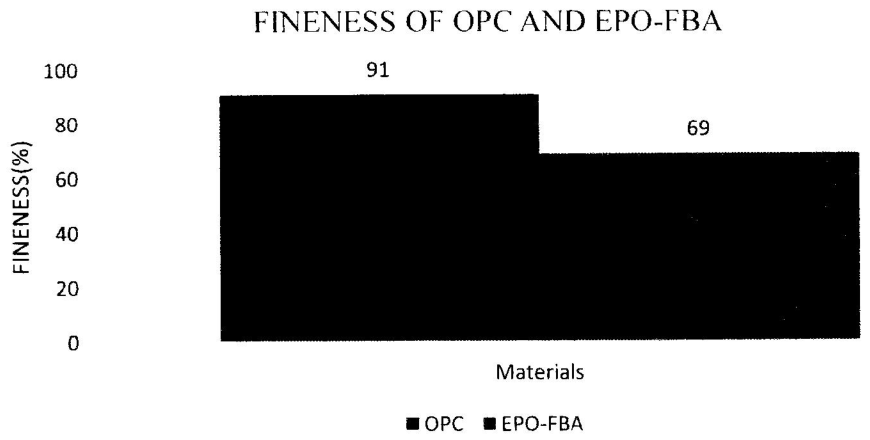

Figure 4.1: Fineness of Materials (EPO-FBA and OPC)

4.1.3 Consistency

The result of standard consistency for each replacement level is shown in Table 4.3 and Figure 4.2. The graph of percentage of cement replacement level versus standard consistency is as represented in Figure 4.3. From the graph in Figure 4.3, it can be seen that the water required for standard consistency linearly increases with an increase in EPO-FBA content. This occurred as a result of the fact that EPO – FBA is hygroscopic (Readily taking up and retaining water, especially from the atmosphere.) in nature. In addition to this, EPO-FBA has a very large specific surface area (Fapohunda and Ahmed, 2017) compared to OPC, which means it requires more water.

Table 4.3 : Consistency of cement paste with EPO-FBA as partial replacement of OPC

EPO-FBA (%)	CONSISTENCY(P)%
0	27
5	32
10	34
15	39

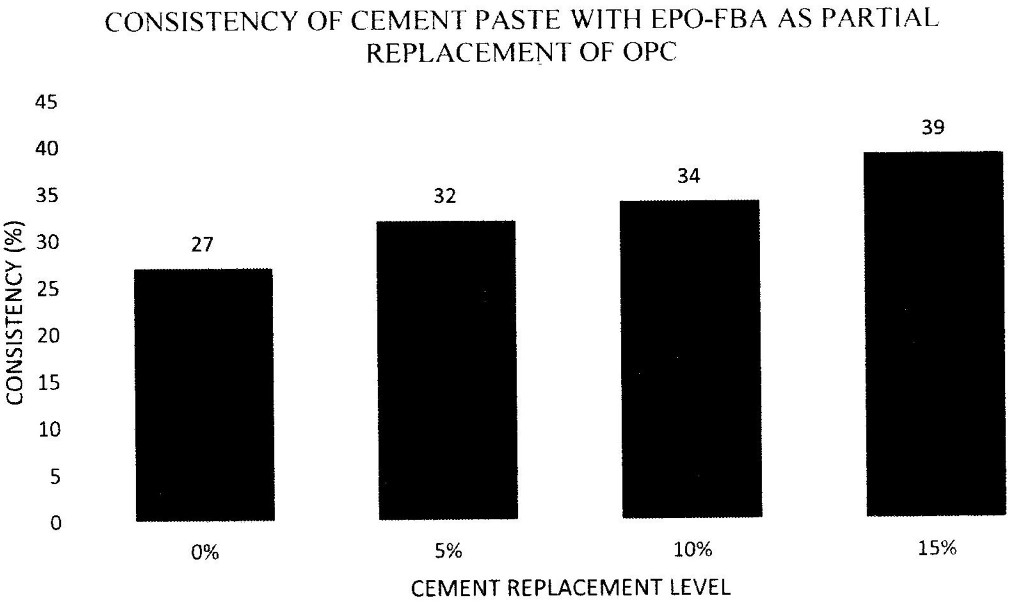

Figure 4. 2 Consistency of cement paste with EPO-FBA as partial replacement of OPC

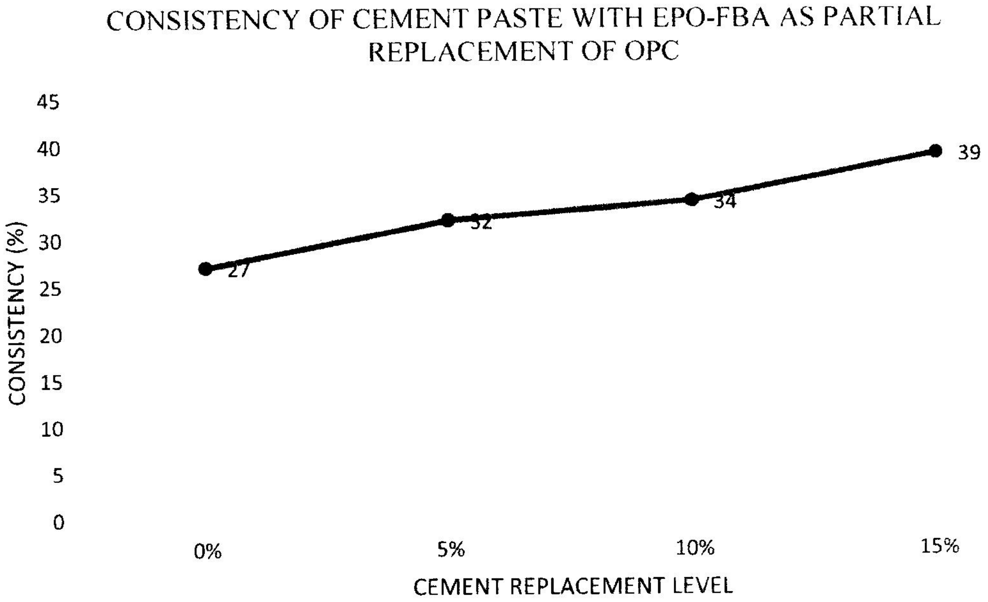

Figure 4. 3 Consistency of cement paste with EPO-FBA as partial replacement of OPC

4.1.4 Setting Time

The Initial and Final setting times obtained for each cement replacement level with EPO-FBA is as shown in Table 4.4 and Figure 4.5. From Figure 4.4, it can be seen that there is only a slight difference between the initial setting time of control cement paste and 5% replacement level, the initial setting time of the control paste is 80minutes while that of 5% replacement is 82minutes. For the 10% replacement level, there is a significant decrease in the initial setting time (27min) compared to 0% and 5%. The 15% replacement level was found to be 67min which is more than that of 10% replacement level. On the other hand, the final setting time of OPC was found to be 149min which is less than that of 5% which took the longest time to finally set. The final setting time decreases linearly with increase in EPO-FBA content from 10% to 15%. This result can be attached to the fact that EPO –FBA possess a very small specific surface area (Fapohunda *et al.*, 2017) which gave it the property of low water absorption rate and which in turn delayed the hydration process of the OPC/EPO-FBA paste.

