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EFFECTS OF CRUDE OIL CONTAMINATED CURING WATER ON STRENGTH PROPERTIES OF CONCRETE PREPARED FOR BRIDGE SUB-STRUCTURES

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Abstract: In this study aggregate characteristics were studies and the cylindrical concrete specimens were prepared at the mix ratio of 1: 1½: 3 and cured in curing water of 0%, 5%, 10%, 15%, 20%, 25% and 30% contamination with crude oil. The compressive strengths of the concrete specimens were evaluated at the 3rd, 7th, 14th, 28th and 56th day age, split tensile strengths and flexural strengths of the specimens were evaluated at the 7th and 28th day age. The strength properties evaluated increased with increase in age and decreased with increase in percentage contamination of the curing water with crude oil. Concrete specimens cured with portable water containing 0%, 5%, 10%, 15%, 20%, 25% and 30% of crude oil contamination satisfied the minimum 28 days compressive strength. The research therefore concludes that concrete bridge sub structures exposed to crude oil contaminated environment should be monitored and maintained regularly.

Keywords: *Crude oil, compressive strength, concrete, contaminated environment, sub-structures.*

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1.0 Introduction

A bridge is a structure that facilitates the crossing of the deep valleys full of water or other obstructions (Gupta and Gupta, 2009). A bridge is a structure which provides passage over an obstacle without closing the way underneath. The required passage may be for a railway track, road, or pedestrians etc. The obstacle to be crossed may be traffic, deep valley full of water, river etc. Before constructing a bridge at a particular site, it is essential to consider the factors such as, need of the bridge, present and future traffic volume, characteristic of the stream, sub soil conditions, cost of the project, alternative sites available and their relative merits, aesthetics etc. The aim of the investigation is to select a suitable site for the construction of the bridge. The site for a bridge is governed by engineering factors, economics, demands of traffic, condition of stream and aesthetics etc. In the case of old alignment the bridge site is governed by existing roadway or railway alignments while in the case of new alignments social and commercial benefits govern the site selection. The success of the bridge project depends on the thoroughness of the information furnished by the officer in charge of the investigations. Thus it is very important that the engineer in charge of investigations should have a good knowledge of the fundamental factors which influence the choice of a site. (Gupta and Gupta, 2010). The sub-structure of a bridge consists of piers, abutments, wing wells, approaches and foundations to support the super-structure. Foundation is that part of the structure, which is in direct contact with the loads and transmits them to the ground below. It is a very important part is every structure (Gupta and Gupta, 2009).

Over the past two decades, the amount of hydrocarbon contamination of soil and the environment has continually increased and presently it constitutes a significant fraction of waste materials in the environment. Some major causes of hydrocarbon contamination are oil spill, leaking of petroleum from underground storage terms, oil pipe vandalizing, drilling, and treatment activities for exploration and production of hydrocarbons and hydrocarbon waste disposed from industries (Wasiu *et al*., 2012). In a study Hamad *et al.* (2003), concluded that used engine oil improves the fluidity of concrete mix and reduces the properties of hardened concrete.

Osuji and Nwankwo (2015) investigated the effect of crude oil contamination on the compressive strength of concrete. They concluded that the presence of crude oil in concrete making hinders the bound formation between constituent materials, brings about segregation and results in variations in workability. They also concluded that the higher the percentages of crude oil in the fine aggregate, the higher the workability and the lower the compressive strength. They suggested that crude oil is a compressive strength inhibitor in the production of concrete. Ejeh and Uche (2009) also investigated the effect of crude oil spill on compressive strength of concrete materials. They concluded that the undiluted crude oil has the highest deterioration effect in concrete materials, when compared with values of the control medium (water). They also suggested that mixing and curing water should be free of crude oil spill to ensure durability and stability of cement – based structures, as the compressive strength of materials will be adversely affected if otherwise.

