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INFLUENCE OF SUGAR CANE BAGASSE ASH AND SAW DUST ASH ON CHARACTERISTICS OF CONCRETE BRIDGE SUBSTRUCTURES EXPOSED TO CRUDE OIL CONTAMINATED ENVIRONMENT

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Abstract: Two different concrete mixes containing 0%, and 20% mixture of sugar cane begasse ash and saw dust ash were prepared and cured in portable water of 0%, 5%, 10%, 15%, 20% , 25% and 30% contamination with crude oil. The compressive strengths of concrete specimens were evaluated at the 3rd, 7th, 14th, 28th, and 56th days. The compressive strength of the concrete specimens increased with increase in age and decreased with increase in contamination of curing water with crude oil. The concrete specimens containing 20% percentage replacement of cement with mixture of sugar cane bagasse ash and saw dust ash showed increase in compressive straight, split tensile strength and slump values. The research therefore concluded that mixture of sugar cane bagasse ash and saw dust ash should be used as partial replacement of cement in production of high performance concrete for bridge substructures exposed to crude oil contaminated environment.
Keywords: bridge substructures, compressive strength, crude oil contaminated environment, high performance concrete, slump

INTRODUCTION

A bridge is a structure which provides passage over an obstacle without closing the way underneath. The required passage may be for a rail 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 some factors such as: need for the bridge, present and future traffic volume, characteristics of the stream/river, sub soil conditions, cost of the project, alternative sites available and their relative merit, aesthetics etc (Gupta and Gupta, 2010). Figures 1a, b and c show typical bridge substructures and superstructures. 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. The bridge substructures are all that part of the structure below the bearings of simple and continuous spans, skewbacks of arches and top of footings of rigid frames; including back walls, wing walls, and wing protection railings. The bridge superstructures are all that part of the structure above the bearings of simple and continuous spans, skewbacks of arches and top of footings of rigid frames; excluding back walls, wing walls and wing protection railings (Ohio department of transportation Columbus [ODOT], 2013, Oregon department of transportation [ODOT], 2015, Arizona department of transportation [ADOT], 2008, Tennessee department of transportation [TDOT], 2015, Colorado department of transportation [CDOT], 2011, North Carolina department of transportation [NCDOT], 2012, Florida department of transportation [FDOT], 2010 and Indiana department of transportation [INDOT], 2014). 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 undercopings 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 (Portland cement association [PCA EB233], 2005).

Ejeh and uche (2009) investigated the effect of crude oil spill on concrete materials. They conclude that the undiluted crude oil has the highest deterioration effect in concrete materials, when compared with the 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 material will be adversely affected if otherwise.

American concrete institute (AC1 232.1R, 2000) and American concrete institute (ACI 232.2R, 2002) defined pozzolan as a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divide form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. Natural pozzolan is defined as either raw or calcined natural material that has pozzolanic properties. The natural pozzolans in the raw or calcined state are designated as class N pozzolans and are describe in the specification as " Raw or calcined natural pozzolans that comply with the applicable requirements for the class". Raw or processed natural pozzolans are used in the production of hydraulic- cement concrete and mortars in two ways: as an ingredient of blended cement, or as a mineral admixture (AC1 232.1R 2000, and American society for testing and materials (ASTM

C618, 2015). A ternary mixture is simply a mixture of three components. In the case of a ternary mixture of cementitious materials, for example the component could be Portland cement, fly ash, and slag. Likewise, the combination could be a blended cement (already a binary mixture) and slag. Ternary mixtures are becoming more prevalent because they can enhance performance and reduce cost. The reduction in cost is associated with the fact that most supplementary cementations materials are by-products. However the used of these materials also decrease the amount of Portland cement that must be manufactured. This makes the cement industry more sustainable (ASTM C618 2015, AC1 232.1R 2000, ACI 232,2R 2002).

