INVESTIGATION OF OIL DRILL CUTTINGS AS PARTIAL REPLACEMENT OF CEMENTS IN CONCRETE FOR LOW STRENGTH STRUCTURES

Jacob Olumuyiwa IKOTUN
Department of Civil Engineering and Building, Vaal University of Technology, Vanderbijlpark – 1911, South Africa

Joshua Olusegun OKENIYI
Mechanical Engineering Department, Covenant University, Ota – 112001, Nigeria
Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg – 2006, South Africa

Esther Titilayo AKINLABI, Stephen Akinwale AKINLABI
Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg – 2006, South Africa

Elizabeth Toyin OKENIYI
Petroleum Engineering Department, Covenant University, Ota – 112001, Nigeria

Deborah Olukemi OLANREWAJU
Department of Building Technology, Lagos State Polytechnics, Ikorodu – 104001, Nigeria
Petroleum Engineering Department, Covenant University, Ota – 112001, Nigeria

Nduka Ekene UDOYE, Joseph Osekhogene DIRISU
Mechanical Engineering Department, Covenant University, Ota – 112001, Nigeria

ABSTRACT

This study investigates the use of oil drill cuttings (ODC) as partial replacement of Portland cement (PC) and cementitious materials in binary and ternary cement compositions. Concrete specimens were prepared incorporating 0, 5, 10 and 20% by mass of ODC replacements in Portland cement (PC) and 10% of the ODC replacement in specimens having ground granulated blast furnace slag (GGBS) and pulverised fly ash (PFA) respectively. The fresh and hardened state properties of the concretes were studied. Results showed that use of ODC contributed improvements to the fresh concrete properties, while it also exhibited good comparisons of hardened concrete properties with the non-ODC containing concretes. Findings in the study support the use of ODC-containing concrete mixes for low strength structures such as foundation blinding and infilling materials, in structural fills applications requiring no future excavations. These combined the advantages of cost reduction in concrete production with utilization of the waste ODC materials, which is a considerable *solution approach to the environmental problems being encountered in ODC wastes disposal.*

Key words: Concrete, Oil drill cutting, Cement, Filler, Fresh and hardened concrete

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1. INTRODUCTION

Oil drill cuttings (ODC) are wastes produced from the extraction of crude oil from the ground in both on and offshore drillings. The cuttings contain rock chips and sand, which is obtained by drilling through the geological formations [1-2]. A sample of oil drill cuttings from Caspian Sea were reported to contain 60-80% of rock solids, 8% of organic matter, 6% of mineral salts and components of drilling mud which include clay, oil products, stabiliser, viscosity regulators and other materials [3].

The disposal of these materials in major oil producing countries, like Nigeria, the UK, and other oil producing countries constitutes an environmental problem and more of these materials are being generated yearly [3-7]. A survey conducted by American Petroleum Institute (API) revealed that 6000 million litre per annum of drill cuttings are generated in the US and between 56000 and 80000 tonnes per annum of drill cuttings have also been reported to arise in the UK [8]. It is anticipated that the need for fossil fuel will increase further the production of oil drill cuttings [5].

In the past, oil drill cuttings were discharged into the sea, this led to the depletion of marine resources due to the presence of hydrocarbon. For the last 10 years, this method of sea disposal has not been permitted by the legislative arm of each country. Therefore, many countries have now set up onshore treatment facilities to remove hydrocarbon contamination and the resulting cleaned cuttings are sent to land fill [9]. However, the disposal of this material through land fill is not sustainable; hence, identifying the alternative routes to accommodate cleaned cuttings becomes an issue of great urgency [10].

Oil drill cuttings have found some use in the construction industry and research is ongoing to examine their applications. The study in [10] worked extensively on the physical and chemical composition of oil drill cuttings for its use as filler in bituminous mixtures. The compositions and the resulting mixtures with oil drill cuttings compared very well with bituminous mixtures with limestone. Fillers are fine inert material that passes 0.063mm sieve, it improves the concrete properties by filling the inter-granular voids between cement particles and thus improve the compactness of the concrete [11]. It enhances the cement hydration by acting as nucleation sites which become an integral part of the cement paste. Reactive fillers react with calcium hydroxide, forming additional cement gel [12]. The large surface of the small particles promotes nucleation, densification and homogenisation of the cement paste [12]. This has a direct influence on the rheological property of fresh concrete which in turn affects the hardened properties of the concrete. Some of the fillers used in recent time include limestone, quarry dust and quartz sand. These are chemically inert materials that have potential of showing pozzolanic activity at a later age, depending on their particle size, shape and age of the concrete.