Table 4.4: Setting times of Cement paste with EPO-FBA as partial replacement of OPC

EPO-FBA%	**Initial Setting times(min)**	**Final Setting times(min)**
0	80	149
5	82	189
10	27	165
15	67	146

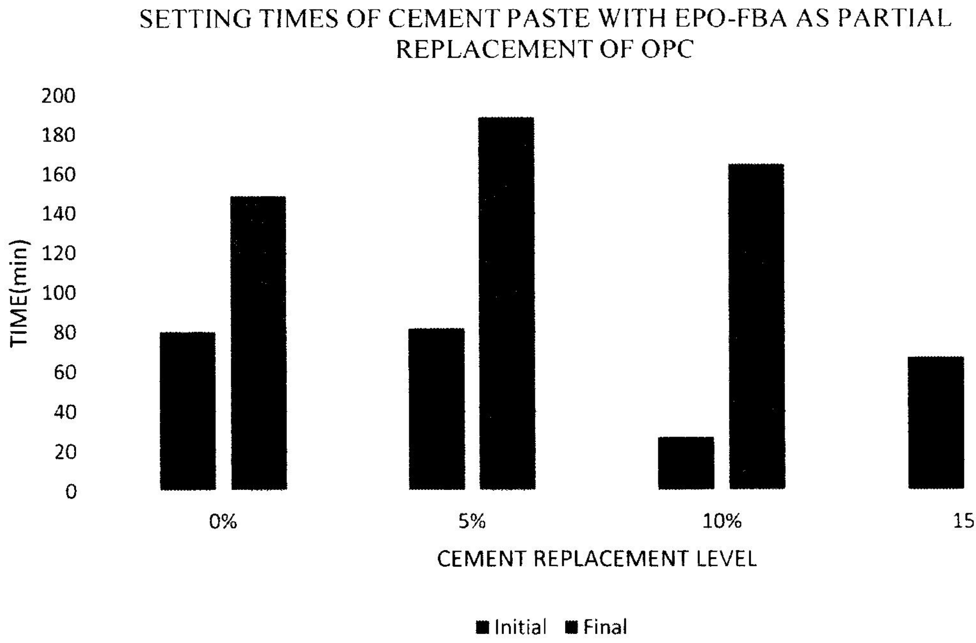

Figure 4.4 : Setting times of Cement paste with EPO-FBA as partial replacement of OPC

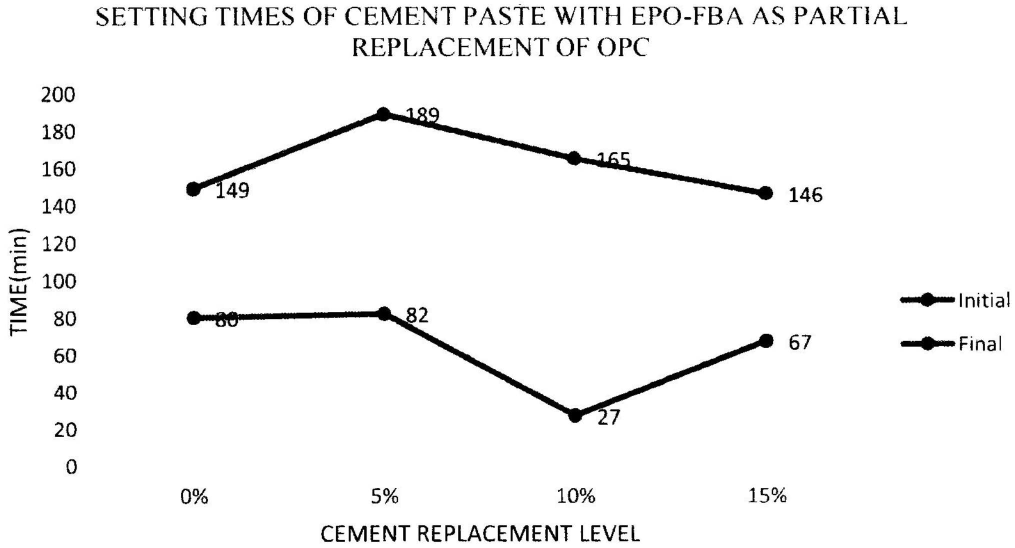

Figure 4.5 : Setting times of Cement paste with EPO-FBA as partial replacement of OPC

4.2 Main Test

4.2.1 Workability

The workability characteristics of freshly mixed concrete with EPO-FBA as partial replacement of OPC is as shown on Table 4.5 and represented in Figure 4.5 and 4.6. The workability result which evaluates the ease with which freshly mixed concrete of each replacement level can be worked on, transported and compacted to a dense mass without bleeding or segregation gave low slump values. For the control mix, 30mm slump was achieved while the other replacement levels (5%, 10% and 15%) gave 20mm slump. This result showed that EPO-FBA produces a harsh and lean mix as the replacement level increases. This result can then be attached to the fact that EPO-FBA possess a low percentage of fineness which in turn gave its large surface area characteristics. This means that large surface area of EPO-FBA is exposed for water to wet making the water to be insufficient as quantity of EPO-FBA increases. This in turn produces harsher mix which is less workable and which bring about the reason for a very low slump all through.

This result fall within the range of concrete classified as low workability (Neville 2013). Due to the fact that all the samples indicate a cohesive mix and no segregation, the slump can be classified as true slump (Shetty, 2009). In the other hand, according to (Gambhir 2013), such concrete is applicable in lightly reinforced sections and for mass concrete production.

Table 4.5 : Workability characteristics of concrete samples with EPO-FBA as partial replacement of OPC

Replacement Level (%)	Slump (mm)
0	30
5	20
10	20
15	20

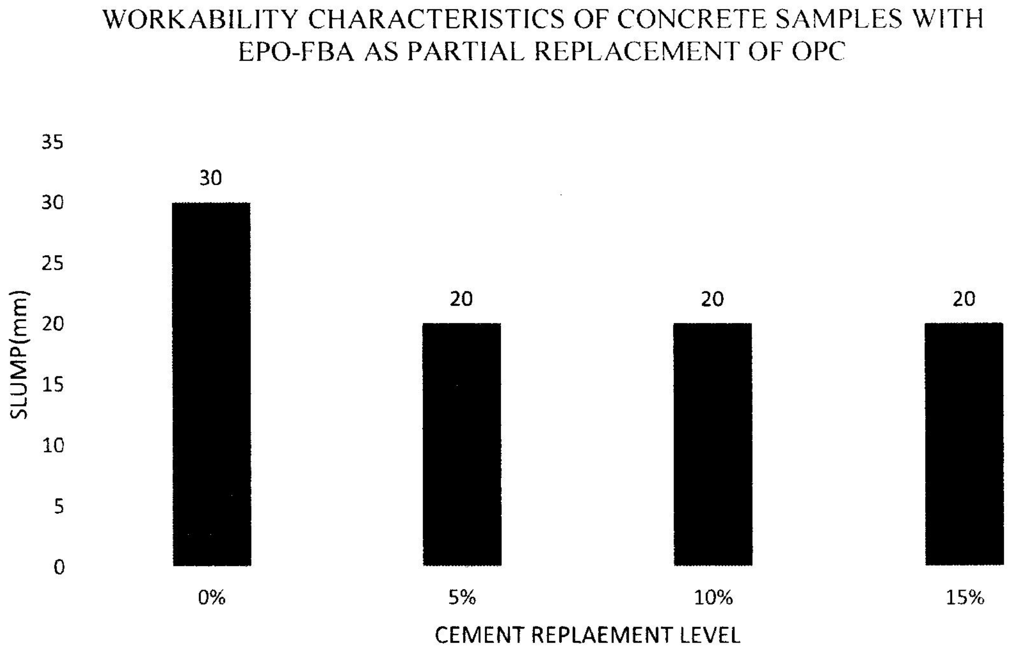

Figure 4.5: Workability characteristics of concrete samples with EPO-FBA as partial replacement of OPC