Crude oil contamination reduces the compressive strength of polymer concrete, by affecting the 3-D cross linking of the polymer or its curing. Increase contamination of sand with crude oil lead to a reduction in the compressive strength suggesting that proper care should be taken to use sand from crude oil contamination of any form, since fine aggregate have proven to show great deviation when slightly contaminated with crude oil. The durability analysis of concrete exposed to a crude oil products environment shows significant reduction in compressive strength. When designing a structure of cement constructional material in contact with crude oil products, apart from checking the value of neutralization number, checks should be made on presence of organic polar active molecules by the infra-red spectroscopy (Blaszczynski, 2011).This research therefore aims at investigating the effects of crude oil contaminated curing water on the strength properties of concrete prepared for bridge substructures.

2.0 Materials and Methodology

2.1 Materials

2.1.1 Hydraulic Cement, Crude Oil and Aggregate.

The hydraulic cement used in this research conforms to the specifications of AASHTO M85 (2016) and ASTM C150/C150M-16E1 (2016). The crude oil used in this study was analyzed in accordance with ASTM D2892 (2015), ASTM D1298-12b (2012), and ASTM D8056 (2016). The fine and coarse aggregate used in this study conform to the specifications of AASHTO M6 (2013), AASHTO M80 (2013), and PCA EB 233 (2005).

2.2 Methodology

2.2.1 Physical and Mechanical Properties of Fine and Coarse Aggregate

The sieve analysis was conducted for fine aggregate and coarse aggregate in accordance with ASTM C136/C136M (2015), and AASHTO T27 (2015). The specific gravity and water absorption of the fine and coarse aggregates were conducted in accordance with WSDOT M23 – 50 (2016). The aggregate crushing value and the Los Angeles abrasion value tests were conducted for the coarse aggregate in accordance with ASTM C33/C33M-16E1 (2016) and ASTM C131/C131M (2014).

2.2.3 Compressive Strength

2.2.3.1 Mix Design, Slump Test and Curing Media

The test specimens were mixed at 1: 1½: 3 mix ratio of cement, fine aggregate and coarse aggregate respectively. The water-cement ratio was maintained at 0.45. The batching was by weight and in accordance with ASTM C94/C94M-16b (2016), and WSDOT M23 – 50 (2016). The slump test was carried out in conformance with ASTM C143/C143-15a (2015). The concrete specimens marked CM1 were cured in portable water medium conforming to ASTM C1602/C1602M (2012) and ACI 308.1 (2011). The concrete specimens marked CM2, CM3, CM4, CM5, CM6, and CM7 were cured in portable water/crude oil media of 5%, 10%, 15%, 20%, 25%, and 30% by weight of crude oil. The portable water/crude oil media were prepared to represent different concentration

The concrete specimens were of 150mm diameter and 300mm long. The compressive strength values of the concrete specimens were determined at the 3rd, 7th, 14th, 28th, and 56th day age. Four specimens from each of the curing medium were crusted at the 3rd, 7th, 14th, 28th and 56th day age and the average strength recorded as the compressive strength value in accordance with the provision of ASTM C39/C39M (2017) and FDOT (2012).

2.2.4 Splitting Tensile Strength and Flexural Strength

The splitting tensile and flexural strengths of concrete are among the basic and important properties of concrete. The flexural strength (modules of rupture) was conducted in accordance with ASTM C78/C78M: 2016 ASTM international, standard test method for accordance to ASTM C78/C78M (2016). The results were calculated and reported as the modules of rupture. For the same specimen size the flexural strength determined will vary if there are differences in specimen preparation, curing procedure and moisture condition at the time of testing. The sizes of the beams used were 150mm depth, 150 mm breadth and 700mm long. The span-overall dept ratio of 4.0 was maintained. The split tensile strength was conducted in accordance with ASTM C496/C496M-17(2017). Splitting tensile strength is generally greater than the direct tensile strength and lower than the flexural strength (modules of rupture). The concrete cylindrical specimens used were of 150mm diameter and 300mm long.

