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EFFECTS OF CRUDE OIL CONTAMINATION OF MIXING WATER ON STRENGTH PROPERTIES OF CONCRETE BRIDGE AND CONCRETE STREET PAVEMENT

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Abstract: The effects of crude oil contaminated mixing water on strength characteristics of mixed traffic concrete street pavement were evaluated. The properties of fine and course aggregates were studied and concrete specimens were prepared at mix ratio of 1: 1½: 3 with 0%, 2.5%, 5%, 7.5%, 10%, 12.5% and 15% crude oil contamination of mixing water. The splitting tensile and flexural strengths were evaluated at 7 day and 28 day age. The compressive strength was evaluated at the 3rd, 7th, 14th, 28th and 56 day age. The results indicate increase in slump value as the percentage contamination of mixing, water with crude oil increases. The strength properties of the hardened concrete increases with increase in age and decreases with increase in percentage contamination of mixing water with crude oil. Concrete pavements manufactured with 2.5% contamination of mixing water with crude oil at 1:1½:3 caused up to 20% reduction in compressive strength of concrete pavement. The research therefore concludes that mixing water for concrete pavements must conform to the specification of ASTM C192/C192M – 16a (2016).
Keywords: Concrete pavement, Crude oil, Mixing water, Compressive strength, splitting tensile strength

1. INTRODUCTION

A bridge is a structure, including supports, erected over a depression or an obstruction, as water, highway or railway and having a track or passageway for carrying traffic or other moving loads and having an opening measured along the center of the roadway of more than 20 feet (6.09600 meters) between under-copings of abutments or extreme ends of openings for multiple boxes. The bridge length is the greater dimension of the structure measured along the center of the roadway between the backs of abutment back walls or between ends of bridge floor. The bridge roadway width is the clear width of the structure measured at right angles to the center of the roadway between the bottom of the curbs or, if curbs are not used, between the inner faces of parapet or railing. A bridge is a structure including supports erected over a depression or an obstruction, such as water, highway, or railway, and having a track or passageway for carrying traffic or other moving loads, and having an opening measured along the center of the roadway of more than 6.5m between under-copings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes; it also may include multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening (PCA EB233, 2005). Concrete is a mixture of cement, water, fine and coarse aggregate which hardens to a stone – like mass. Concrete is used more than any man made materials on earth. The concrete strength is often regarded as the most important property of concrete. Concrete suffers from one major drawback compared with other materials like steel and timber. Its strength cannot be measured prior to it being placed. Factors affecting compressive strength are water cement ratio, mix ratio, degree of compaction, type of cement, the grade of aggregate, design constituent, mixing method, placement, curing method and presence of contaminates (Hashem 2011).

According to Girish, et al, (2014), Abdul, et al, (2000) and Ejeh and Uche (2009), spillage of petroleum products adversely affects marine life and environment. Spillage of petroleum on roads leads to cracks and consequently failure of the roads. Petroleum products pose high degree of adverse effects on the properties and performance of concrete thus degrades it. Ayinimuola, (2009), studied the influence of diesel oil and bitumen contaminated sand on the compressive strength of concrete and concluded that the presence of diesel oil and bitumen of any proportion in sand result in concrete of lesser compressive strengths. This indicates that diesel oil and bitumen are compressive strength inhibitors in concrete production. He also concluded that the 28 day compressive strength of concrete made of contaminated sand of 2% to 10% diesel oil were in the range of 96.8% to 77.4% of uncontaminated sand. Likewise those of bitumen are in the range of 76.2% to 26.2%. He suggested that the higher the percentage of oil in the sand, the lower the compressive strength obtained. This research aims at evaluating the effect of crude oil contaminated mixing water on the compressive strength of mixed traffic concrete street pavements.

