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THE EFFECT OF SEAWATER ON SHRINKAGE PROPERTIES OF CONCRETE

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ABSTRACT

This research presents the effect of seawater on shrinkage properties of concrete. Concrete cubes of 150x150x150 (mm) with mix ratio 1:2:4 by weight of concrete 0.6 water-cement ratio were made in two batches. Half of the cubes (i.e. were made using fresh water and the other half were made using seawater. They were cured in fresh and sea water respectively for 90 days. Shrinkage at 90 days and ultimate shrinkage were analysed in accordance to American Concrete Institute manual on concrete and BS 8110: Part 2 respectively. Also coefficient that deals with concrete compositions such as slump, cement content, and aggregate size were varied so as to evaluate its effect on shrinkage. The findings revealed that shrinkage was interdependent on concrete composition and the result exhibited a higher shrinkage value for concrete with higher cement content and with higher slump value. However, reduced shrinkage values were noticed with higher aggregate sizes. It was also observed that concrete mixed or cured with seawater has higher shrinkage value than the control batches with dry shrinkage analysis value of 83.5% increase for concrete mixed with seawater (CSW) when compare to the shrinkage value of the control batches.

KEYWORDS: Concrete, Sea Water, Shrinkage

INTRODUCTION

The challenge of building and maintaining durable concrete structures in seawater environment is on the increase. Structures in coastal and offshore areas are exposed to the continuous action of physical and chemical deterioration processes due to the effects of chemical reaction of seawater on concrete when the chemical constituents in seawater react with cement hydration products. Other causes of the deterioration of concrete in marine environs may be as a result of alkali-aggregate expansion which occur when reactive aggregates are present; crystallization pressure of salts within concrete when one face of the structures is subject to wetting and others to drying conditions; frost action in cold climates; corrosion of embedded steel in reinforced or prestressed members, and physical erosion due to wave action and floating objects [1, 2]. The effect of sea water on concrete was first discussed in 1840 by J. Smeaton and L. J. Vicat. Their two-year examination on the research topic titled "What is the trouble with concrete in sea water" revealed that a large number of concrete structures in sea water in the United States, Canada, Cuba and Parama are exposed to chemical deterioration [3].

Since this early time, several works has been done on the durability of concrete and reinforced concrete in marine environment. Portland Cement Association (PCA) provided excellent reviews on research advances of concrete in seawater. Their long time study of cement performance in concrete provides key insights into the performance of concrete in seawater. The results of their study revealed that seawater had no damaging effect on submerged concrete specimens, regardless of their cementitious composition; whereas, concrete positioned above high tide suffered more corrosion damage than concrete placed at mean tide levels [4]. Also, concrete had been observed to deteriorate by stresses caused by crystallization of salts in the pores when one side of a slab or retaining wall of a permeable solid is in contact with a salt solution and the other sides are subjected to loss of moisture by evaporation [5]. The afore-mentioned findings revealed some very important facts and implying the importance of the topic. Yet, the effect of sea water on concrete requires special attention and still remains a dynamic subject for study and research.

Thus, this paper is aimed at investigating the effect of seawater on shrinkage characteristics of concrete. The research paper provides very useful information on concrete composition suitable to reduce shrinkage occurrence in marine environs and it also explores the use of seawater in production of mass concrete. Its usefulness will also be appreciated by construction industries with view of producing durable marine concrete structures.

REVIEW OF LITERATURE

Advances of Seawater in Concrete

Seawater is fairly uniform in chemical composition, which is characterized by the presence of about 3.5 percent soluble salts by weight [6, 2]. The concentration of major salt constituents of seawater were given in weight percentage of salt as 78%NaCl, 10.5% $MgCl_2$, 5% $MgSO_4$, 3.9% $CaSO_4$, 2.3% K_2SO_4, 0.3% KBr [7]. However, the feasibly aggressive constituents of seawater as regards concrete are the sulphate, chloride, carbonate, bicarbonate, alkali metal, and magnesium ions. From the above salt concentration, it is apparent that sodium chloride is the predominant salt component of seawater. Nonetheless, the sulphate component in seawater with higher chemical reaction on concrete is magnesium sulphate rather than sodium or calcium sulphate as is more often the case in sulphate-attack situations not involving seawater [1, 2].