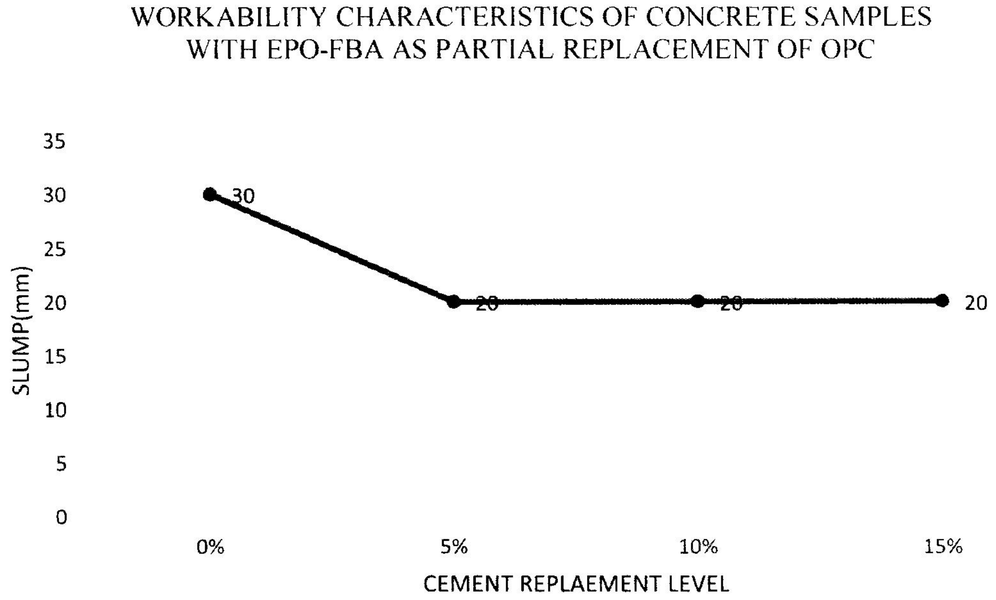

Figure 4.6: Workability characteristics of concrete samples with EPO-FBA as partial replacement of OPC

4.2.2 Density

The average densities of concrete specimens with EPO-FBA as partial replacement of OPC cured for 7, 14, and 28 days are presented on Table 4.6 and represented in Figure 4.6 and 4.7 below. The resulting density of concrete blended with EPO-FBA falls between the range of 2459kg/m^3 - 2406 kg/m^3 which tallies with the standard density of concrete (2400kg/m^3).

The air dry density of concrete is very important for the weight of the structure and it defines the compactness, the amount of reinforcement and sizes of structural member in a particular structure (Bello 2017). From Figure 5.1, it can be seen that the densities of each curing days decreases with increase in EPO-FBA content, but at 5% replacement level, the concrete gave a promising result which is very close to that of control mix. In the other hand, considering the three classes of concrete on the basis of weight namely, lightweight concrete, normal weight concrete and heavy weight concrete with densities 300 - 1920 $\boldsymbol{kg/m^3}$, 2240 - 2480 $\boldsymbol{kg/m^3}$ and greater than 2500$\boldsymbol{kg/m^3}$ respectively (Falade *et al.*, 2011), it can be seen that all the replacement values of EPO-FBA with OPC falls within the range of normal weight concrete. Finally, since the density of 5% replacement level for all curing ages is very close to that of control mix density, it is recommended for use in normal weight concrete production.

Table 4.6 : Density Characteristics of Concrete Samples with EPO-FBA as partial replacement of OPC

Replacement Level(%)	Density ($\boldsymbol{kg/m^3}$) of concrete specimens with respective curing ages		
	7 DAYS	**14DAYS**	**28DAYS**
0	2441.5	2483.0	2488.9
5	2417.8	2483.0	2483.0
10	2414.8	2432.6	2474.1
15	2405.9	2423.7	2474.1

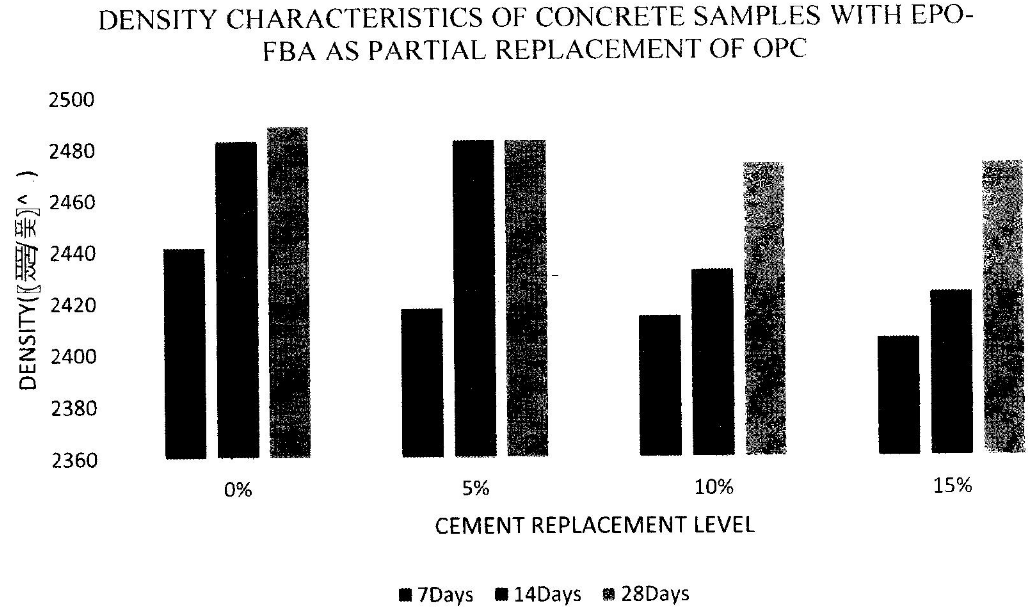

Figure 4.7 : Density Characteristics of Concrete Samples with EPO-FBA as partial replacement of OPC

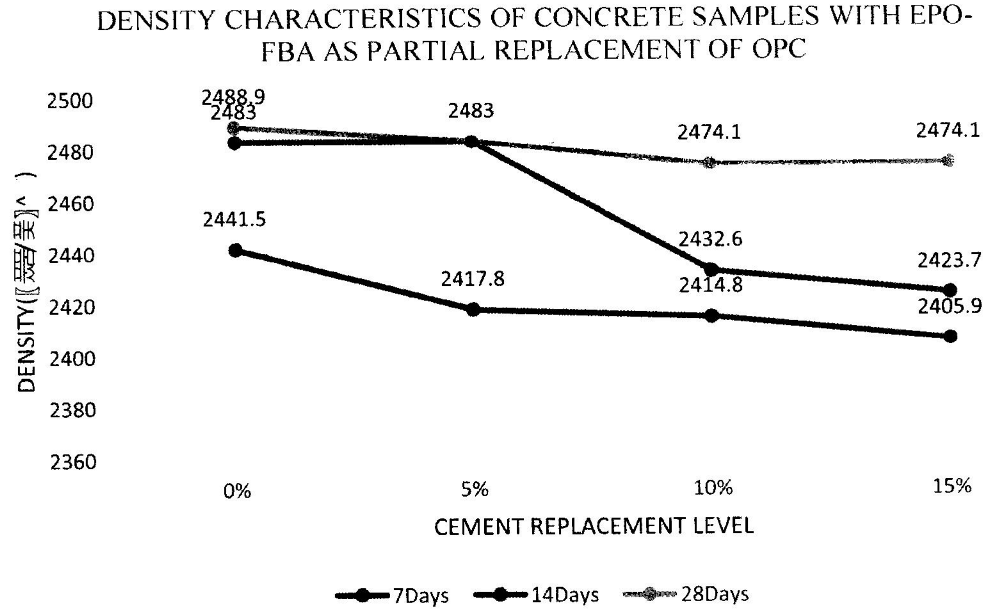

Figure 4.8 : Density Characteristics of Concrete Samples with EPO-FBA as partial replacement of OPC