The use of limestone as filler in concrete has been investigated in the literature [13]. A concrete mixture containing 15% of limestone filler (partially replacing Portland cement) was produced and cured for 28 days in water. X-ray diffraction (XRD) analysis of the concrete microstructure was carried out and the result showed an improved concrete microstructure compared to the control concrete. The enhancement in micro-structure was due to formation of new hydrated compound (carbon-aluminates). Also, the cited work in [12] investigated the function of fillers as cement replacement in concrete, quartz sand were used at replacement of 10, 20, 30, 40 percent of the cement volume. Water/cement ratio and aggregate content were kept constant at various percentages. The results showed that addition of filler improved the concrete pore structure, which directly influenced the strength and durability.

In [14], Topçu & Uğurlu investigated the use of mineral filler on the property of concrete. Mineral filler was used to replace the sand content of the concrete. The 7-10% replacement was used to produce optimum performance in workability, durability and strength of the concrete. Above the optimum replacement level of the sand with mineral filler resulted in a harsh mix with lower strength and durability performances. It was reported in [11] that presence of fines in concrete below the optimum value improves the cohesiveness, workability of fresh concrete and the possibilities of segregation and bleeding of fresh concrete are reduced as well. In [15], the suitability of quarry dust as partial replacement material for sand in concrete was also studied. Result obtained from that work showed lower compressive strength at 28th days with improved workability of the fresh concrete. The lower compressive strength observed is in contrary to the previous assertions and the reason may be due to the presence of clay particles which reduces the rate hydration in cement [16].

In an attempt to create awareness in the use of oil drill cuttings in concrete, treated oil drill cutting was used to produce interlocking concrete bricks in [17], while this material was also used to produce sandcrete blocks in [18]. The concrete bricks in those studies performed very well in strength, but the durability aspects were less successful. More investigations are still needed for gaining insights into the wider application of treated oil drill cuttings in concrete. The successful applicability of this will implies reductions in the use of cement and sand, using the wastes material of oil drill cuttings, and thus promotes sustainable wastes management.

Therefore, this paper reports the result of laboratory study that investigates the benefits of utilizing oil drill cuttings as filler in cement and ternary cement concretes for a sustainable development. The main objective is to provide information about the effects of various proportions of oil drill cuttings content as partial replacement of Portland cement, GGBS and PFA on workability, compressive strength, water penetration, water absorption, chloride permeability and carbonation of concrete and to suggest a rational use of this material. Once the effects of oil drill cuttings on fresh and hardened concrete properties are obtained, it will be possible to take necessary measures on how to reduce ODC impact on the environment.

2. EXPERIMENTAL DETAILS

The laboratory investigation was subdivided into two parts. In the first part, cement was replaced by oil drill cuttings at 0, 5, 10 and 20% (represented by mix codes M1, M2, M3 and M4) while in the second part, GGBS and PFA were replaced with 0 and 10% oil drill cuttings (represented by the mix codes M5 (PC/GGBS), M6 (PC/ODC/GGBS), M7 (PC/PFA) and M8 (PC/ODC/PFA)). Concrete mixes were produced using these binders at various replacement levels. Fresh properties of the concrete which include slump, compacting factor and cohesion were studied and compared with the control concretes having 0% ODC. Also, hardened concrete properties such as compressive strength, water penetration, water absorption, chloride permeability and accelerated carbonation tests were carried out to see the effects of oil drill cuttings when used as a filler in the different compositions, including binary and ternary, cements.

2.1. Materials

Portland cement of strength 52.5 (CEM I 52.5) conforming to BS EN 197-1:2011 [19] were used in this experimental investigation and were obtained from a local commercial manufacturer in Dundee, UK. Treated oil drill cuttings used in this study were obtained from a location in the North Sea, since it has been established by many authors [9-10] that oil drill cuttings from different locations in the North Sea exhibited typically similar properties. The drill cuttings were milled and processed to remove heavy metals and hydrocarbon conforming to less than 1% content of hydrocarbon as limit requirement in BS EN 197-1:2000 [19]. Again, for the oil drill cutting to fulfil the requirement of filler material, the nominal size must have ≥ 70% passing 63 µm [10,20-21], this was achieved by mechanical milling machine to the required size. The GGBS were obtained from local commercial supplier in Dundee. Pulverised fly ash (PFA) was obtained from local supplier in Dundee and conformed to BS EN 450-1:2012 [22]. The storage and handling of GGBS and PFA were the same as that of Portland cement.

2.2. Materials Morphology Examination

The morphology of the cements were examined using Philips X30 ESEM FEG Field Emission Scanning Microscope with an EDAX energy dispersive X-ray fluorescence analysis and phoenix X-ray microanalysis software. For this, samples were dusted on the aluminium stubs through the adhesive conductive carbon pads and images at appropriate magnification of each cement samples were obtained for comparisons.

2.3. Mix Design

For the test concretes, eight mixes were designed. The PC replacements were put at 0, 5, 10 and 20% by the ODC in binary composition with PC and 10% replacement of the GGBS and PFA in ternary composition with PC. Super-plasticiser (SP) was used to limit the water content to 165 L/m^{3}and was maintained at (0.5 w/c) for all the eight mixes.

