Strength and durability assessment of concrete substructure in organic and hydrocarbon polluted soil

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Abstract: *Physical and chemical properties of host environment to concrete structures have serious impact on the performance and durability of constructed concrete facilities. This paper presents a 7-month study that simulated the influence of soil contamination due to organic abattoir waste and indiscriminate disposal of spent hydrocarbon on strength and durability of embedded concrete. Concrete mix, 1:1.5:3 was designed for all cube and beam specimens with water-cement ratio of 0.5 and the compressive and flexural strengths of the specimen were measured from age 28 days up to 196 days in the host environment. It was found that both host environments attack the physical and strength of concrete in compression and flexure. However, hydrocarbon had much greater adverse effect on the load-carrying capacity of concrete structures and hence make constructed facilities less serviceable and vulnerable to premature failure.*

Keyword: *concrete, durability, compressive strength, flexural stiffness, organic waste, Soil pollution, hydrocarbon, deterioration*

I. INTRODUCTION

Durability of concrete in underground structures depends on the chemical properties of the soil and groundwater. Oftentimes, properly designed and constructed concrete infrastructure systems are threatened by deterioration tendencies due to alterations in the internal or host environmental conditions. Consequently, increasing percentages of existing buildings and civil infrastructure have become either structurally deficient or functionally obsolete or both in past one decade as a result of construction defects, aging, material degradation and structural deterioration due to harsh environmental condition [1-3]. Concrete is one of the strongest construction materials applied in centuries all over the world. Buildings and other structures undergo biodeterioration when exposed to contact with soil, water, sewage, as well as food, agricultural products and waste materials [4, 5]. Concrete is a vulnerable material when it comes to microbiologically influenced deterioration especially by algae [6] which may be triggered by corrosion-enhancing bacteria such as sulphate reducing bacteria and sulphur oxidizing bacteria.

Deterioration of concrete occurs due to the porosity of concrete, its use in exterior environments and tendency was exposed to deleterious chemicals. Biologically influenced corrosion of concrete has most often been detected in building foundations and walls and also in constructions such as dams, harbor and maritime structures, bridges, tanks, pipelines, cooling towers, silos and many others [5]. This type of concrete deterioration occurs often in the food processing and storage works and in the abattoirs and buildings of holdings, in which the different microorganisms including bacteria, microscopic fungi, and algae are usually present at increased concentrations. The contribution of microorganisms to the deterioration of materials as a whole in the United States is about 30% [7].

Adewuyi et al. [4] reported significant loss in compressive and flexural strengths of concrete substructure founded in cassava effluent contaminated soil. Ajagbe et al. [8] also found that concrete produced from 2.5% crude oil impacted sand has resulted in about 20% loss of its compressive strength, while 10% crude oil contaminated sand caused loss of 50% compressive strength. On the other hand, strength reduction of healthy concrete in oil contaminated host environment is less than concrete made from oil impacted aggregates [9-10]. Regular crude oil spillage on the surface and sub-surface water resources, erosion and drainage problems of the built environs results in progressive deterioration leading to dysfunctional facilities and frequent structural failure concrete infrastructure systems [10]. Adewuyi et al. [11] also investigated the physical properties and compressive strength of concrete exposed to progressive heat up to 500ºC. The total loss of compressive strength at the end of each of the five cycles at 100°C, 200°C, 300°C, 400°C and 500°C were 3.48%, 21.97%, 24.56%, 33.06% and 33.81%, respectively.

This goal of this study was to assess the load carrying capacity in compression and flexure of concretes embedded in abattoir waste and hydrocarbon contaminated soil. The mass loss of concrete was measured to predict porosity of concrete as a physical property, while compressive and flexural strengths were investigated to assess the durability as a function of the load-carrying capacity of concrete.