3.0 Results and Discussion

3.1 Properties of Crude Oil Used and Aggregate Characteristics

Table I shows the results of laboratory analysis of crude oil used for this study. The results satisfied the specifications of the ASTM D2892 (2015) and Table 2 shows combine sieve analysis results of fine aggregate and coarse aggregate. It can be seen from Table 2 that the aggregates used were well graded of 19.00mm maximum size. Table 3 shows the physical and mechanical properties of the fine and coarse aggregate. The results shown in Tables 2 and 3 shows that the fine and coarse aggregates used in this study satisfied the specifications of ASTM C33/C33M – 16el (2016), ASTM C94/C94M-16b (2016), WSDOT M23 – 50 (2016), AASHTO M6 (2013).

Table 1: Properties of Nigerian bonny light crude oil used.

S/N	*Parameters*	*Values*
1.	Specific gravity	0.85
2.	API specific gravity	36.80
3.	Density at 60^{o}F or 15.55^{o}C (kg/m^3)	0.84
4.	Pour point	3.8^{o}C
5.	Sulfur content, % weight	0.13
6.	Colour	Dark brown
7.	Salinity T.B at 0.10% BS & W	46
8.	Acid number	0.38
9.	Reid vapour pressure	6.41 psig
10.	Water and sediment content pct (%)	0.9
11.	Iron weight, PPM	0.83
12.	Nickel weight PPM	4.0
13.	Vanadium wt.ppm	1.89

Table 2: Combined aggregate gradation (fine and coarse aggregates)

Sieve size (mm)	*Percentage retained (%)*	*Cumulative percentage retained (%)*	*Percentage passing (%)*
25	0.00	0.00	100
19	3.42	3.42	96.58
12.50	21.21	24.63	75.37
9.5	13.10	37.73	62.27
4.75	12.42	50.15	49.85
2.36	10.85	61.00	39.00
1.18	15.84	76.84	23.16
0.6	6.11	82.95	17.05
0.3	8.31	91.26	8.74
0.15	4.72	95.98	4.02
0.075	2.22	98.17	1.83

Table 3: Physical and mechanical properties fine aggregate and coarse aggregate.

S/N	*Properties of aggregate*	*Fine aggregate*	*Coarse aggregate*
1.	Specific gravity	2.61	2.7
2.	Water absorption (%)	2.19	3
3.	Los Angeles Abrasion value (%)	-	29
4.	Aggregate crushing value (%)	-	24

3.2 Mix design and curing media

Table 4 shows the concrete mix design ratio of 1:1½:3 by weight of cement, fine and coarse aggregates and the percentage contamination of portable water with crude oil used to cure the concrete cylindrical specimens. The water cement ratio was kept constant for all the specimens. The design mix conforms to the specifications of WSDOT M23 – 50 (2016), FDOT (2010) and PCA EB 233 (2005) which specify minimum cement content of 300 to 360 kg/m^3.

Table 4: Concrete mix design of 1: 1½: 3, and curing media

Concrete cylindrical specimen (150mm diameter by 300mm long)	*Percentage contamination of curing water with crude oil (curing media) (%)*	*Water cement ratio*	*Mixing water (kg/m^3)*	*Cement (kg/m^3)*	*Aggregates*	
					Fine (kg/m^3)	*Coarse (kg/m^3)*
CM1	0	0.45	205	455	682	1364
CM2	5	0.45	205	455	682	1364
CM3	10	0.45	205	455	682	1364
CM4	15	0.45	205	455	682	1364
CM5	20	0.45	205	455	682	1364
CM6	25	0.45	205	455	682	1364
CM7	30	0.45	205	455	682	1364