2. MATERIALS AND METHODOLOGY

Materials

The hydraulic cement used in this research conform to the specifications of AASHTO M85 (2016), ASTM C150/C150M – 16e1 (2016), ACI 225R (2016) and WSDOT standard practice QC1 (2016) and WSDOT M46 – 01.25 (2016). The fine and coarse aggregates used in this research satisfied the specifications of AASHTO M6 (2013) and AASHTO M80 (2013) respectively. They also satisfied the specifications of ASTM C33/C33M – 16e1, (2016), and WSDOT M46 – 01.26 (2017). The crude oil used in this research was analyzed in accordance with ASTM D1298 12b (2012) and ASTM D8056 (2016).

Methods (Aggregate characteristics, Mix design, Properties)

The sieve analysis was conducted for the fine and coarse aggregates in accordance with ASTM C136/C126M (2014), AASHTO T27 (2015), WSDOT M46-01.25 (2016). The specific gravity and water absorption of the fine and coarse aggregates were conducted in line with the procedures specified in AASATO T84 (2013) and AASATO T85 (2014), respectively. The procedure employed also conform to the provisions of WSDOT M46 – 01.26 (2017), ODOT (2017), ASTM C128 (2015) and ASTM C127 (2015). The Los Angeles abrasion value was conducted for coarse aggregate in accordance with ASTM C121/C131M (2016), WSDOT M46 – 01.26 (2017), ODOT (2017) and ACI 121R (2008). The aggregate crushing value was conducted for coarse aggregate in accordance with WSDOT M46-01.26 (2017) and ASTM C131/C131M (2016).

The test specimens were prepared at 1:1½:3 mix ratio of hydraulic cement, fine and coarse aggregate respectively. The batching was by weight in accordance with ASTM C94/C894M – 16b (2016), PCA EB001. 15 (2011), NRMCA version I (2014), AC1 363.2R (2011) and AC1 304R – 00 (2009). The maximum size of coarse aggregate used was 19.00mm. The water cement ratio was maintained at 0.5 and the mixing water used for the control mix conforms to the specifications of ASTM C1602/C1602M (2012). Mixing water for subsequent concrete specimens marked DM2, DM3, DM4, MD5, DM6, and DM7 were contaminated with 2.5%, 5%, 7.5%, 10%, 12.5%, and 15% by weight of crude oil. The slump test was performed for all the concrete mixes in accordance with ASTM C143/143M – 15a (2015) and WSDOT M46 – 01.26 (2017).

According to NRMCA CIP-16 (2000), the National Ready Mixed Concrete Association (NRMCA) and American Concrete Pavement Association (ACPA) have a policy that compressive strength testing is the preferred method of concrete acceptance. AC1 325, 9R – 15 (2015) and ACI 330R (2008) point to the use of compressive strength as more convenient and reliable to judge the quality of concrete. The compressive strengths of the concrete specimens were evaluated at the 3^{rd}, 7th, 14th, 28^{th} and 56^{th}days age. The specimens were of the 150mm diameter by 300mm long.

The compressive strength test was conducted in accordance with ASTM C39/C39M – 16b (2016), WSDOT M46 – 01.25 (2016). IDOT D&E – 2 (2012) and IDOT (2008), and IDOT MAT 13 (2014), TXDOT manual notice (2011). The flexural strength (modulus of rapture) was conducted in accordance with ASTM C78/C78M (2016). The sizes of the beams used were 150mm breath, 150mm dept and 700mm long. The span – overall depth ratio of 4.0 was maintained. The split tensile strength was conducted in accordance with ASTM C496/C496M – 11 (2004). The concrete cylindrical specimens used were of 150mm diameter and 300mm long.

3. RESULTS AND DISCUSSION

Table 1 shows the results of the laboratory analysis of the crude oil used for this experiment. The results satisfied the specifications of ASTM D1298 – 126 (2012) and ASTM D8056 – 16 (2016). Table 2 shows the combine sieve analysis result of fine and coarse aggregate. It can be seen that the aggregate used were well graded of 19mm maximum size. The sieve analysis results satisfied the specification of ASTM C136/C136M (2014), AASHTO T27 (2015) and WSDOT M46 – 07.25 (2016).

