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Effect of Curing Conditions on Durability and Strength of Concrete Containing Chemical Admixtures

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Abstract: *The effect of curing conditions on the compressive strength, surface absorption and permeability of concrete containing admixtures was investigated. Five mixes were designed: a control mix and four admixtures; waterproofer, chloride free accelerator, two superplasticizers- Polycarboxylate Ether (PCE) and Sulphonated Naphthalene Formaldehyde condensates (SNF) were used. M30 concrete of 0.55 water cement ratio (w/c) and 150- 180mm slump was designed as the control mix. Appropriate water reduction was made for mixes with admixtures to obtain the design slump. The concrete samples were separated into two; water and air cured samples. Compressive strength was tested at 3, 7 and 28 days; whereas Initial Surface Absorption Test ISAT and High Pressure Permeability Tests HPPT, were done at 28days. Results reveal that adequate curing is essential for optimum concrete performance even in mixes containing admixtures. In addition, the effects of improper curing is more manifested on durability parameters like water absorption and permeability than compressive strength.*

Keywords*: Curing, admixtures, durability, permeability, surface absorption, compressive Strength.*

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I. Introduction

Curing is the second most critical factor, after placement that influences cement hydration [1]. Appropriate curing can provide sufficient moisture and temperature for cement hydration so that the desired properties of concrete can be achieved. Sufficient water is essential for curing because hydration of cement can only take place in water filled capillary of not less than 80% relative humidity [2, 3]. Thus, extra moisture has to be provided to saturate the concrete and to compensate for moisture loss due to evaporation, self-desiccation (mostly occurring in low w/c concrete) and chemical shrinkage, until the water-filled pores in the cement paste are substantially reduced by hydration products [2, 3, 4].

On the other hand, improper curing may occur due to excessive evaporation [2] in some cases occasioned by hot weather and low humidity [5] thereby retarding cement hydration. Site constraints in the form of shortage of portable water in certain regions could also be a factor. Poor curing could also be as a result of poor construction practices leading to impairment of concrete performance [6]. The consequence is insufficient development of Calcium Silicate Hydrate (CSH) and poorly refined pore structure [3]. These will compromise strength, affect transport properties, increase porosity and permeability- particularly at the concrete surface, thus paving the way for the ingress of deleterious agents which can cause durability issues in concrete [7, 8, 9, 10, 11]. Regrettably, the effect of improper curing cannot be suitably assessed on the short run using strength parameters [8, 12], but it is a long term durability issue affecting the service life of the structure with its attendant economic loses elicited by repairs [13]. Thus durability indices such as permeability and surface absorption provides an appropriate measure of the degree of curing. From the foregoing, it becomes pertinent that concrete element be kept saturated as much as possible until the water-filled spaces are significantly occupied by hydration products [14].

II. Research Significance

A considerable amount of work has been done on the effect of curing on the performance of concrete containing mineral admixtures such as: silica fume, micro silica, fly ash, Ground Granulated Blast Furnace Slag (GGBFS) etc [15, 16, 3, 1]. Unfortunately, research has not done much on the effect of different curing conditions for concrete containing chemical admixtures regardless of the fact that these chemical admixtures have wider applications than the mineral admixture. This work will attempt to investigate the effect of poor and proper curing on concrete properties such as compressive strength, initial surface absorption as well as high pressure permeability of concrete made from different admixtures. The aim is to simulate the performance of concrete in areas where poor curing occasioned by scarcity of water and poor site practices prevail.