In order to maintain constant water cement ratio in the concrete mixtures and to account for the water absorption by the cement partial replacement materials, which include the ODC sample for the study, super-plasticiser (Glenium 51) made up of poly-carboxylic group was added to all the mixes. The super-plasticiser maintains the electrostatic charge existing in cement particles (PFA, GGBS, ODC, and PC) and prevents the flocculation by absorption on the surface of the cement particles, thereby reducing the water demand of the cements [23]. The admixture conformed to BS EN 934-2:2009

[24] requirements. Portable water at room temperature was used in all the concrete mixes and for curing of the concrete test samples. Portable water was also used in the permeation test. Water content was put at 165 l/m^3 and maintained for all the concrete batches.

Workability with the slump range of 80 to 120 mm was targeted in all the mixes with super-plasticiser. The dosage of super-plasticiser was varied to obtain the required slump range in all the mixes. By this, the super-plasticiser (SP) admixture design was initially set at 0.025% for the normal concrete mixes but with the dosage increased for the concretes containing ODC to satisfy slump range designed for this study. The method of mix design of the Building Research Establishment [25] was employed for calculating the proportions of concrete materials. The details of the mix proportions used in the experiment are given in Table 1.

Table 1 Mix proportions of the test concretes†

Mix proportions (kg/m^3)‡									
Mix Reference	PC ,	GGBS	Fly Ash	ODC	Water (L/m^3)	SP (%)	Aggregates		
							0/4	4/10'	10/20'
M1	330	0	0	0	165	0.025	760	380	760
M2	314	0	0	17	165	0.035	760	380	760
M3	297	0	0	33	165	0.040	760	380	760
M4	264	0	0	66	165	0.040	760	380	760
M5	150	180	0	0	165	0.025	770	380	760
M6	150	162	0	18	165	0.035	770	380	760
M7	210	0	115	0	165	0.025	750	375	750
M8	210	0	103	12	165	0.025	750	375	750

†Partial replacement model: M1: PC100%; M2: PC95%ODC5%; M3: PC90%ODC10%; M4: PC80%ODC20%; M5: PC45%GGBS55%; M6: PC45% GGBS45% ODC10%; M7: PC65%PFA35%; M8: PC65%PFA25%ODC10%

‡Except unit is indicated otherwise in the table

2.4 Concrete Mixing and Casting

Concrete was done as described in BS 1881-125:2013 [26]. The workability of each of the concrete batch was measured using slump test as described in BS EN 12350-2:2009 [27]. The cohesion of each concrete batch was measured using visual observation. The degree of fresh concrete compaction was determined in accordance with BS EN 12350-4:2009 [28] for all the concrete mixes.

Concrete test specimens were cast into the steel moulds of 100 mm × 100 mm × 100 mm sizes to determine the compressive strength and 150mm × 150 mm × 150 mm cubes for water permeation test, 100 × 100 × 500 mm prisms for carbonation test and Ø100 mm x 300 mm cylinders for water sorptivity and rapid chloride permeability (RCPT) test. The specimens were placed and covered with polythene sheeting for 24±2 hours, after which all the specimen were de-moulded, marked for future identification and transferred to water curing tank under laboratory temperature of 28±2 ºC for the required number of days for respective tests.

2.5 Test Methods

2.5.1 Compressive strength

Compressive strength tests were conducted on the concretes in accordance with standard practice in the literature [29-33] and prescriptions from BS EN 12390-3:2009 [34] at 1, 3, 7, 28 days using Avery-Denison™ Compression Machine®. The loading rate to failure was at 0.2-0.4 N/mm^2 as per operating manual for the machine equipment. Three cubes per concrete mixture were selected for each of the test duration and the result expressed as the average of the three measurements for a concrete mixture.

2.5.2 Water penetration

Water penetration tests were conducted in accordance with BS EN 12390-8:2009 [35]. This was done with the aim of determining the resistance of oil drill cutting concrete to water penetration. Concrete samples were put in the test device as shown in Figure 1. Water was applied to underneath face of the concrete sample at a pressure of 500 kPa for 72 hours. The samples were split open after 72 hours using Park Industries™ X-18 Hydra Split Masonry Splitter® and depth of water penetration was measured to the nearest millimetre. Three cubes per concrete mixture were selected and tested for water penetration and the result is expressed as the average of the three measurements for a concrete mixture.

Figure 1 Water penetration test apparatus with concrete samples

2.5.3 Water sorptivity

Permeation properties of the concretes were assessed using a water sorptivity test. The test measures the water absorption capacity of concrete specimens. The test was done in accordance with STM C 1585-13 [36]. A concrete cylindrical samples from each mixtures was selected after curing in water for 28 days, they were cut into 50 mm thickness using a diamond saw and stored in an oven chamber at a temperature of 50±2 ºC for 3 days ±2 hours. The concrete disc samples were later stored in the laboratory at 23±2 ºC for two weeks The oven temperature and duration was selected to result in a minimum degree of micro-structural alteration of the concrete disc samples, while still maintaining the internal moisture equilibrium. After preconditioning the samples, the sides and one of the opposite ends were sealed with tape to disallow any evaporation from taking place during the absorption. Initial weight of the specimen was taking before immersing it in water with one side face exposed to water. The weights of the partially immersed samples were measured over the time interval of 6 hours followed by daily measurement for 8 days. The average of 4 water sorptivity measurements from the same concrete mix represents the water sorptivity of that particular mix.

