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PERFORMANCE OF BLACK OLIVE OIL AS PERMEABILITY REDUCING ADMIXTURE IN CONCRETE

H. E. Ogbo[1*], and O. O. Ugwu[2]

[1]Department of Civil Engineering, College of Engineering, Joseph Sarwuan Tarka University, Makurdi, Nigeria.
[2]Department of Civil Engineering, University of Nigeria Nsukka, Enugu State, Nigeria.

*corresponding author (Phone Number: +123-080-62165437. Email: erimahappi@gmail.com)

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Abstract
The study is aimed at improving the permeability aspect of concrete durability. The main reason for black olive oil (BLO) as the choice material relies on its inherent hydrophobic properties. The effect of BLO admixture on strength and permeability properties of concrete grade C30 was experimentally examined. BLO was integrated into the fresh concrete mix at percentages of 0.3%, 0.5%, 0.7% and 1% by weight of cement content and a water-cement ratio of 0.5 was used throughout the study. Compressive and flexural strength, permeability properties in terms of water adsorption, porosity, coefficient of permeability and sorptivity of the concrete samples were investigated after curing in water at 3, 7, 28, 60, 90 and 180days hydration period. The BLO test admixture acted as a workability improving admixture and air entraining admixture in the fresh concrete. The various water permeability parameters of BLO-concrete samples were significantly improved for all the percentage inclusion of BLO. However, the mechanical strength properties of concrete sample containing the admixture decreased steadily with increase in BLO content. The 28days compressive strength of 03%, 05%, 0.7% and 1% BLO concrete samples decreased approximately by 3%, 13%, 6% and 13% respectively.The adverse impact on the strength properties of BLO-concrete mixes attributed to the effect of increased air content and workability induced by the BLO admixture can be compensated by reducing the water-cement ratio. The 0.3% BLO-concrete which exhibited the least reduction in strength and also meeting the design strength required for residential buildings is considered the optimum content.

Keywords: Concrete, Black olive oil (BLO), Durability, Admixture, Permeability, Mechanical properties.

1.0 INTRODUCTION

Concrete is a structural construction material that has being in use for many decades. Its applications in construction practices are numerous, hence making it one of the most universal resourceful construction raw material on which virtually all construction practices depends. Unfortunately, concrete has two major drawbacks with regards to cost and sustainability. Sustainability of concrete basically focuses on improving construction durability to maximize significant service life. Therefore, durability is a critical issue requiring attentive consideration in concrete design and applications where longer life cycles and long-term response of concrete are required for greater sustainability. The durability performance of concrete material is also considered to be significant to cost as the total financial cost of a concrete structure includes not only the principal cost of the raw construction materials and services but consist as well the cost of maintenance and repairs and/or renovation. Beside the socio-economic implications of durability, there is also a clear link between durability and the environment, such that, by extending the life cycle of construction materials, we conserve valuable natural resources.

Concrete is a naturally pervious material and very susceptible to moisture in-take through the existing capillary pores [1], [2]. Water is considered an elementary negotiator for concrete deterioration, it contributes intensely virtually in all forms of concrete deterioration [3], [4]. Therefore, the principal durability problems connected with concrete involves the transportation of water (with corrosives agents) into the concrete; since all unfavorable chemical reactions requires water as a reaction medium [4], [5]. Considering the emergent consciousness of the intense contribution of permeability to the lack of durability performance of concrete, it is imperative to sort for techniques that will swiftly tackle the permeability of concretes

Sustainability, durability, and economy are the principal objectives for the introduction of admixtures in concrete. More so, admixture concrete possesses additional desirable technical properties than conventional concrete [5]. It is also suggested that aside durability, functionality, character and aesthetics, unconventional materials such as BLO should be embraced for their additional benefits of availability and affordability. The prevailing demands to return to the traditional or unconventional construction materials is typically hinged on the huge cost of both the modern and innovative construction materials and their inadequate supply in the market which largely contributes to the general price instability. The requisite to revert to locally sourced materials are also traceable to prevalent dictates of some neo-global concepts as regarding sustainability, and the use of biodegradable and renewable materials [6]. Most admixtures and additives are synthesized and are based on mineral oil derivatives. To preserve a sustainable development in the nearest future, natural substitutes are required, hence “bio-admixtures”. Unlike these admixture substances, Black olive oil is a natural substance, it is a green material, its production and usage does not emit hazardous gases into the atmosphere, it poses no abnormal health and safety risk. It is a renewable and sustainable material. In Nigeria, Black olives plants are found in abundance in the North especially in Plateau State, it has very little economic value as it is not very popular.