II. DESCRIPTION OF THE STUDY AREAS

The abattoir that simulated the effect of organic wastewater disposal was situated along the Cele-Ijesha Road by the Odo market in Lagos, Nigeria. The abattoir was established in the 1970s. It is located at the bank of elevated concrete floor slab, which serves as a slaughtering surface. A certain amount of animals such as cows, goats and pigs are slaughtered daily. In the Cele-Odo abattoir, an estimate of 80 – 90 cows are slaughtered on each weekdays. The cows are killed manually by falling the cows with strong thick ropes. The cows are killed with sharp deep knife cut through the neck, releasing blood and led to the complete death of the animals include blood, flesh particles, soluble protein, urine, faeces and other organic materials. There are small drainage channels around the slab that is connected to a large channel through which the animal waste is being discharge into the abattoir dumping area. The waste is been taken care by the Lagos State Waste Management (LAWMA) at the end of every month. Water traps are mounted around the slab area used to supply the water in preparing the slaughtered animal in washing the slab after the slaughtering of the animals. Station 1 is a slaughterhouse wastewater at the point of discharge (source), while Station 2 is 10m upstream from the source. The water flows from station 2 to 1. At high tides, the water flows upstream and when the flow will be backwards.

The mechanic village investigated for the effects of hydrocarbon contamination of soil on embedded concrete was situated along the Oshodi-Apapa Expressway by Ilasamaja also in Lagos, Nigeria. The mechanic village was established in the 1980s.The mechanic village comprises of different diesel engines and it leads to deterioration of reinforced concrete structures as a result of the effect of crude oil spill on concrete structures particularly in this area.

III. EXPERIMENTAL PROGRAMME

3.1. Materials

Grade 42.5 ordinary Portland cement conforming to BS 12 [12] was used in this study. The properties of cement such as consistency, setting times, soundness and compressive strength are summarized in Table 1. Coarse aggregate was crushed granite of maximum nominal size of 19 mm sourced from Shagamu, Southwestern Nigeria. Fine aggregate was natural coarse sand collected from Ogun River of maximum nominal size of 4.75 mm. The both aggregates were free from deleterious materials and the physical properties were carried out in accordance with BS 812 [13]. The properties of fine and coarse aggregates are presented in Table 2 and the particle distribution curves are plotted in Figure 1. It is obvious that the fine and coarse aggregates employed as constituents of the concrete in the study are well-graded. Potable water of pH of 7.1 which conformed to the requirements of BS 3148 [14] was used in mixing the aggregates and cement.

Table 1: Physical Properties of Cement

Standard Consistency (%)	30
Specific gravity	3.15
Initial setting time (min)	118
Final setting time (min)	215
Soundness (mm)	1.0
Compressive strength (N/mm^2)	
3 days	24.5
7 days	30.8

Table 2: Properties of aggregates

	Sand	Crushed granite
Specific Gravity	2.64	2.70
Bulk Density (kg/m^3)	1240	1464
Moisture content	4.09	0.6
Fineness modulus	3.00	6.15
Aggregate Crushing Value (%)		12.9
Impact Value (%)		7.13

