International Journal of Modern Engineering Research (IJMER)
www.ijmer.com Vol.3, Issue.2, March-April. 2013 pp-709-714 ISSN: 2249-6645

Influence of curing regime on strength development of grade C60 concrete

A.E. Abalaka, [1] O. G. Okoli[2]
[1]*Department of Building, Federal University of Technology, Minna, Nigeria*
[2]*Department of Building, Ahmadu Bello University, Zaria, Nigeria*

Abstract: Compressive strength of grade C60 concrete cubes cured in water and ambient air (uncured) were determined at 3, 7, 14, 28 and 90days. At 90 days, uncured specimens recorded strength reduction of 15.50% compared to control. Furthermore, cubes of the same grade of concrete were cured for limited durations in water and then removed and subsequently stored in air, and their compressive strength determined at 28 and 90 days. At test age of 28days, cubes that were water cured for only 3days recorded maximum compressive strength of 74.15N/mm^2. However at 90 days, cubes that were water cured for only 28 days recorded the maximum compressive strength of 77.58N/mm^2. The sorptivity and coefficient of water absorption did show improved pore structures and reduced permeability as water curing days increased.

Keywords: Curing, hydration, compressive strength.

1. Introduction

Proper curing of concrete is important in ensuring that concrete structures meet expected performance criteria with reduced maintenance costs. Curing of concrete is the process used for promoting the hydration of cement and consists of the control of temperature and of the moisture movement from and into the concrete, and it is generally accepted that concrete has to be sufficiently cured to provide optimum performance (Khatri *et al.*, 1977; Tasdemir, 2003). The aim is to keep the concrete saturated or as nearly saturated as possible until the originally water-filled space in the fresh cement paste has been filled to the desired extent by the products of cement hydration (Mamlouk and Zaniewski, 2011; Neville, 1981; Taylor, 2000; Stark, 2011). For hydration to proceed, it is important to saturate calcium silicate hydrate (C-S-H) gels with water. This water is usually provided externally by curing or internally using water saturated porous aggregates. Proper curing reduces the rate of moisture loss and provides a continuous source of moisture required for the hydration that reduces the porosity and provides a fine pore size distribution in concrete (Alamri, 1988). Though cement hydration produces many solid hydration products, the major hydration product responsible for compressive strength of concrete is a rigid C-S-H gel. Though the atomic structure of C-S-H gel, the nature of its formation, and its molecular bonding is not certain, studies suggest that the gel has a complex amorphous composition (Harris *et al.*, 2002; Murray *et al.*, 2010) that is mainly responsible for the compressive strength development in concrete. The work of Masoero *et al.* (2012) shows that CSH particles form at very diverse sizes and the diversity in the size of the nanoscale units leads to a denser, disorderly packing of the particles, which corresponds to stronger cement paste.

Though it is known that the growth of CSH gels and other solid hydration products in concrete is promoted by curing, studies have shown that the strength of concrete and microscopic pore structures are also affected by the degree of hydration. The study by Nassif *et al.* (2005) using high performance concrete show higher elastic modulus for specimens that were cured using burlap compared to air-dry cured specimens.

The work of Soroka and Baum (1994) showed that at 28 days, compressive strength of concrete cube specimens continuously wet cured was 40% higher than those uncured and at 90days, specimens continuously moisture cured had compressive strength 20% higher than those of uncured cubes. Alizadeh *et al*. (2008) reported compressive strength increases of concrete cubes cured in water compared to air cured cubes at 7 and 28 days using Portland cement at cement content of 400kg/m^3: importantly, compressive strength increases were reported to be more significant after 1, 3 and 6 days of moisture curing than 27days, though strength increase was recorded at 27 days. At specimen ages of 7 and 28 days there were no significant compressive strength difference between 6 and 27days of wet curing; this appears to suggest that the first 6 days of wet curing was more important in compressive strength increase over air curing.

The work of Parrott (1992) on the effects of 1, 3, and 28 days initial moisture curing on the permeability of concrete subjected to drying for 6 and 18 months at 60% RH shows that the permeability of concrete samples subjected to 3 days curing was about one-sixth of the samples cured for only one day. Similarly, the permeability of concrete subjected to 28 days initial curing was one quarter of the permeability of samples cured for only 3 days.

In another study by Shafiq and Cabrera (2004), ordinary Portland cement (OPC) concrete dry cured had total porosity 5-10% higher than wet cured samples at 28 days. Similarly, the coefficients of oxygen and water permeability of air dried samples were 2-19 times higher than coefficients obtained for water cured samples.

