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Effect of Crude Oil Spill on Compressive Strength of Concrete Materials

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Abstract: While interacting with its service environment, concrete often undergoes significant alterations that often have significant adverse consequences on its engineering properties. This paper reports the results of investigation on the effect of crude oil spillage on the strength properties of concrete made with ordinary Portland cement (OPC) used in construction in Nigeria. Concrete specimens were prepared and subjected to concentrated crude oil solution and simulated water/crude oil mix. The samples were cured in the media with ambient temperature at immersion ages of 3, 7, 28 and 56 days. The results obtained showed that the ordinary Portland cement concrete is susceptible to different aggressiveness of the solutions of crude oil concentrations as they led to low rates of strength development of concrete specimens. Corrosion rate is highest in undiluted crude oil than in the crude oil/water mix as the reductions in compressive strength are in the ratio 23:13 percent. It is also found that the entire media even the control medium led to increase in strength of concrete specimens after two months of immersion but the rate of compressive strength development is low in the crude oil and crude oil/water mix.

Key words: Compressive strength, Crude oil, ordinary Portland cement (OPC) and Concrete

INTRODUCTION

The occurrence of concrete deterioration and cracking as a result of crude oil spill has remained a green area in literature. This is contrasted by a large number of research works written on the adverse effect of crude oil spill on aquatic lives and environmental degradation: Lee and Nico,[11,12,2,15,1,5,6].

Recent research have shown that concrete deterioration and cracking in marine environment is more severe than in any other terrestrial environment and this has elicited more investigation on the causes of concrete deterioration in similar environment. In their report on the bond between repair materials and concrete substrate in marine environment, they observed that deterioration occur as result of such factors as physical and chemical characteristic of repair compound, initial curing periods, environmental conditions among other factors. Onabolu,[16] in his work on some properties of crude oil soaked concrete exposed at ambient temperature observed variations in mechanical properties of the concrete materials with time. He further reiterated that the variations in compressive strength, length change, and absorption characteristics of typical offshore concrete structure exposed to crude oil for 365 days compromised the durability and the serviceability of the storage tank structures.

Studies by Matti,[13,18,9] have shown that the factors significantly affecting concrete properties include conditions of curing prior to exposure, moisture condition of the concrete at the time of exposure, storage temperature of the crude oil as well as the cement type. These studies concluded that the presence of pulverized fuel ash (PFA) in the concrete increases its resistance to underwater exposure conditions. This was attributed to the changes in pore structure as a result of pozzolanic activities, as well as to the packing effect of PFA particles in the microstructure.

Ukoli[20] observed that for over four decades that Nigeria have continued to experienced remarkable increases in operational activities in her oil and gas exploration, exploitation, refining and product marketing which is concentrated in Niger Delta region, and that the region has been mired by various degree of health and environmental pollution problems. Regular crude oil spillage on the surface and subsurface water resources, erosion and drainage problems of the built environs culminating to incessant failure of buildings and other onshore structures have become a regular news item. Ukoli[20] also reported on the various control programmes and polices articulated by government for the mitigation or ameliorating of environmental problems associated with the oil and gas industry, but the problem remains whether the measures are being implemented efficiently.

Crude oil or petroleum is a naturally occurring liquid that can be distilled or refined to make fuels, lubricating oils, asphalts and other valuable products. It is a hydrocarbon composed mainly of hydrogen and carbon, along with minor impurities like sulphur, nitrogen and oxygen.

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One aspect that is true of all crude oil type is that each has differing amounts of sulphur content, which is usually in compound form.

Kline,[10] has shown that sulphurous compounds are aggressive medium for cement based materials. According to his report, concrete deterioration in sulphur pit environment is characterized by the concrete cement paste matrix being chemically modified and no longer exhibiting properties consistent with structural support/containment. Usually, the concrete/mortar mass exposure to suphurous products normally undergoes chemical reactions that expand the mortar fraction. This expansion always proves fatal to long term concrete durability as it causes increase in solid volume. The formation of ettringite is the root cause of most expansion and disruption of mortar/concrete caused by sulphate solutions. This problem can only be exacerbated by changes in temperature as well as other erosive agents like the sea water.