3.3 Concrete Characteristics

Table 5 shows the slump, density and compressive strength of concrete cured with curing water containing different percentage contamination with crude oil. The curing water used satisfied the specifications of ASTM C1602/C1602M (2012), ACI 308.1 (2011) and FDOT, (2010). Slump and density were constant indicating consistency in preparation of the concrete specimens. From Table 5 and Figure 1, it can be observed that the compressive strength of concrete decrease with increase in crude oil contamination of the curing water. The compressive strength of all the concrete specimens increased with increase in age irrespective of the increase in the contamination of the curing water with crude oil. From Figure 2, it can be observed that the 28 day compressive strength of the concrete decreases with increase in the percentage contamination of curing water with crude oil. Table 5 and figures 1 and 2 show that up to 30% contamination of curing water with crude oil produced concrete that satisfied the minimum 28 day compressive strength of 31N/mm^2 for high performance concrete for bridges as specified by WSDOT M23 – 50 (2016), FDOT (2010), and PCA EB 233 (2005). Table 6 shows that there are significant increase in the split tensile strength and the flexural strength at the 28 days curing split in all the test specimens. It is observed that increase in age increases the splitting tensile strength and the flexural strength of the concrete irrespective of the curing media.

Table 5: Slump, density and compressive strength of concrete

Concrete cylindrical specimen mark	*Percentage contamination of curing water with crude oil (%)*	*Slump (mm)*	*Density kg/m³*	*Compressive strength (N/mm²)*				
				3 day age	*7 day age*	*14 day age*	*28 day age*	*56 day age*
CM1	0	83	2428	16.84	26.32	35.24	42.61	49.64
CM2	5	83	2428	14.66	24.70	33.10	41.87	48.24
CM3	10	83	2428	14.04	24.00	32.14	40.68	46.62
CM4	15	83	2428	13.36	22.51	30.15	38.16	44.00
CM5	20	83	2428	12.87	21.69	29.00	36.76	42.45
CM6	25	83	2428	11.63	19.60	26.24	33.22	39.86
CM7	30	83	2428	10.23	17.93	24.35	32.09	37.51

Table 6: Splitting tensile and flexural strength of concrete at 7 and 28 days

Specimens	*Crude oil (%)*	*Splitting tensile strength (N/mm²)*		*Flexural strength (N/mm²)*	
		7 day	*28 day*	*7 day*	*28 day*
CM1	0	3.08	3.61	4.18	4.96
CM2	5	2.63	2.70	3.56	4.01
CM3	10	2.44	2.61	3.31	3.82
CM4	15	2.14	2.41	2.90	3.35
CM5	20	1.89	2.11	2.57	3.00
CM6	25	1.67	1.89	2.26	2.91
CM7	30	1.53	1.79	2.07	2.44