1a)

(1b)

(1c)

Figure 1a, b and c. Bridge substructures and superstructures

Artificial pozzolans are finely divided cementations material other than Portland cement, consisting of mainly of fly ash, ground blast furnace slag, or silica fume (Micro silica), and have been considered in the production of high-strength concrete because of the required high cementitious materials content and low water cementitious material ratio. These materials can help control the temperature rise in concrete at early ages and may reduce the water demand for a given workability. However early straight gain of the concrete may be decreased (American concrete institute [ACI 211.4R], 2008 and ASTM C618). This research therefore aims at evaluating the influence of ternary mixed containing sugar cane bagasse ash and saw dust ash on compressive strength of concrete bridge substructures exposed to crude oil contaminated environment.

MATERIALS AND METHODS

— Materials

Cementitious materials, fine aggregate and coarse aggregate

The hydraulic cement used in this study conforms to the specifications of American association of state highway and transportation officials (AASHTO M 85, 2016). The saw dust ash and sugar cane bagasse ash used have the same properties with the class F fly ash in line with the specifications of ASTM C618 (2015), ACI 232.1R (2000), ACI 232.2R (2002) as shown in the Tables 1. The fine aggregate used in this study satisfied the specifications of American association of state highway and transportation officials (AASHTO M6, 2013) and, the course aggregate used satisfied the specifications of American association of state highway and transportation officials (AASATO M80, 2013). Both aggregate conform to the specifications of American society of testing and materials (ASTM C33/C33M, 2016).

Table 1. Average chemical composition of sugar cane ash and saw dust ash.

Chemical composition	Percentage composition (%)	
	Saw dust ash	Sugar cane bagasse ash
SiO_2	65.62	56.70
Al_2O_3	5.69	6.81
Fe_2O_3	2.16	15.52
CAO	9.82	9.30
MgO	4.23	4.50
SO_3	0.04	-
Na_2O	2.38	0.12
K_2O	7.89	3.46
LOI	2.89	1.08
$SiO_2+Al_2O_3+Fe_2O_3$	73.47	79.03

Crude oil, mixing water and curing water

The crude oil used in this study satisfied the specifications of American society of testing and materials (ASTM D2892, 2016), American society of testing and materials (ASTM D1298-12b, 2012) and American society of testing and materials (ASTM D8056, 2016). The mixing water and curing water for 0% contamination of curing water with crude oil conform to the specifications of Washington state department of transportation (WSDOT M23-50, 2016), FDOT (2010), NCDOT (2012), CDOT (2011) and PCA EB 233 (2005).

— Methods

Physical properties of fine and coarse aggregate

The sieve analysis was conducted for fine and coarse aggregate in accordance with American society of testing and materials (ASTM C136M, 2014). The specific gravity and water absorption of the fine and coarse aggregate were conducted in accordance with American association of state highway and transportation officials (AASHTO T84, 2013) and American association of state highway and transportation officials (AASHTO T85, 2013) respectively. The aggregate crushing value and the Los-Angeles abrasion value tests were conducted for the coarse aggregate in accordance with ASTM C33/C33M – 16el (2016) , American society of testing and materials

(ASTM C131/C131M, 2014), and American concrete institute (ACI 201.2R, 2016).

Mix design and slump test

The concrete mixes were designed and batched in accordance with the specifications of ACI 211.4R (2008), ODOT (2013), ODOT (2015), and ADOT (2008). The mixing water confirms with the specifications of TDOT (2015), CDOT (2011), NCDOT (2012), FDOT (2010) and INDOT (2014). The water cement ratio was maintained at 0.55 and the maximum size of coarse aggregate used was 19mm. The slump test was carried out to determine the consistency of the fresh concrete and it is in conformance with WSDOT M23-50 (2016), ODOT (2013), ODOT (2015), and ADOT (2008).

Curing media

The concrete specimens marked D1 were cured in portable water medium conforming to WSDOT M23-50 (2016), FDOT (2010), NCDOT (2012), CDOT (2011) and PCA EB 233 (2005). The concrete specimens marked D2, D3, D4, D5, D6 and D7 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 of crude oil contamination of the environment.