Nigeria crude oil has been rated as both sweet and sour crude as a result of suphur content percentages which is greater or equal to 10%[20]. Though sulphur content is expected to be removed during refining, it requires extra processing and records have shown that most of oil spill in the Niger delta area is of crude type, thereby endangering aquatic, human and may be cement-based materials.

The need to investigate the extent of deterioration caused on cement-based materials as a result of crude oil spill become necessary and this is what the study tends to achieve.

MATERIALS AND METHODS

2.1 Materials:

2.1.1 Cement: Ordinary Portland cement brand manufactured by Dangote plc was used in the experiment. Generally, care was taken in both material procurement and experimental procedure to ensure test reliability.

2.1.2 Aggregates: The fine aggregate was naturally occurring clean sand obtained at River Gwarzo in Kano, while the coarse aggregate was made of crushed granite obtained from Dantata and Sawoe quary site along Rano Road in Kano, both were supplied to the Department of Civil Engineering, Bayero University, Kano, Nigeria for experimental purposes. Sieve Analyses were conducted in accordance to BS 812,[4]. The results of the analyses are shown in Figure 1 and 2.

2.1.3 Crude Oil Media: The Crude Oil was obtained from Kaduna Refinery and Petrochemicals and its properties rated using the American Petroleum Institute (API) gravity scale degree, widely used in expressing quality of crude oil and this is shown in Table 1. The media were prepared into two concentrations of 100% crude oil (undiluted) and 30%:70% crude oil/water mix. The crude oil/water mix is to represent oil spillage in coastal water ways. These solutions were labelled 'A' and 'B' with the control medium (water) labelled 'M'.

2.2 Methods:

2.2.1 Concrete Compression Test: The absolute volume method of design was used to produce concrete of nominal mix of 1:2:4 at water cement ratio of 0.53. The concrete cubes produced were of size 150mm x 150mm x 150mm.The filling of the mould was in three layers and were manually compacted using 16mm diameter metal rod at minimum strokes of 35. Under this concrete cube tests, about thirty six cubes were produced and cured under different concentration of the crude oil in addition to the control medium (water) at 3, 7, 28, 56 days. Compression test was carried out on the concrete cube specimens in accordance to EN197-1[7] specifications using Avery Denison machine of 2000KN capacity and at constant rate of 15KN/s load application.

The results of the compression tests are as shown in Table 2.

RESULTS AND DISCUSSION

3.1 Chemical Media for Curing: From the result of the chemical analysis of the curing media shown in Table 1, the crude oil is slightly acidic while the control medium is neutral. Portland cement being highly alkaline is susceptible to attack by the acidic media. The crude oil medium also contains 0.3% by weight of sulphur while the rest are negligible. The concentration of sulphur ions in crude is far above the threshold quantity of 250mg/l that initiates attack in cement based materials[14,19].

3.2 Compressive Strength of Concrete Cubes: The results of compressive strength of concrete cubes cured in the various media displayed in Table 2 shows that the curing media have effect in the compressive strength of concrete cubes. The values of the control medium (water) maintained a consistent increase in compressive strength as the curing ages increased. This is not surprising as the strength of cement- based materials cured in water increases with age. The crude oil media (A and B) also show increases in compressive strength as the age of curing increases but at low strength development. The difference in results under the two conditions of curing may be attributed to effect of chemical reaction taking place in crude oil solution but absent in control medium (water). The