4.2.3 Compressive Strength

Compressive strength of concrete mixes with and without EPO-FBA was determined at 7, 14 and 28 days, the test results are given in Table 4.7 and represented in Figure 4.9. Compressive strength decreases as the percentage of EPO-FBA increases. However, for 5% EPO-FBA added, the compressive strength development at 7 Days was greater than the control samples while that of 28 Days showed insignificant difference compared to that of the control samples. As represented in Figure 4.8, the 28 Days compressive strength of concrete samples with 10% and 15% replacement of OPC with EPO-FBA decreases from 24.38 to 22.34N/mm^2 respectively. As per IS456:2000, the specified characteristics compressive strength of 150mm concrete cubes at 28Days for M25 grade concrete is 25N/mm^2. From this result, it can be observed that up to 5% replacement of OPC with EPO-FBA, a compressive strength of 25N/mm^2 can be obtained, but when more than 5% is replacing OPC, then the compressive strength goes below the targeted strength

Table 4.7 : Compressive Strength characteristics of concrete samples against curing ages

Replacement Level (%)	Compressive strength (N/mm^2) of concrete specimens with respective curing ages		
	7 DAYS	**14DAYS**	**28DAYS**
0	24.84	25.34	29.78
5	24.96	24.82	26.42
10	17.82	22.71	24.38
15	15.71	18.85	22.24

From Figure 4.9 and 4.10 below, compressive strength of all specimen and replacement levels increased with increasing curing ages. This is expected to happen because, according to (Fapohunda *et al.*, 2017), the strength forming product of hydration (C-S-H gel) increases with increasing curing ages. Hydration is one of the major determinant of concrete strength because it forms the strength forming product (C-S-H gel). However, from the previous results, two properties of EPO-FBA contributed to its dehydrating character. The first property is the chemical content; EPO-FBA consist of a very low **SiO_2** and **CaO** content compared to OPC, meanwhile, these two parameters highly contribute to the strength of concrete. The second property is the fineness of EPO-FBA which is also very low compared to that of OPC, meanwhile, the higher the surface area due to fineness of binder, the larger the area that is watered for hydration which in turn produces higher strength development in concrete.(Awal and Ugung 2010)

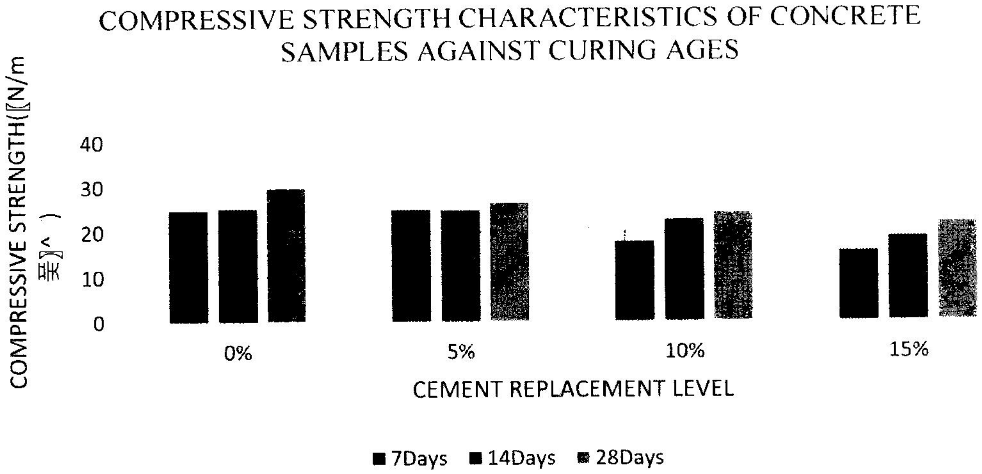

Figure 4.9 : Compressive Strength characteristics of concrete samples against curing ages

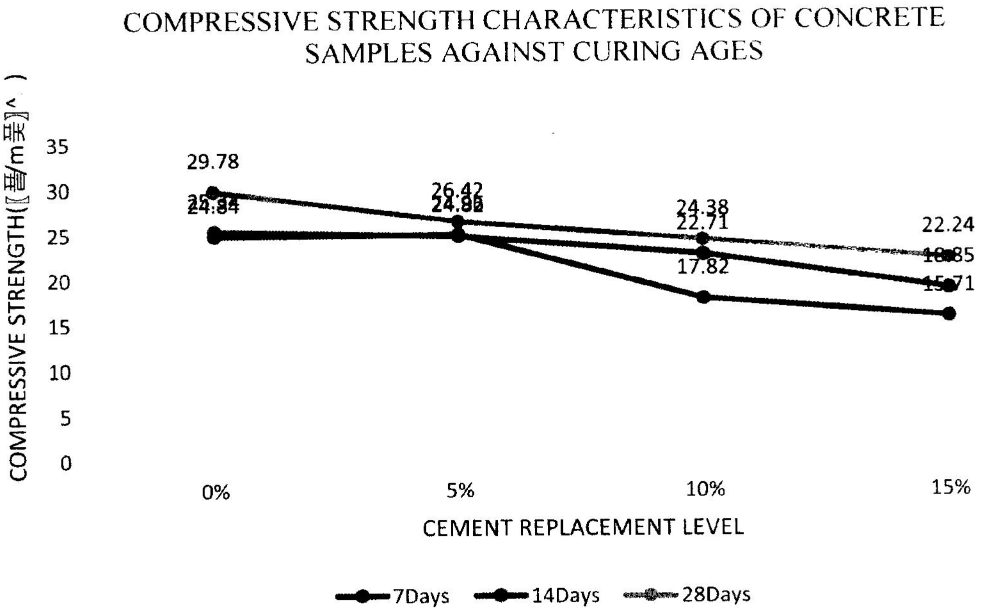

Figure 4.10 : Compressive Strength characteristics of concrete samples against curing ages

Table 4.8: Determination of the Pozzolanity of Empty Palm Oil Fruit Brunch Ash (EPO-FBA) through Strength Activity Index (SAI)

EPO-FBA (%)	**Compressive Strength, CS (N/ mm^2) and Strength Activity Index, SAI (%) Against Curing days.**									
	7DAYS		14DAYS		**28DAYS**		60DAYS		90DAYS	
	CS (N/mm^2)	**SAI (%)**	CS (N/mm^2)	SAI (%)	**CS (N/mm^2)**	**SAI (%)**	CS (N/mm^2)	SAI (%)	CS (N/mm^2)	SAI (%)
0	**24.84**	**100**	25.34	100	**29.78**	**100**	33.61	100	35.28	100
5	**24.96**	**100.50**	24.82	97.95	**26.42**	**88.72**	34.12	101.52	34.11	96.68
10	**17.82**	**71.74**	22.71	89.62	**24.38**	**81.87**	30.75	91.49	32.90	93.25
15	**15.82**	**63.69**	18.85	74.39	**22.24**	**75.00**	27.51	81.85	30.84	87.41

The computation of pozzolanity of Empty palm oil fruit bunch ash (EPO-FBA) through strength activity index is shown in Table 4.8 above. The strength activity index is measured by calculating the strength developed by the blend of the suspected pozzolan relative to the control. For any material to be classified as a pozzolan, the strength of the blended sample at 7-days and/or 28-days must not be less than the 75% of the strength of control specimens.

From Table 4.8, it can be seen that at 7-days only the sample with 5% of cement replaced with empty palm oil fruit brunch ash (EPO-FBA) met the criterion of pozzolanity. However, at 28-days curing, all the mixes exhibited pozzolanic traits because the 28-days strengths of specimens containing empty palm oil fruit brunch ash (EPO-FBA) were all more than 75% of the strength of specimens without EPO-FBA, that is, the control specimens. It can thus be concluded that EPO-FBA is pozzolanic.