2.5.4 Rapid chloride permeability test

The need to assess the potential movement of chlorides in concretes in a short period had led to the development of rapid chloride permeability test. The test involves utilising voltage gradient to force chloride ions to migrate more rapidly through the pores of the concrete under test. This method measured the total charge passed through the concrete sample over a period of time, mostly 6 hours. The resistance is calculated by dividing the voltage by the current passing through the concrete in a given time. The classification and interpretation of measured chloride charge as proposed in [37] is given in Table 2, while the testing system is as shown in Figure 2.

Table 2 Interpretation of RCPT measurements as per [37]

Charge Passed (Coulombs)	Potential Chloride ion penetration
> 4000	High
2000 – 4000	Moderate
1000 – 2000	Low
100 – 1000	Very low
< 100	Negligible

Figure 2 Rapid chloride permeability testing apparatus

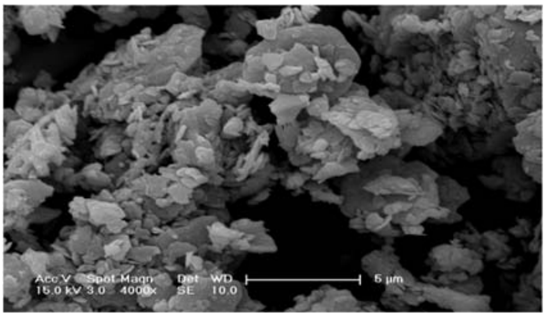
2.5.5 Carbonation

The concrete prisms of 100 mm × 100mm × 500mm length were made from the mix proportions shown in Table 1. The concrete samples were cured in water for 28 days at 20±2 ºC, after which they were air cured for seven days in a chamber at 20±2 ºC and relative humidity of 55% to allow surface dryness before exposure to carbon dioxide. The prisms were kept inside the accelerated carbonated tank for 7, 14, 21 and 28 days. At each specified days 100 mm piece of concrete was cut from the prism using masonry cutter.The extent of carbonation depth was determined by spraying the freshly cut surface with a solution of 1% phenolphthalein in 70% ethyl alcohol. The sprayed concrete was left for 1 h ± 15 minutes after which the measurements were taken. The carbonated zone showed no colouration while the purple-red zone showed unaffected zone. Carbonation depth of a particular concrete mixture was determined by taking an average of 12 measurements from the cut surface (three measurements on each face).

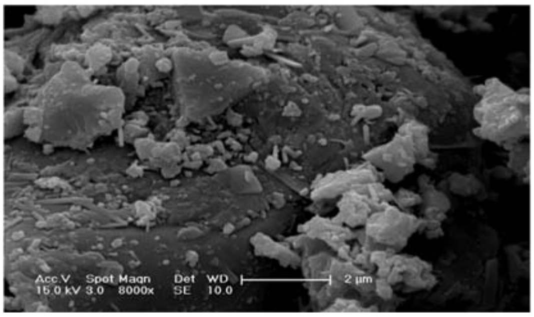
3. RESULTS AND DISCUSSION

3.1 Micrograph Morphology of Cement/Cementitious Materials

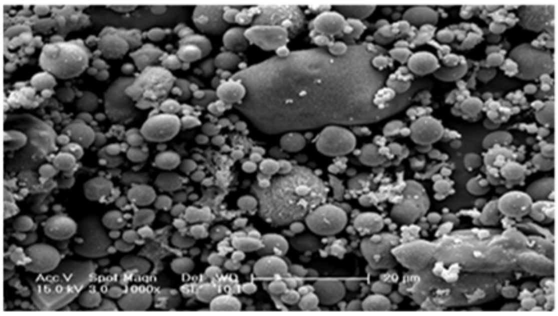
The SEM images obtained from the morphological characterizations of the cement/cementitious materials are presented in Figure 3. From the figure, it could be noted that the ODC, PC, and GGBS exhibited similarity in morphology in comparison to the FFA that exhibited spherical shapes. Also, from the SEM photographs of the studied particles, both the ODC and GGBS materials portrayed relatively large specific surface areas compared to the PC and PFA.