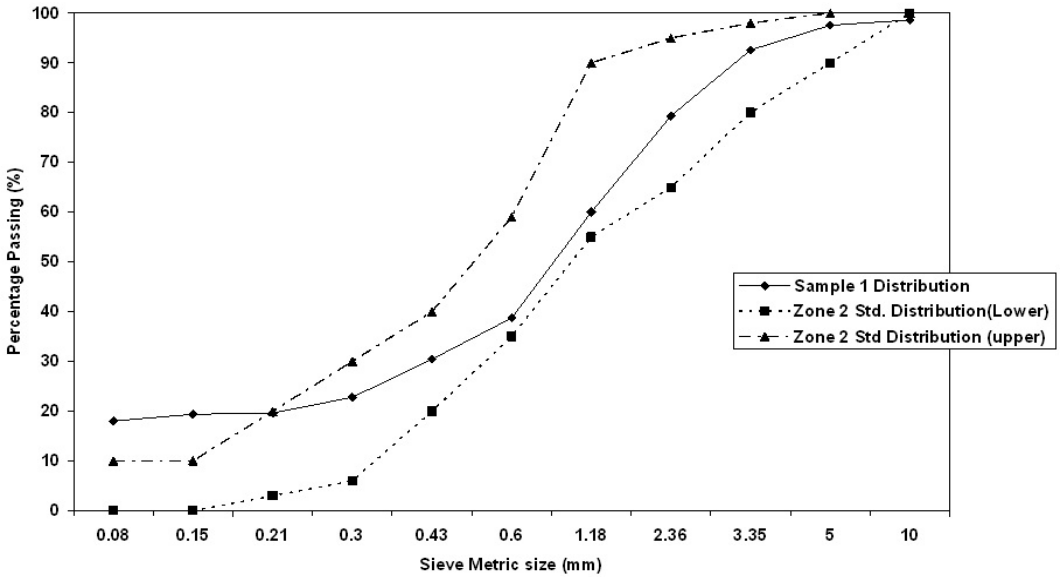

Fig. 1: Particle Size Distribution of Fine aggregate Sample 1

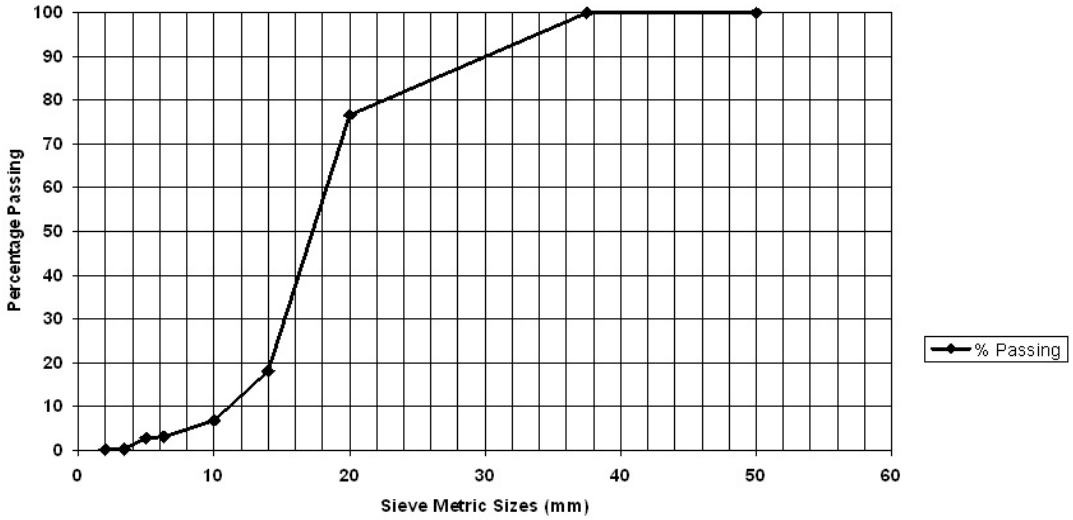

Fig. 2: Particle Distribution of Coarse Aggregate

Table 1: Properties of Nigeria Crude Oil.

S/No	Parameters	Magnitude
01	Gravity Degree, API	>35.00
02	Specific Gravity, 15°C	0.812
03	Sulphur Content, % by weight	0.30
04	Moisture Content, % by volume	0.40
05	Wax content, % by weight	7.0
06	Carbon Residue, % by weight	2.10
07	Melting point of Wax, °C	57
08	Viscosity at 21°C	6.81
09	Acidity, mg/KOH/g	0.05

Table 2: Comparison of Concrete Compressive Strength for Different Curing Media,

S/No	Age in (days)	Curing Media		
		M(water)	A(crude oil)	B(crude oil/water)
		Compressive Strength (N/mm^2)		
1	3	25.18	23.43	23.75
2	7	31.57	26.78	30.45
3	28	43.26	34.75	39.75
4	56	47.04	36.00	39.35