Table 1: Results of the laboratory analysis of crude oil used

Parameters	Values
Specific gravity at 60°F (15.55°C)	0.85
API specific gravity at 60°F (15.55°C)	36.80
Density at 60°F (15.55°C)	0.84
Pour point	3.8°C
Sulfur content, % weight	0.13
Colour	Dark brown
Salinity T.B at 0.10% BS & W	46
Acid number	0.38
Reid vapour pressure	6.41 psig
Water and sediment content pct (%)	0.9
Iron weight, PPM	0.83
Nickel weight PPM	4.0
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
9.50	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
0.60	6.11	82.95	17.05
0.30	8.31	91.26	8.74
0.15	4.75	95.98	4.02
0.075	2.22	98.17	1.83

Table 3 shows the physical and mechanical properties of the fine aggregate and the coarse aggregate. The results shown in tables 2 and 3 show that the fine and coarse aggregates used in this study satisfied the specifications of ASTM C33/C33M – 16el (2016), ASTM C94/C04M – 16b (2016), WSDOT M41-10 (2017), AASHTO M80 (2013), AASHTO M6 (2013), ACI 363. 2R (2011) and ACI 304 R – 00 (2009).

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

Specific gravity	2.61	2.7
Water absorption (%)	2.10	3.0
Loss Angeles abrasion value (%)	-	29%
Aggregate crushing value (%)	-	24%

Table 4**:** Shows the concrete mix design ratio of 1:1½:3 by weight of cement, fine and coarse aggregates respectively and the percentage contamination of mixing water with crude oil. The water cement ratio for the control mix (DM1) was 0.45 and the crude oil contaminated water cement ratio of 0.45 was also kept constant for other specimens. The mixing water used for the control mix (DM1) satisfied the specifications of ASTM C1602/C1602M – 12 (2012). The concrete specimens were prepared and cured in accordance with ASTM C192/C192M – 16a (2016), AC1 304R – 00 (2009), ACI 363.2R (2011).

Table 4: Concrete mix design of 1: 1½: 3

Concrete cylindrical specimens mark	Percentage contamination of mixing water with crude oil (%)	Mixing water (Kg/m^3)	Crude oil (Kg/m^3)	Water -cement ratio/ crude oil contaminated water-cement ratio	Cement (Kg/m^3)	Aggregates (Kg/m^3)	
						Fine	Coarse
DM1	0	205	-	0.45	455	682	1364
DM2	2.5	194.75	10.25	0.45	455	682	1364
DM3	5.0	184.5	20.5	0.45	455	282	1364
DM4	7.5	235.75	30.75	0.45	455	682	1364
DM5	10.0	164.00	41.00	0.45	455	682	1364
DM6	12.5	153.75	51.25	0.45	455	682	1364
DM7	15.0	143.5	61.5	0.45	455	682	1364

Table 5: Slump, density and compressive strength of concrete.

Concrete cylindrical specimens mark	Percentage contamination of mixing water with crude oil (%)	Slump (mm)	Density (kg/m^3)	Compressive strength (N/mm^2)				
				3 day Age	7 day Age	14 day Age	28 day Age	56 day Age
DM1	0	73	2451	22.88	28.81	33.17	39.11	42.41
DM2	2.5	84	2447	18.48	21.11	27.08	31.46	35.91
DM3	5.00	88	2443	16.11	18.81	25.08	29.82	33.81
DM4	7.5	95	2438	13.60	16.61	22.81	26.18	30.01
DM5	10	108	2434	11.60	14.72	21.51	24.19	27.61
DM6	12.5	117	2428	9.80	11.81	19.14	22.11	25.21
DM7	15.00	123	2414	6.81	9.11	16.21	20.88	23.88

The design mix satisfied the minimum cement content of 300kg/m^3 – 360 kg/m^3 for standard and high performance concrete as specified by NCDOT (2012), INDOT (2014), WSDOT M41-01.27 (2017), WSDOT M46-01.25 (2016), WSDOT M41-10 (2017), TXDOT (2011), ACI 325.9R (2015), IDOT (2008), IDOT D&E-2 (2012), PCA EB 001.15 (2011), ODOT (2017), and PCA EB (2005).