III. Materials

Ordinary Portland Cement of Grade 52.5 manufactured by Hanson Heidelberg cement group, United Kingdom (UK) was used. It has a density of 3029kg/m3 and complies to BS EN 197-1.
The aggregates conform to BS EN 12620. The sand density is 2670kg/m3 while that of the granite is 2525kg/m3 with maximum aggregate size of 14mm. The aggregates particle size distribution is represented in Fig.1.
Clean portable water was used.
The four different admixtures conform to BS EN 934-3: 2009. An average of the dosage range specified by the manufacturers were used.
Waterproofing admixture: Produced by the Sika group, UK. 1% by weight of cement dose was used.
Accelerator: Sika Accelerator- a chloride free rapid hardener manufactured by Everbuild Building Products Limited, UK. 3.75 litres/50kg of cement dose was used.
Sulphonated Naphthalene Formaldehyde Condensates (SNF) Superplasticizer (Conplast SP430). Produced by Fosroc limited, UK. 1.35 litres/100kg of cement dose was administered.
Polycarboxylate Ether (PCE) Superplasticizer (Auracast.200): Manufactured by Fosroc limited, UK. 0.75litres /100kg of cement dose was used.

IV. Experimental Plan

Sieve analysis was carried out in accordance with BS 882: 1992 and the particle size distribution curve of the constituent aggregates was plotted (See Fig 1). Grade 30 concrete as control was designed using the British mix design developed by the Department of Environment (1988). Other mixes comprised of four different admixtures: waterproofer, accelerator, two superplasticizers- Polycarboxylate Ether (PCE) and a Sulphonated Naphthalene Formaldehyde condensates (SNF). Thereafter, mixing was done in compliance with BS 5328: 1997. Suitable water reduction was carried out on addition of admixtures so that slump values are within the designed range of 150 – 180mm (See Table 1). After that, the fresh concrete was cast into 150mm cubes as well as 50mm diameter x 100mm high cylinders, compacted on a vibrating table and then allowed to set. After 24 hours, the hardened concrete specimens were demoulded. The specimens were separated into two; one half cured by total immersion in water and the other half kept in dry condition to simulate improper curing (air curing). Both sets of specimens were kept at temperature of 22°C ±3°C.

The following tests were then carried out by testing three specimens and the average results taken.

Compressive strength test in accordance with BS EN 12390-3-2009 was done after 3, 7 and 28 days. Also, the Initial Surface Absorption Test (ISAT) in compliance with BS 1881- 208:1996 was done after 28 days. Here, water cured samples were first removed from water and allowed to dry for 24 hours before testing. However, the air cured samples were tested directly on their due date as they do not require further drying.

Also, the High Pressure Permeability Test (HPPT) was carried out after 28 days. The apparatus is an adaptation of the Hoek cell. Here, the cylindrical concrete specimen were cut into cylindrical concrete disc of 50mm diameter by 30mm thickness. It is important the cut is smooth to avoid rough edges which may create visible pores- a possible source of error in the concrete specimen. When the apparatus is switched on, the time taken for a given volume of water to permeate through the concrete disc is recorded. Afterwards, Darcy's equation (equation 1) below is applied to calculate the coefficient of permeability K.

$$Q = \frac{KA\Delta P}{\mu L} \qquad 1$$

Where:
Q= flow rate in (m^3/sec)
K= coefficient of permeability (m^2)
A= Cross sectional area of sample (m^2)
ΔP = water pressure difference
μ= Viscosity of water (N.s/m²)
L= Length of sample