M- Control Medium- Water

Table 3: Percentage Reduction in Concrete Compressive Strength

S/No	Age in (days)	Curing Media		
		M(water) %	A(crude oil) %	B(crude oil/water) %
		Compressive Strength (N/mm^2)		
1	3	0	07	06
2	7	0	15	04
3	28	0	20	08
4	56	0	23	13

M- Control Medium- Water

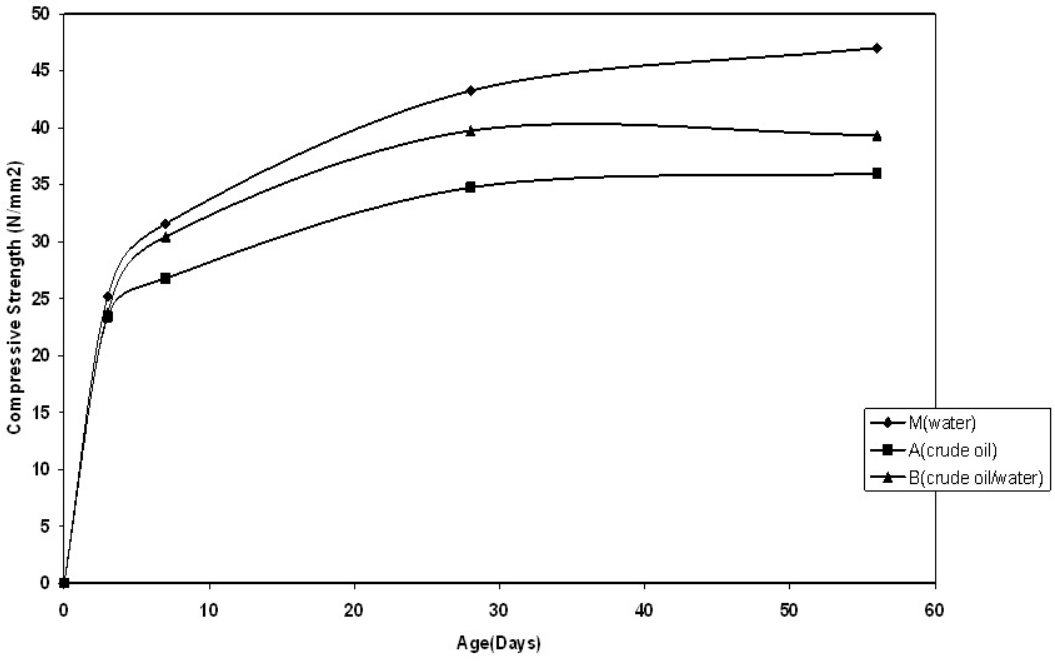

Fig. 3: Compressive strength Development of Concrete Cured in Different media

reductions in strength can be related to the pattern of crude absorption, which is greater in 100% concentration (medium A) than in medium 'B' . The absorption of crude oil into the microstructure of the matrix of concrete may have caused dilation of the gel and weakening of the cohesive forces in the paste and hence low strength development of the concrete cured in media A and B. This process termed 'wetting-weakening effect' is consistent with the results of Bangham,[3,17,16]. Onabolu,[16] also posited that decrease in surface energy caused by the adsorption of crude oil onto C-S-H gel surface may also have contributed to the reduction compressive strength of the material. When the values of the control medium are compared to the rest values, they are always higher and the other media of curing deteriorates with time as curing age

