THE INFLUENCE OF METAKAOLIN/USED ENGINE OIL AS ADMIXTURES ON THE PERMEABILITY OF CONCRETE

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***Abstract** -This paper evaluates the influence of used engine oil and metakaolin on concrete permeability. 36 number of 100mm × 100mm × 100mm cube samples were cast for porosity and sorptivity test. A mix design method of M30 concrete was used to determine the quantities of materials. The samples were prepared at 20% constant replacement of metakaolin with cement and the percentage of the used engine oil was varied. The specimens were cured for 28 days and preconditioned in an oven to dry out the samples at the temperature of 110^0C, until the attainment of constant weights. For sorptivity test, after oven drying, the four sides of the specimens were sealed with silicon 30mm from the base to avoid evaporation effects and maintain uniaxial water flow during the tests, then sorption weights were determined at 30, 60, and 90 minuites. For porosity test, the samples were further submerged in water for the attainment of saturated weight. The results showed that the interaction of used engine oil and metakaolin, caused an improvement in air contents which led to improvement in workability of concrete. The results also affirmed a decrease in porosity and sorptivity of concrete. The control sample recorded a porosity of 27%, against 23% recorded in the sample containing 1.0UEO + 20Mk, while sorption value decreases from 42% for (0.2UEO + 20Mk, 0.4UEO + 20Mk, 0.6UEO + 20Mk) to 20% for 1.0UEO + 20Mk. The improvement in permeability properties was due to the dual influence of the two materials in the composites.*

***Key Words*: Metakaolin, Sorptivity test, porosity test, Composites, Uniaxial, Mix design**

1. INTRODUCTION

Permeability of concrete generally refers to the rate at which water or other aggressive substance (sulphates, chlorides ions, etc.) can pass through the concrete. It plays an important role in the long term durability of concrete material. Low permeability is an important requirement for hydraulic structures and in some cases water tightness of concrete may be considered to be more significant than strength although, other conditions being equal, concrete of low permeability will also be strong and durable. A concrete, which readily absorbs water, is susceptible to deterioration. This deterioration is determined largely by the ability of the cover zone concrete to resist the ingress of deleterious agents from the environment [1]

Permeability is the most important factor affecting the durability of the concrete structure considerably. Concrete permeability might evolve related to the capillary pore volume of the concrete at the internal structure, and the connection between those pores. Mineral and chemical admixtures can be used in the mixtures in order to reduce the concrete permeability against the mentioned harmful effects [2]

It is a known fact that mineral admixture use in cementitious systems increases the strength and durability of the cementitious systems due to the physicochemical impacts created. Since the mineral admixtures are finer in terms of physical structure, a less porous structure occurs by blocking the pores of the cement systems. On the other hand, in terms of chemical structure, it turns calcium hydroxides (CH) into calcium silica hydrates (CSH) with stronger structures and providing binding properties to the cement systems, as a result of the pozzolanic reaction. Fineness, amorphism level and chemical compound of the mineral admixtures affect the pozzolanic reaction considerably. Therefore, pozzolanic reaction occurs at early ages when the mineral admixtures are finer as well as higher reactive silica is included [3].

The addition UEO to the fresh concrete mix could be similar to adding an air entraining chemical admixture, thus enhancing some durability properties of concrete while serving as another technique of disposing the oil waste. It was also discussed by [4] that UEO has similar superplasticizer properties because of the SO_3 content. Oil is a common and highly visible form of pollution. Oil and water are immiscible and even a smallspillage can cause significant pollution. Studies have shown that 5 litres of it can cover a small lake [4].