Hydration of cement is a long term process which requires water and proper temperature; longer curing duration results in increased hydration and strength. Since cement hydration is a long term process that can continue beyond 30 years (Wood, 1991), in practical concrete production this process cannot continue indefinitely for years, the important factor is how long the curing process should last to ensure that concrete reaches acceptable level of performance.

In this study, the compressive strength, tensile strength and durability properties of grade C60 were measured. The curing regime adopted was such that samples were cured for limited period of time and then stored on the laboratory floor (uncured) to determine the effect of limited water curing on concrete.

2. Materials and Method

A commercial brand of OPC (type 1) in Nigeria was used for this study. The compositions of the OPC used are given in Table 1.

Crushed granite of 20mm maximum size with specific gravity of 2.63 was used as coarse aggregates; natural river bed quartzite sand with specific gravity of 2.73 was used as fine aggregates. The results of the sieve analysis of the aggregates are given in Table 2. The particle size distribution of the fine aggregates correspond to zone 2 sand by the BS 882: 1983 classification. The concrete mix proportions used are given in Table 3.

The concrete was mixed in a tilting drum mixer for 3 minutes, and manually compacted in two layers in 100mm steel moulds. A chloride free lignosulphonate based plasticizer (Fosroc Conplast P505) complying with BS EN 934 standard was used to increase the slump of the concrete mix. After 24hrs in the moulds, the cubes were de-molded and cured in water in compliance to BS 1881. P111:1997 standard.

The study was done in two stages: The stage I study was to determine the separate effects of continuous water curing and open air storing conditions on compressive strength at ages of 3, 7, 14 and 28days; concrete cubes cured in water were used as control for this first stage. The cubes that were cured in water were removed at the ages 3,7,14, 28 and 90 days, excess surface water wiped off and the compressive strength determined. The cubes that were stored on the laboratory floor were tested at the ages of 3,7,14, 28 and 90 days and their compressive strength determined. In the technical term of curing, the cubes that were stored in the open air in the laboratory would be considered as uncured specimens.

In the stage II, concrete cube specimens cured in water for limited durations of 1, 2, 3, 4, 5, 6, 7, 14 and 28 days were removed from the curing tank and then stored on laboratory floor and their compressive strength was determined at test ages. The age of test was inclusive of the continuous wet curing duration. The chosen regime was such that cubes that were cured in water for 1 day for example, were removed from the curing tank at that age and then stored on the laboratory floor for another 27 days and the compressive strength determined at the age of 28 days. The relative wet curing durations of these specimens at 28 days are shown in Figure1. At 90 days, the compressive strength of the cubes that were cured for limited durations and that of the cubes continuously cured in water were determined. Figure 2 shows the relative durations of water and air curing days of the cubes at 90 days. The split tensile strength of cylinders (150mm×300mm), sorptivity and coefficient of water absorption of the cubes were determined at 90 days. The average daytime temperature recorded was 23^{o}C at an average daily relative humidity of 44%.

The compressive strength of the cubes were determined in compliance to BS 1881: part 4:1970 standard using *ELE ADR 3000* digital compression machine at a loading rate of 3.00kN/s; split tensile strength of concrete cylinders were determined in compliance to BS 1881: Part 117: 1983 standard using the same machine at a loading rate of 2.10kN/s.
Three samples were tested for each parameter investigated and the results are averages of three specimen tests.

Table 1. Composition of OPC by XRF

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O
24.79%	6.35%	0.92%	58.50%	2.87%	4.91%	0.80%
Na_2O	**Mn_2O_3**	**P_2O_5**	**TiO_2**	**Cl-**	**SR**	**AR**
0.65%	0.0%	0.15%	0.06%	0%	3.41	6.88

SR: silica ratio=SiO_2/ (Al_2O_3+Fe_2O_3), AR=alumina ratio= Al_2O_3/Fe_2O_3

Table 2. Particle size distribution of aggregates as percentage by weight passing sieve sizes

	Sieve size (mm)							
	20	**10**	**5**	**2.36**	**1.18**	**0.60**	**0.30**	**0.15**
Fine aggregates	-	-	92.4	81.6	61	38.3	14.5	5.3
Coarse aggregates	95.00	40.62	0.80	-	-	-	-	-