The basic techniques for resisting moisture intake or movement through concrete involves the use of admixtures that are either integral to the concrete or barriers applied to the external surface of concrete after hardening. But physical or chemical barriers spread on concrete surface may be effective only a few distance underneath the surface. Such technique may be temporary; as they are exposed to destructive action of weathering and wearing off by abrasion. It may also alter the appearance of the surface. Therefore concrete water repellent materials incorporated as an integral part of the blend and dispersed all through the structure may achieve a long-term effect which is not subjective to weathering attacks on the surface [7]. It is in this regard that the effect of black olive oil as integral water resisting admixture in concrete is experimentally investigated.

“Permeability Reducing Admixtures” (PRAs) is a collection of materials developed to improve concrete durability by regulating the passage of water and moisture through the concrete, intake of chloride ion and permeability is restricted in addition [1]. The hydrophobic PRAs consist of materials made from long-chain fatty acid derivatives, vegetable oils and petroleum based products (Paraffin waxes and bitumen emulsions). The materials in this group are hydrophobic in nature and therefore take advantage of its nature to create a water repelling coat deposited round the pores surface in the concrete, with the pores still containing open voids [8]. Hydrophobic admixtures are typically formulated to be soluble and can bond chemically with the calcium ion liberated from hydrated cement paste to produce a distinct insoluble material that is retained in the capillary surface. The hydrophobic film created on the capillary surface restrains water access into the capillary once it is dry.

Oils and fats basically fit into a collection of organic matters known as lipids which are insoluble in ordinary water [9]. Fresh mortar is mainly an alkaline medium with a pH value $\geq$ 12. Glyceride similar to other esters is chemically unstable in an alkaline medium of the cement paste [10]. Therefore oils once introduced into the cement paste, the triglycerols contained in the oil partakes in the hydration reaction which results in the creation of an insoluble calcium salt of fatty acids [11]. The fatty acid is then locked up in the mortar while the hydrophobic fragment of the molecule build the water repellency. “The incurred fatty acids are hydrophobic as a result of their alkyl chains which are same as triacylglycerols and due to its reaction with calcium, they are well bounded in mortar structure and the hydrophobic alkyl chain cause mortar repellency” [11].

Black olives fruits are similar in appearance to olives and are usually called African olives or African Canarium or African Elemi [12], [13]. The *canarium schweinfuthii (Engl. and linn)* appears to be the most broadly distributed specie found in Africa especially Nigeria. The indigenous names for the plant in Nigeria includes; ‘atile’ (Hausa), ako (Yoruba), agba (Igbo) and Odah (Igala and Idoma) [14], [15].

Canarium schweinfulhii fruit is recognized as an excellent source of natural oil which is highly medicinal, both the mesocarp and seed contains oil. They are habitually cultivated for its fruits which are edible; the fruits (skin/pulp-mesocarp) are boiled and eaten while the seed is often discarded despite it containing edible kernel [16]. Only recently that the oil is beginning to be processed traditionally from the fruits and seeds and utilized in crude form for cooking and body cream by certain ethnic groups. There is now also an increasing realization and awareness among nutrition experts, pharmacological and cosmetic industries on the usefulness of the oil. Therefore much interest has been developed by recent researches on the chemical compositions of the fruits and seeds of the *C. schweinfurthii*. Most researches however are geared towards the nutritional values and the pharmacological aspects of using the oil. Information on the possibility of *C. schweinfurthii* (Black olive) oil been used as an admixture in concrete is rare. Olive oil, sunflower, rapeseed and linseed oils have been studied as admixtures in mortar and have proven to improve the properties of mortar [17]-[20]. Therefore, investigation to evaluate BlO effects on cementitious matrix is of particular interest.