4.2.4 Tensile Strength

The results of tensile strength of concrete mixes with and without EPO-FBA measured at 28 days and 90 days are given in Table 4.9 below. Test results indicate that the tensile strength reduces as the percentage of EPO-FBA increase from 0% to 15%. When the replacement of EPO-FBA is increased, strength goes on decreasing. However, for 10% at 28days ash added, the tensile-strength development was the same as the 15%. These results are represented graphically below in Figure 4.11 and 4.12.

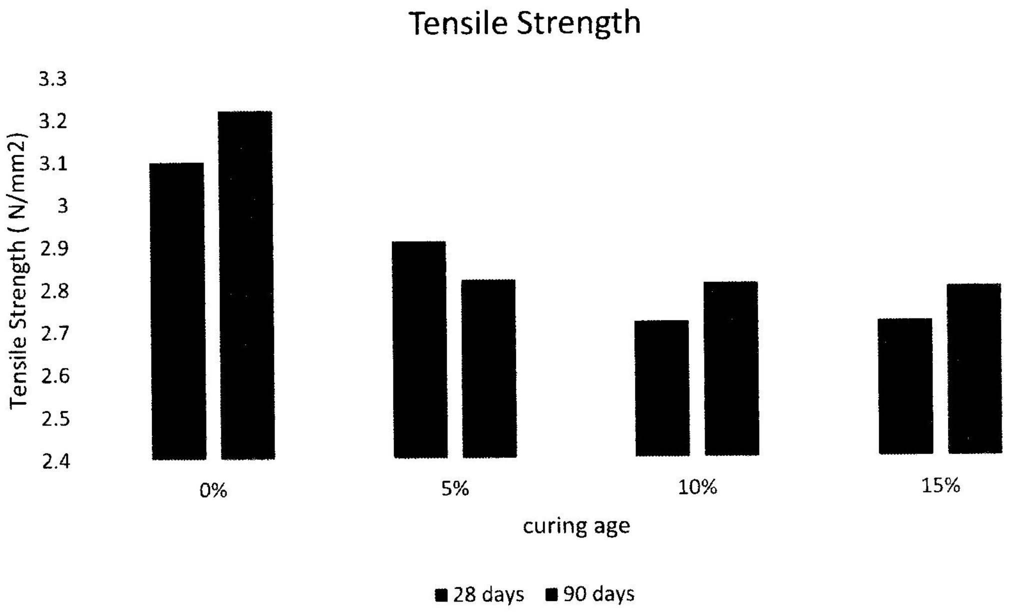

Figure 4.11: Tensile strength of concrete of different proportion of EPO-FBA

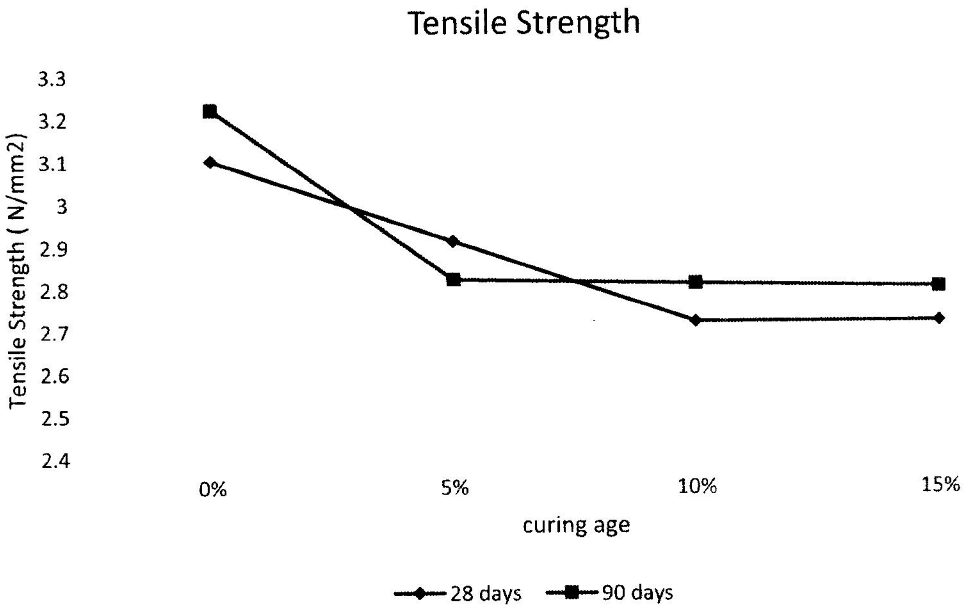

Figure 4.12: Tensile strength of concrete of different proportion of EPO-FBA

Table 4.9: Tensile strength of concrete of different proportion of EPO-FBA

Proportion (%)	Curing Age (N/mm²)	
	28 Days	90 Days
0	3.10	3.22
5	2.91	2.82
10	2.72	2.81
15	2.72	2.78

4.2.5 Durability

The result of durability performance of Concrete with EPO-FBA as partial replacement of OPC assessed by testing for water absorption and sorptivity after 28 and 90 days of curing are as shown in Table 4.10 and 4.11 respectively and represented in Figure 4.13 and 4.14 respectively . From the result, it can be seen that both the sorptivity and water absorption of all the tested samples showed the same pattern. The water absorption rate increases with increase in quantity of EPO-FBA. This result can be connected to the withdrawal of mixing water from the mix as EPO-FBA content increases which then leads to the formation of unhydrated compounds without the product of hydration (C-S-H). This left some pores within the concrete structure which then led to the increase in water absorption. In the other hand, the result of water absorption rate and after 90Days curing is less than that of 28Days. This result can be due to the fact that more hydration product (C-S-H) was produced at later curing ages which are responsible for filling the pores in the concrete structure and which in turn reduces the water absorption rate. The hydration products can also bring about a state of discontinuity of pores in the internal matrix, thereby making the material impervious (Fapohunda *et al.*, 2017).

Table 4.10 : Water absorption results for 28Days and 90Days Curing Ages

Replacement Level (%)	Water Absorption (m^2/s) of concrete specimens with respective curing ages	
	28 DAYS	**90 DAYS**
0	2.32×10^{-9}	1.11×10^{-9}
5	4.08×10^{-9}	2.34×10^{-9}
10	1.81×10^{-9}	3.80×10^{-9}
15	8.05×10^{-9}	5.03×10^{-9}

Table 4.11 : Sorptivity results for 28Days and 90Days Curing Ages

Replacement Level (%)	sorptivity ($mm/m^{0.5}$) of concrete specimens with respective curing ages	
	28 DAYS	**90 DAYS**
0	0.585	0.362
5	0.508	0.466
10	0.557	0.637
15	0.755	0.803