Al-Amoundi [8] described the sequence of attack by magnesium sulphate in seawater by a simple equation as:

$$Ca(OH)_2 + MgSO_4 + 2H_2O \rightarrow CaSO_4.2H_2O + Mg(OH)_2 \quad (1)$$

$$C\text{-}S\text{-}H + MgSO_4 + 2H_2O \rightarrow CaSO_4.2H_2O + Mg(OH)_2 + 2SiO_2.H_2O \quad (2)$$

$$4Mg(OH)_2 + SiO_2.H_2O \rightarrow M\text{-}S\text{-}H + H_2O \quad (3)$$

$Ca(OH)_2$ calcium hydroxide (portlandite)

$MgSO_4$ magnesium sulphate

$CaSO_4.2H_2O$ calcium dehydrate (gypsum)

$Mg(OH)_2$ magnesium hydroxide (brucite)

$SiO_2.H_2O$ hydrosilicate (silica gel)

C-S-H calcium silicate hydrate (~3(CaO).2(SiO_2).8H_2O)

M-S-H magnesium silicate hydrate (4(MgO).SiO_2.8.5H_2O)

In spite of this, seawater with a maximum concentration of salts of the order of 3.5 percent was also observed not to appreciably reduce the strength of concrete. As a matter of fact, seawater has been used in mixing plain concrete without incurring trouble at later periods. Seawater was used in the concrete mix for the foundation of the light house, built by the U. S. Army Corps of Engineers in 1910, at the extremity of the Los Angeles breakwater, and that 25 years later it was examined and found to be in good condition with sharp edged corners and no disintegration. Also, much of concrete in Florida East Coast Railway were mixed with seawater, with no detrimental effect due to its use [9]. In addition, several literatures have also indicated that concrete has been made with seawater under certain circumstances with no adverse effect reported on concrete strength. Concrete mixed and cured with seawater has been found to gain strength more rapidly when compared with conventional concrete [10, 11, 7, and 6]. The only risk reported with seawater in construction work is its use in reinforced and prestressed concrete due to the chloride salt which can corrode the steel.

Akinsola et al [12] also observed that the autogenous shrinkage strain of concrete mixed using sea water tends to be slightly larger than that of concrete with tap water. However, the drying shrinkage strain was slightly smaller than that of concrete with tap water by a margin of 500 ™ 10-6 to 700 ™ 10-6 in all cases. Conversely Ken [13] observed shrinkage in concrete to become a problem when the shrinking concrete is connected to fixed objects like walls, columns, adjacent slabs, concrete substrates or the subgrade. This would develop tensional stresses in the concrete and as soon as this tension becomes greater than the tension strength of concrete, the concrete cracks. Basf [14] and Luke [15] also observed loss of water by evaporation from the surface of concrete or by the absorption by aggregate or subgrade to be another reason for plastic shrinkage. The loss of water often results in the reduction of volume and when this happens, the aggregate particles or the reinforcement in concrete comes in the way of subsidence due to which cracks may appear at the surface or internally around the aggregate or reinforcement.

In case of floors and pavements where the surface area exposed to drying is large as compared to depth, when this large surface is exposed to hot sun and drying wind, the surface of concrete dries very fast which results in plastic shrinkage [15]. Sometimes even if the concrete is not subjected to severe drying, but poorly made with a high water/ cement ratio, large quantity of water bleeds and accumulates at the surface. When this water at the surface dries out, the surface concrete collapses causing cracks plate 1 below shows plastic shrinkage crack in floors.

