Effects of Curing Environment on the Performance of Concrete Containing Sodium Chloride Additive

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***Abstract* - The research scrutinized the effects of varying amount of sodium chloride (NaCl) addition and type of curing water on the workability, density and the compressive strength of concretes produced from Portland limestone cement (PLC) at 7, 14, 21 and 28 days. The percentages of NaCl added to the concrete mix were 0, 2, 6 and 10 %. A constant water / binder ratio of 0.5 was used for all mixes. The results showed that raw and 2 % NaCl concrete mixes have similar slump and reasonably competitive strength properties. Generally, the performance of concretes decreases with increasing NaCl contents and concretes cured in sea water have poorer results compared to those cured in ordinary water. It is recommended that the common cement (PLC) may not be used for constructions around sea areas as they would be prone to more deterioration, but pozzolans or other chloride resisting cements should be applied.**

***Keywords* - Compressive strength, Curing water, Density, Portland limestone cement, Sodium chloride (NaCl).**

I. INTRODUCTION

The progression of hydration reactions in cementitious binders is essential to improve he potential mechanical properties (e.g. compressive strength, modulus of elasticity, volume stability etc.) and the durability performance of concretes made from such binders. The continuation of hydration depends on the type and duration of curing conditions, type and fineness of binder in use and the water binder ratio of the concrete mix among other factors [4]. Curing is therefore described as a way of creating a favourable environmental conditions (temperature and humidity) within a concrete structure to ensure the progress of hydration reactions till the desired concrete properties aer developed through the filling of capillary voids by hydrated compound products [5].

Moreover, an excessive temperature imbalance through the cross section of a concrete element can cause early thermal cracking as a result of restraint to contraction of the cooling outer layers from the warmer inner layer of the concrete. Poor, inadequate or zero curing will majorly affect the near surface layer (Up to 20 – 50 mm) of concrete in term of compressive strength, abrasion resistance and durability. In conjunction, the type of loading applied and size of the concrete element will determine the extent of the effects especially on the compressive strength of the concrete member [10].

Various countries have standard codes that relate to recommendations for curing duration. In the United Kingdom (UK), [3] recommends 0 – 10 days. [1] stipulates 3 days of moist curing, though not in cold weather. However, recent discovery on the influence of binder types on concrete microstructural properties has necessitated that curing period should be extended (even beyond 28 days) for concretes containing supplementary cementitious materials. All over the world, the cement market is growing on a trend away from conventional Portland cement and moving towards supplementary cementitious materials. Therefore, prolonged curing duration is a necessary requirement for modern concretes produced from supplementary cementitious materials such as slag, PLC, fly ash, silica fume and natural pozzolan due to their slow hydration reactions [2], [5].

Since maturity concept only relates to concrete strength and cannot directly predict the durability and abrasion resistance aspects of concrete properties, therefore, when concrete properties other than strength are required, it is necessary to extend curing beyond the period predicted [10]. Curing has been found to improve the quality of concrete cover by preventing the ingress of aggressive substances into the concrete structure, thus improving the durability of concrete.

Seawater usually contains some dissolved salts. When concrete is exposed to seawater, it is subjected to both chemical and physical attacks. The chloride ion induced corrosion is the chief and most serious attack to reinforced concrete structures. Other chemical attacks that can occur include salt weathering and freeze-thaw attack. Moreover, the intensity of the attack depends on the location of the concrete with reference to the seawater level. The surfaces of concrete in the tidal and splash zones (intermittently wetted) are usually vulnerable [6].

The methods of measuring degradation of concrete in aggressive environment have been researched for a while now. A decrease in flexural strength was used as a measure of concrete degradation. Change in mass was considered as a measure of degradation in the laboratory experiments on the (biogenic) sulphuric acid corrosion. Change in radius, reduction in sound velocity, electrochemical potential, change in pH etc are other factors that have also been used as parameters to quantify degradation in concrete materials [4], [5], [8].