V. Results

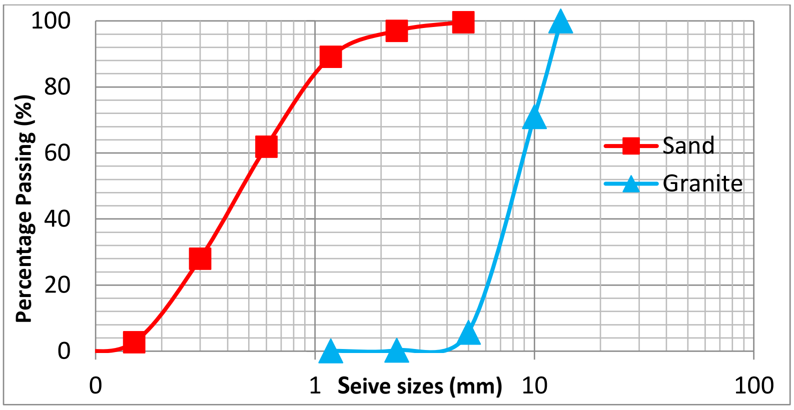

Fig. 1: Particle size distribution of aggregates

Table 1: Mix design results

MIX	ABBREVIATION	MIX RATIO	W/C	WATER REDUCTION (%)
Control	CON	1: 1.75: 2.40	0.55	0
Control + Waterproofer	WP	1: 1.75: 2.40	0.52	5.36
Control + Accelerator	ACC	1: 1.75: 2.40	0.45	18.17
Control + SNF Superplasticizer	SP1	1: 1.75: 2.40	0.35	36.66
Control + PCE Superplasticizer	SP2	1: 1.75: 2.40	0.34	37.59

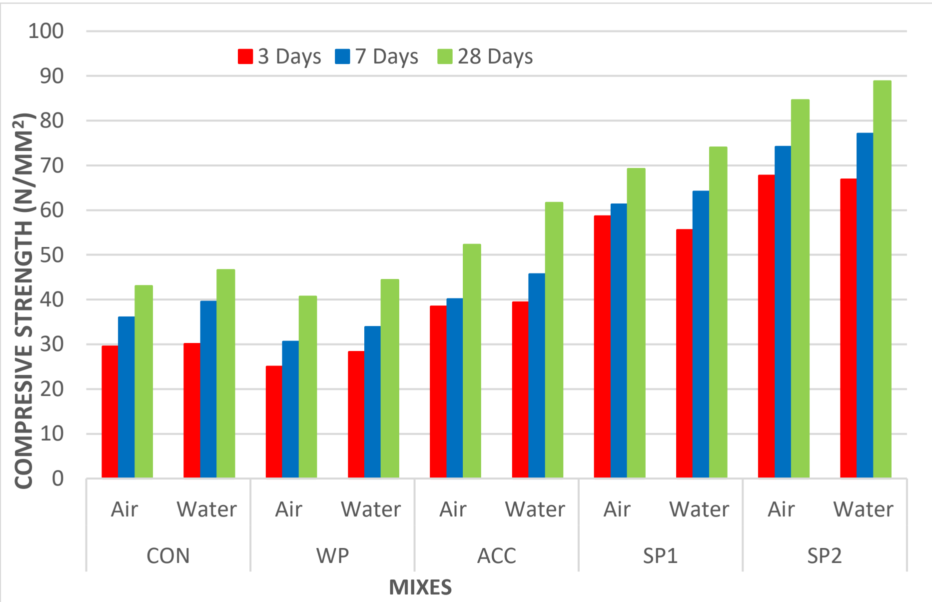

Fig. 2: Compressive strength development with age for different mixes subjected to air and water curing

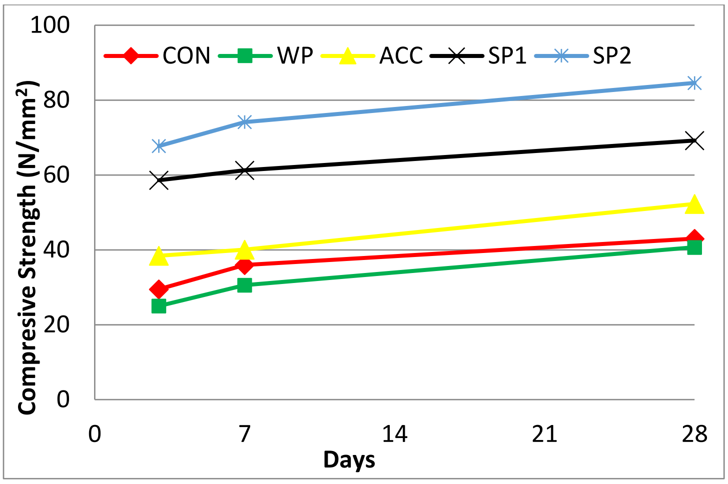

Fig. 3: Compressive strength against age for different mixes subjected to air curing