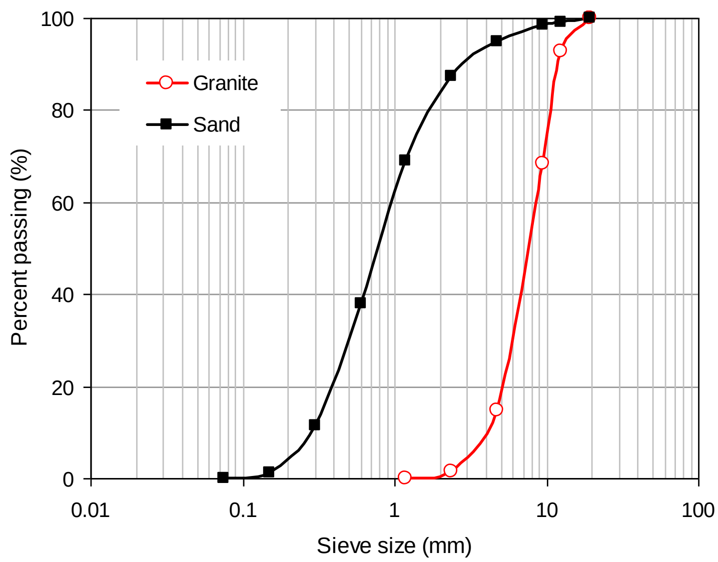

Fig. 1 Particle distribution curves of fine and coarse aggregates

2.2. Concrete mix proportions

Concrete mix 1:1.5:3 (cement:sand:coarse) of water-cement ratio (w/c) of 0.5 corresponding to characteristic compressive strength of 25 N/mm^2 was employed in the study. The mixture of concrete was prepared in a rotating drum mixer. The aggregates and cement were placed in the drum and mixed in parts with water to ensure a better bond between the cement paste and the aggregates as shown in Figure 2. All mixing and sampling of concrete were carried out in accordance with the procedure in BS 1881 [15].

Fig. 2 Casting of concrete to the beams and cubes

2.3. Preparation and casting of concrete specimens

A total of fifteen 150 mm cubes each for control, abattoir and hydrocarbon environmental conditions were cast, cured and tested at curing ages 28 days, 56 days, 84 days, 140 days and 196 days for compressive strength according to BS 1881 [16], while twelve 150 1000 mm concrete beams each for the three media were also cast, cured and tested at ages 56 days, 84 days, 140 days and 196 days. Concrete specimens were cast and then covered with thin polythene membrane to minimize moisture loss. The concretes were stored and tested in the laboratory under mean air temperature of 26 ± 1 ˚C. The specimens were demoulded after 24 ± ½ hours and then transferred into a water-curing tank for the test periods.

The specimens were thereafter carefully arranged in three 1.2 × 1.2 × 1.7 m excavated pits corresponding to the unpolluted soils which served as control, abattoir and hydrocarbon contaminated soils as shown in Figure 3. The pits were thereafter covered up with their respective excavated soils and sprinkled with natural water. The activities at the two different sites were not impaired while the study lasted for a maximum of 196 days. Specimens were taken from the pits only on test days, while the remainders remained covered until the end of the test periods. The pH values of the soils of the three environment dissolved in distilled water were comparable. They were all in the range 7.6-7.9 indicating alkalinity (>7.1).

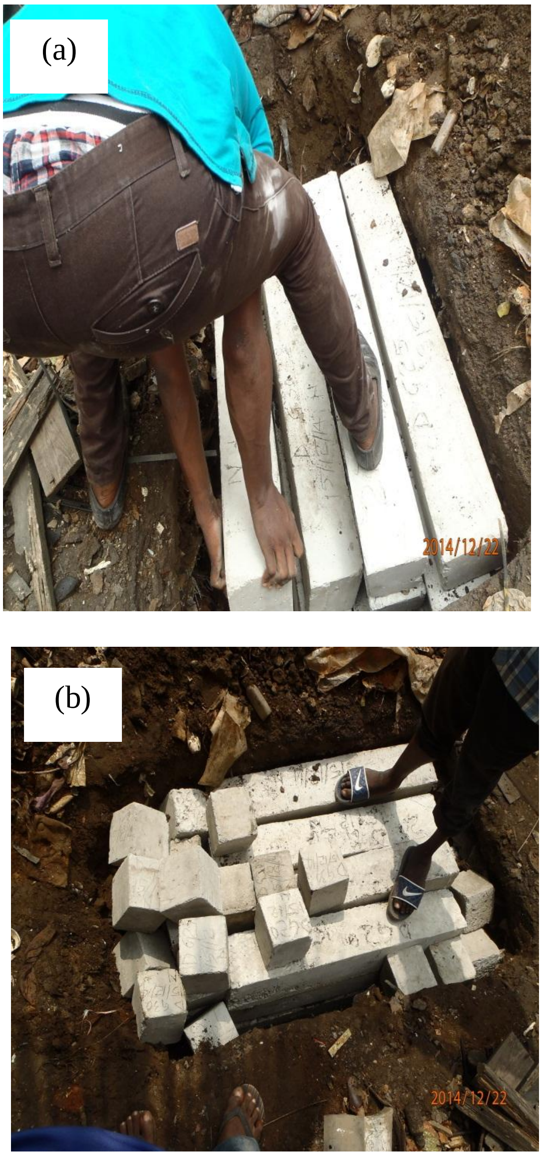

Fig. 3 Placement of concrete specimens in excavated (a) abattoir and (b) hydrocarbon contaminated pits

