Performance of Castor Oil as Admixture in Fresh Cementitious Matrix

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Abstract

Most organic admixtures for mortar and concrete are based on mineral oil derivatives. The need for natural replacement that can secure sustainable development cannot therefore be over emphasized. This study therefore focus on characterizing the oil extracted from locally sourced castor seed, verifying the effects of castor oil on setting times of ordinary Portland cement paste and also establishing the effects of castor oil on the workability and air entrainment of both fresh mortar and Concrete. The castor oil dosages by weight of cement adopted were 0.0, 0.3, 0.5, 0.7 and 1.0%. Fresh mortar mixes used were M 1:4 and M 1:3 while Concrete grade C20 and C25 were used for the fresh concrete. The study found that the physiochemical properties of the castor oil meet the standards and also comparable with other vegetable oils. From the study the duration between the initial and final setting times for all the dosages tested remains almost same but the values for 0.5% and 0.7% shows higher values. At a dosage of 0.5% oil, the workability value in lean mix was higher than the rich mix. However there was a drop in the workability values after the increase in the oil dosage above 0.5% which could be due to the excess oil addition which makes the mix stickier. The study on Air entrainment shows that richer mixes entrains more air than leaner mixes at any particular oil dosage for both concrete and mortar mixes. It further shows that air entrained drops steadily after the oil added in the mixes exceeds 0.5%. The study therefore, recommends 0.5% castor oil by cement weight in mortar and concrete as satisfactory dosage.