The study of the effects of UEO on properties of concrete has been carried out. Mixes containing 0.075, 0.15 and 0.30% of UEO by weight of cement. Result shows that UEO acted as a chemical plasticizer improving the fluidity and almost double slump of the concrete mix and supported by [6]. UEO did not adversely affect the strength development process of concrete with silica fume, 28 days' strength was achieved as 76MPa with 4% UEO. It was also stated that UEO act positively towards the concrete performance [7]. Concrete mixes containing high percentage of fly ash (40% and 50%) followed the same trend [8]. The research of UEO effects in concrete were then publish by [9] that stated the inclusion of 0.5% UEO gave the highest compressive strength and comparable with super plasticizer [10] concluded that an optimum UEO dosage of 0.3% of cement mass was found, beyond which detrimental effects on initial slump, setting time, and compressive strength can be encountered. Hence, accordingly, adding used engine oil to the fresh concrete mix could be similar to adding an air entraining chemical admixture, thus enhancing some durability properties of concrete while serving as a technique of disposing the oil waste [11]. It was also stated that UEO act positively towards the concrete performance [12].

Metakaolin is produced by calcination of kaolin clay at temperatures ranges from 700 to 900^{0}C. The heat treatment or calcinations, serves to break down the structure of kaolin. Bound hydroxyl ions are removed and resulting disorder among alumina and silica layers yields a highly reactive, amorpous material with pozzolanic and latent hydraulic reactivity, suitable for use in cementatious applications. Metakaolin is fine clay which contains the highest content of siliceous, is called high reactivity metakaolin [12].

During cement hydration process, water reacts with Portland cement and formed calcium silicate hydrate (CSH). The byproduct of this reaction is the formation of calcium hydroxide (lime). This lime has weak link in concrete and hence reduces the effects of the CSH. When metakaolin is added in the hydration process, it reacts with free lime to form additional CSH material, thereby increasing the density of the matrix and more durable [13] Khatib and Herbert, 2005).

According to [14], Metakaolin can successfully be used to partially replaced cement paste or mortar applications. Like clay, the main oxides in metakaolin are silica and alumina. Partial substitution of cement of cement with metakaolin can increase the mechanical and durability performance of cement based materials. There is also noticeable increase in compressive strength of concrete mainly during the first 14 days of curing at normal temperatures. The increase in compressive strength of concrete is attributed to the pozzolanic reaction, the fineness of metakaolin and acceleration of cement hydration [15], which is somewhat similar to that of silica fume. Replacing cement with 20% metakaolin gives maximum enhancement in pore refinement of paste. The combinations of pore refinement and reduction in calcium hydroxide when cement is partially replaced with metakaolin leads to improve durability [15]. Other traditional cement replacement like fly ash or granulated blast furnace slag can be used in conjunction with metakaolin to cause further pore refinement [15]. The objective of this research is to investigate the permeability properties of concrete, with the blends of used engine oil and metakaolin.

2. MATERIALS

Ordinary Portland cement (OPC) used in this study include Dangote 3× brand grade 42.5R conforming to the requirements of BS 12 for ordinary Portland cement [16]. The cement has a specific gravity of 3.15 and specific surface of 320m^2/kg. Kaolin was obtained from Alkaleri L.G.A of Bauchi state in Nigeria in pulverized form. The pure sample was processed by calcination at 700^{0}C for an hour, in a kiln. The heating process drives off water from the mineral kaolinite ($Al_2O_3{\cdot}2SiO_2{\cdot}2H_2O$), the main constituent of kaolin clay, and collapses the material structure, resulting in an amorphous aluminosilicate ($Al_2O_3{\cdot}2SiO_2$), metakaolinite. The process is known as dehydroxylation and may be presented by simple equation: $Al_2O_3{\cdot}2SiO_2{\cdot}2H_2O \rightarrow Al_2O_3{\cdot}2SiO_2 + 2H_2O\uparrow$. The sample was cooled in the kiln for 24hours and then pulverized before it was sifted with a 75μm sieve.

The metakaolin has a specific gravity of 2.25 and a compacted bulk density of 14414kg/m^3. The waste engine oil is used as additive in the concrete. The used engine oil was obtained from car workshop at Farin Gada, plateau state Nigeria. The type of used engine oil used in this research is the Mobil super XHP, 20w- 50, extra high performance Motor Oil. The percentage of engine oil used in this research are 0.2, 0.4, 0.6, 0.8 and 1.0 percent of the weight of cement [2].