In many field studies, surface softening and loss of structural stability are the commonest damage indicators. It is noted that the choice of the degradation measure may lead to different conclusions, regarding the relative performance of concrete types. Therefore, one single measure may not suffice to characterize the degradation sufficiently. Therefore, the use of multiple (combination of two or more) relevant indicators to investigate the resistance of concrete against attack in aggressive aqueous solution is recommended [7].

The objective of this work is to explore the effect of salt as an additive on concrete and to investigate the performance of concretes cured in varying environments. The indicators used are changes in density (weight) and compressive strength of the concrete specimens.

II. MATERIALS AND METHODS

The data presented in this paper are part of an on-going research in the concrete laboratory of Civil Engineering Department of the Federal polytechnic, Ado-Ekiti, Nigeria. The binder used for the tests is PLC with a fineness of 340 m^2 / kg. The PLC is CEM II B-L containing between 21 and 35 % limestone replacing clinker and the binder is of strength class 32.5 N. The binder was obtained from one of the commercial cement shops in Ado-Ekiti, Ekiti State, Nigeria. It was selected based on the fact that it is the commonest cement type used by concrete producers in Ekiti State, Nigeria. The chemical composition of the binder is presented in Table 1. The fine aggregate used for the concrete mixes is a natural sand of 2 mm maximum aggregate size with a fine modulus of 2.27. The sand was obtained along Afao / Ado road. The coarse aggregate used was crushed granite stone of size 12 mm with a specific gravity of 2.6. The mixing water used was potable tap water supplied by the Federal Polytechnic, Ado-Ekiti borehole. Moreover, some of the concrete samples were prepared without additives the others were prepared with NaCl as additive. The proportion of the NaCl addition were 0, 2, 6 and 10 % by mass of the binder.

Table 1: The Chemical Composition of the Binder

SiO_2	Al_2O_3	Fe_2O	CaO	MgO	K_2O	Na_2O	SO_3	TiO_2	P_2O_3	LOI
16.8	3.42	2.10	59.4	2.15	0.57	0.15	1.83	0.29	0.06	13.3

The concrete mixes were prepared in a pan mixer of 50 litres capacity. The Water / Binder (W/B) ratio was kept constant at 0.5 for all mixes. The batching was done by weight. All the constituent materials (binder, aggregates and water) were kept constant for all mixes in order to have a reasonable comparison. The mixing pan was first charged with the coarse aggregate, then the sand and binder. These were dry mixed for about 3 minutes before water was slowly added to the mix. After mixing properly, slump test was performed for each concrete. Then the concrete was poured into 100 X 100 X 100 mm cube plastic moulds that have been prepared.

The wet density of each concrete mix sample was also determined immediately. After casting, the specimens were placed undisturbed on tables and flat surfaces for 24 hours at room temperatures in the laboratory. They were placed appropriately. The concrete specimens were removed from the moulds after 24 hours. The concrete specimens were divided into two groups (M and S) such that each concrete mix has sample specimens in each group. The specimens were labelled as presented in Table 2 based on the percentage of NaCl additive and the type of curing water. The concrete were fully immersed in water for curing. Two types of curing water were used in this study. The concrete specimens in group M were cured in ordinary portable water while group S specimens were cured in seawater obtained from the Atlantic ocean (Bar beach, Lagos, Nigeria). Curing regimes were allowed to last for 7, 14, 21 and 28 days. The density and compressive strength of the concretes were determined simultaneously at those ages. The concrete specimens were exposed to varying curing conditions. The density was determined by finding the average of the results obtained from three specimens. The workability of the concrete mixes was determined by performing slump test according to [9] test standards and procedures. The results presented show the average of three specimens tested for compressive strength and density.

Table 2: Concrete Mix Identification

Mix Identification Name	Salt Content (%)	Type of Water
M0	0	Ordinary water
S0	0	Sea water
M2	2	Ordinary water
S2	2	Sea water
M6	6	Ordinary water
S6	6	Sea water
M10	10	Ordinary water
S10	10	Sea water

III. RESULTS AND DISCUSSION

The slump results for the concrete mix were shown in Table 3. The results ranged from 100 to 125 mm. The results showed that concrete mix containing 2 % NaCl gave similar slump and reasonably competitive properties with raw concretes. It was observed that slump values increased with increasing salt content.