Table 5 shows the slump, density and compressive strength of concrete made with different percentage contamination of mixing water with crude oil. The slump increases with increase in percentage contamination of mixing water with crude oil as shown in Table 5 and Figure 3. From Table 5 and figure 1, it can be observed that the compressive strength decreases with increase in crude oil contamination of the mixing water. The compressive strength of all the concrete specimens increased with increase in age irrespective of the increase in contamination of mixing water with crude oil.

Table 6: 7days and 28 day split tensile and flexural strengths of concrete

Concrete cylindrical specimen mark	Percentage contamination of mixing water with crude oil (%)	Split tensile strength (N/mm²)		Flexural strength (N/mm²)	
		7 day	28 day	7 day	28 day
DM1	0	3.00	3.62	4.11	4.40
DM2	2.5	2.17	2.49	2.81	3.08
DM3	5.0	2.00	2.21	2.52	2.84
DM4	7.5	1.72	1.98	2.21	2.67
DM5	10.0	1.36	1.63	2.01	2.33
DM6	12.5	1.27	1.48	1.77	2.08
DM7	15.0	1.03	1.21	1.42	1.70

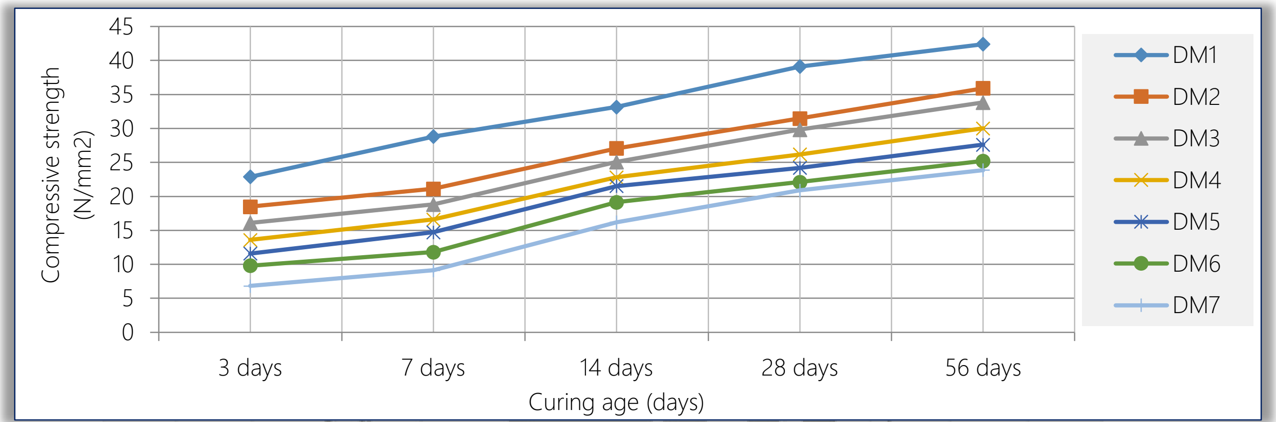

Figure 1. Relationship between the compressive strengths and curing age

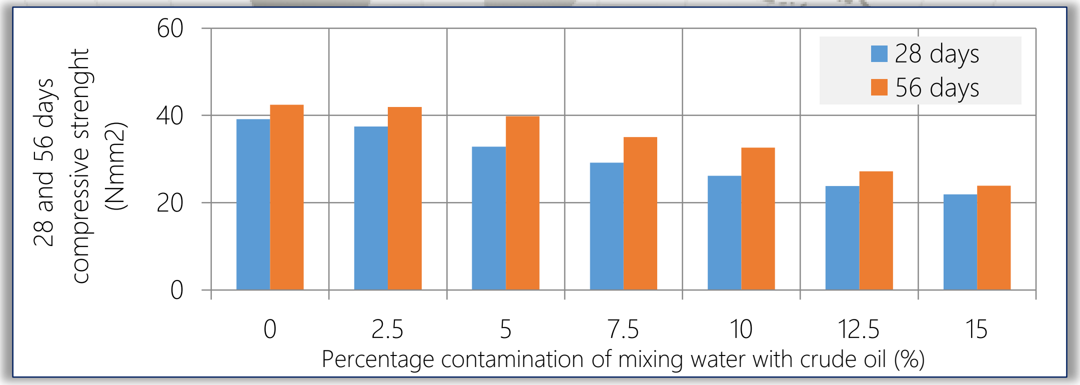

Figure 2. Relationship between percentage contaminations of mixing water with crude oil and 28 and 56 days compressive strength

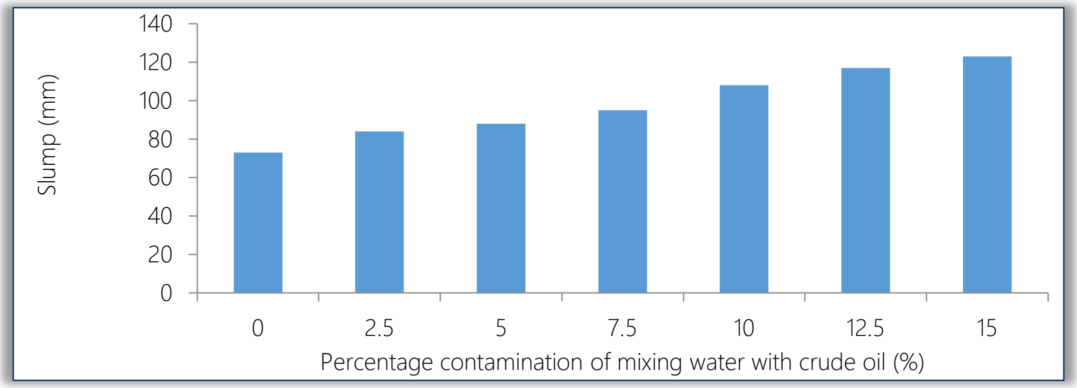

Figure 3. Relationship between percentage contamination of mixing water with crude oil and slump

From figure 2 it can be observed that the 28 and 56 days compressive strength of the concrete decreases with increase in the percentage contamination of mixing water with crude oil. Table 5 and figures 1 and