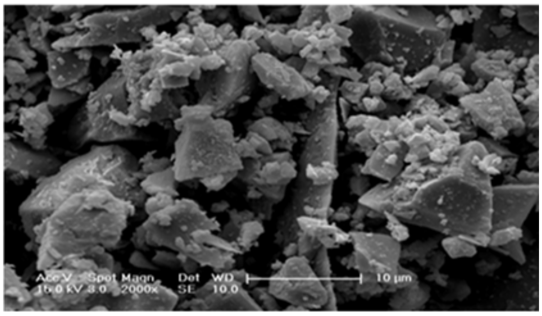
(a) ODC (×4000)



(b) PC (×8000)



(c) PFA (×1000)



(d) GGBS (×2000)

Figure 3 SEM micrograph of the ODC, PC, PFA and GGBS particles

3.2 Fresh Properties of the Concretes

The results of fresh properties for the concrete samples for the study are as shown in Table 3. These include the results of slump tests for the concrete mixes employed. All concrete mixes achieved the desired workability (80-120mm slump), which was as a result of using the super-plasticiser, SP, varied in the range detailed in Table 2.

Table 3 Variation of slump and compaction factor of fresh concrete with ODC

Mix Ref	Slump (mm)	Compacting Factor	Cohesion†
M1	80	0.99	2
M2	90	0.97	2

M3	120	0.96	1
M4	80	0.88	1
M5	80	0.99	2
M6	100	0.86	2
M7	100	1.00	2
M8	80	0.91	1

†1-Over cohesive; 2- cohesive; 3- little cohesive

From the result, control concrete, M1, gave 80 mm slump at 0.025% dosage of super-plasticiser. At 5% replacement of cement with ODC the dose was increased by 40%, and at 10 and 20% replacement the dose was increased by 60% to give the targeted slump range. The reason for increase in the super-plasticiser demand was to have the required workability for the ODC concretes because of the high specific surface area and fineness of ODC particles (measured at 712 and 749m^2/kg), compared to cement particles (measured at 251 and 405 m^2/kg). However, all the mixtures have good workability without bleeding or segregation.

Moreover, replacement of GGBS with 10% oil drill cuttings, M6, had an effect on the workability of the fresh concrete in that low slump of 50 mm was obtained with 0.025% SP. The super-plasticiser was increased by 60% to cater for the 10% replacement with ODC and 100 mm slump was obtained. The increase in super-plasticiser dose for PC-ODC-GGBS concrete mixture can be attributed to the combined effect of angular shape and large specific surface areas of ODC and GGBS as shown by the SEM photographs in Figure 3. Replacement of PFA with 10% ODC did not have any effect on the super-plasticiser dosage, for the recorded slump was still within the set limit. This can be attributed to the spherical shape of the PFA particles as shown by the SEM photograph in Figure 3. However, all the mixes have good workability and stability at the specified super-plasticiser dosages.

Visual observation and tapping method were used in assessing the cohesiveness of the mixes. The results obtained are presented in Table 3. The results obtained indicate that all the mixes have good cohesion. The results of the compacting factor are shown in Table 3.This is a measure of density ratio between un-compacted concrete and fully compacted concrete in a mould. From the result shown in Table 3, increase in the ODC percentage from 0 to 5%, 10% and 20% replacement of Portland Cement reduces the degree of compacting factor of the concrete by 2%, 3% and 11% respectively. The reason for this could be as a result of variation in the cement content of the mixtures brought about by inclusion of ODC. With this it can be concluded that increasing the percentage of ODC in the concrete mix led to the reduction in the compacting factor of the concrete. This compaction reduction is, especially, more pronounced either with high ODC proportion for PC replacement or when ODC is used for partial GGBS and PFA replacements.

3.3 Hardened Properties of the Concretes

3.3.1 Compressive Strength

The results of compressive strength testing are shown in Figure 4. From the figure, it could be noted that the trends of the compressive strength for all the tested concrete mixes satisfy the criteria of increasing compressive strength as the concrete age increases, as specified in ASTM C150/150M [38]. The control concrete, M1, with 100% PC, exhibited compressive strength that is consistently higher than the compressive strength from the other concrete mixes. In spite of this, however, the compressive strength results of the concrete specimens having PC partially replaced by ODC are higher than the strength from the concrete having PC replaced by the other cementitious materials, for the tested concrete age, 1 to 28 days. The exception to this is the M5 sample, having 45%PC/55%GGBS, which have 28th day compressive strength that surpasses strength values of the M3 (PC/10%ODC) and of the M4 (PC/20%ODC) samples.