Compressive strength and splitting tensile strength

The concrete specimens were of 150mm diameter and 300mm long. The compressive strength of the specimens was evaluated at the 3rd, 7th, 14th, 28th, and 56th day age. The average compressive strength value for each age was recorded as the compressive strength in accordance with the specifications of WSDOT M23-50 (2016), FDOT (2010), NCDOT (2012), CDOT (2011) ODOT (2013), ODOT (2015), ADOT (2008), TDOT (2015), CDOT (2011), NCDOT (2012), INDOT (2014), ACI 201.2R (2016) and PCA EB 233 (2005). The splitting tensile strength was conducted in accordance with WSDOT M23-50 (2016), and PCA EB 233 (2005). The concrete cylindrical specimens used for the splitting tensile strength test were of 150mm diameter and 300mm long.

RESULTS AND DISCUSSION

— Properties of crude oil used and aggregate characteristics

Table 2 shows the results of the laboratory analysis of the crude oil specimen used in this study. The results satisfied the specifications of the ASTM – D2892 (2016).

Table 2. Results of the laboratory analysis of the crude oil specimen

S/N	Parameters	Values
1.	Specific gravity @ 60°F or 15.55°C	0.85
2.	API specific gravity at 60°F or 15.55°C	36.80
3.	Density at 60°F or 15.55°C	0.84
4.	Pour point	3.8°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 3 shows the combine sieve analysis results of the fine and coarse aggregate from Table 3 it can be seen that the aggregate used were well graded of 19.00mm maximum size. The results shown in Tables 3 and 4 show that the fine and coarse aggregate used in this study satisfied the specifications of ASTM C33/C333M – 16E1 (2016), WSDOT M23-50 (2016), AASTHTO M80 (2013), FDOT (2010), and NCDOT (2012).

Table 3. Physical properties of fine and coarse aggregate

S/N	Properties	Fine aggregate	Coarse aggregate
1.	Specific gravity	2.61	2.73
2.	Water absorption (%)	2.10	3.0
3.	Los Angeles abrasion value (%)	-	29
4.	Aggregate crushing value (%)	-	24

Table 4. Combined aggregate gradation (fine and coarse aggregate)

Serve size (mm)	Percentage retained (%)	Cumulative percentage retained (%)	Percentage passing (%)
25	0.00	0.00	100
19	3.42	3.42	96.58
12.5	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

— Concrete mix design and curing media

Tables 5 and 6 show the concrete mix design of the specimen containing 0% and 20% replacement of cement with sugar cane bagasse ash and saw dust ash respectively.

Table 5. Concrete mix design of 1: 2: 3 for specimens containing 0% sugar cane bagasse ash (SBA) and saw dust ash (SDA)

Concrete cylindrical specimen mark	Percentage contamination of curing water with crude oil (curing media) (%)	Water cement ratio	Cement (kg/m³)	Fine Aggregate Kg/m³	Coarse Aggregate Kg/m³
0D1	0	0.55	400	800	1200
0D2	5	0.55	400	800	1200
0D3	10	0.55	400	800	1200
0D4	15	0.55	400	800	1200
0D5	20	0.55	400	800	1200
0D6	25	0.55	400	800	1200
0D7	30	0.55	400	800	1200

The water cement ratio in Table 5 was kept content for all specimens containing 0% and 20% sugar cane bagasse ash and saw dust ash. The fine aggregate to total aggregate ratio is 0.4. The physical properties of the aggregates shown in Table 3, the combine sieve analysis results shown in Table 4 and the design mixes shown in Tables 5 and 6 conform with the specifications of ACI 211.4R (2008), ODOT (2013), ODOT (2015), ADOT (2008), TDOT (2015), INDOT (2014), PCA EB 233 (2005), NCDOT (2012), WSDOT M23-50 (2016), CDOT (2011) and FDOT (2010), which specified 20% maximum replacement of cement with fly ash or processed pozzolan materials, minimum cement content as 300 to 360 kg/m^3 and fine aggregate to total aggregate ration of 0.35 to 0.45 for standard and high performance concrete.