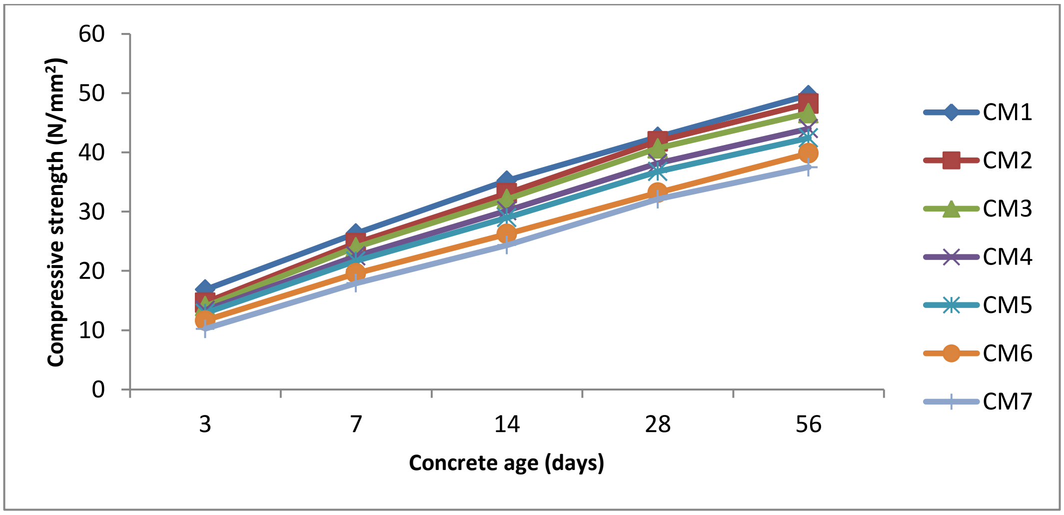

Figure 1: Compressive strength of concrete vs. age of curing.

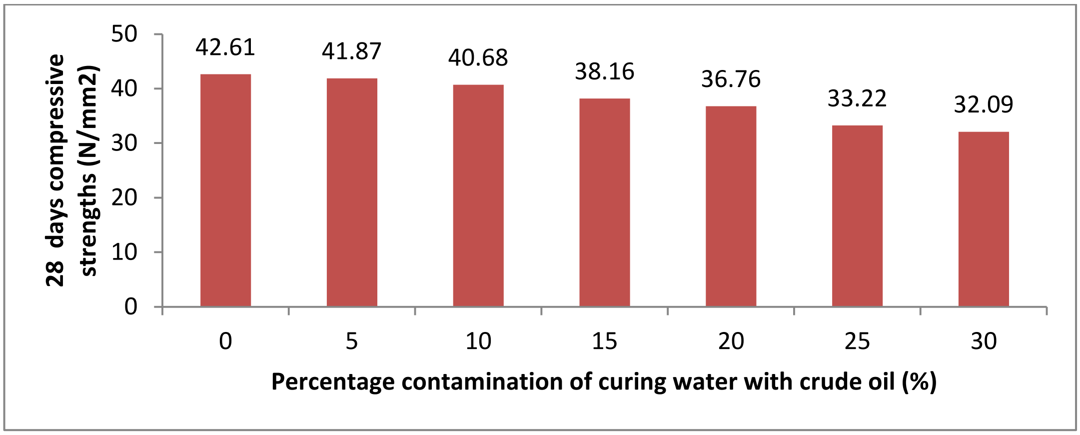

Figure 2: Effect of crude oil contaminated curing water on 28 days compressive strength (N/mm^2).

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4.0 Conclusion and Recommendations

4.1 Conclusion

At the end of this research, it was concluded that:

a. Increase in crude oil contamination of curing water decreases the compressive strength, split tensile strength and flexural strength of concrete.

b. Strength properties (compressive strength, split tensile strength and flexural strength) of concrete bridge sub-structures exposed to crude oil contaminated environment increase with age.

c. Concrete bridge substructures exposed to 0% to 30% crude oil contamination of curing water or environment have minimum 28 day compressive strengths which satisfy the 31 Nmm^2 specified by the American concrete revenue association (2014), Guide specification and material manual M46-01 (2016), WSDOT, FDOT (2010) and ACI 301-05 (2005) American Concrete Institution, specification for structural concrete.

4.2 Recommendations

a. Concrete bridge sub-structures exposed to crude oil contaminated environment should be monitored and maintained regularly by relevant government agencies and regulatory authorities.

b. Comprehensive environmental impact assessment should be carried out particularly within the crude oil producing areas to ascertain the level of contamination of the environment due to crude oil spillage and crude oil exploratory activities.

c. Players of the upstream and downstream sectors of the petroleum industry should adhere strictly to environmental standards and regulatory in all their operations.

d. Government at all levels should improve heavier penalties to defaulters of environmental acts, laws and regulations in the petroleum sector.

e. Government at all levels, researchers, consultants and the organized private sector should organize regular and sustainable public enlighten companies, seminars, conferences etc. on the negative effects of crude oil spillage on concrete bridge infrastructure and on the environment at large.

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