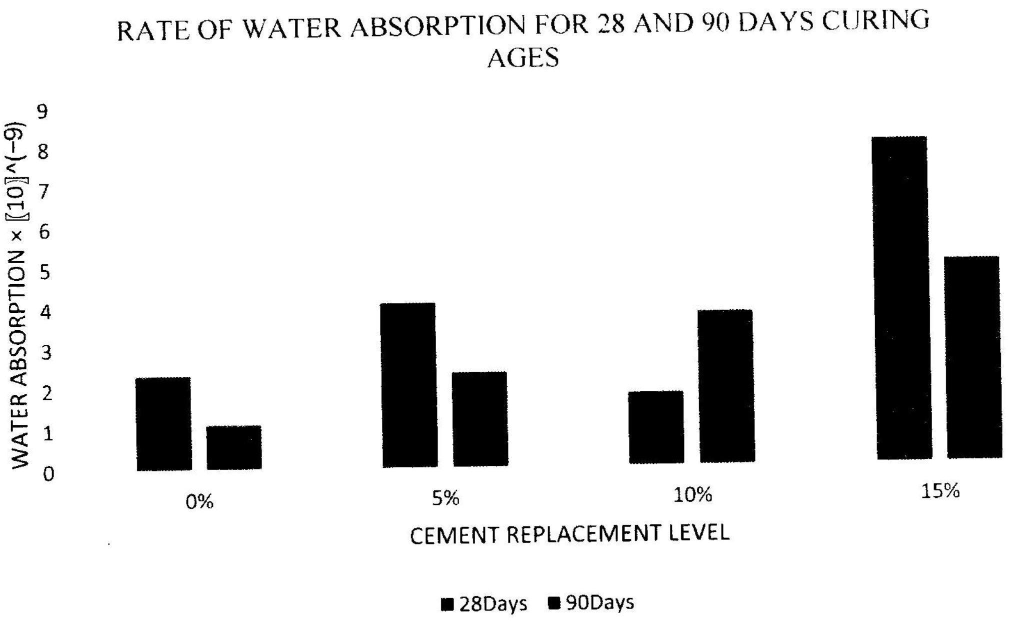

Figure 4.13 : Water absorption results for 28Days and 90Days Curing Ages

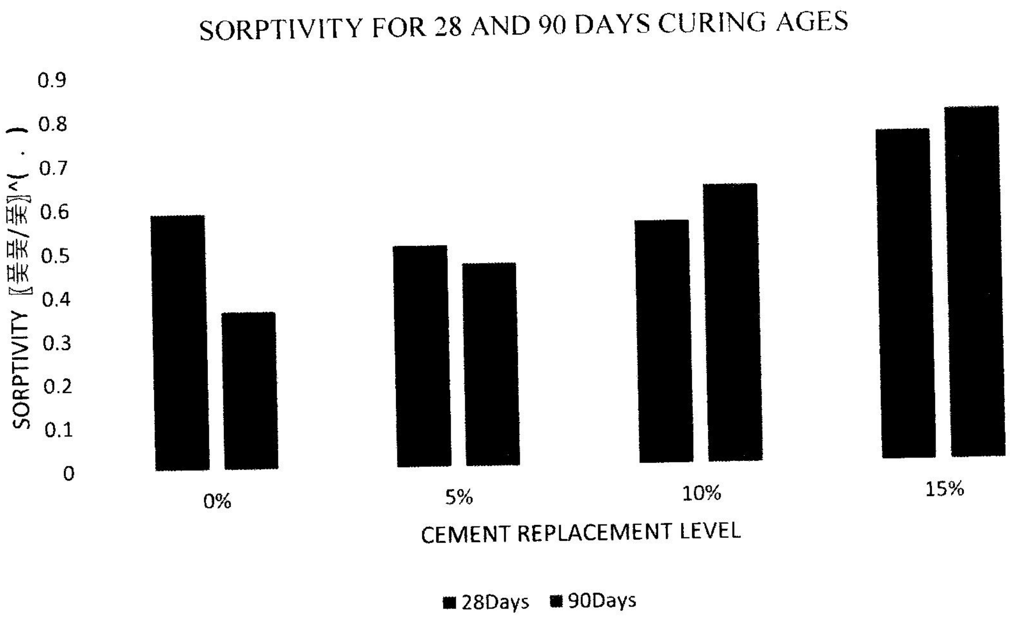

Figure 4.14 : Sorptivity results for 28Days and 90Days Curing Ages

4.2.6 Microstructure

The microstructural examination of selected samples was conducted to analyse the bond between the concrete aggregate and cement paste at the microscopic level. According to (Mindess *et al.*, 2003) the bonding between the aggregate and binder is considered vital for better transfer of stresses between the binder and aggregates especially at the interfacial zone, which influences the concrete strength. The main source of strength in concrete is the adhesion between the solid products of hydrated cement paste. This adhesion can be attributed to the van der Waals forces of attraction with a degree of adhesive depends on the extent and the nature of the solid surfaces involved. Some of hydrated products, such as C-S-H crystals, calcium sulfoaluminate hydrates, and hexagonal calcium aluminate hydrates, possess vast surface areas and adhesive capability. Therefore, they tend to adhere strongly to each other and at the same time to solids with low surface areas fine and coarse aggregate particles.(Just *et al.*, 2013)

The SEM analyses were conducted on selected concrete samples at replacement level 0%, 5%, 10% and 15% cured for 28 days. Figure 4.15 shows the SEM micrograph taken on the fractured surface of concrete without EPO-FBA. This Diagram shows a well-developed aggregate–cement paste interface and the hydration product C-S-H (Calcium Silicate Hydrate) can be seen as honeycombs structure with some surrounding pores but no crack. In the other hand, from Figure 4.16, the 5% replacement level with EPO-FBA shared similar characteristics with that of the control sample. The strength forming product of hydration C-S-H can be seen surrounding the whole aggregate structure with no cracks and little pores compared to that of 0% replacement. This later age development of the strength forming hydration product C-S-H can be connected to the promising result of compressive strength in the 5% replacement with EPO-FBA which is very close to the strength of Control sample.

It can be observed from the remaining Figure (4.17-4.18), 10% and 15% respectively, as the quantity of EPO-FBA increases, the pores reduces and the structure became densely packed. This can be connected to the fact that there is reduction in the quantity of strength forming hydration product C-S-H as the quantity of EPO-FBA increases which makes the remaining unreacted EPO-FBA particle to fill the pores in the structure. This shows that EPO-FBA possess void-filling ability and explains the low result of compressive strength at 28Days especially at larger replacement with EPO-FBA. In the other hand, the increase in the content of unreacted EPO-FBA shows the reason why the rate of water absorption increases with increasing EPO-FBA. However, traces of dense C-S-H gel can be seen as the percentage replacement of EPO-FBA increases, this shows the pozzolanity of EPO-FBA which has been proved through the strength activity index of concrete samples at later ages.