2.0 MATERIALS AND METHODS

General purpose 'Dangote' commercial brand of Portland cement in Nigeria was used because of its common usage for general construction purposes within the region of study, natural river bed sand (fine aggregate) corresponding to zone one (1), machine crushed coarse aggregate having maximum size of 20mm diameter and, clean water were selected.

Grade C30 concrete which satisfies the requirement of concrete for residential building construction was investigated. Concrete mix design according to British standard specification for normal concrete was used in quantifying the ingredient for the mix. The physical and chemical properties of BLO were investigated and thereafter incorporated into the fresh concrete at 0.3%, 0.5%, 0.7%, and 1% by weight of cement. A total of two hundred and seventy (270) cubic samples of 100mm x 100mm x 100 mm BLO-concrete specimens were cast and the compressive strength, water absorption, porosity, water permeability coefficient and sorptivity properties were examined. Water–cement ratio of 0.5 was maintained all through the entire experiment. The BLO admixture was dispersed into the mixing water by stirring with a metal rod just before adding it to the already mixed dry ingredients. Subsequently, the entire ingredients were adequately mixed to achieve consistency. Air entrainment test preceded by slump and compacting factor tests were conducted on the fresh concrete. Thereafter, the fresh concrete mix was cast into standard metal moulds and vibrated for 3 minutes using an electrically operated vibrating table. The concrete cubes were carefully removed from the moulds after 24 hours, cleaned, weighed and placed inside water for curing at normal room temperature. The concrete cube samples were tested for compressive strength at curing ages of 3, 7, 28, 60, 90 and 160 (6 months) days respectively, followed by other various tests conducted on the hardened concrete cubes.

2.1 Black Olive Oil Characterization

Traditional (local) method of oil extraction was employed in the extraction of the oil from the fruit mesocarp. Sample of the BLO was assessed in terms of physical and chemical properties at Grand Cereal Oil and Mill Laboratory Jos, Plateau State, Nigeria. Figure 1 presents sample of black olive (C. schweinfurthii) fruits from which oil was extracted.

Figure 1: Black olive fruits sample

2.2 Characteristics of Fresh BLO - Concrete

Workability and air entrainment tests were conducted on the fresh concrete samples immediately after mixing. The workability was assessed by the standard slump cone and compacting factor tests conducted in accordance with the requirements of the standard test method for slump of hydraulic-cement concrete, BS EN 12350 [21] and ASTM C143M-15 [22]. The Air Entrainment meter apparatus was used in accordance with ASTM C231 [23].

2.3 Tests on Hardened BLO Concrete

Various tests on the hardened concrete samples were investigated after curing for 3, 7, 28, 60 and 90 and 180days. The effect of BLO addition on concrete compressive, flexural strength, and several concrete transport properties such as water absorption, porosity and capillary sorption tests were performed in accordance with the relevant sections of British Standard Specifications [24]-[27].

For the permeability related tests, the concrete cube specimens were dried to a constant weight in an electrical oven at a regulated temperature of 100±5°C (control specimen), and at 60±5°C (BLO -concrete), because high temperature may destroy some of the oil structure [10],[17]. The total porosity was determined by vacuum saturation method [28].

Figure 2: Experimental set up for capillary absorption measurement

For determining the permeability coefficient of water absorption, the surfaces of the individual specimens were exposed to capillary absorption test. The surfaces of the cube specimen were coated with silicon sealant up to 30mm depth to allow the flow of water on only one surface of the cube. The cube samples were placed in water to a depth of 10mm. See Figure 2 for experimental set up. The coefficient of water absorption of the concrete cube samples were quantified using Equation (1) [29].

$$Ka = \left(\frac{Q}{A}\right)^2 x \left(1/t\right) \quad (1)$$

where, Ka is the coefficient of water absorption (m^2/s), Q is the quantity of water absorbed (m^3), t is the time taken to absorb the water (1.0 hour = 3600 seconds), and A is the surface area (m^2) through which water was absorbed.