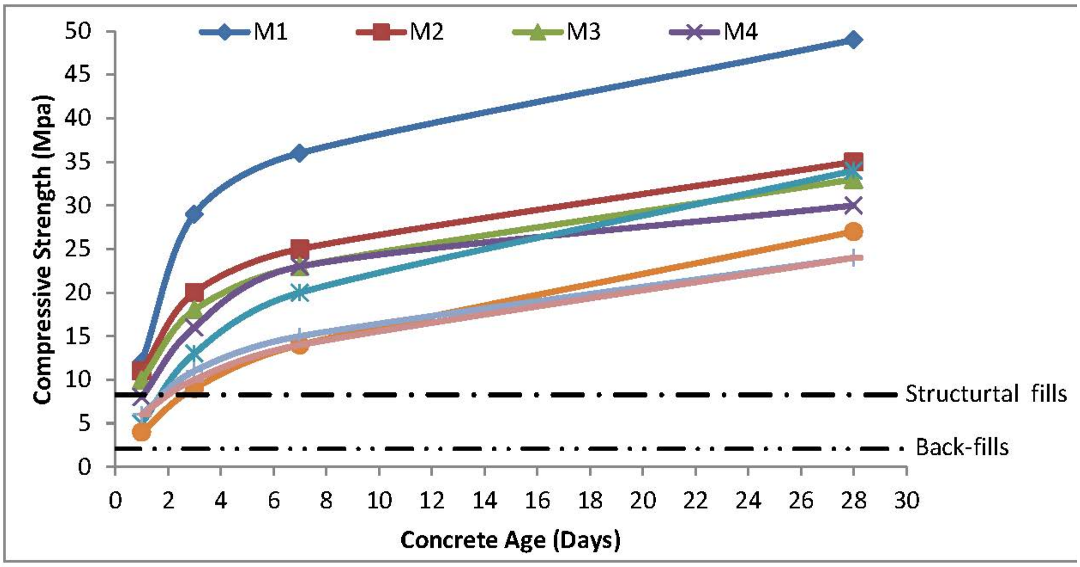


Figure 3 Compressive strength developments of concretes

It had been indicated in studies [39-40] the reference for compressive strength of recycled-materials-admixed-concrete may not be of normal concrete only, but on other low strength structural application for which the concrete having recycled material could be employed. Such applications include the back fills for which there could be future excavation, and for this the compressive strength may not exceed 2.07 MPa or 300 psi. Other applications for concrete having recycled materials as admixtures include the structural fills applications for which compressive strength could be as high as 8.27 MPa or 1200 psi. These compressive strength criteria of low strength and recycled materials (CLSM), in concrete, are indicated as linear plots in Figure 3, for direct comparison with compressive results from the concrete mixes in this study. From these, therefore, it could be noted that the compressive strength of the binary and ternary concrete mixes in this study well surpassed the strength of the CLSMs. This is indicating the binary and ternary concrete mixes in the present work will very well be suitable for concrete for low strength structures for which future excavation is not expected. Examples of these include the use of ODC-partial replacement of cement in concrete for filling road bases, foundation support above weak or uneven soils, or underground of buildings [39].

3.3.2 Water penetration depth and water sorptivity

The results of water penetration and of the water sorptivity tests conducted, after 28 days, on all the test cubes of the concrete batches are shown in Figure 4. The figure shows that water penetration depth increases with increasing percentages of ODC in the concrete. Similar results were also obtained for ternary cement concretes when GGBS and PFA were replaced with 10% ODC. The increase in the water penetration depth of the ODC concretes suggests presence of clay minerals in the materials. This is because it is well known that clay minerals have the tendency for high water absorption capacity when exposed to water.