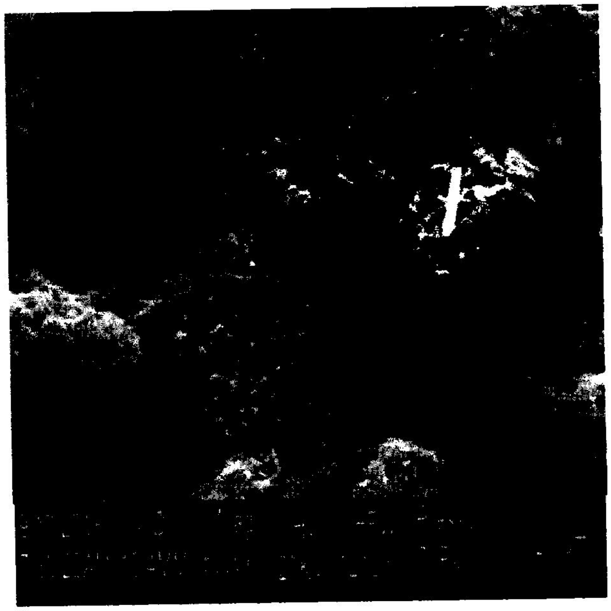

Figure 4.15 : SEM microghraph of concrete with 0% EPO-FBA

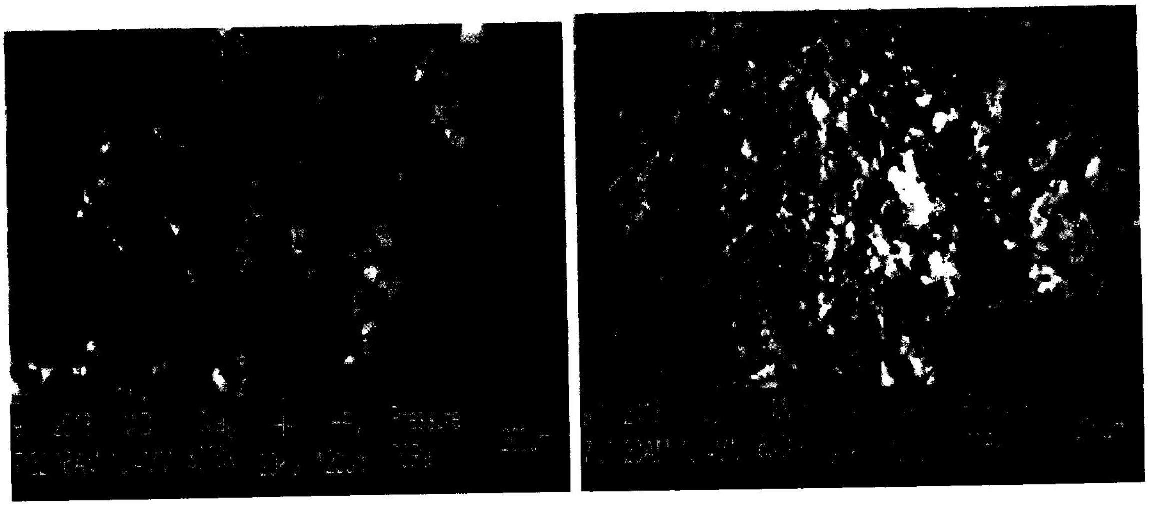

Figure 4.16 : SEM microghraph of concrete with 5% EPO-FBA

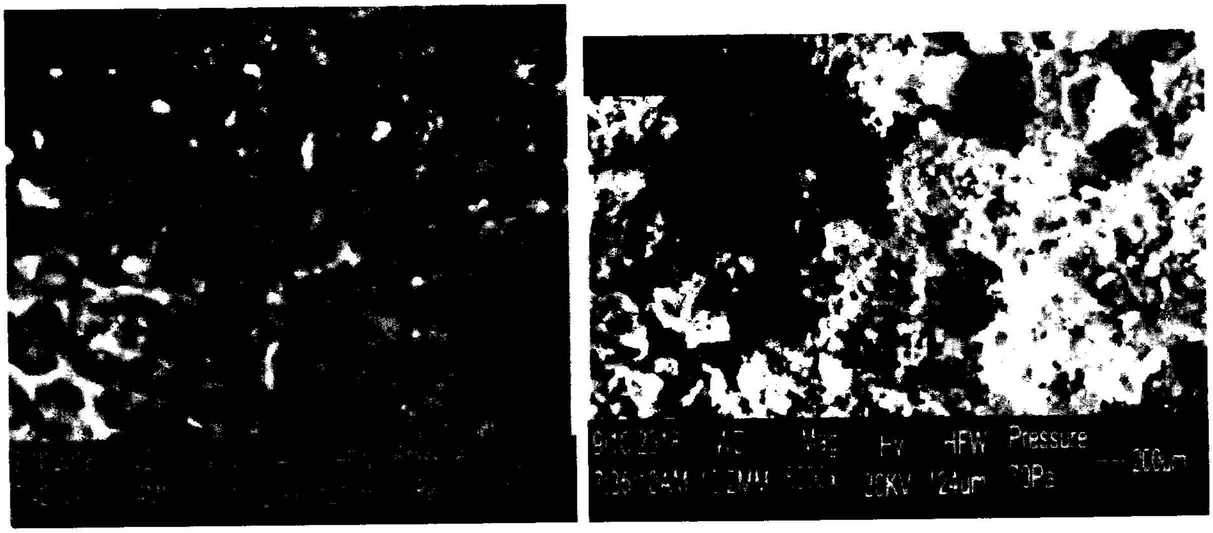

Figure 4.17: SEM microghraph of concrete with 10% EPO-FBA

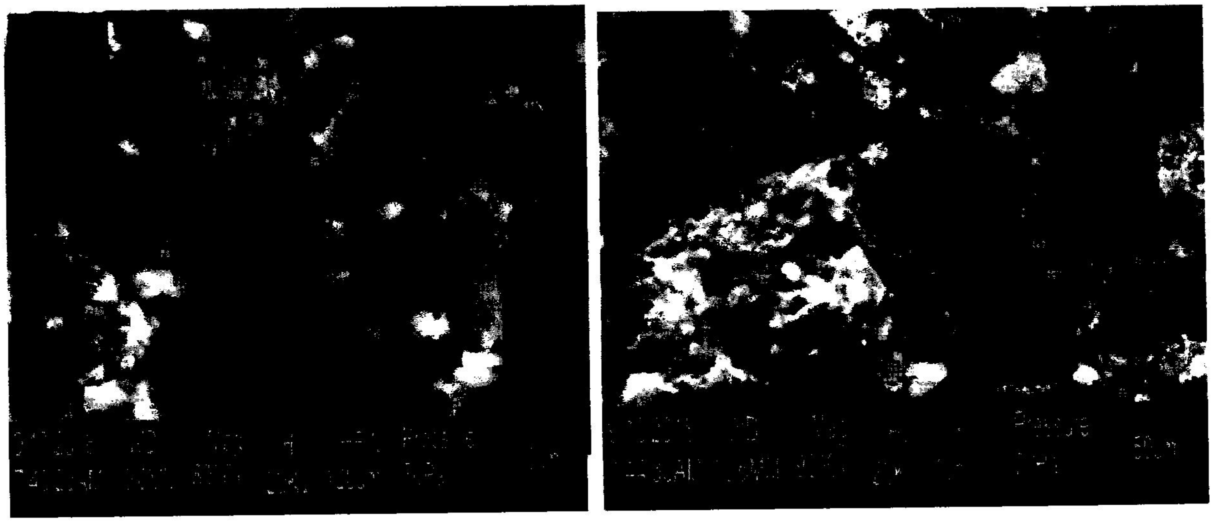

Figure 4.18 : SEM microghraph of concrete with 15% EPO-FBA

The EDX spectrum of the concrete samples are shown in Figure 4.19-4.22. It can be seen that the count of Silicon and Calcium which are the main element responsible for the strength forming and bonding of concrete structure decline with increasing EPO-FBA. This contributes to the reason why there is decrease in the compressive strength of concrete with increasing EPO-FBA.