The sorptivity of the specimens were also calculated using the data recorded from capillary absorption test. The sorptivity (S) is the slope of the cumulative volume of water absorbed per unit area (i) against the square root of time (t). Therefore, the sorptivity value of the specimen for one dimensional flow is calculated using Equation (2) [29], [30].

$$i = S\sqrt{t} = St^{1/2} \quad (2)$$

Where, S = sorptivity ($m/\sqrt{s} = m/s^{1/2}$).
t = elapsed time in minutes,
i = the cumulative water absorption per unit area of the surface (m^3/m^2), expressed as
$i = \Delta w/Ad$
Δw = Change in weight = $W_2 - W_1$
W_1 = oven dry weight in grams
W_2 = weight of sample after capillary suction
A= surface area of the specimen through which water penetrates m^2
d = density of water = 10^{-3} g/mm^3

3.0 RESULTS AND DISCUSSION

3.1 Physical and Chemical Characteristics of BLO (*Canarium schweinfurthii*)

The specific gravity of the BLO test admixture as recorded in Table 1 is 0.91< 0.945 at a temperature of 25 °C as required for any oil to be used as chemical admixture in concrete/mortar. Hence, the BLO is suitable for use as admixture in concrete.

Table 1: Physicochemical properties of BLO sample

Parameter	Values
Moisture Content (%)	0.23
Free Fatty Acid (%)	0.71
Acid Value (mg NaOH/g)	1.41
Saponification Value (mg KOH/g)	178.91
Iodine Value (wij's)	89.17
Specific Gravity (g/cm^3)	0.91
Viscosity (cSt)	4.1, 120rpm @26 ^{0}C
Refractive Index (RIU)	1.462
pH Value	6.61
Peroxide Value (mEq/kg)	10.68
Ester Value	89.74
Sludge	3.20%
Insoluble Impurities	0.98%

Table 1 revealed that the BLO test admixture has a high iodine value of 87.17; indicating a high degree of unsaturation. Unsaturated fatty acids are more reactive with lower melting temperatures and tend to be liquid at room temperatures [10], [11]. The BLO therefore meets the number one criteria for any oil to be used as admixture in concrete/mortar.

3.2 Workability

The workability of the fresh BLO –concrete recorded in Table 2 increased gradually with increase in BLO content. The highest slump recorded at 1% BLO content increased by 40% percent. The compacting factor also recorded significant improvement at the highest dosage of 1% BLO content. The oil is assumed to act as grease, lubricating the grains which results in more workable concrete mix.

Table 2: Properties of fresh BLO – concrete

BLO content	Slump (mm)	Compacting Factor	Air Entrained (%)
0%	20	0.84	3.8
0.3%	22	0.89	3.9
0.5%	32	0.92	4.5
0.7%	25	0.88	6.4
1.0%	28	0.88	5.3

3.3 Air Entrainment Test Result

It is also observed from Table 2 that the air content increased progressively by 0.1%, 0.7%, 2.6%, and 1.5% with increasing BLO addition of 0.3, 0.5, 0.7 and 1 percentage weight of cement respectively. The increase in the percentage of entrained air possibly may be as a result of the increased workability which makes the concrete paste more moist and sticky as BLO percentage increases. The mode of action of hydrophobes on concrete matrix could also be one of the reasons; BLO as a hydrophobic agent offers a water-repellent coating along pores surface by enclosing the pores (voids) in the concrete. [7], [9].

3.4 Compressive Strength

The compressive strength results of BLO- concrete at the different percentage proportion of BLO, cured at different ages is presented in Figure 3.

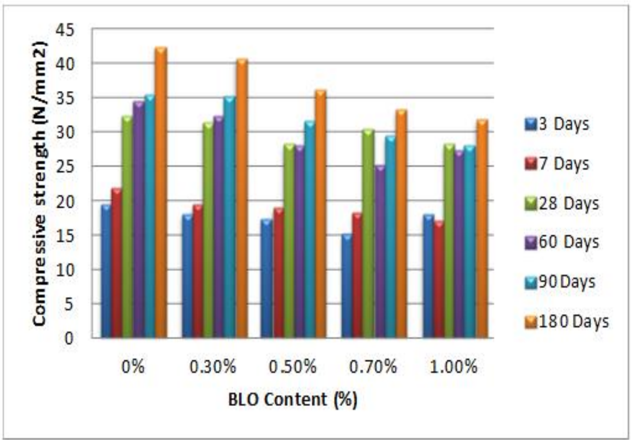

Figure 3: Compressive strength of BLO- concrete with hydration period.