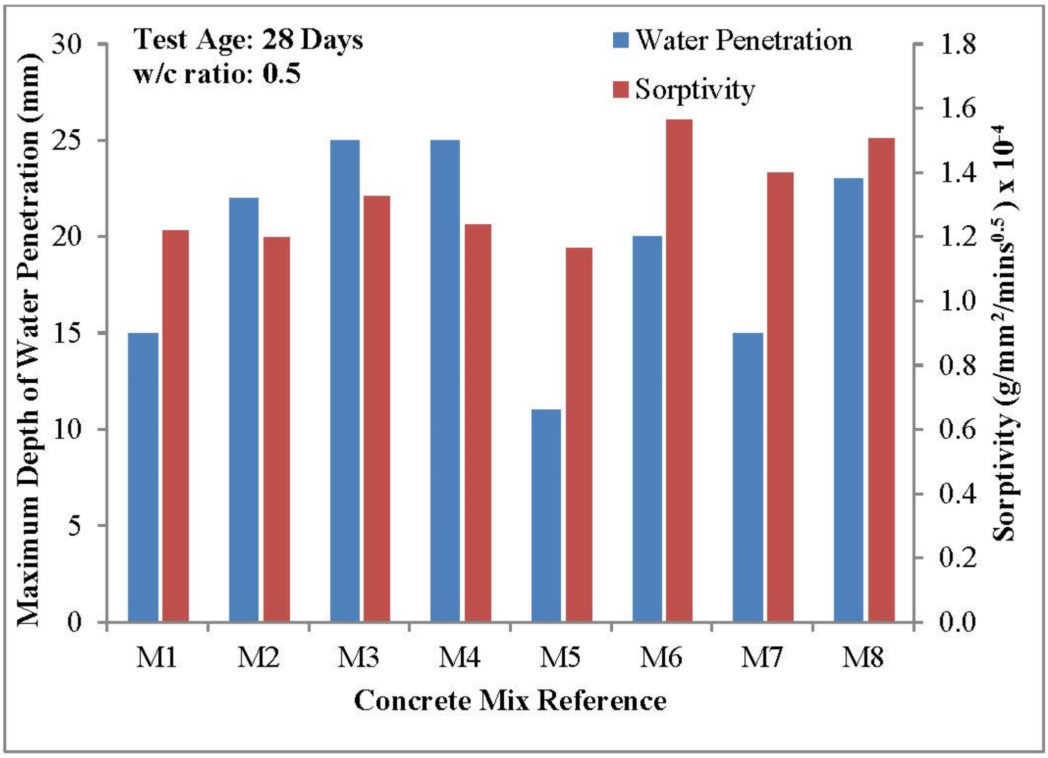


Figure 4 Comparison of maximum depth of water penetration and sorptivity

Also, the sorptivity test-results in Figure 4 depicted the change in behaviour of the concretes at different replacement levels of PC with ODC. Among these, the 10% ODC replacement of PC mixes (M3) has the highest sorptivity of 1.325 × 10^{-4}g/mm^2/min$^{0.5}$ while the 5 ODC replacement of PC (M2) gave the lowest sorptivity of 1.198 × 10^{-4}g/mm^2/min$^{0.5}$ compared to the control concrete (M1). The increase in sorptivity can also be attributed to the partial replacement of PC with ODC culminating to introduction or increment of clay minerals into the concrete mix. However, it is still worth noting that 5% replacement with ODC reduces sorptivity by 1.7%, relative to the control (M1), which confirm the filler effect of oil drill cuttings in refinement of concrete pores for low water absorption. Similar effect could be seen in PC/ODC/PFA concrete (M8), where sorptivity was reduced by 3.7% relative to the PC/PFA concrete (M6) via the replacement of PFA by 10% ODC. This is implying that the 5% replacement of PC and 10% replacement of PFA with ODC exhibit beneficial effect to the water absorption property of the tested concrete.

3.3.3 Rapid chloride permeability

The results of the rapid chloride permeability testing of concrete mixes are shown in Figure 5. These showed decreases of 9.38%, 11.81% and 11.47% in total charges passed at the introduction of 5%, 10%, and 20% ODC for partial replacement of PC. In similar manner, the partial replacements of GGBS and of PFA by ODC led to 3.56% and 8.71% respective reductions of total charges passed through the concretes. By this, therefore, the control concrete (M1) has the highest total charge of 5843 Coulombs. In furtherance of comparisons, there was 55.98% reduction in the total charges when GGBS was used to partially replace PC (M5) and 18.60% reduction in total charges when Fly Ash was used to partially replace PC (M7). Introducing 10% ODC to replace GGBS and PFA further reduced their total charges by 3.56% and 8.71% respectively.

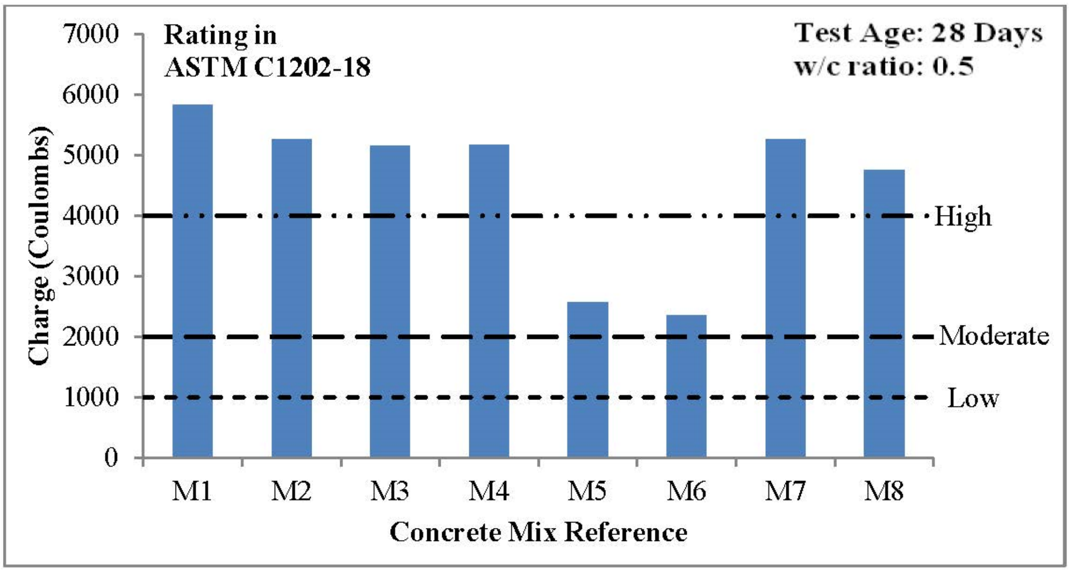


Figure 5 Plots of rapid chloride permeability testing of concrete mixes

The beneficial effect of GGBS and Fly Ash arise from their denser microstructure in hydrated cement paste. The values of potential chloride ion penetration interpreted to "High" in all the concrete mixes except the PC/GGBS and PC/GGBS/ODC concrete mixes (M5 and M6) for which it interpreted to "Moderate" as per ASTMC1202-18 [37]. In spite of these, concretes with additives, i.e. the binary and ternary concretes in the study exhibited comparably lower chloride ion permeability.