Plate 1: Typical Plastic Shrinkage Crack

MATERIALS AND METHODS

Concrete cubes of 150x150x150 (mm) with mix ratio 1:2:4 by weight of concrete 0.6 water-cement ratio were made in two batches. Half of the cubes (i.e. were made using fresh water and the other half were made using seawater. They were cured in fresh and sea water respectively for 90 days. Concrete specimens were tested to predict its effect with respect to shrinkage. The cube specimens were measured with vernier caliper and analytical method for predicting dry shrinkage was also used. Shrinkage at 90 days and ultimate shrinkage were analysed in accordance to American Concrete Institute manual on concrete [16] and BS 8110 [17] respectively. Shrinkage values were determined for varying slump values between 75mm to 125mm; aggregate size of 12.5mm to 37.5mm; and cement content ranging from 300kg/m^3 to 500kg/m^3.

Plate 2: Measuring Cubes Dimension

PLASTIC SHRINKAGE CRACKING TEST

In order to predict the occurrence of plastic shrinkage crack, the evaporation rate of the concrete was determined. The equation for calculating the evaporation rate in concrete is given by equation (1) as:

$$E = 5[(T_c + 18)^{2.5} - r\,(T_a + 18)^{2.5}][V + 4] \times 10^{-6} \quad (1)$$

where; E = Evaporation Rate, kg/m^2/hr

T_c = Concrete Water Surface Temperature, ^{0}C

- T_a = Air Temperature, ^{0}C
- r = Relative Humidity (percent)/100
- V = Wind Velocity, kph

The temperature of the concrete was determined by inserting the concrete thermometer into the concrete immediately after mixing as shown in plate 1 and the same equipment was also used to determine the air temperature. The average relative humidity (outdoor) and wind velocity were gotten. Plastic shrinkage is likely to occur for evaporation rate is between 0.5 and 1.0 kg/m^2/hr.

Plate 3: Determining Concrete Temperature

PREDICTION OF DRY SHRINKAGE

This was determined in accordance to ACI 209.R-92. Shrinkage (s_h) at 90days for moist curing was estimated using the following using the expression below:

$$S_h(t, t_o) = \frac{t - t_o}{35 + (t - t_o)} S_{h\infty} \quad (2)$$

Where $S_{h\infty}$= ultimate shrinkage, and

$S_{h\infty}$=780 x 10^{-6} k_1' k_2' k_3' k_4' k_5' k_6' k_7'

k_1' = shrinkage coefficient,

Table 1: Values of Shrinkage Coefficient k_1'

Period of Moist Curing (Days)	Shrinkage Coefficient k_1'
1	1.2
3	1.1
7	1.0
14	0.93
28	0.86
90	0.75

- k_2' = humidity coefficient,
- k_2' = 1.40 – 0.010h (40≤h ≤80)
- k_2' = 3.00 – 0.3h (80≤h ≤100)

Where h = relative humidity (percent)

- Coefficient k_3'
- for $(t-t_o) \leq$ 1year
- k_3' =1.23 – 0.006V/S

k_3' allows for the size of the member in terms of the volume/surface ratio as shown in table 2:

Coefficients responsible for the composition of concrete are k_4', k_5', k_6' and k_7'. They are given by:

k_4' = 0.89 + 0.067s

Where s = slump of fresh concrete (mm),

k_5' = 0.30 + 0.0014 A_f/A, ($A_f/A \leq 50$)

k_5' = 0.90 + 0.002 A_f/A, ($A_f/A > 50$)

Where a_f/A = fine aggregate/total aggregate ratio by mass (percent). Values of are given in table 3.

Table 2: Shrinkage Coefficient k_3'

Volume/Surface Ratio V/S (mm)	Coefficient k_3'
12.5	1.35
19	1.25
25	1.17
31	1.08
37.5	1.00

Table 3: Approximate Ratio of Fine to Total Aggregate

Nominal Maximum Size Aggregate & Type of Coarse Aggregate	Fine Aggregate/Total Aggregate Ratio (%)
75mm, Crushed	29 – 36
75mm, Rounded	27 – 34
37.5mm, Crushed	39 – 47
37.5mm, Rounded	35 – 45
19.0mm, Crushed	48 – 59
19.0mm, rounded	41 – 45

Also $k_6' = 0.75 + 0.00061\gamma$

Where γ =cement content (kg/m^3), and

$k_7' = 0.95 + 0.008A$

Where A = air content (%). Values are given in table 4.