Table 6. Concrete mix design of 1: 2: 3 for specimens containing 20% sugar cane bagasse ash (SBA) and saw dust ash (SDA)

Concrete cylindrical specimen mark	Percentage contamination of curing water with crude oil (curing media) (%)	Water cementitious materials ratio	Cementitious materials Kg/m^3			Fine Aggregate Kg/m^3	Coarse Aggregate Kg/m^3
			Cement	Sugar cane bagasse ash	Saw dust ash		
20D1	0	0.55	320	40	40	800	1200
20D2	5	0.55	320	40	40	800	1200
20D3	10	0.55	320	40	40	800	1200
20D4	15	0.55	320	40	40	800	1200
20D5	20	0.55	320	40	40	800	1200
20D6	25	0.55	320	40	40	800	1200
20D7	30	0.55	320	40	40	800	1200

— Concrete characteristics

From Tables 7 and 8 and Figures 2 and 4 it can be observed that compressive strength of all the concrete specimens' decreases with increase in crude oil contamination of the curing water but increases with increase in age irrespective of the degree of contamination of curing water with crude oil. The 28 and 56 days compressive strength of concrete specimens containing 20% mixture of sugar cane bagasse ash and saw dust ash are higher than that of concrete specimens containing 0% mixture of sugar cane bagassse ash and saw dust ash as shown in Figures 3, 5, and 6.

Concrete specimens containing 20% mixture of sugar cane bagasse ash and saw dust ash show increase in slump values and low strengths at early age and higher strength at later age which is in agreement with the properties on natural and processed pozzolan materials stated in ACI 211.4R (2008), ODOT (2013), ODOT (2015), ADOT (2008), TDOT (2015), INDOT (2014), PCA EB 233 (2005), NCDOT (2012), WSDOT M23-50 (2016), CDOT (2011) and FDOT (2010).

The 28 days compressive strengths of all the concrete specimens for 0% and 20% mixture of sugar cane bagasse ash and saw dust ash satisfied the minimum compressive strength range of 31N/mm^2 to 41N/mm^2 for high performance concrete for bridges as specified by the ACI 211.4R (2008), ODOT (2013), ODOT (2015), ADOT (2008), TDOT (2015), INDOT (2014), PCA EB 233 (2005), NCDOT (2012), WSDOT M23-50 (2016), CDOT (2011) and FDOT (2010). Table 9 shows higher splitting tensile strengths for concrete specimens containing 20% mixture of sugar cane bagasse ash and saw dust ash.

Table 7. Fresh and hardened properties of concrete specimens containing 0% sugar cane bagasse ash (SBA) and saw dust ash (SDA)

Concrete cylindrical specimen mark	Percentage contamination of curing water with crude oil (curing media) (%)	Slump (mm)	Density (kg/m3)	Compressive strength N/mm2				
				3 days age	7 days age	14 days age	28 days age	56 days age
0D1	0	73	2423	16.84	26.36	35.24	41.61	46.64
0D2	5	73	2423	14.66	24.70	33.10	39.87	44.24
0D3	10	73	2423	14.04	24.00	32.14	38.68	43.83
0D4	15	73	2423	13.36	22.51	30.15	37.16	41.79
0D5	20	73	2423	12.87	21.69	29.00	36.76	39.11
0D6	25	73	2423	11.63	19.60	26.24	33.22	36.86
0D7	30	73	2423	10.23	17.93	24.35	32.09	35.51

Table 8. Fresh and hardened properties of concrete specimens containing 20% sugar cane bagasse ash (SBA) and saw dust ash (SDA)