2 show that up to 10% contamination of mixing water with crude oil satisfied 24.13kg/m3 to 31kg/m3 (2500 psi to 4500 psi) minimum 28 day compressive strength specified by NCDOT (2012), INDOT (2014), WSDOT M41-01.27 (2017), WSDOT M46-01.25 (2016), WSDOT M41-10 (2017), TXDOT (2011), ACI 325.9R (2015), IDOT (2008), IDOT D&E-2 (2012), PCA EB 001.15 (2011), ODOT (2017), and PCA EB (2005). However 2.5% contamination caused up to 20% reduction in the 28 days compressive strength. Table 6 shows that increase in crude oil contamination of mixing water decrease the split tensile and flexural strengths of concrete pavement. Both the split tensile and flexural strengths increased with increase in age.

4. CONCLUSIONS

The following conclusions were made at the end of this research.

a) Increase in crude oil contamination of mixing water decreases the strength characteristics of concrete pavement made with crude oil contaminated mixing water.
b) Strength properties of concrete pavements made with crude oil contamination mixing water increases with age irrespective of the degree of contamination.
c) Concrete pavements manufactured at 1:1½:3 mix ratio with 0 to 10% crude oil contamination of mixing water satisfied the minimum 28 day compressive strength of $24N/mm^2$ to $31N/mm^2$ specified in the relevant code of practice.
d) Mixing water for concrete pavement must conform to the specifications of ASTM C192/C192M – 16a (2016), WSDOT M41 – 10 (2017), ASTM C1602/C1602M (2012).

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