The fine aggregate used was river sand and was sourced at Lamingo road Jos plateau state. The coarse aggregates are of 19mm crushed granite.

3. METHODS

The mix proportioning involved the British mix- design approach for normal concrete and water/cement ratio of the mix- design for requisite workability to be adhere to. A characteristic strength of 25N/mm^2, was assumed and a target mean strength of 38N/mm^2, was calculated. A free water/ cement ratio of 0.57 was obtained. The maximum aggregate size is 20mm and a specified slump of 10-30mm for normal workability, a free water/ cement content of 190kg/m^3, was determined. The results of the mix design are tabulated on table 1. The samples were prepared by partially substituting cement with metakaolin at blending ratio of 80:20 respectively. The used engine oil was added as an additive at 0.2%, 0.4%, 0.6%, 0.8% and 1.0% of the weight of cement [2]. 100mm × 100mm × 100mm steel moulds were thoroughly cleaned and coated with oil before casting in each case to ensure easy remoulding and smooth surface finish. The test wet mixture was cast into moulds, immediately after mixing manually. The moulds were filled in three layers of 50mm each, compacted using the compaction rod (25mm diameter steel rod), the minimum of 35 strokes uniformly distributed over its surface during casting. It was then vibrated on a vibrating machine until when the slurry from the concrete overflows. The specimens were referenced for easy identification and kept in the laboratory free of direct sunlight and heat. The specimens were covered with a polyethane bags and after 24 hours, the specimens were demoulded and subject to curing, by immersion in a big container filled with clean water and cured for 7, 14 and 28 days. Slump tests were carried out as a measurement of workability. The slump test was performed in accordance with the provision of B.S 1881, Part 102 [17]. The results of the slump tests are presented in table 2. The pressure type "B" meter housed in the Department of Building, was used to measure the air content of concrete, based on pressure to volume relationship of Boyles law. The pressure was applied to the to compress the air in the pores. The readings were not affected by atmospheric pressure. The results are presented in table 6.

Water absorption tests were carried out to determine the sorptivity coefficient of concrete samples. The cubes of 100 mm x 100mm x 100mm are cast and after casting were immersed in water for 28 days of curing age. The specimens were preconditioned in an oven to dry out the samples at the temperature of 110^0C and until the attainment of constant weight. Four sides of the specimens were sealed with silicon 30mm from the base to avoid evaporation effects and maintain uniaxial water flow during the tests. The face adjacent to the silicon coat, was in contact with water. The water absorption at predetermined interval periods of 0, 2, 4, 6, 8, 10, 20, 30, 60 and 90minutes was. The sorptivity coefficient was calculated from the formular: $S = It^{1/2}$, where S = sorptivity in mm, t = elapsed time in minute. I = $\Delta w/Ad$, ΔW = change in weight = W_2-W_1, W_1 = Oven dry weight of the cubes in grams, W_2 = Weight of sample after 30-minute capillary suction of water in grams. A = surface area of the specimen through which water penetrated. d = density of water[18].

The 100mm ×100mm × 100mm cube specimens were cast and cured for 28 days. These specimens were then oven dried at the temperature of 110°C until the mass became constant and again weighed. The weights were noted as the dry weight (W_1) of the cylinder. The specimen was kept in water for 24 hours and weighed again. This weight was noted as the wet weight (W_2) of the specimens. The percentage of water absorption was calculated from the formular: % water absorption= $[(W_2-W_1)/W_1]$x100. Where, W_1 = Oven dry weight of samples in grams, W_2 = weight of wet samples after 24 hours of immersion in grams. Porosity test was carried out by casting 100mm × 100mm ×100mm cube samples of concrete cured at 28 days for the different samples with varying doses of used engine oil. After curing for 28 days, the samples were oven dried at 110^0C to attain a constant weight.