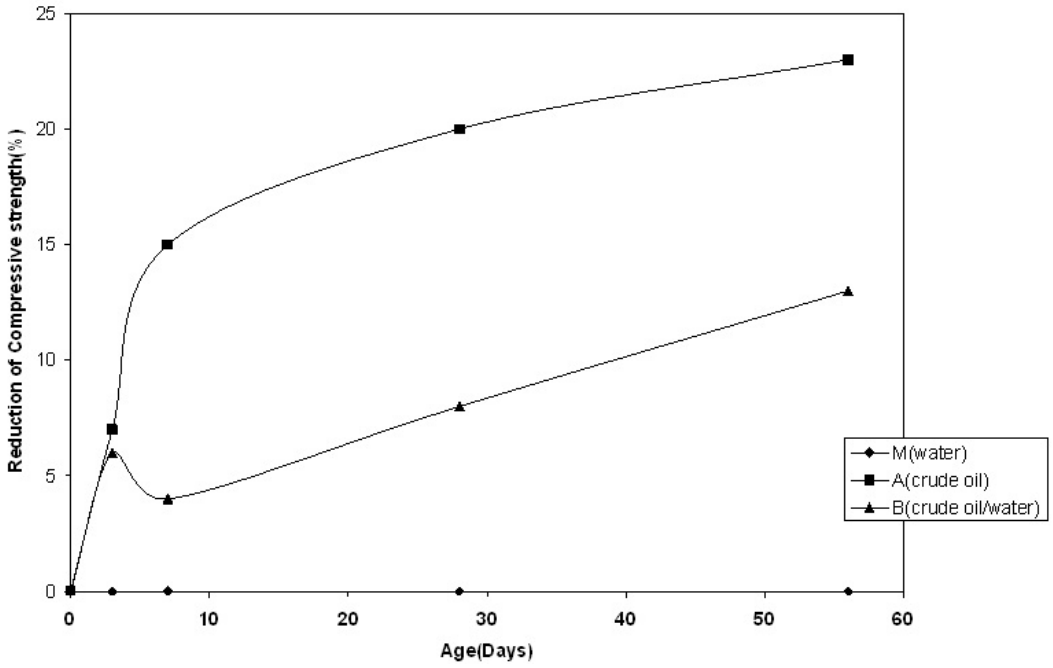

Fig. 4: Percentage Reduction in Compressive Strength of Concrete in crude oil media

increases. Thus apart from reducing the compressive strength values, it worsens with time in most cases. Table 2 is represented graphically in Figure 3.

Considering the control medium (water) as base, the values at control media are subtracted from the values of the rest media to see the effect of each medium on the specimens. It is evident that soaking in crude oil and crude oil/water mix is aggressive to concrete material as the resistance of the concrete cubes reduces with time as the compressive strength drops. Putting the reduction in compressive strength in percentage using the control medium as base, the percentages are as shown in Table 3. This showed that for medium A, the reduction in compressive strength increased from 7% at 3 days to 23 % at 56 days of curing whereas the crude oil/water mix has reduction of 6% at 3 days and 13% at 56 days. It therefore can be said that undiluted crude oil medium generally has the worst effect on concrete at short, medium and longer periods of curing ages. Table 3 is represented graphically in Figure 4. The trend of variations in aggressiveness of the media may not be unconnected with the concentration and conductivity of the earlier identified ions of sulphur, and other chemical reactions which may cause alteration of paste composition with monosulfate phase converting to ettringite and also loss of bond between the cement paste and aggregates thereby creating overall loss in concrete strength.

Conclusions and Recommendations: After the experimentations, observations, analysis and discussions on the effect of crude oil media conditions on compressive strength of concrete, the following conclusions/recommendations are made:

1. All the curing media except the control medium (water) has one form of compound or the other considered injurious to cement- based materials.
2. All the concrete specimens cured in control medium (water) increased steadily in compressive strength as ages increase from 3, 7, 28 and 56 days.
3. The Ordinary Portland cement concrete have weak resistance to chemical and environmental aggressions as they displayed slow compressive strength development and ultimately reduction in strength in all ages of exposure in various media when compared to the control medium.
4. Undiluted crude oil has the highest deterioration effect in concrete materials, when compared to the values of the control medium (water).
5. Generally, the effect of the aggressive media on concrete is such that it causes deterioration which is characterized by the cement paste matrix being chemically modified and no longer exhibiting properties consistent cementitious character usually shown in concrete
6. To ensure durability and stability of cement-based structures, mixing and curing water should be free of crude oil spill as the compressive strength of materials will be affected if otherwise.

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