Keywords: *Admixture, Air entrainment, Castor oil, Setting time, Workability.*

I. INTRODUCTION

Cementitious matrix according to Naaman (2007) is a composite with several components, which could be cement paste, mortar or concrete containing all the aggregates and additives/admixture also air voids entrapped in the matrix during mixing are assumed to be part of the matrix. Concrete is any product or mass made by the use of a cementing medium. Generally, this medium is the product of the reaction between hydraulic cement and water (Neville and Brooks, 2010). However, Job (2009) observed that the medium covers several types of cements and pozzolanas. Neville and Brooks (2010) further described concrete as consisting two phases which includes the hydrated cement and aggregates. The aggregates include fine and coarse aggregates. Despite several technical and economic advantages of concrete, Neville (1996) observed many problems associated to concrete which includes perviousness, low crack resistance, poor elastic modulus, poor weather/microbial resistance and poor inhibition of reinforcement corrosion. These result in premature deterioration of concrete and sometimes collapse of structure. These concerns necessitates search for materials that will make concrete denser, stronger, more complaint with different functionality, chemically resistant and water proof/water repellent. Suguma (2005) and Gani (1997) observed that admixtures could be used to achieve higher performance cementitious matrix. Admixtures are added to concrete batch immediately before or during mixing concrete. Concrete admixtures can improve concrete quality, manageability, acceleration or retardation of setting time among other properties that could be altered to get specific results (Zakka *et al* 2015). Many concrete mixes today contain one or more concrete admixtures that will make the pouring process drive down cost while increasing productivity. Similarly, concrete admixture prevents concrete from shrinking when the product is used, the concrete will tend to dry in a progressive control way so heat will be released uniformly in the concrete mix. This tends to reduce the chance for cracks to show up, minimizing the cost of repairs and liabilities associated with these problems (Maxwell and Job, 2015). The effectiveness of an admixture depends on several factors, including: type and amount of cement, water content, mixing time, slump and temperatures of the concrete and the temperature of the air. Admixtures are classed according to function. There are five distinct classes of Admixtures: air entraining, water reducing, retarding, accelerating and plasticizers (Super plasticizers). All other varieties of admixtures fall into the special category whose functions include corrosion inhibition, shrinkage reduction, alkali – silica reactivity reduction, workability enhancement, bonding, damp – proofing and colouring (Portland Cement Association, 2006). Water repellent (permeability reducing) admixtures are materials that reduce the capillary absorption of fluids by the hardened concrete thereby lowering its permeability. Mineral and vegetables oils or metallic soaps (such as Calcium stearate) exhibit this property. Also some pozzolanic materials used as fillers (or pore blockers) which fills the micro pores in concrete are claimed to exhibit this property too. Using combination of both materials above, in a concrete gives a perfect result in water- repellency in concrete (Neville and Brooks, 2010 and Cement Admixtures Association, 2006). Reducing permeability is a key factor in improving many aspects of concrete durability, such as corrosion resistance, mitigating sulphate attack and combating alkali – silica reactions. As permeability is reduced, the transport of deleterious substances within the concrete and propagation of deterioration mechanisms are commensurately reduced. The dosage of water resisting admixture (WRA) depends on the type being used and these values should be regarded as typical. It ranges from 0.2 to 2.0 percent by weight of cement content. Hydrophobic admixtures are usually used at 1.0 to 2.0 percent. Pore blockers are added at 5.0 to 10.0 percent by weight of cement content in the mix or more often as dose per cubic metre of Concrete (Cement Admixtures Association, 2006). Cement Admixtures Association (2006) reported that strength, workability, slump loss, setting time, Air entrainment and durability are factors affecting water (permeability) reducing admixtures. Vegetable oils from sun-flower, olives, soya beans, peanuts, linseeds, corn and rapeseeds were tested as water repellents for mortar in Norway (Justnes, Ostnor and Vila, 2003). They used dosages of 0.0, 0.5, 1.0 and 1.5% oil by cement weight. The oils were dispersed in the mixing water by the aid of lignosulphonate (which evaporates afterwards). The flexural and compressive strength of 1:3 mortars with water cement ratio of 0.5 at 1 and 28 days for some oils at the highest dosage were determined. They reported that capillary water absorption was greatly reduced by the oils compared to the reference (0.0% dose), while water vapour diffusion was only marginally reduced. Chandra and Xu (1995) reported that direct addition of up to 0.8% of linseed, corn and mustard oil to mortar reduces the water absorption. They reported some hydration retardation problems and possible improper dispersion of the oil. Similarly, Vikan and Justnes (2007) reported that the influence of some vegetable oils on durability and pore structures of mortar is optimum at 0.55% for water repellent vegetable oil by cement weight. The results further showed that the compressive strength measurements after 3 years of curing gave both the 1-day and 28 – day strengths for the mortars with vegetable oil were not significantly lower than the reference mortar (0.0% vegetable oil). The 3-years compressive strengths in their studies were approximately 30% lower for samples with oil compared to the reference sample. Castor plant, is an African and evergreen shrub that can grow to the size of a small tree in the tropics with lobed serrated leaves, yielding the seeds from which castor oil is obtained and widely naturalized in warm countries (Brown, 2001). The average castor bean seed according to Community Research Bureau (2007) contains 35 to 55% oil content however Ogunniyi (2006) obtained a range of 46 to 55%. This shows that seed has a good proportion of oil stored in the endosperm. The oil is usually removed from the bean seed by solvent extraction. Nowadays, Castor oil is finding increasing applications in the industrial world in the areas of Agriculture, Food Industry, Textile Chemicals, Paper Industry, Plastic and Rubber industry, pharmaceuticals and as lubricants for extra ordinary engines like, aeronautic engines. Vegetable oils according to Vikan and Justnes (2007) consist primarily of glyceries (i.e. esters of glycerol and fatty acids) but also other lipids in minor quantities. The acids can be broadly divided into saturated and unsaturated ones. The saturated ones contain only single bonds between carbon atoms in their fatty acids such as in Lauric oil and are characterized by relatively high melting point temperatures, while saturated acids have one or more pairs of carbon atoms joined by double bonds such as in the sunflower oil, canola oil, kernel seed oil and castor oil and are low melting and more chemically reactive. The ester which most of the other oils do have in small quantity is in large amount in castor oil but is chemically unstable in the highly alkaline interior of cement mortar. It hydrolyzes to glycerol and fatty acid anions consuming all three hydroxyl in the process coordinating strongly with calcium. The fatty acid will thus be stocked inside the mortar and the hydrophobic part of molecule creates repellency property in particular if good distribution is secured by dispersing the oil in the mixing water prior to mixing (Justnes, et al., 2003). Castor oil main fatty acid, ricinoleic fatty acid which is about 90% in castor is a monounsaturated oil or fatty acid. From Justnes, et al (2003) and Vikan and Justnes (2007) they found out that the monounsaturated fatty acid in vegetable oil generally was responsible for water repellency (reduced permeability) in concrete and mortar. They investigated on some vegetable oils, like linseed, olive, rape seed, corn, sunflower, soy bean, peanut and found that among all these vegetable oils, it was the olive oil (which has greater percentage of monounsaturated fatty acid 70%) repels or reduce water in concrete and mortar the most. This means that castor oil which has high percentage (90%) of fatty acid might have the capacity to repel or reduce water in concrete and mortar in greater extent to olive oil and all other vegetable oils. It is on the basis of the physiochemical properties and the remarkably constant composition of castor oil fatty acids and esters that makes the castor oil promising in use as an admixture in mortar and concrete production. This research work is therefore aimed at assessing the performance of castor oil as an admixture in fresh cementitious matrix with the following objectives:

a) Characterizing the properties of the local variety of castor oil and compare with other vegetables oils of known standards,
b) Verifying the effects of castor oil on setting times of ordinary Portland cement paste and
c) Establishing the effects of castor oil on the workability and air entrainment on both fresh mortars and concretes.

II. EXPERIMENTAL DETAILS

The castor oil concentrations used were 0.0, 0.3, 0.5, 0.7 and 1.0 % by weight of cement into the various cementitious matrixes. Absolute volume method of batching by ACI Standard 211.1 (1989) was used to produce two mortar mixes M 1:3 (cement: sand) and M 1:4 (cement: sand) respectively as well as fresh concrete grades C20 and C25. The batch materials quantities required per m^3 were carefully measured and kept for the mixing process see Table 1. The dried ingredients (cement and fine aggregate at saturated surface dry conditions) were mixed together by hand shovel twice within three minutes, before the mixing water containing the admixture quantity was added (while stirring the mixture of mixing water and the required castor oil inside the container together with smooth stainless rod) and thereafter the whole ingredients were mixed together twice, within three minutes to obtain an evenly wet mixture of the mortar. Same procedures were used in the production of the concrete except that coarse aggregates were added. Initial and final setting times of the mixture of cement and castor oil pastes were carried out using the Vicat apparatus in accordance with BS 12 (1999). The slump test was carried out on the fresh samples in accordance with the provisions of BS 1881: Part2 (1983) while compacting factor test adopted the recommendations of BS 1881: Part 103 (1983).

Table 1: Quantity of Ingredients Required (Kg) Per Cubic Meter of Mortar and Concrete

	Mortar Mix ratio		Concrete Grade	
Ingredient	M 1:4	M 1:3	C20	C25
Cement	402	483	340	380
FA	1786	1610	770	825
CA	-	-	1100	970
Castor oil dosage				
0.0%	0	0	0	0
0.3%	1.206	1.449	1.02	1.14
0.5%	2.010	2.415	1.70	1.90
0.7%	2.814	3.381	2.38	2.66
1.0%	4.020	4.830	3.40	3.80

Where FA = Fine Aggregates and CA = Coarse Aggregates.

III. DISCUSSION OF RESULTS

A. Physiochemical Properties of The Castor Oil as Compared with Other Vegetable Oils

The physiochemical properties of the oil and specifications as given by ASTM, D 960 – 52 are as shown in Table 2. The properties determined of the locally sourced castor oil shows that the castor oil possesses the quality of other castor oils sourced around the globe having satisfied the ASTM, D 960-52 ranges with few exceptions. Table 3 compares the castor oil used with sunflower oil, kernel oil and canola oil used in researches as adapted from works by (Aboki, et al. 2012, Yusuf, et al. 2012 and Przybylski, 2010). From the comparative analysis the castor oil shows a better quality for use as admixture having an Ester value of 83.3, low moisture content with no unsaponification value. Furthermore, the uses of castor oils are dictated by its acid value, moisture level, colour and purity (Caschem, 2006).

Table 2: Comparism of Physiochemical Properties of Castor Oil used in this Work with ASTM, D 960 – 52 Ranges.