All the BLO-concrete samples displayed lower compressive strength compared to the reference mix of 0% BLO at the various curing ages. The reduction is proportional to the amount of BLO in the matrix. The percentage decrease compared to the 28 days compressive strength of the reference mix ranges from 2.57%, 12.62%, 5.66% and 12.62% for BLO content of 0.3%, 0.5%, 0.7% and 1% BLO respectively at 28days. The strength at higher curing period of 180 days recorded a reduction of 4.12%, 14.52%, 21.58% and 24.99% for BLO addition of 0.3% 0.5%, 0.7% and 1% respectively. However, there was no much reduction in strength observed for sample mixes comprising 0.3% BLO dosage.

The observed reduction in the compressive strength obtained corroborate other researches conducted on the effect of vegetable oil on mortar; where a reduction in strength and density was also observed [17]-[20], [31]. Cechova [11] however reported an increase in strength of concrete and mortar incorporating linseed oil. Nevertheless, decrease in strength was observed at higher dosage of 1% and 3% linseed oil respectively [11]. The apparent strength loss was attributed to the approach adopted in dispersing the oil in the water using lignosulphonate rather than simply adding it to the mixture directly [10], [17]. In this present research, despite BLO test admixture was added directly to the mixing water without lignosulphonate, a slight reduction in strength was observed. It is therefore worthy to note that BLO is different from other vegetable oil. Hence, the decrease in strength observed with BLO admixture may be ascribed to the effect of the BLO on modifying the air content, and workability, which in turn affects the hardened properties of the concrete [32]. An additional reason for lesser strength suggested that the pathway for movement of water within the microstructure may be clogged, therefore preventing interconnectivity of the pores for transportation of the water needed for hydration.. Theoretically, increased porosity is associated with high air content and increased workability is accompanied with reduction in strength [5], [8].

3.5 Flexural Strength Test

The performance of flexural strength is similar to that of the compressive strength of concrete specimen made with BLO admixture. The flexural strength decreased gradually with increased BLO (Figure 4). Typically, the flexural strength of concrete is between 10-12% its compressive strength [5]. Hence, the flexural strength of the control concrete (0% BLO) in Figure 4 recorded an approximated value of 11% of its 28days compressive strength. The ratio then decreased to 10.29%, 9.95%, 8.80% and 7.47%

of compressive strength respectively at 0.3%, 0.5%, 0.7% and 1% BLO percentage content.

Generally, The 28 days flexural strength of BLO - concrete presented in Figure 4 decreased progressively by 9.75%, 21.73%, 29.53%, and 41.23% at BLO percentage content of 0.3%, 0.5%, 0.7% and 1% respectively. The reasons for non-improvement of flexural strength for BLO-concrete are attributed to same factors responsible for compressive strength decrease.

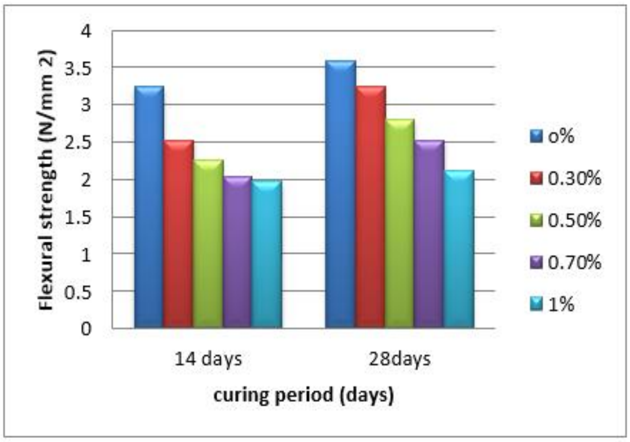

Figure 4: Flexural strength of BLO-concrete at 14 and 28days

3.6 Water Absorption of BLO - Concrete

The amount of water absorbed by the entire BLO cube sample decreased progressively with increase in hydration period and as the BLO content increased as illustrated in Figure 5.