IV. RESULTS AND DISCUSSION

4.1 Physical properties of concrete

The deterioration of concrete specimens due to different host environments in organic and diesel contaminated soils are presented in Figure 5. Control, abattoir and diesel contaminated cube specimens are designated as C, A and D respectively. The porosity (n) of a cube is the ratio of the void space to the total volume in the cubes. It is expressed as a percentage. Physical deterioration is a measure of mass loss or simply porosity of concrete specimens.

$$n = \frac{v_a}{v} \times 100\% \qquad (1)$$

where v_a is the volume of void (or pores) and v is the total volume.

The porosity of a cube depends upon a number of factors, such as particle size distribution, sorting, grain, shape, degree of compaction and cementation, fabric, solution, effects and mineralogical composition. In respect to the weight of the cubes, porosity is usually less than, when the cubes are affected by some environmental conditions and the value is usually due to the quality of the cubes. In a situation where the cubes are affected, the mechanical properties such as the unrefined compressive strength and the modules of elasticity can be related to porosity, but there is a large scatter and correlation is not perfect. As the weight of the cubes becomes more and more dense, their values decrease. Deterioration of concrete worsens with increase in concrete mass loss. The variation in mass of concrete cube specimens of the three different grades in the three environment regimes is presented in Figure 5. It is obvious that the mass decreased with ages of the specimens in the three environments. The mass in the control is the highest, while concrete in hydrocarbon contaminated soil had the least mass. The percentage mass loss to the organic (abattoir) and hydrocarbon (diesel) environments with respect to the control is plotted in Figure 6.

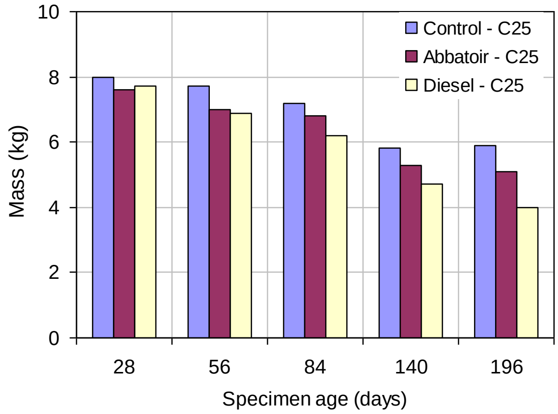

Fig. 5. Physical deterioration of concrete in terms of mass fluctuation in (a) control, (b) abbatoir and (c) hydrocarbon environments.

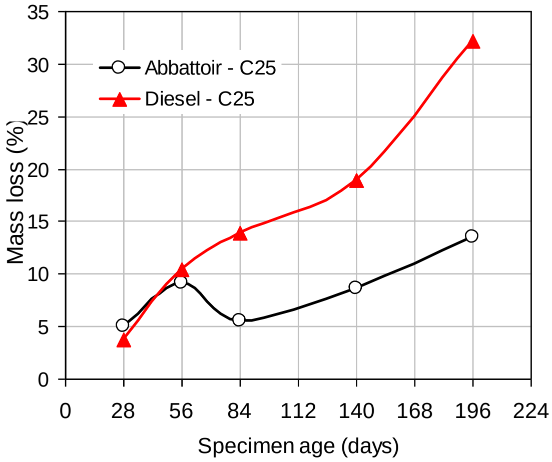

Fig. 6. Percentage mass loss of concrete specimen to (a) abbatoir and (b) hydrocarbon environments.

4.2 Compressive strength

This test was conducted to compare the strengths between the cubes buried under organic (abattoir waste) and hydrocarbon (petroleum product) environments with the control. It is evident from Figure 7 that cubes under control had more compressive strength than the two environmental conditions such as cubes buried under the abattoir environment soil condition had higher strength than the cubes buried under the diesel environment soil condition at different days respectively. It is clear from the study that the compressive strength decreases with the specimen age in the three exposure conditions.