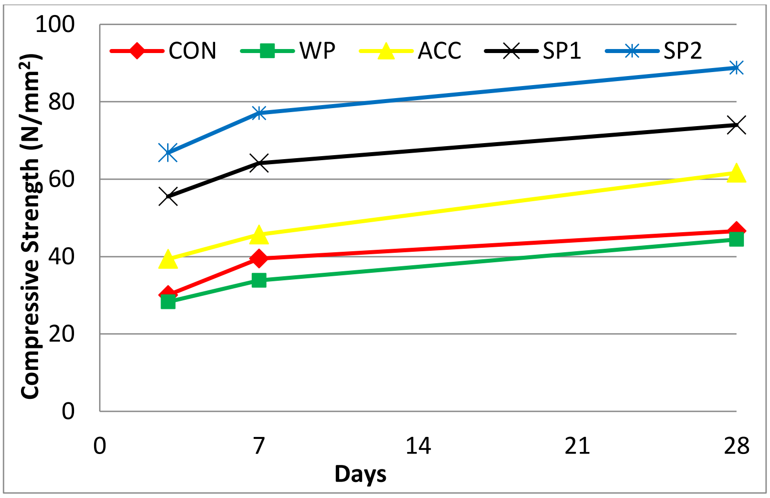

Fig. 4: Compressive strength against age for different mixes subjected to water curing