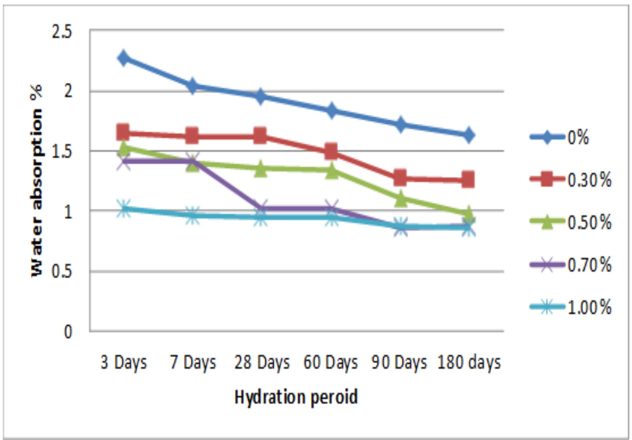

Figure 5: Water absorption of BLO - concrete.

The minimum amount of water absorbed for all the mixes is at 1% BLO addition at 180days. The decrease in water absorption observed with the BLO-concrete is directly related to improvement of the pore spaces in the cement matrix. Therefore, the reduction in water absorption recorded is as a result of oil droplet, contributed by the BLO, enveloping (blocking) the capillary pores, consequently disconnecting the pores and preventing free flow of water.

3.7 Porosity Test Result

The BLO samples exhibited lower porosity at all curing ages (Figure 6). At early age of 3days, porosity of all concrete mixes were measured within the range of 5.81% to 11.73%, which is an indication of better performance of concrete to be exhibited in the long term. The result presented in Figure 6 illustrates that concrete with 1%BLO yielded the lowest porosity compare to that of 0%, 0.3%, 0.5%. and 0.7% BLO concrete samples implying that total porosity improves with increase in BLO percentage content. The reduction in total porosity arises from the alteration of the microstructure of the specimen to a less porous structure caused by the BLO droplets blocking the capillary pores, thereby reducing the pore sizes and creating a pore system which is not connected.

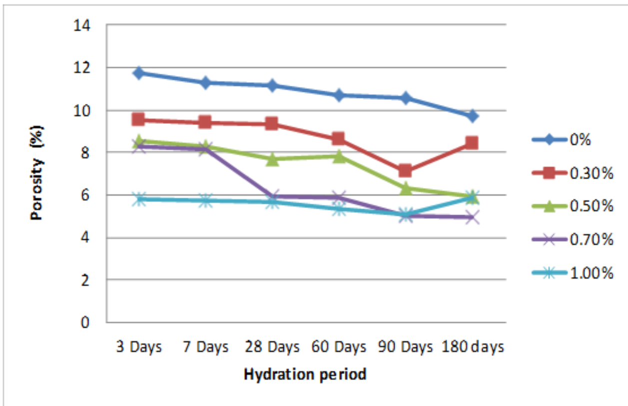

Figure 6: Total porosity of BLO- concrete with curing periods

It is anticipated that any slight improvement in porosity should results in increased density and strength of cement paste. However, a decrease in strength of the cement matrix with BLO admixture was observed while porosity decreased. Hence, it is assumed that the observed reduction in mechanical strength of the BLO-concrete sample may not be associated with porosity of the concrete; but could be resulting from poor bonding of the cement matrix.

3.8 Coefficient of Water Absorption

The result shows that the coefficient of water absorption of the BLO concrete reduces relative to the reference mix (Table 3). And it is evident that the higher the BLO content, the lower the coefficient value. The values of the water permeability coefficient; Ka for 0.3% BLO concrete cured beyond 28days were observed to be approximately 2 times less than the reference (0% BLO) concrete. Likewisely, the 1% BLO-concrete at 90days records Ka values approximately 7 times less than the reference. Similar result was also recorded by Ogbo [32]. The observed decrease in the numerical value of permeability coefficient of BLO concrete is enhanced as hydration progresses especially beyond 28days (Table 3). This is associated with improvement in the BLO-concrete porosity (capillary pores).