Figure 8 shows that hydrocarbon is more severe on concrete than organic conditions for the three concrete grades. Concrete lost about 18 – 28% and 12 – 22% of its compressive strength to hydrocarbon and organic substances respectively. The two exposure conditions showed tendencies for increase in strength loss with duration of exposure. The behavior of concrete of grade 30 to hydrocarbon and organic matters was quite different from the other two grades. Strength losses in compression were 17 – 28% and 11 – 16% in hydrocarbon and organic wastes environments respectively. The highest strength loss was recorded on the 84th day specimen age in the two media.

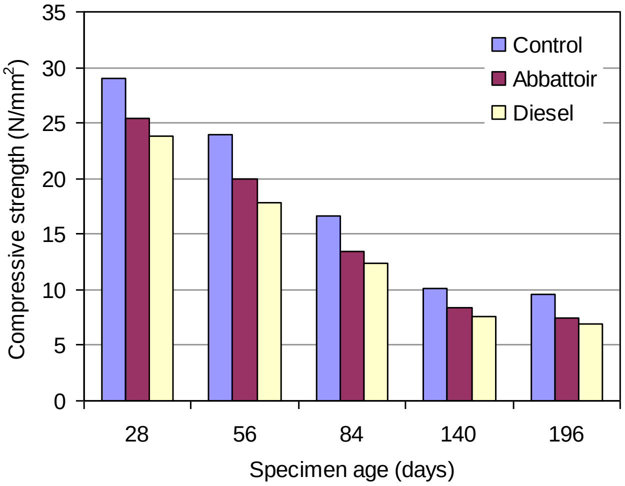

Fig. 7. Compressive strength of different grades of concrete in varying soil environmental conditions

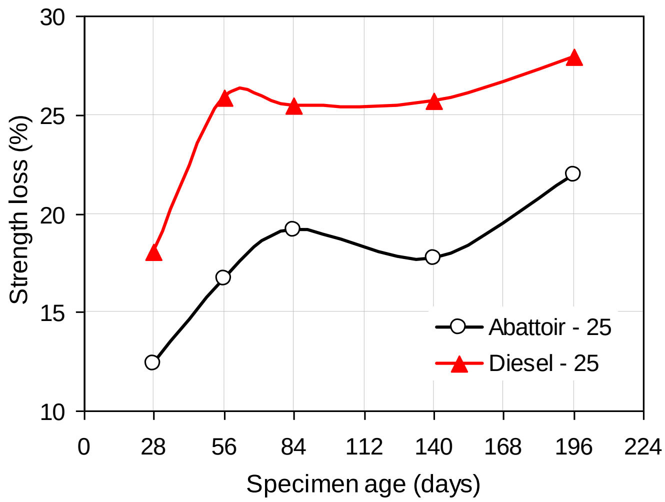

Fig. 8. Loss in compressive strength of concrete of different grades in varying soil environmental conditions compared to the control

4.3 Flexural strength test on beams

The determination of flexural tensile strength was conducted to estimate the load at which the concrete members failed. The test was conducted on the reinforced concrete beams in accordance with BS 1881 Part 118. A four point flexural test was adopted because it is mostly used for composite material and also to avoid premature failure. The hydraulic loading force jack was applied on the steel beams that act on the fixed and roller support placed on the concrete beams at a spacing of 250 mm from the center of the hydraulic loading force jack and the concrete beams was placed on fixed and roller support at a distance of 450mm from the center of the hydraulic loading force jack. Loads were applied on the concrete beams at different loading by the hydraulic loading force jack till the beams started experiencing failure at some points. The hydraulic loading force jack read in unit ton which is approximately to 10 kN. The table below shows the result of the flexural failure of beams.