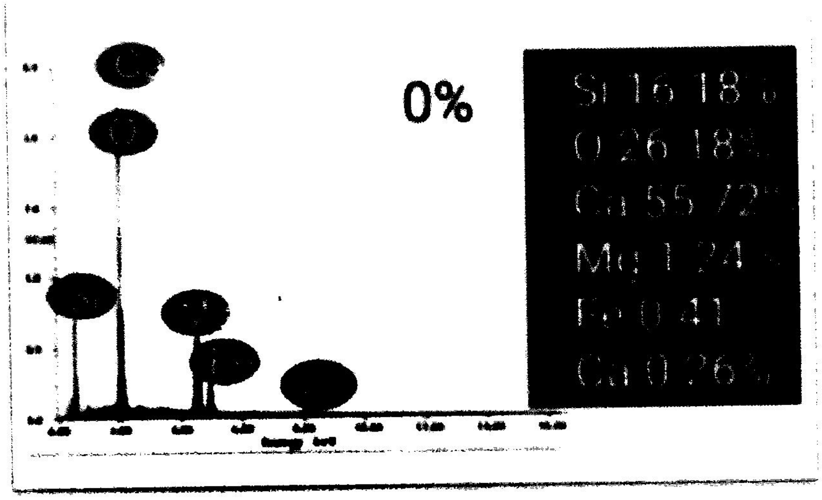

Figure 4.19 : EDX spectrum of concrete with 0% EPO-FBA

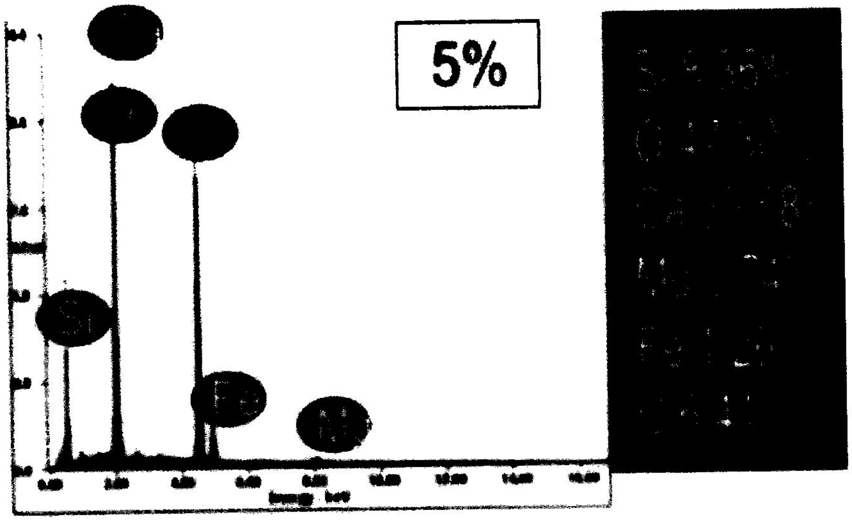

Figure 4.20 : EDX spectrum of concrete with 5% EPO-FBA

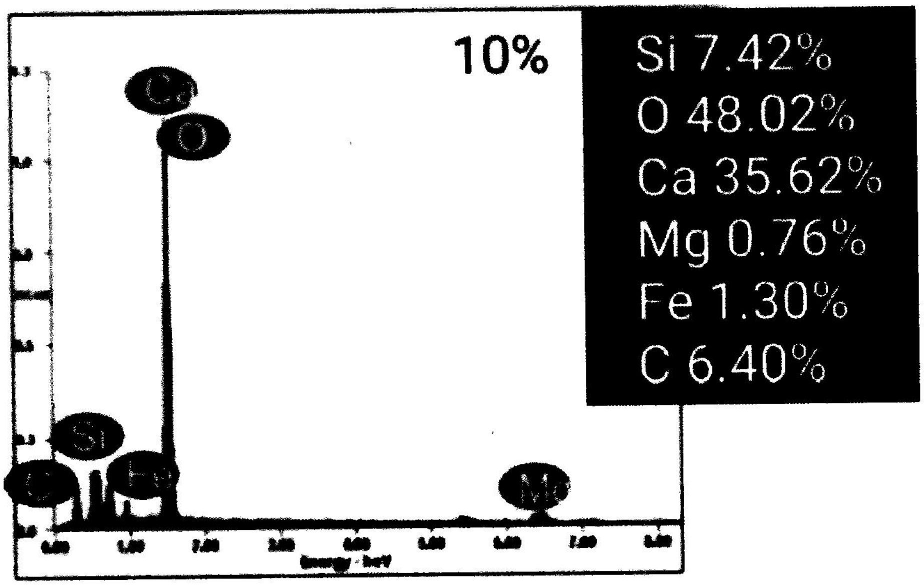

Figure 4.21 : EDX spectrum of concrete with 10% EPO-FBA

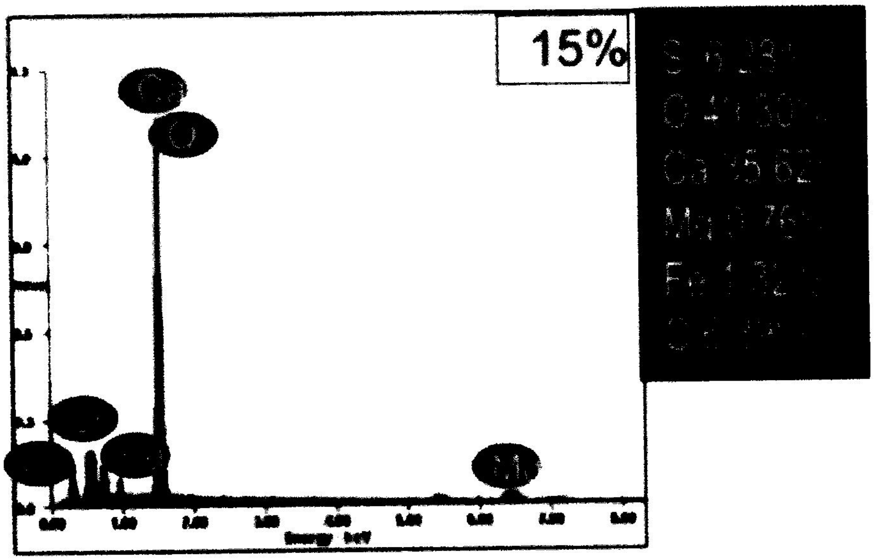

Figure 4.22 : EDX spectrum of concrete with 15% EPO-FBA

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This is a work that studied the microstructure and durability performance of concrete containing empty palm oil fruit bunch ash (EPO - FBA) as partial replacement of Ordinary Portland Cement. During the course of this study, preliminary investigations including chemical analysis, fineness, setting time and consistency were carried out. In addition to these, major investigations including compressive strength, microstructure and morphological study, water absorption and sorptivity were also carried out.

Based on the above mentioned investigations, the following conclusions can be drawn;

1. From the preliminary investigations, the result obtained from the chemical analysis of EPO-FBA clearly demonstrate that EPO-FBA exhibit not none but poor pozzolanic property compared to OPC. Also, Empty palm oil fruit bunch ashes gotten from close burning of empty palm oil fruit bunches collected from local palm oil industries located around Ikole Campus is less fine compared to OPC. However, the percentage of water required for standard consistency of cement paste increases with increase in the OPC replacement with EPO-FBA. Finally, increase in the OPC replacement with EPO-FBA increases the setting time of cement paste.
2. The Compressive strength of concrete samples increases with increase in EPO-FBA content, however, Optimum cement replacement with EPO-FBA occurs at 5% EPO-FBA replacement level with compressive strength which was very close to that of control samples. This shows that 5% by weight of OPC can be replaced with EPO-FBA without any adverse effect on the compressive strength. In addition to this, the replacement of OPC with EPO-FBA produces a normal weight concrete with densities falling within the range
3. EPO-FBA produces a little effect on the microstructure of concrete samples at later age (28 days). The improvement of microstructure occurred mostly in the pore structure and a little in the interfacial transition zone.
4. The sorptivity of concrete specimen at later ages (28 and 90 Days) increases with increase in percentage replacement of Ordinary Portland Cement (OPC) with Empty Palm Oil Fruit Bunch Ash (EPO-FBA). This implies that introduction of EPO-FBA as partial replacement of OPC in concrete production increases the required capillary forces for the pore structure to draw fluid into the body of the concrete specimen.

5. The water absorption of concrete specimen after 28 and 90 Days curing increases with increase in percentage replacement of Ordinary Portland Cement (OPC) with Empty Palm Oil Fruit Bunch Ash (EPO-FBA). This implies that the replacement of OPC with EPO-FBA increases the pore volume which is occupied by water in saturated condition of hardened concrete.
6. Generally, Empty Palm Oil Fruit Bunch Ash (EPO-FBA) as an agricultural waste material showed a manageable potential to be used as partial replacement of Ordinary Portland Cement (OPC). Taking compressive strength, morphology and durability of concrete specimen as reference properties, OPC can be successfully replaced with EPO-FBA at five percent (5%) replacement level without any adverse effect on the aforementioned properties.

5.2 Recommendation

1. More studies need to be carried out on the microstructure and durability of concrete containing EPO-FBA as partial replacement of OPC as only a few literatures were noticed.
2. In order to alter workability, setting times and some other related properties, the effect of chemical admixtures needs to be included in the study.
3. Based on the study, the processing method of EPO-FBA needs to be checked, improved and monitored so as to enhance its quality and other related properties such as fineness.
4. So as to increase the quantity of effective EPO-FBA at the same time improve the strength of the concrete samples, the type of cement used could be changed.
5. The above study should not only be limited to concrete. Effect of EPO-FBA as partial replacement of OPC in mortal could also be investigated.

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