Table 4: Air Content of Concrete

Nominal Maximum Size Aggregate mm (in)	Air Content, Percent*		
	Severe Exposure**	Moderate Exposure †	Mild Exposure ††
< 9.5			
(3/8)	9	7	5
9.5 (3/8)	7 ½	6	4 ½
x	7	5 ½	4
19.0 (3/4)	6	5	3½
25.0 (1)	6	4 ½	3
37.5 (1½)	5 ½	4 ½	2 ½
50.0 (2)	5	4	2
75.0 (3)	4 ½	3 ½	1 ½

The graphical illustration in section 7.3 of BS 8110: Part 2: 1985 was later used to determine the value of shrinkage for concrete mixed with fresh water for the same period of exposure and relative humidity.

RESULTS AND DISCUSSIONS

The result of the chemical analysis of the seawater used is presented in table 5.

Table 5: Chemical Analysis of Fresh Water and Sea Water

Test	Fresh Water	Sea Water
PH	7.0	7.8
Electrical Conductivity	1053 micro s/cm	57.9 Micro s/cm

Table 5: Contd.,		
*T. D. S	1490 mg/l	31200 mg/l
Nitrate	-	-
Chloride	220 mg/l	6000 mg/l
Hardness	246 mg/l	-
Calcium	62 mg/l	210.6 mg/l
Magnesium	28 mg/l	1644 mg/l
Acidity	-	-
Alkalinity	-	0.8 mg/l
Iron	-	0.14 mg/l
Sulphate	110 mg/l	1400 mg/l
Potassium	-	475 mg/l
Chromium	-	0.03 mg/l
Phosphate	-	1.10 mg/l
Salinity	-	32. 6 g/l
Total suspended solid	-	-
Total solid	-	-
Odour	Unobjectionable	Unobjectionable
Colour	-	Blue
Temperature	20 ^{O}C	32.6 ^{O}C

* TDS – Total dissolve solids.

Table 6: Variation of Cube Dimension at 90 Days

Concrete Designation	Initial Volume x 10^{-3} (m^3)	Final Volume x 10^{-3} (m^3)	Change in Volume x 10^{-3} (m^3)
FF	3.375	3.357	0.018
FS	3.375	3.355	0.020
SF	3.375	3.350	0.025
SS	3.375	3.354	0.021

In Table 6 above, slight reduction in volume of the cube specimens were observed for all batches at 90 days, with concrete batches SF having the highest reduction value.

ANALYTICAL EXAMPLES

Analysis I: Result of Plastic Shrinkage Cracking test

The water surface temperature of the concrete, T_c was 29^0C; the air temperature, T_a was 32^0C, the relative humidity, r was 84%, and wind velocity, V of 10.8kph.

Evaporation Rate was calculated for concrete mixed with seawater (CSW) and concrete mixed with fresh water (cfw) using the formula r in equation (1). The result was evaluated to be 0.00265 kg/m^2/hr. Evaporation Rate, Ewas observed to be lesser than 0.5kg/m^2/hr. Hence, it was safe against plastic shrinkage crack.

Analysis II: Result of Dry Shrinkage Test for CSW

Shrinkage (S_h) at 90 days for moist curing was estimated using the formula r in equation (2). Shrinkage values were determined for varying slump values between 75mm to 125mm; varying aggregate size of 12.5mm to 37.5mm; and varying cement content ranging from 300kg/m^3 to 500kg/m^3. The results are presented in tables below.