Table 3. Concrete mix proportions

Cement content	Sand	Coarse aggregates	Free w/c ratio
400kg/m^3	512.4kg/m^3	1317.6kg/m^3	0.30

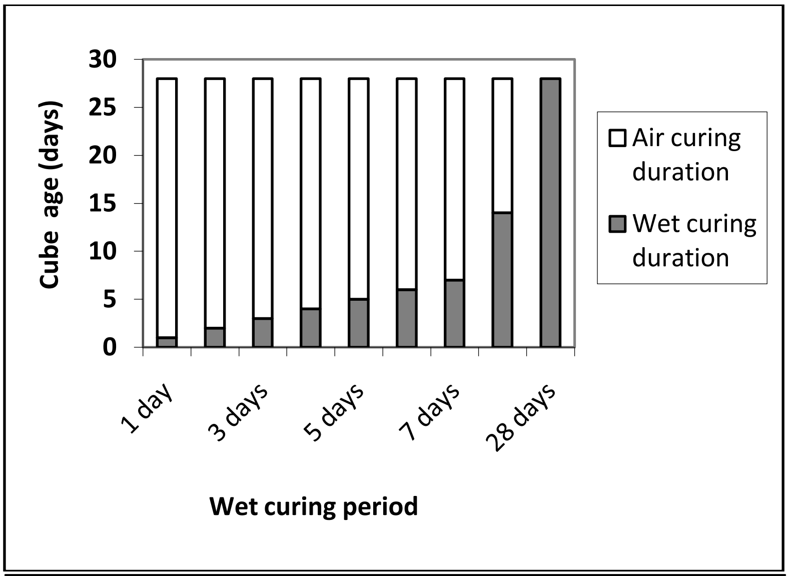

Figure 1. Relative proportions of specimen curing periods at 28 days for stage II study.

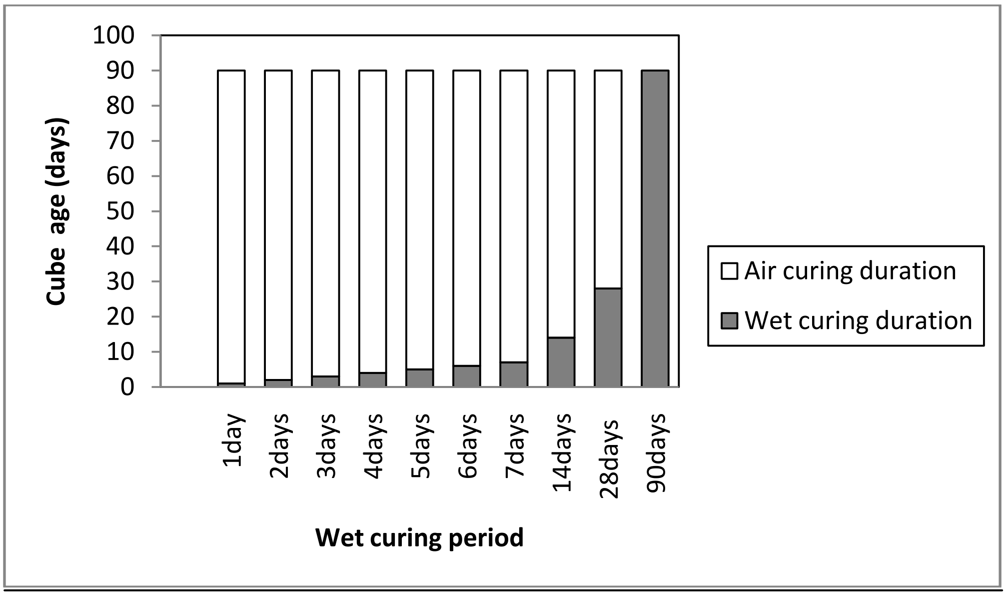

Figure 2. Relative proportions of specimen curing periods at 90days for stage II study.

2.1. Coefficient of water absorption

Coefficient of water absorption is a measure of permeability of concrete (Ganesan, 2008; Giannotti da Silva *et al.*, 2008). This is determined by measuring water uptake in dry concrete in a time of 1 hour. The concrete specimens were heated in an oven at 98^{o}C until a constant weight was attained at ten days and the cubes were allowed to cool gradually to room temperature for 24hrs. Four sides of 100mm cube samples were sealed with 1mm thick silicone sealant to a height of 30mm to allow water absorption on only one surface of the cube. The samples were immersed to a depth of 10mm in water as shown in Fig. 3. After immersion in water for one hour, the cubes were taken out and the wet surface was wiped of excess water and weighed. The coefficient of water absorption of the specimens at 90 days was calculated from the formula,

$K_a = \left[\frac{Q}{A}\right]^2 \times \frac{1}{t}$, where K_a is the coefficient of water absorption (m^2/s), Q is the quantity of water absorbed (m^3) by the oven dry specimen in the time (t), t=3600 seconds and A is the surface area (m^2) through which water was absorbed (Ganesan *et al.*, 2008).