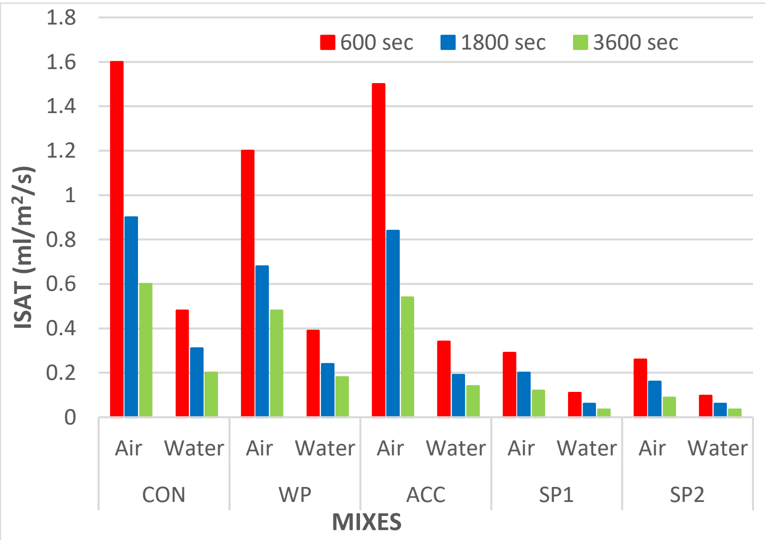

Fig. 5: ISAT result for all mixes

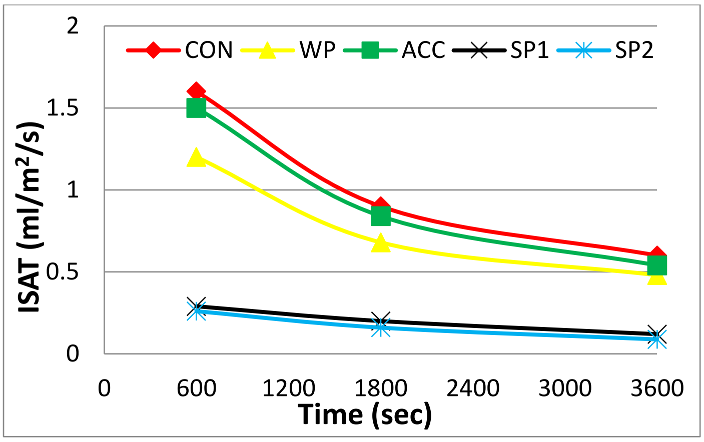

Fig. 6: ISAT graph for different mixes subjected to air curing

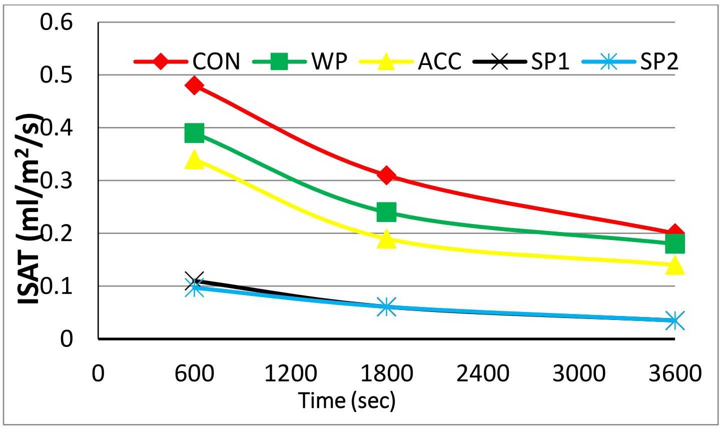

Fig. 7: ISAT graph for different mixes subjected to water curing

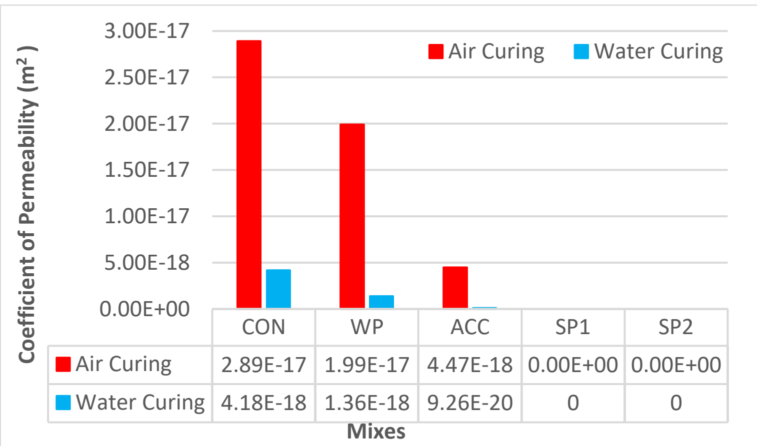

Fig. 8: Coefficient of permeability k for different mixes at 28 days

VI. Discussions

6.1 Compressive Strength

Results show that for all mixes, compressive strength generally increased with age owing to continuous cement hydration and subsequent development of Calcium Silicate Hydrate CSH.

It was also observed that for all mixes, the strength for samples cured in water was generally higher than corresponding samples cured in air at all ages. This could be attributed to presence of sufficient water required for hydration of cement and subsequent development of CSH [3]

At 28 days, the SP2 mix showed the least difference in strength between cured and uncured samples with a strength loss of 4.73 % whereas the ACC mix showed the most strength loss of 15.21%. This high difference could be as a result of catalyzed hydration reaction. Accelerators increase rate of hydration of tricalcium silicate (C3S) and tricalcium aluminate (C3A) phases of cement leading to increased temperature [17, 18]. The consequence is increased evaporation which reduces relative humidity and available moisture, thus CSH development is retarded [3].