Concrete cylindrical specimen mark	Percentage contamination of curing water with crude oil (curing media) (%)	Slump (mm)	Density (kg/m3)	Compressive strength N/mm2				
				3 days age	7 days age	14 days age	28 days age	56 days age
20D1	0	89	2438	12.47	20.06	28.19	46.87	51.80
20D2	5	89	2438	10.73	18.76	26.48	44.06	48.88
20D3	10	89	2438	10.03	17.71	25.71	41.75	46.34
20D4	15	89	2438	9.09	16.01	24.12	40.08	44.11
20D5	20	89	2438	8.21	14.65	23.20	39.04	41.88
20D6	25	89	2438	7.43	13.21	20.99	36.04	40.08
20D7	30	89	2438	6.88	11.89	19.48	34.30	38.42

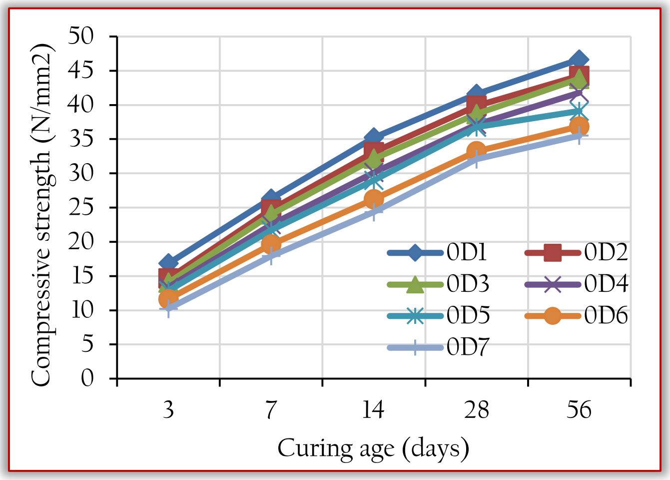

Figure 2. Relationship between the compressive strength and curing age of concrete specimens containing 0% sugar cane bagasse ash (SBA) and saw dust ash (SDA)

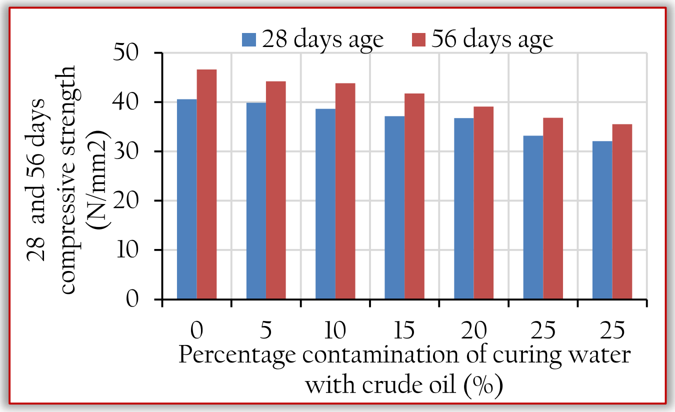

Figure 3. Relationship between the percentage contaminations of curing water with 28 and 56 days compressive strength of concrete specimens containing 0% sugar cane bagasse ash (SBA) and saw dust ash (SDA)

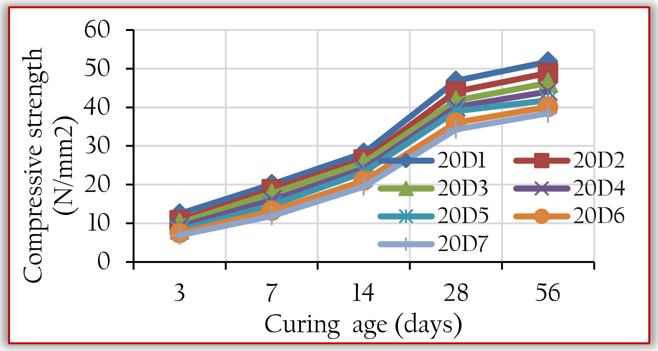

Figure 4. Relationship between the compressive strength and curing age of concrete specimens containing 20% sugar cane bagasse ash (SBA) and saw dust ash (SDA)