Figure 9 shows the flexural strength results obtained for beam specimens in the three host environments at 28 days, 84 days, 140 days and 196 days. The flexural stiffnesses of the beams were comparable at ages 28 days and 84 days. However, It is obvious that the flexural stiffness of the beams thereafter decreased with age in each of the environment due to severity or harshness of the exposure conditions to concrete matrix and reinforcements. The higher the slope of the load-deflection (P – δ) curves the higher the stiffness of the RC beams. At 140 days, hydrocarbon severely affected concrete more than those in the other two media. At 180 days, the organic substances reduced the flexural stiffness of the beam through decomposition of the waste into hydrogen sulphide and subsequently H_2SO_4. The specimens in the control environment had the highest stiffness, followed by the diesel-contaminated RC beams. Finally, the first cracking and ultimate loads of the beam specimens increased with the grade of the concrete, but reduced with duration of exposure in the media.

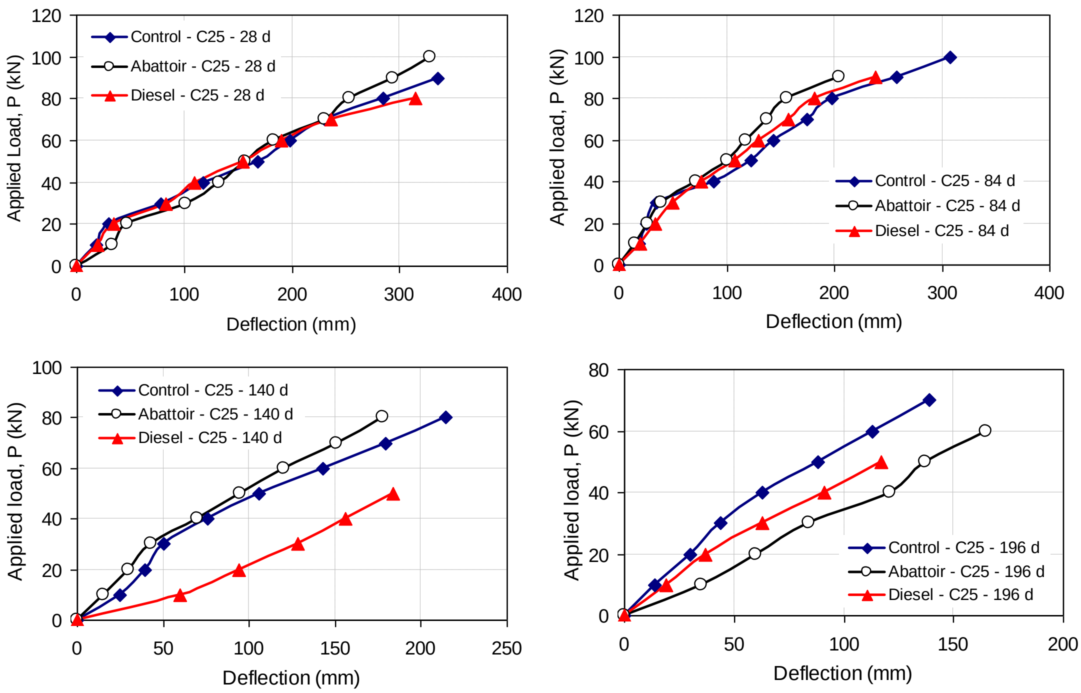

Fig. 9. Flexural behaviour of concrete of different grades in varying soil environmental conditions at 28 days

V. CONCLUSION

Based on the experimental results reported on the structural performance and durability of concrete structures in organic (abattoir waste) and hydrocarbon (petroleum product) environments. The following conclusions drawn from the mass loss, compressive strength and flexural strengths between 28 days and 196 days are presented as follows:

1. The compressive strength test results on the specimens exposed to spent hydrocarbon and abattoir wastes at different ages are lower than the control for the same ages. Abattoir wastes and diesel causes the deterioration of concrete and reduces its compressive strength.
2. Considerable differences were observed in the flexural strength and load-carrying capacity of beams buried in organic and hydrocarbon environment, the strength of beams were deteriorated when exposed to abattoir and diesel wastes as age increases and the beams deteriorated as load increased.
3. Concrete structures should be adequately protected from chemical attack and harsh conditions of the host environment. The flexural strength of the beams under control condition decreases as the curing period increases respectively.
4. Hydrocarbon is much harsher on concrete than organic waste from abattoir wastewater and sludge.

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