Property determined	ASTM, D 960 – 52 Ranges	Sample Castor Oil Value
Moisture Content	0.50% Max	2.64%
Free Fatty Acid	-	0.17
Acid value (mg NaOH/g of oil)	4.0 Max	0.33
Saponification Value (mg KOH/g of oil)	175 – 187	180.88
Unsaponification Value	0.3 – 0.7	-
Iodine Value (g I_2 / 100g of oil)	82 – 90	95
Specific gravity 25^0 C	0.954 – 0.967	0.957
Viscosity @ 25^0 C (St)	6.3 – 8.8	8.50
Refractive index @ 28^0 C	1.476 – 1.479	1.46
pH Value	-	6.15
Hydroxyl Value	160 Min	-
Peroxide Value (ml/kg)	-	2.30
Ester value	-	83.30
Sludge	-	2.15%
Insoluble Impurities	-	0.53%
Appearance	Pale Dark Yellow	Pale Dark Yellow

Where: Max means Maximum while Min means Minimum

Table 3: Comparism Between of Physiochemical Properties Value of Castor Oil Used in This Work with Sun Flower Oil, Kernel Seed Oil and Canola Oil Used by Other Researchers in Similar Works.

Property determined	Castor Oil*	Sun flower Oil**	Kernel seed oil***	Canola Oil+
Moisture Content	2.64%	-	-	-
Free Fatty Acid	0.17	0.04	-	1.2
Acid value (mg NaOH/g of oil)	0.33	0.95	22.4	-
Saponification Value (mg KOH/g of oil)	180.88	182.14	182.32	-
Unsaponification Value	-	-	0.44	1.2
Iodine Value (g I_2 / 100g of oil)	95	119.92	4.17	-
Specific gravity 25^0 C	0.957	0.915	0.88	2.0
Viscosity @ 25^0 C (St)	8.50	-	-	78.2
Refractive index @ 28^0 C	1.46	-	1.48	1.5
pH Value	6.15	-	6.19	-
Hydroxyl Value	-	-	-	-
Peroxide Value (ml/kg)	2.30	6.322	2.02	-
Ester value	83.30	46.2	-	-
Sludge	2.15%	-	-	-
Insoluble Impurities	0.53%	-	-	-
Relative density	-	-	0.82	1.0

Source:
*Value of castor oil physiochemical properties used in this research work.
**Value of Sun flower oil physiochemical properties adapted from work by (Aboki, et al. 2102)
***Value of Kernel Seed oil physiochemical properties adapted from work by (Yusuf, et al. 2012)
+Value of canola oil physiochemical properties adapted from work by Przybylski, R. (2010).

B. Setting Times

Table 4 shows the initial and final setting times of the cement paste while Figure 1 shows the results graphically. The result shows that the setting time retards with oil as compared to the ones without oil (control). The retardation increases with the percentage increase of the oil content. But presence of oil in the cement paste (up to 1.0% content studied) does not affect the standard consistency value paste; since the standard consistency test for the control and the paste with oil gave same value (30%). The initial setting time for the control paste (without oil) was determined to be 156 minutes, which is in accordance with BS 12 (1999) limits, which should be more than

45 minutes for ordinary Portland cement (OPC). With the addition of 0.3% oil in the cement paste, the initial setting time was increased to 198 minutes; delays the initial setting time up to 42 minutes (27%) more. While 1.0% oil increases the initial setting of the paste to 250 minutes that delays 94% minutes (60%).the final setting time for the control paste (without paste) was determined to be 266 minutes which is also in accordance with BS 12 (1999) limits, which must be less than 600 minutes for ordinary Portland cement (OPC). With addition of 0.3% oil in the cement paste, the final setting time was increased to 303 minutes; that delays the final setting up to 37 minutes (14%) more. While 1.0% oil increases the final setting of the paste to 360 minutes (35%). That means the percentage of retardation, due to the oil on the setting time, is more on the initial than the final setting time; at any amount of oil added up to 1.0% quantity. The duration between the initial and final setting times for all the dosages tested remains almost the same but the values for 0.5% and 0.7% shows higher results which could be that the variation on the quantity of oil content does not affects the duration of the settings (between initial and final). That means the oil only delays the beginning of the initial setting time of cement pastes. However the setting time (Initial and final) of all mixes is in accordance with BS 12 (1999) limits.