3.3.4 Carbonation depth

The result of the accelerated carbonation test is shown in Figure 6 wherein carbonation depths were plotted against the exposure ages. Carbonation depth was zero in all the concretes at the inception of carbonation test. In all the concretes, carbonation depths increased with the exposure age. The control concrete (M1) has the lowest carbonation depths at 14, 21, and 28 days than the ODC concretes (M2, M3 and M4).

Some higher carbonation depths were also observed with GGBS and PFA concretes (M5 and M6) compared to the control concrete (M1) at all the exposure ages. This is attributed to the higher reduction in the PC contents of those mixtures containing GGBS and PFA. Carbonation depths were further increased at every exposure age when 10% ODC was used to partially replace GGBS and PFA (M6 and M8). This trend confirmed the assertion that carbonation depth is a function of cement content. The higher the cement contents of a mixture the higher the calcium hydroxide responsible for their carbonation reaction and the lower the carbonation depth of such concretes.

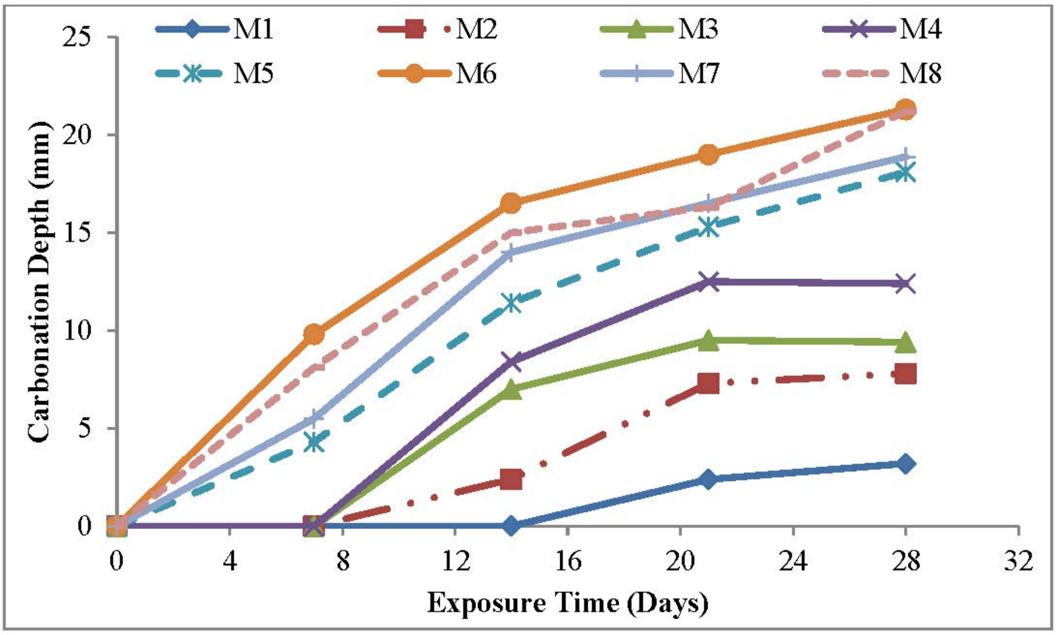


Figure 6 Plots of carbonation depth with increasing exposure age of the concrete mixes

4. CONCLUSIONS

This paper explores the benefits of utilizing oil drill cuttings as filler replacement in Portland and ternary cement concrete. Fresh properties including slump, compaction and cohesion were observed. Also, hardened properties of compressive strength, water permeation (sorptivity and water penetration), rapid chloride permeability and accelerated carbonation were considered in the study. The results from the study identified some benefits for the use of ODC for partially replacing cement in concrete. Improvements were recorded for the fresh properties of ODC concretes while the influence of it on hardened properties of concrete showed benefits on chloride permeability. While other results from the study indicated that ODC partial replacement of cement may not culminate in concrete of high strength, the fact that the mixes can be used for low strength concretes have the added advantage of wastes ODC material utilization. These pose the added advantages of wastes materials valorization, means of avoiding strict regulation against ODC disposal, as well as form of construction material inclusions that could contribute to affordable and sustainable housing solution in oil producing regions. Thus, it is based on these advantages that results from this study is further supporting use of ODC in lower strength concrete grade applications such as foundation blinding and concrete fill materials, and, especially, in structural fills requiring no future excavations.

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