After attaining constant weights, the samples were submerged in water for 24 hours and were weighted to determine the water absorption. The samples were further submerged in water, until when they have attained a constant saturated weight. The saturated samples were further weighed with a Mono Blog (PG 5002-S), Techonology weighing balance, to determine the mass of saturated sample in air and mass of saturated sample in water. Porosity was calculated by the formular: P= (Ws-Wd)/(Ws-Ww) x 100, Where P = total porosity in percentage, Ws = mass of saturated samples measured in the air, in grams, Wd = mass of oven dried samples measured in the air, grams and Ww = mass of saturated samples measured in the water, grams [18].

Table 1. Quantities of Materials

Quantities	Cement (kg)	Water (kg)	Fine Agg. (kg)	Coarse Agg (kg)
Per m^3 to nearest 0.05kg	335	190	668	1240

Table 2 Concrete Mix Proportions

Percentage Replacement	OPC (Kg)	UEO (Kg)	MK (Kg)	C. A (Kg)	F. A (Kg)	w/b (Kg)
Control (0)	2.42	-	0.603	11.16	6.012	0.57
0.2 UEO + 20Mk	2.42	0.005	0.603	11.16	6.012	0.57
0.4 UEO + 20Mk	2.42	0.010	0.603	11.16	6.012	0.57
0.8 UEO + 20Mk	2.42	0.0193	0.603	11.16	6.012	0.57
1.0 UEO + 20Mk	2.42	0.0242	0.603	11.16	6.012	0.57

Table 3 Chemical Composition of used engine oil and metakaolin

Chemical Composition	Used engine oil Percentage	Metakaolin
SiO_2	-	51.34
Al_2O_3	0.43	41.95
CaO	15.90	19.50
SO_3	37.0	-
P_2O_5	8.95	-
ZnO	17.70	-
Cl^-	15.9	-
Fe_2O_3	-	0.40

Table 4 Physical properties of materials

Properties	OPC	Mk
Plain specific surface area m^2/kg	340	
% retained on mesh 325 (45µm)	22	
Specific gravity	3.15	2.25
Bulk Density (kg/m^3)	1440	-
Loose bulk density (kg/m^3)	-	1285.7
Compacted bulk density (kg/m^3)	-	1414

4. RESULTS AND DISCUSSION

4.1 Slump Test of Concrete

The results of various fresh properties tested by slump test, for various mix compositions are given in Table 5. The slump test results indicated that the increase in the dosage of used engine oil to the blended samples caused a significant improvement in the workability of the fresh concrete. The sample containing 1.0U% + 20%MK recorded the optimum slump of 18mm, in comparison with the control sample that recorded the slump of 10mm. The results from the slump test affirmed that the used engine oil blended samples increased the workability of concrete. This is attributed to the engine oil acting as lubricant, thereby overcoming the friction between the particles in the concrete. The engine oil also formed air bubbles which act as a sort of ball bearing between the particles to slide past each other and give easy mobility to the aggregates, hence increasing the fluidity of the concrete.

Table 5. Workability of concrete

Percentage Replacement	Slump(mm)
0	10
20MK+0.2UEO	13
20MK + 0.4UEO	12
20MK + 0.6UEO	15
20MK + 0.8UEO	17
20MK + 1.0UEO	18

4.2 Air Entrainment of Concrete

The amount of air entrapped in the concrete is given in table 6. From the table, it can be observed that the UEO additive has a significant effect on the air entrainment of the blended samples. The control sample recorded 2.7% air content, while other samples containing UEO recorded higher values of air contents than the control sample. The improvement in the air contents of the blended samples caused improvement in workability; decrease in permeability; reduction in the tendencies of segregation and a slight reduction in strength.