Furthermore, results show that as w/c reduced on addition of admixtures, compressive strength generally increased (see Fig. 2 and Table 1). The PCE superplasticizer (SP2) gave the highest water reduction and strength. In comparison to the control, a 96.72% and 90.62% strength increase was recorded for air and water curing at 28days respectively. The high strength obtained by the PCE superplasticizer could be attributed to its high ability to deflocculate and disperse cement thereby allowing for greater interaction between cement and concrete constituents thus giving rise to more hydration reaction and products [19]. Conversely, WP mixes showed lower strength values at all ages compared to the control despite reduced w/c. At 28 days, a strength reduction of 5.37% and 4.68% was observed for air and water curing respectively. This anomaly may be due to the ability of WP to entrain air thereby leading to a loss of compressive strength [20, 21].

6.2 ISAT Results

The surface absorption for all mixes reduced with increasing time as water filled length of capillaries (see Fig 5-7).

It was observed that for all mixes, the water absorption for air cured samples was generally higher than the corresponding water cured samples at all ages of measurement. Moisture loses which is prominent at the surface of air cured samples could be responsible for this [3]. Secondly, this moisture loses could induce volume changes, shrinkage and build up tensile stresses and cracks at the concrete surface leading to higher absorption [3] [17].

The disparity between absorption values of air and water cured samples is highest in ACC mixes. For ages tested (600, 1800 and 3600 seconds), results show that air cured samples in ACC gave an average of 323% more water absorption than water cured ACC samples. The nearest disparity is from SP1 with a value of 211.45% and the least coming from SP2 with a value of 160.59%. This high disparity of ACC could have resulted from the accelerated hydration rates of C3S and C3A cement phases thereby causing increased evaporation, reduced humidity, drying out as well as increased cracks culminating in higher absorption. In addition, the uneven cooling of the concrete can set up temperature gradient and thermal stresses leading to cracks [17, 18].

Results show that as w/c reduced due to addition of admixtures, the water absorption values also reduced (See Table 1 and Fig. 5). However, results of WP mixes were very much comparable to ACC mixes for both air and water cured samples. This is despite WP mixes having a higher w/c than ACC mixes. This could be attributed to hydrophobic effects of the water proofing admixture which reduces capillary absorption for water under non-hydrostatic condition [20, 21, 22].

6.3 High Pressure Permeability Test HPPT

HPPT results are presented in Fig. 8. It was observed that results were not obtained for SP1 and SP2 mixes for both air and water curing even when the samples were tested for 72 hours and the water pressure maintained at 50 bars. The excellent dispersion ability of cement particles by superplasticizers during mixing may have resulted in the production of less porous and dense concrete with discontinuous pores [9]. Thus giving rise to impermeable concrete at the testing pressure of 50bars.

From the results obtained, it could be seen that water cured samples were less permeable than air cured samples for all mixes. As already explained in previous section, this is as a result of sufficient CSH produced by water curing. The CSH act as pore blocker, enhances concrete dense microstructure as well as ensuring discontinuity of pores thereby reducing permeability [3].

Once again, ACC mixes showed enormous difference between air cured and water cured samples. In this case, air cured samples were over 4700% more porous than water cured samples. The reason remain the crack/pore network development and moisture loses associated with accelerated C3S and C3A cement phases. Also, the very high disparity emphasis the effect of hydrostatic pressure on poorly cured ACC specimens.

Results also show a steady decline in permeability as w/c reduced. This may be attributed to reduction in concrete capillary pore network/volume as w/c reduces.

Finally, the waterproofing admixtures did not perform satisfactorily here, indicative that its hydrophobic action is not effective under hydrostatic pressure.

VII. Conclusion

- Adequate curing is essential for optimum concrete performance even in cases where chemical admixtures are used.
- Moisture losses are not observed in water curing thus high relative humidity is maintained to enable complete concrete hydration.
- The effect of poor curing is more profound on durability parameters such as surface water absorption and high pressure permeability rather than on compressive strength.
- Concrete performance should be assessed on durability parameters rather than compressive strength
- The disparity in performance between cured and uncured concrete is most manifested in concrete containing accelerating admixtures.
- Superplasticizers, particularly the Polycarboxylate Ether (PCE) are very effective in the production of durable concrete

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