Table 7: Variation of Shrinkage with Slum

Slump Value (mm)	Shrinkage Coefficient (k_4')	Ultimate Shrinkage ($S_{h\infty}$) x 10^{-4}	Shrinkage (S_h) x 10^{-4}
75.0	0.8950	4.7990	3.4445
87.5	0.8959	4.8035	3.4477
100.0	0.8967	4.8080	3.4509
112.5	0.8975	4.8125	3.4542
125.0	0.8984	4.8170	3.4574

Table 8: Variation of Shrinkage with Aggregate Size

Aggregate Size (mm)	Shrinkage Coefficient (k_3')	Ultimate Shrinkage ($S_{h\infty}$) x 10^{-4}	Shrinkage (S_h) x 10^{-4}
12.5	1.35	5.1849	3.7214
19.0	1.25	4.8008	3.4458
25.0	1.17	4.4936	3.2252
31.0	1.08	4.1479	2.9771
37.5	1.00	3.8408	2.7566

Table 9: Variation of Shrinkage with Cement Content

Cement Content (kg/m^3)	Shrinkage Coefficient (k_6')	Ultimate Shrinkage ($S_{h\infty}$) x 10^{-4}	Shrinkage (S_h) x 10^{-4}
300	0.9330	4.8008	3.4458
350	0.9635	4.9578	3.5584
400	0.9440	5.1147	3.6711
450	1.0245	5.2717	3.7837
500	1.0550	5.4286	3.8963

The graphical representation showing variation of shrinkage with varying values of slump, aggregate and cement are presented in figure 1 to figure 4 below:

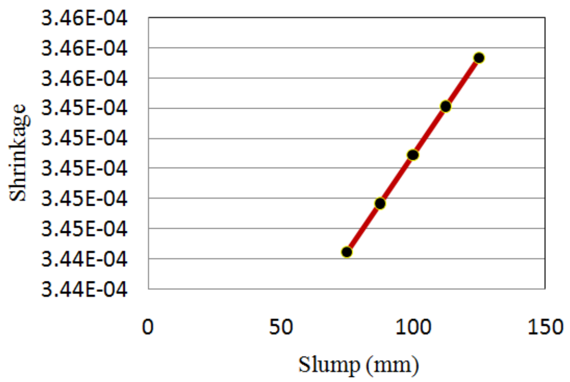

Figure 1: Shrinkage versus Slump

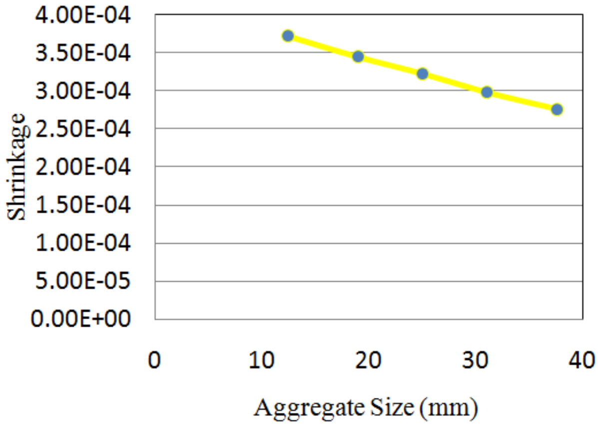

Figure 2: Shrinkage versus Aggregate Size

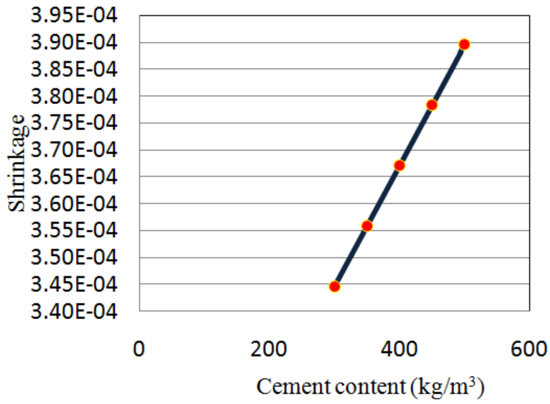

Figure 3: Shrinkage versus Cement Content

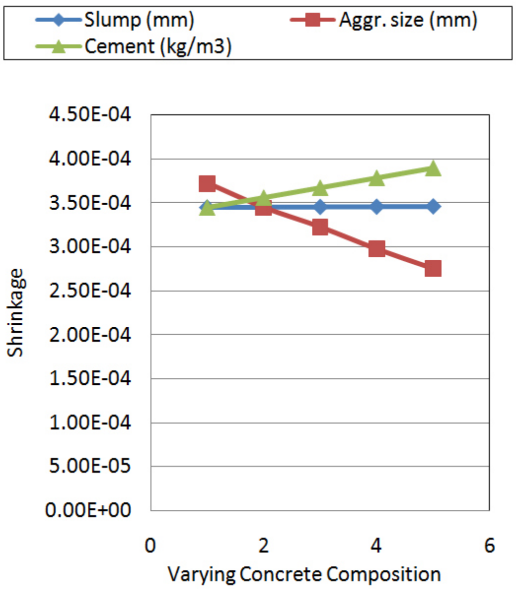

Figure 4: Shrinkage versus Varying Concrete Composition

Analysis III: Result of Dry Shrinkage Test for cfw (Concrete Mixed with Fresh Water)

From the graphical illustration in BS 8110: Part 2: 1985 Figure 7.2, as shown Figure 3 below, using the relative humidity value of 84%, and 150mm effective thickness. The ultimate shrinkage $S_{h\infty}$ is 80 x 10^{-6}.

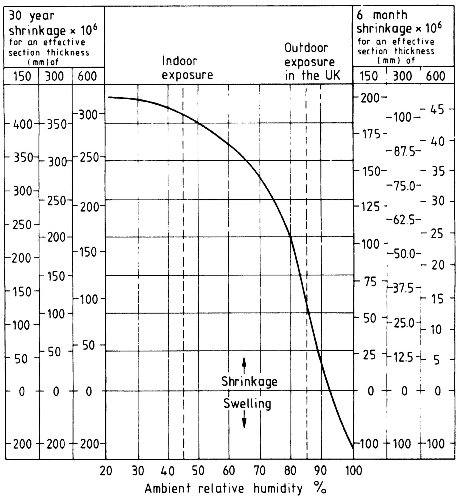

Figure 5: Dry Shrinkage of Normal-Weight Concrete (BS 8110: Part 2, 1985)

Substituting the ultimate shrinkage value into equation (2);

$$S_h(90days) = \frac{90-1}{35+(90-1)} 80 \times 10^{-6}$$

$$S_h(90days) = 0.57 \times 10^{-4}$$

The 90 days dry shrinkage analysis revealed that the value of shrinkage in concrete mixed with salt water (CSW) increased by 83.5% when compare to the shrinkage value of the control batches. The results from concrete compositions variation, in Tables 7 and 9 as well as Figures 1 and 3 show a proportional increase in shrinkage at higher slump and cement content. This implies that shrinkage is directly proportional to slump and cement content.

While in Table 8 and Figure 2, a proportional decrease in shrinkage was noticed as the aggregate size increases. Therefore it shows that shrinkage is inversely proportional to the aggregate size.

CONCLUSIONS

The analysis revealed that shrinkage was interdependent on concrete composition and the result exhibited a higher shrinkage value for concrete with higher cement content and with higher slump value. However, reduced shrinkage values were noticed with higher aggregate sizes. It was also observed that concrete mixed or cured with seawater has higher shrinkage value than the control batches with dry shrinkage analysis value of 83.5% increase for concrete mixed with seawater (CSW) when compare to the shrinkage value of the control batches. Therefore, water/cement ratio that will give the minimum value of slump with adequate workability as well as minimum cement content should be exploited with maximum aggregate size in order to minimize the shrinkage cracking.

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