Table 6: showing Air Entrainment of Concrete

Percentage Replacement	Air Entrainment (%)
0	2.7
20MK + 0.2UEO	4.4
20MK + 0.4UEO	2.75
20MK + 0.6UEO	4.48
20MK + 0.8UEO	3.0
20MK + 1.0UEO	4.10

4.3 Porosity of Concrete

Table 7, showed the results of porosity tests of used engine oil blended metakaolin samples at 28 days of curing age. From the table, control sample was more porous, recording a porosity value of 27%, in relation to 25% for (0.2UEO + Mk20), 24% for (0.4UEO + 20Mk, 0.6UEO + 20Mk, 0.8UEO + 20Mk), and 23% for (1.0UEO + 20Mk). It can be inferred that the increase in the quantity of UEO, decreased the size of cavities of the concrete. The filler effects of the pozzolan also helped in reducing the sizes of the capillaries in the concrete. The metakaolin also help in making a coarser C-S-H gel, and accelerated conversion of $Ca(HO)_2$, into cementatious products. Hence, the dual effects of UEO and metakaolin caused a significant improvement in porosity of concrete.

Table 7: 28 days' results of porosity tests at different percentage of replacement and UEO dose

Percentage replacement	Saturated dry weight in air (Ws) g	Saturated dry weight in water (Ww) g	Oven dry weight in air (Wd) g	Porosity (%)
Control (0)	2694.36	1702.61	2426.54	27
20MK + 0.2 UEO	2676.84	1645.79	2420.15	25
20MK + 0.4 UEO	2767.80	1743.52	2519.52	24
20MK + 0.6 UEO	2987.50	1879.80	2718.77	24
20 MK + 0.8 UEO	2757.75	1746.39	2505.19	24
20 MK + 1.0 UEO	2695.42	1678.45	2458.55	23

4.4 Sorptivity of Concrete

The results of sorptivity tests presented on table 8 showed that the control sample has the highest sorptivity of 0.055×10^{-4} g/mm/min $^{0.5}$, in comparison with blended samples containing (0.2UE0 + 20Mk, 0.4UEO + 20Mk and 0.6UEO + 20Mk) that recorded 0.035×10^{-4} g/mm/min $^{0.5}$. The decrease in sorptionof these samples in comparison with control sample is 41.81%. The sample containing (0.8UEO + 20Mk), recorded 0.027×10^{-4} g/mm/min $^{0.5}$, with 20% decrease in pearmeability of concrete. Since metakaolin is a very active pozzolan, and used engine oil is viscous, the interaction of these two materials causes a reduction in the capillary sorption of concrete.

Table 8. 28 days' results of sorptivity tests at different percent of replacement and UEO dose

Percentage replacement	Oven dry weight of sample (W1) g	Sample weight after 30 min suction (W2) g	Sorptivity (g/mm/min $^{0.5}$) 10^{-4}	Percentage Decrease
Control (0)	2470	2480	0.055	-
20MK + 0.2 UEO	2409	2415	0.032	42
20MK + 0.4 UEO	2598	2604	0.032	42

20MK + 0.6 UEO	2477	2453	0.032	42
20 MK + 0.8 UEO	2536	2541	0.027	50
20 MK + 1.0 UEO	2561	2569	0.044	20

5.0 CONCLUSION

Based on the experimental investigations of used engine oil/metakaolin concrete, the following observations were made:

1. The used engine oil/ metakaolin blended samples showed lower sorptivity, in comparison with the control sample at 28 days of curing age.
2. Sorptivity decreases as the percentage of used engine oil increases for the engine oil/metakaolin blended samples.
3. The lowest sorption value of 0.027×10^{-4}g/mm/min $^{0.5}$, was recorded in the sample containing 20%Mk + 0.8% UEO, against 0.055×10^{-4}g/mm/min $^{0.5}$ that the control sample recorded.
4. The used engine oil/ metakaolin blended samples also showed lower porosity in comparison with the control sample at 28 days of curing age.
5. Porosity decreases as the percentage of used engine oil increases for engine/ metakaolin blended samples.
6. The lowest porosity of 23% was recorded in the sample containing 1.0% UEO + 20%Mk, against the control that recorded 27%.

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