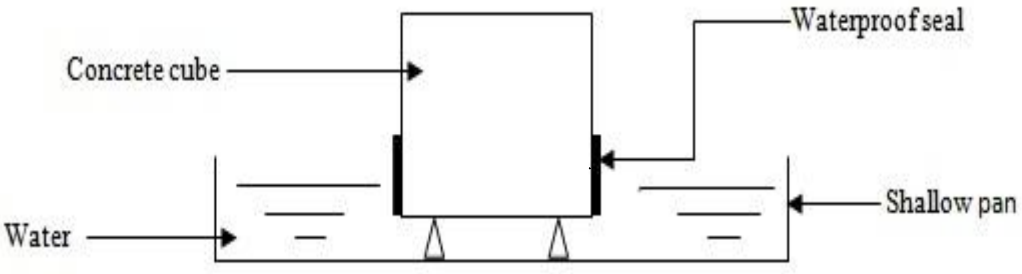

Figure 3. Coefficient of water absorption and sorptivity test

2.2. Sorptivity

Sorptivity is a measure of the capillary forces exerted by the pore structure causing fluids to be drawn into the body of the material (Ganesan *et al*., 2008; Hall, 1989). The concrete specimens were heated in an oven at 98°C until a constant weight was attained at ten days and then allowed to cool to room temperature for 24hrs. The sides of the cubes were coated with silicone sealant to allow the flow of water on only one surface of the cube specimen. The cube specimens were immersed to a depth of 10mm in water on only one surface. The initial mass of the cube was taken at time 0 and at time intervals of 1, 2, 4, 8, 10, 20, 30, 60 and 90 minutes, the samples were removed from water and excess water blotted off and the sample weighed. It was then placed back in water and the process repeated at the same selected time intervals. The sorptivity value of the specimens at 90 days were calculated using the formula,
$i = S/\sqrt{t}$, where i is the cumulative water absorption per unit area of the surface (m^3/m^2); S is the sorptivity ($m/\sqrt{t}$) and t is the elapsed time (s) (Stanish *et al*., 1997).

3. Results

The results of compressive, split tensile strength tests on the concrete specimens at different ages for air cured (uncured) and water cured specimens are given in Tales 4 and 5. The results of coefficient of water absorption and sorptivity tests on water cured and uncured specimens at 90 days are also shown in the same Tables. The results in Tables 4 and 5 represent the stage I data.

Table 4. Effects of water curing on concrete for stage I study

Plasticizer (l/m^3)	**Slump (mm)**	**Wet curing** Compressive strength (N/mm^2)					Sorptivity $s\ (m \times \sqrt{t})$	Coefficient of water absorption **Ka** (m^2/s) $\times 10^{-8}$	Tensile strength (N/mm^2)
		3days	**7days**	**14days**	**28days**	**90days**	**90days**	**90days**	**90days**
5.0	5	54.30	54.58	63.65	66.25	72.15	0.810	1.406	4.817

Table 5. Effects of air curing on concrete for stage I study

Plasticizer (l/m^3)	**Slump (mm)**	**Air curing** Compressive strength (N/mm^2)					Sorptivity $s\ (m \times \sqrt{t})$	Coefficient of water absorption **Ka** (m^2/s) $\times 10^{-8}$	Tensile strength (N/mm^2)
		3days	**7days**	**14days**	**28days**	**90days**	**90days**	**90days**	**90days**
5.0	5	49.21	53.56	54.92	60.55	60.93	1.244	4.933	4.198

The results of the stage II study are given in Table 6. The compressive strength of 61.63N/mm^2 represents the results of cube tests on specimens that were cured in water for only 1day, removed at the end of one day and stored in the laboratory for another 27days and tested on that day. The compressive strength of 62.22N/mm^2 represents the result of the same set of cubes that were previously cured in water for only 1 day, but stored in air and tested at the age of 90days. The split tensile test, sorptivity and coefficient of water absorption tests on specimens at the age of 90 days are given in Table 6.