Table 4: Setting Times of Mixture of Cement and Castor Oil in Various Proportions

Admixture Dosage (%)	Standard Consistency (%)	Initial (min)	Final (min)	Setting Duration (min)
Control	30	156	266	110
0.3	30	198	303	105
0.5	30	205	320	115
0.7	30	220	335	115
1.0	30	250	360	110

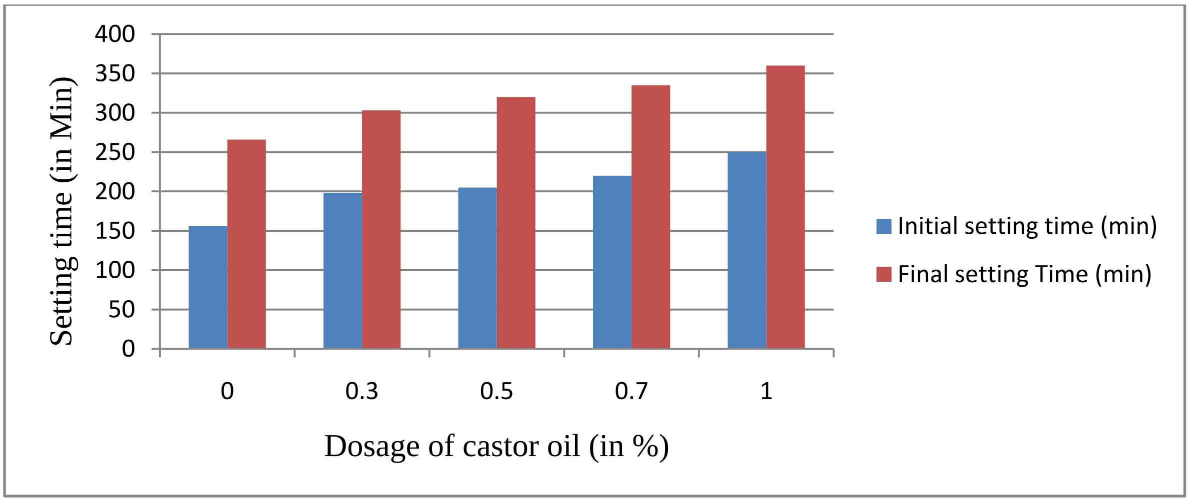

Figure 1: Setting Time of Mixes With Varying Castor Oil Dosages

C. Workability

The fresh cementitious matrix investigated here are the grade 20 concrete (C20) and grade 25 concrete (C25). They represent lean and rich mixes of concrete respectively. The workability tests conducted on them were the slump test and the compacting factor test. Results in Table 5 shows that the oil improves the workability of the concrete up to a certain quantity, then declines from that point. There is gradual increase in workability as the oil was added into the mix from control up to dosage of 0.5% which gave maximum workability after which the workability begins to decline. This shows an optimum dosage of 0.5% of the oil for the workability of the concrete mix. The workability of the control mixes were observed to be "very low" 15mm slump and 0.85 compacting factor (CF) for grade C20 concrete also "very low workability" 20mm slump and 0.85 CF for grade C25 concrete. While at 0.5% oil content, the workability results obtained were "low workability" 25 mm slump (67% increase) and 0.89 CF (5% increase) for grade C20 concrete; also “low workability” 30mm slump (50% increase) and 0.86CF (1% increase) for grade C25 concrete. The results give the same degree of workability for each dosage of oil used independent on the grade of the concrete mix. However, the improvement in the workability values recorded, when compared with the control value were higher in lean mix than in rich mix by using castor oil admixture. The drop in the workability values after the increase in the oil dosage from 0.5% can be explained to due to the excess oil addition; the mix becomes sticky and very harsh to work with because the particles are no longer free to move but sticks together due to excessive oil in the mix.

Table 5: Results of Slump and Compacting Factor of Fresh Concrete

Concrete Grade	Admixture Dosage	Slump (mm)	Compacting Factor	Degree of Workability
C20	Control (0%)	15	0.85	Very low
	0.3%	25	0.87	Low
	0.5%	25	0.89	Low
	0.7%	10	0.85	Very low
	1.0%	15	0.85	Very low
C25	Control (0%)	20	0.85	Very low
	0.3%	25	0.90	Low
	0.5%	30	0.86	Low
	0.7%	0	0.78	Very low
	1.0%	0	0.80	Very low