Table 9. 7 and 28 days splitting tensile strengths

Percentage contamination of curing water with crude oil (curing media) (%)	Split tensile strength of concrete specimens containing 0% sugar cane bagasse ash and saw dust ash		Split tensile strength of concrete specimens containing 20% sugar cane bagasse ash and saw dust ash	
	7 days	28 days	7 days	28 days
0	2.98	3.09	3.11	3.50
5	2.33	2.40	2.68	2.84
10	2.10	2.21	2.41	2.61
15	2.04	2.11	2.26	2.34
20	1.69	1.91	2.00	2.18
25	1.37	1.59	1.82	2.00
30	1.23	1.39	1.51	1.78

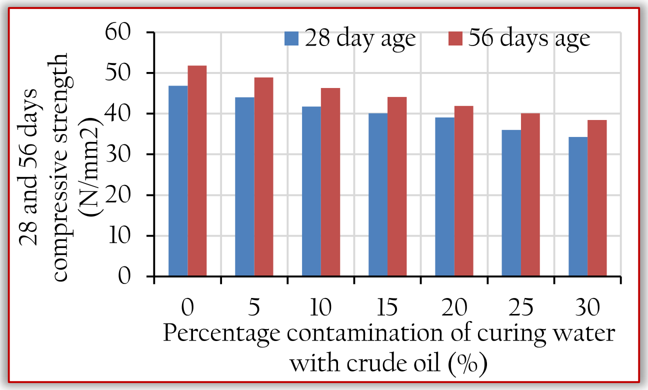

Figure 5. Relationship between the percentage contaminations of curing water with 28 and 56 days compressive strength of concrete specimens containing 20% sugar cane bagasse ash (SBA) and saw dust ash (SDA)

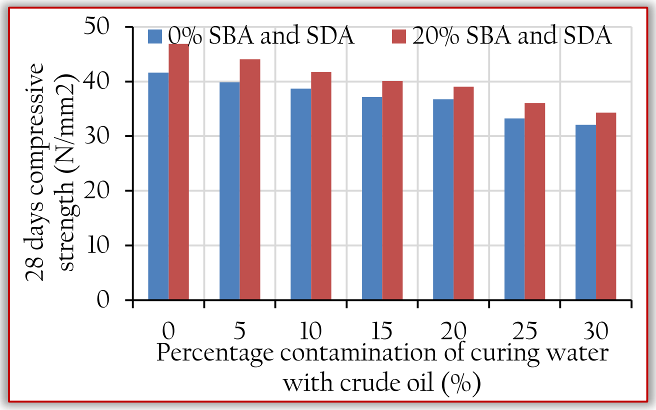

Figure 6. Relationship between the percentage contaminations of curing water with 28 days compressive strength of concrete specimens containing 0% and 20% sugar cane bagasse ash (SBA) and saw dust ash (SDA)

CONCLUSIONS

The following conclusions were made at the end of this study:

- Increase in crude oil contamination of the environment will negatively affect the compressive strength and split tensile strength of concrete bride substructures exposed to crude oil contaminated environment.
- Concrete specimen containing 20% mixture of sugar cane bagasse ash and saw dust ash show significant increase in slump values and in later days compressive strength.
- Concrete specimen containing 20% mixture of sugar cane bagasse ash and saw dust ash satisfied the minimum compressive strength range of 31N/mm^2 to 41N/mm^2 for high performance concrete for bridges as specified by the ACI 211.4R (2008), ODOT (2013), ODOT (2015), ADOT (2008), TDOT (2015), INDOT (2014), PCA EB 233 (2005), NCDOT (2012), WSDOT M23-50 (2016), CDOT (2011) and FDOT (2010).
- Sugar cane bagasse ash and saw dust ash should be used where available in high performance concrete production particularly in crude oil contaminate environment
- The use of ternary mixes should be encouraged. They are cost effective considering the quantity of cement that will be saved. Ternary mixtures also ensure sustainable cement and concrete industries.
- The use of high performance concrete for concrete bridge works should be encouraged particularly in crude oil contaminated environment.

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