Table 6. Effect of limited wet curing duration on compressive strength of concrete for stage II study

		Wet curing duration									
	Test age	**1day**	**2days**	**3days**	**4days**	**5days**	**6days**	**7days**	**14days**	**28days**	**90days**
Compressive strength (N/mm^2)	**28days**	61.63	60.77	74.15	65.09	68.57	64.88	66.13	72.99	64.57	-
	90days	62.22	62.67	74.94	69.90	70.58	71.10	67.75	73.32	77.58	72.15
Tensile strength (N/mm^2)	**90days**	4.083	4.831	4.729	4.994	4.173	4.884	4.951	4.474	5.471	4.817
Sorptivity s $(m \times \sqrt{t})$	**90days**	0.893	0.891	0.891	0.884	0.887	0.884	0.884	0.884	0.880	0.810
Coefficient of water Absorption **Ka** (m^2/s) $\times 10^{-8}$	**90days**	2.259	1.968	1.875	1.870	1.865	1.765	1.755	1.631	1.575	1.406

4. Discussion

The results of compressive strength tests for the stage I study on water cured and uncured cubes in Tales 4 and 5 show substantial strength reductions for the uncured specimens compared to the water cured specimens at all the ages tested. The compressive strength loss of uncured cubes compared to water cured cubes was highest at 15.50% at the age of 90 days. Similarly, tensile strength of uncured cylinders was 12.85% less than the water cured cylinders at 90 days. The increases in compressive strength and tensile strength as a result of water curing recorded are due to the increased hydration of cement, promoted by curing. It is well known that increased hydration promotes the growth of calcium silicate hydrate (CSH) gels that are mainly responsible for the high compressive strength of concrete. The values of the coefficient of water absorption and sorptivity measurements of the cubes show a more compact microstructure of the concrete as a result of increased hydration. The sorptivity of uncured cubes was 53.58% higher than that of water cured cubes at 90 days. In a similar manner, the coefficient of water absorption of uncured cubes was 250.85% higher than that of water cured cubes. During cement hydration, other solid hydration products are formed in addition to CSH gels, and since curing promotes the formation more of these products, a more compact concrete results from water curing.

The results in Table 6 show the effects of limited water curing on mechanical properties of concrete for the stage II study at 28 and 90days. The maximum compressive strength value of 74.15N/mm^2 was recorded at only 3 days of wet curing and test age of 28 days. The results of stage I tests and stage II tests can be compared since the specimens are from the same grade of concrete. For example, the compressive strength of cubes cured for only 1day and tested at 28 days (61.63N/mm^2) shown in Table 6(stage II study) was slightly higher than that of cubes air cured for 90 days (60.93N/mm^2) representing stage I study shown in Table 5. Similarly, the values of the sorptivity of cubes cured in water for only 1day (stage II) was 26.61% less than that of uncured cubes of the same age(stage I study). The coefficient of water absorption of cubes cured for only 1day in water was 46.19% less than that of uncured cubes of the same age. These results show the significant compressive strength and microstructure improvement resulting from only 1day of moisture curing of concrete compared to uncured concrete at test age of 90 days.

At the age of 90 days, the maximum compressive strength recorded was at 28 days of limited water curing. The results indicate that limited curing saturates the concrete microscopic pores, and thus after cessation of curing, water was still available for hydration. The extent to which this water was available was determined by the degree of saturation, which in turn depends on the duration of limited curing. It is known that the degree of hydration of cement is dependent on the vapour pressure. The work of Powers (1947) shows that the degree of hydration is negligible at a vapour pressure below 0.3 of the saturation pressure and low hydration occurs at a vapour pressure of 0.8 of the saturation pressure. Spears (1983) opined that cement hydration does not improve when cured at relative humidity below 80%. Water curing by immersion of the cubes produces saturation pressure that promotes maximum hydration.

Increase in tensile strength of the concrete cylinders that were subjected to limited curing over uncured cylinders was recorded from 2 days and above.

The sorptivity and coefficient of water absorption of the cubes showed reduction in values as the wet curing duration period increased. The results show that though the cubes were removed from water, solid hydration products that improved the microstructure of the concrete were developed.

Though the compressive strength of cubes cured in water for only 1 day was 13.76% less than that cured continuously in water at 90 days, it is none the less 2.12% higher than that of uncured cubes of the same age (stage I study).