Table 3: Slump of Concrete Mixes

Mix Identification Name	Salt Content (%)	Slump (mm)
M0	0	100
S0	0	100
M2	2	100
S2	2	105
M6	6	115
S6	6	120
M10	10	125
S10	10	125

Tables 4 and 5 present the density of concrete specimens containing different percentage of salt additives. It was observed that the density of all the concrete specimens increased with age. The density of mix M6 at ages 7, 14, 21 and 28 days are 2354, 2362, 2370 and 2380 kg / m^3 respectively. The reason for the result could be attributed to increase in hydration products as hydration process progresses [6]. However, it is essential to note that more than 85 % of the total density (density at 28 days) was already attained at earlier age of 7 days. Consequently, only a minimal difference exists between the densities of a particular concrete mix at one age compared to another age. This can be due to similarity in the material constituents and proportions for each concrete mix.

Furthermore, the specimens cured in seawater gave lower density compared to similar specimens that were cured in ordinary water. For instance, concrete mix S10 cured in seawater for 28 days gave a density of 2325 kg / m^3; while the same concrete mix M10 containing equal amount of salt additive at the same age gave a density of 2355 kg/m3. The studies on durability usually indicate that a dense concrete will mostly be a durable concrete.

Table 4: Density of Concretes cured in Ordinary Water

Mix Id.	W / B Ratio	Age (days)	Salt Content (%)	Density (kg / m^3)
M0	0.5	7	0	2390
		14		2393
		21		2397
		28		2405
M2	0.5	7	2	2372
		14		2380
		21		2386
		28		2400
M6	0.5	7	6	2354
		14		2362
		21		2370
		28		2380
M10	0.5	7	10	2325
		14		2337
		21		2349
		28		2355

From Figures 1 and 2 show the compressive strength of concrete specimens with varying salt contents cured in ordinary and sea water respectively. The concrete specimens were produced at the same W/B ratio with similar binder and aggregates contents. It was observed that the compressive strength of all concrete specimens increase with increase in age and period of curing irrespective of the curing environment.

Table 5: Density of Concretes cured in Sea Water

Mix Id.	W / B Ratio	Age (days)	Salt Content (%)	Density (kg / m^3)
S0	0.5	7	0	2370
		14		2381
		21		2385
		28		2393
S2	0.5	7	2	2366
		14		2371
		21		2380
		28		2388
S6	0.5	7	6	2347
		14		2351
		21		2359
		28		2363
S10	0.5	7	10	2392
		14		2308
		21		2317
		28		2325

For instance, the 28 days compressive strength of specimen M0 is about 21, 13 and 7.3 % greater than 7, 14 and 21 days compressive strength respectively. This can be attributed to development of concrete strength with hydration and cementitious materials' hydration improves with increase in age and curing duration. It was also observed that the raw concrete specimens (M0 and S0) gave higher compressive strength than the NaCl concrete specimens at all ages. In the two curing conditions, the compressive strength decreases with increase in salt content. Concrete mix M2 containing 2 % salt additive gave compressive strength of 15.4, 17.1, 18.1 and 18.7 MPa at ages 7, 14, 21 and 28 days respectively. While M10 containing 10 % salt additive gave 13.7, 14.3, 14.7 and 15.2 MPa at ages 7, 14, 21 and 28 days.