D. Air Entrainment

Table 6 and Figure 2 shows the results of the air entrained by various dosages of the oil contained in the concretes and mortars. Generally, the results indicate that the presence of the oil in the cementitious matrix introduces air in them. The maximum air entrained in all the mixes occurs at an oil dosage of 0.5% and these values are higher than their corresponding values. The percentage increase of the air entrained values at 0.5% oil dosage for the concrete and mortar compared to their control are 33% for C20, 21% for C25, 37% for M1:4 and 51% for M1:3. Richer mixes entrains more air than leaner mixes at any particular oil dosage for both concrete and mortar mixes. This might be due to more surfaces of cement particles available in richer mixes for chemical reaction activities with the oil. It was noticed from results that air entrained drops steadily after the oil added in the concrete /mortar mixes exceeds 0.5% till 1.0% tested. This phenomenon further shows that 0.5% oil addition is the optimum dosage for air entrainment.

Table 6: Results of Air Entrainment of Fresh Concrete and Mortar

Admixture Dosage	Air Entrained in Fresh Cementitious Matrix (%)			
	Concrete Grades		Mortar Mixes	
	C20	C25	M 1:4	M 1:3
Control (0%)	3.0	3.3	5.2	5.9
0.3%	3.6	3.7	5.3	6.3
0.5%	4.0	4.0	7.1	8.9
0.7%	3.8	4.0	5.1	5.5
1.0%	3.5	3.8	5.9	6.3

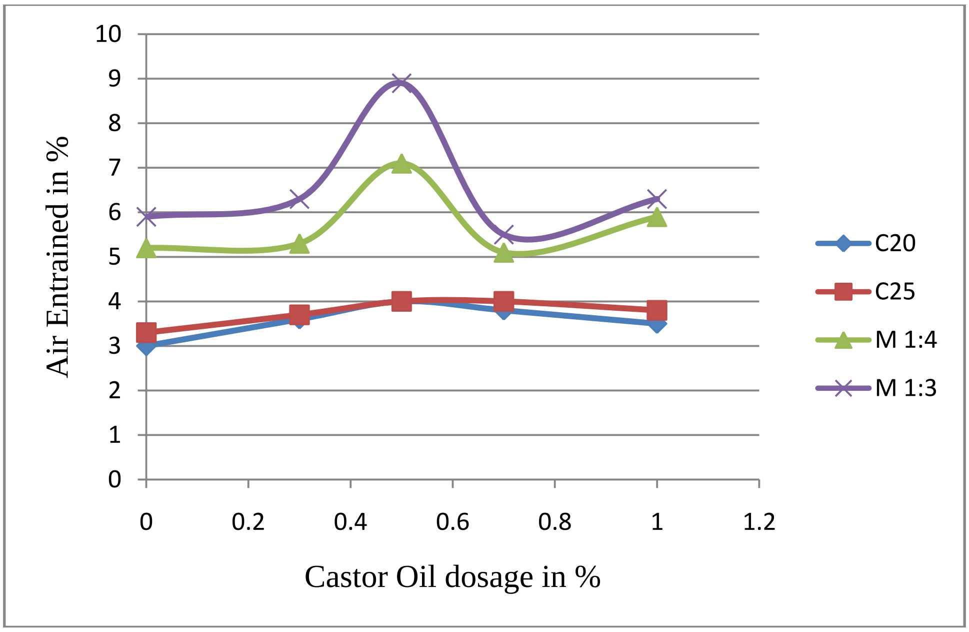

Figure 2: Air Entrained by the Samples with Varying Castor Oil Dosages

IV. CONCLUSION

The research into the use of castor oil as an admixture in fresh cementitious matrix concludes that the physiochemical properties of castor oil meet the minimum requirements of other vegetable oils. Castor oil can therefore be said to be a good admixture in fresh cementitious matrix up to the dosage of 0.5% by weight of cement. From the study, and based on the various tests performed, the optimum dosage of castor oil that should be used in fresh cementitious matrix should not exceed 0.5% by weight of cement. The duration between the initial and final setting times for all the dosages tested remains almost same but the values for 0.5% and 0.7% shows higher results. Studies on the workability shows that the improvement in the workability values recorded, when compared with the control value were higher in lean mix than in rich mix when castor oil admixture is used. The richer mixes entrain more air than leaner mixes at any particular oil dosage for both concrete and mortar mixes. This trend further shows that 0.5% castor oil by cement weight is the most appropriate dosage for air entrainment in cementitious matrix.

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