5. Conclusions

The results have shown that when concrete is subjected to limited early water curing, cement hydration would continue even when it is stopped. This would result in increase in compressive strength of the concrete and improved microstructure of the concrete compared to uncured concrete. Improvement in tensile strength of cylinders subjected to limited curing periods over uncured cylinders started from 2 days of limited water curing. The results have shown that the first six days of water curing was very significant in compressive strength development of concrete.

References

[1] BSI (1970). Methods of testing concrete for strength. BS 1881: Part 4. BSI. London. UK.

[2] BSI (1983). Splitting tensile (indirect) strength of cylindrical concrete specimens.BS 1881: Part 117. London.

[3] BSI (1983). Specification for aggregates from natural sources for concrete. BS 822. BSI. London. UK.

[4] BSI (1997). Methods of normal curing of test specimens. (20 degree C method). BS 1881. P111. BSI. London. UK.

[5] BSI (2001). Admixtures for concrete, mortar and grout. Concrete admixtures. Definitions, requirements, conformity, marking and labeling. BS EN 934-2:2001. BSI. London. UK.

[6] Ganesan K, Rajagopal K, Thangavel K. (2008). Rice husk ash blended cement: assessment of optimal level of replacement for strength and permeability properties of concrete. Construction and Building Materials. Vol. 22(8), p.1675-1683.

[7] Giannotti da Silva F, Liborio J. B. L, Helene P. (2008). Improvement of physical and chemical properties of concrete with Brazilian silica rice husk (SRH), Revista Ingeniería de Construcción Vol. 23:(1)., pp.18-25. Available at http://www.scielo.cl/pdf/ric/v23n1/art02.pdf

[8] Hall C (1989). Water sorptivity of mortars and concretes: a review. Magazine of Concrete Research. Vol. 41(14), p. 51-61.

[9] Harris A.W., Manning M.C., Tearle W.M., Tweed C.J. (2002). Testing of models of the dissolution of cements—leaching of synthetic CSH gels. Cement and Concrete Research. Vol. 32, p. 731–746.

[10] Khatri R.P, Sirivivatnanon V, Yu L.K. (1977). Effect of curing on water permeability of concretes prepared with normal Portland cement and with slag and silica fume. Magazine of Concrete Research. Vol.49 (180), p. 167–172.

[11] Masoero E, Del Gado E, Pellenq R.J, Ulm F.J, and Yip S. 2012. Nanostructure and nanomechanics of cement: polydisperse colloidal packing. Physical Review Letters. Vol 109(15). P, 155503-06.

[12] Nassif H. H., Najm H., Suksawang N. (2005) Effect of pozzolanic materials and curing methods on the elastic modulus of HPC. Cement and Concrete Composites. Vol. 27, p. 661–670.

[13] Neville A. M. (1981). Properties of concrete. Third edition. Longman scientific & technical. England, pp 307-318.

[14] Parrott L. J. (1992). Factors influencing relative humidity in concrete. Magazine of Concrete Research. Vol. 43, p.45–52.

[15] Powers T.C. (1947). A discussion of cement hydration in relation to the curing of concrete. Proceedings of highway research board. Vol.27, p. 177-88.

[16] Shafiq N., Cabrera J.G. (2004). Effects of initial curing condition on the fluid transport properties in OPC and fly ash blended cement concrete. Cement and Concrete Composites. Vol. 26, p. 381–387.

[17] Spears R.E (1983). The 80 percent solution to inadequate curing problems. Concrete international. Vol. 5, p. 15-18.

Stanish KD, Hooton RD, Thomas MDA (1997). Testing the chloride penetration resistance of concrete: a literature review, [19] FHWA contract DTFH61 1997, Department of civil engineering, University of Toronto, Canada. pp 19-22.

[18] Stark J (2011). Recent advances in the field of cement hydration and microstructure analysis. Cement and Concrete Research. Vol. 41, p. 666-678.

[19] Tasdemir C. (2003). Combined effects of mineral admixtures and curing conditions on the sorptivity coefficient of concrete. Cement and Concrete Research. Vol. 33, p. 1637-1642.

[20] Taylor G.D. (2000). Materials in construction, an introduction. Third edition. Pearson education limited. England. U.K, pp 50-51.

[21] Wood S.L. (1991). Evaluation of the long-term properties of concrete, ACI Materials Jour ush_reddy@yahoo.comnal. Vol. 88 (6), p, 630– 643