Table 3: Permeability Coefficient of Water Absorption of BLO Concrete

		Permeability coefficient Ka ($\times10^{-4}$)				
Percentage of BLO Admixture	**3 days**	**7 days**	**28 days**	**60 days**	**90 days**	**180 days**
0%	3.574	3.167	2.250	1.639	1.361	1.240
0.3%	1.380	1.380	1.120	1.018	1.000	0.694
0.5%	1.380	1.389	1.120	0.796	0.694	0.315
0.7%	0.694	0.527	0.527	0.333	0.315	0.250
1%	0.379	0.379	0.250	0.250	0.204	0.157

3.9 Sorptivity

The sorptivity values of the concrete samples presented in Figure 7 also decreased consistently with increased BLO content for all the mixes. The inclusion of BLO admixture into the cement mixes may have decreased the amount of pathways and interrupt connected pores in the surface of the cement paste; hence leading to the recorded decrease in sorptivity.

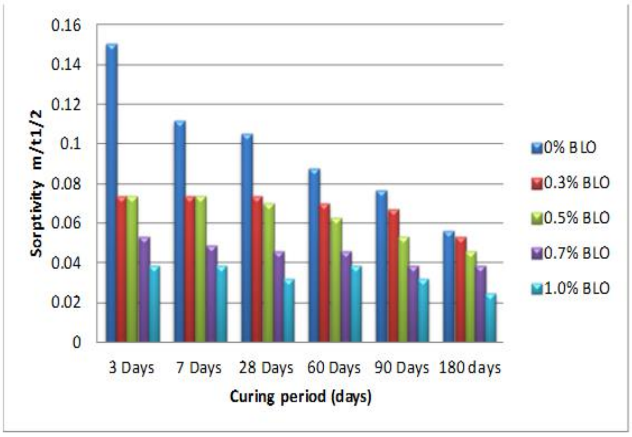

Figure 7: Sorptivity Results of BLO- Concrete

The sorptivity value of BLO concrete mixes at 28days reduced approximately by 30%, 33%, 56%, and 70% respectively at 0.3%, 0.5%, 0.7% and 1% BLO inclusion. The percentage reduction of sorptivity values of BLO-concrete at 90 days were 13%, 31%, 49%, and 58%. While the 180days recorded sorptivity reductions of 5%, 18%, 30%, and 55% respectively at 0.3%, 0.5%, 0.7% and 1% BLO content. It is observed that the percentage reduction of the BLO-concrete sorptivity decreased with longer curing periods.

4.0 CONCLUSIONS AND RECOMMENDATION

The results of the experimental studies of black olive oil (BLO) as admixture in cementitous matrix is presented as follows:

- BLO acts as a plasticizing agent, a water reducing admixture which lubricates the concrete paste, and making the paste more workable.
- Increase in BLO addition resulted in a steady increase in the air content of the BLO concrete. This increase in air content may have resulted in improved workability observed.
- The compressive and flexural strength of BLO-concrete decreased progressively with increase in BLO proportion for all percentage mixes of the BLO. The adverse effect on the mechanical property is attributed to significant role of oil on altering the air content and workability of the fresh cement paste which in turns affects the hardened properties of the concrete.
- BLO addition also decreased the amount of pores easily accessible by water. This is proven by the lower porosity value of BLO concrete mixes compared to the plain conventional mixes. Transport properties measured in terms of water absorption, sorptivity and coefficient of water permeability were improved greatly with the addition of BLO in concrete.
- BLO therefore can function as a plasticizer, air entraining agent and permeability reducing admixture at modest reduction in mechanical properties. BLO admixture is recommended for use in concrete production for residential building construction. The optimal BLO admixture content is assumed to be 0.3 percent. At this content, BLO-concrete samples exhibited the least reduction in strength and significant improvement in permeability parameters. The negative effect on the mechanical properties can be compensated by reducing the w/c ratio.

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