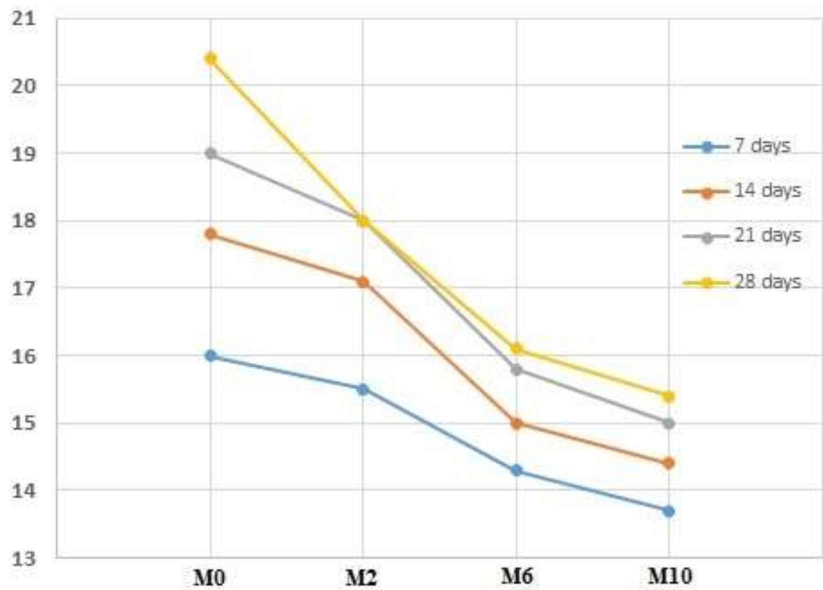

Figure 1: Effect of Salt Content on the Compressive Strength of Concretes cured in Ordinary Water

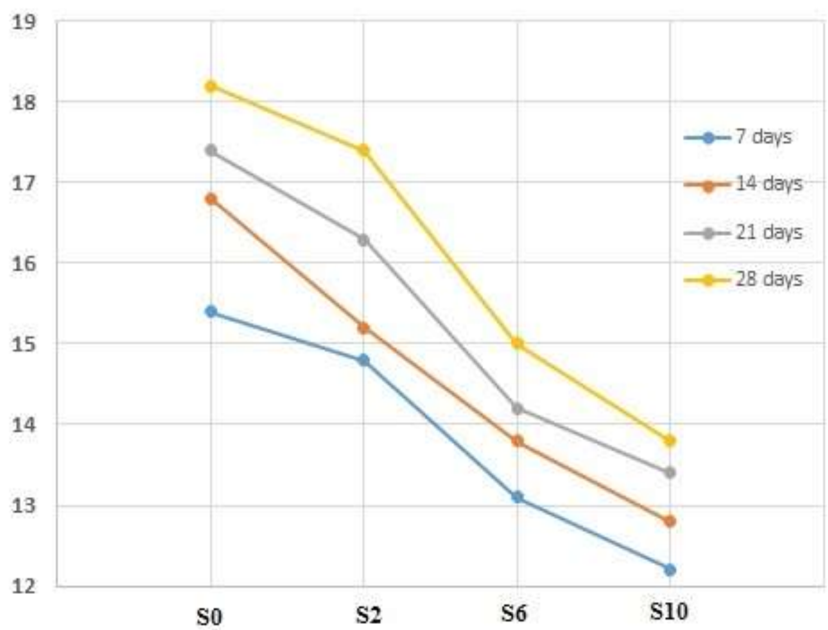

Figure 2: Effect of Salt Content on the Compressive Strength of Concretes cured in Sea Water

Comparatively, concrete specimens that were cured in seawater gave lower compressive strength than those cured in ordinary water. Concrete mix M0 gave the highest 28 days compressive strength of 20.5 MPa while mix S10 gave the least compressive strength of 12.1 MPa at 7 days of curing. The addition of salt has negative effects on the concrete strength.

IV. CONCLUSION

From the above study, the following conclusions were drawn:

1. NaCl concrete gave higher slump values than raw Concrete specimens. This indicates that whenever concrete mixture is suspected to contain salt, the W/B ratio should be kept low.

2. The density of the concrete specimens increase with age since hydration products increase as hydration process progresses.
3. The concrete specimens cured in seawater gave lower density compared to those ones cured in ordinary water.
4. The compressive strength of all concrete specimens increase with age and period of curing irrespective of the curing environment.
5. The compressive strength of concrete decreases with increasing salt content,
6. Concrete specimens that were cured in seawater gave about 12 % reduction in compressive strength compare to those cured in ordinary water at the same age.

Recommendation

It is recommended that further work should be done on the durability performance of the NaCl concrete specimens when exposed to seawater curing. The use of PLC around sea areas should be avoided as it will be prone to more deterioration, but pozzolans or other chloride resisting cements should be applied.

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