EFFECT OF CURING METHODS ON THE COMPRESSIVE STRENGTH OF CONCRETE

T. James, **A. Malachi**, **E.W. Gadzama**, **V. Anametemfiok**[a]
DEPARTMENT OF CIVIL ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY YOLA, NIGERIA.
[a]***Email:*** *gadzymo@yahoo.com (corresponding author).*

Abstract

Different curing methods are usually adopted to evaluate the compressive strength of concrete. This study reports the laboratory results of the effect of curing methods on the compressive strength as well as the density of concrete. A total of 72 cubes of mix ratio 1:2:4 were investigated after subjecting them to various curing conditions, with the aim of finding which of the curing method is best. The cubes were cured in the laboratory at an average temperature of 28°C (82.4°F). The results obtained showed that the average compressive strength values for 7, 14, 21 and 28 days, vary with curing methods. The results show that ponding had the highest compressive strength and density, followed by wet covering, sprinkling, then uncured for two days, with the totally uncured cubes having the least compressive strength and density as well as highest shrinkage limit. Ponding method of curing was recommended to be the best of all the curing methods.

Keywords: curing, compressive strength, ponding, sprinkling, uncured

1. Introduction

To "cure" concrete is to provide concrete with adequate moisture and temperature to foster cement hydration for a sufficient period of time. Proper curing of concrete is crucial to obtain design strength and maximum durability, especially for concrete exposed to extreme environmental conditions at an early age [1]. Others define curing as the process of controlling the rate and extent of moisture loss from concrete during cement hydration.

High curing temperature (up to 212°F or 100°C) generally accelerates cement hydration and concrete strength gain at early age. Curing temperature below 50°F (10°C) are not desirable for early age strength development. When the curing temperature is below 14°F (-10°C) the cement hydration process may cease. Concrete needs to be kept for a longer time in formwork when cast in cold weather condition [2].

On the whole, the strength of concrete, its durability and other physical properties are affected by curing and application of the various types as it relates to the prevailing weather condition in a particular locality, as curing is only one of many requirements for concrete production, it is important to study the effect of different curing method which best adapts to each individual casting process. This study presents the effects of different curing methods on the compressive strength of concrete cured for 7, 14, 21 and 28 days.

2. Review of Related Literatures

In concrete technology, the maintenance of the drying and setting process is referred to as curing. The purpose of curing is to keep adequate moisture content and temperature as soon as the concrete is placed and finished. It is one of the most important (and overlooked) steps and can have the greatest effect on the final outcome [1]. Properly cured concrete can have significantly superior properties compared to concrete left to set after finishing. Improperly cured concrete can be subjected to plastic shrinkage cracking (loss of moisture from fresh concrete) and drying shrinkage (loss of moisture from concrete that has set) among other undesired side effects [3]. Concrete properties and durability are significantly influenced by curing since it greatly affects the hydration of cement. As reported by [4], a proper curing maintains a suitable warm and moist environment for the development of hydration products, and thus reduces the porosity in hydrated cement paste and increases the density of microstructure in concrete. Studies by [5] reported that the hydration products of cement extend from the surfaces of cement grains, and the volume of pores decreases due to proper curing under appropriate temperature and moisture. They went further to report that for any concrete, curing acts just like feeding to a newborn baby, if a concrete is not fed with water at the early age, it cannot gain the properties and durability for its long service life. They therefore suggests that a suitable curing method such as water ponding, spraying of water, or covering with wet burlap and plastic sheet is essential in order to produce strong and durable concrete [2]. Research has shown that curing generally accelerates cement hydration and concrete strength gain at early age. Curing temperature below 50°F (10°C) are not desirable for early age strength development. When curing temperature is below 14°F (-10°C) the cement hydration process may cease. Cement hydration is an exothermic reaction, which generates a certain amount of heat. If the heat of hydration is kept in certain amount, it will benefit the cement hydration and concrete strength development. As a result, insulation and sealing materials are commonly used for concrete curing.

[6] stated that as hydration progresses, the amount of water in mortar pores reduces and the water becomes saturated with Ca^{2+}, Na^{+}, K^{+}, OH^{+}, and other ions are, however, really absorbed by the formation of a thin layer of hydration products, which form an envelope around the unhydrated cement grains. This envelope consists of electrical double layers of absorbed calcium ions and counter-ions that lead to a decrease of both the number and mobility of ions. Consequently, the electrical conductivity of the specimen starts to decrease after reaching maximum.

When concrete is mixed with water, the hydration process occurs. Cement hydration is an exothermal reaction, which depends on both time and temperature; the strength of concrete in the field is often evaluated by concept of maturity. Maturity is expressed as a function of the concrete temperature and time of curing [2].

$$M(t) = \sum (T_a - T_o)\Delta T \tag{1}$$

Where, $M(t)$ = maturity (degree-hours), T_a = average concrete temperature during interval °F, T_o = datum temperature (14°F) and ΔT = time interval (hours).

To account for the effect of initial curing temperature on the strength development of concrete at different ages, a concrete factor is suggested. The concrete strength at different ages different curing temperature will be calculated using equation 2 [7].

$$f_c(T,t) = f_c(T_r,t_e)[1-0.01(1-e^{-0.05t_e})(T-T_r)] \tag{2}$$

Where, $f_c(T,t)$ = the compressive strength of concrete at age t cured at temperature T, $f_c(T_r,t_e)$ = compressive strength of the same concrete at reference temperature T_r, t_e =

Equivalent age at reference Temperature T_r for age t at curing temperature T.

The application of liquid membrane forming curing compound is the most commonly used method of curing. These are organic materials that form a skin over surface of the concrete and help reduce the loss of mixing water (typically limiting water evaporation to about 20% of that of unprotected concrete). Curing compounds are merely temporary coatings on the surface, and will breakdown and degrade with exposure to sunlight and traffic [8].

According to [9], the application of any surface sealer should be done only on concrete that is clean and be allowed to dry for at least 24 hours at temperatures above 60°F [15°C].

3. Materials and Methodology

3.1. Constituent materials of concrete

The following are the constituent materials used to cast the concrete cubes for this study:

1. Fine aggregate (river sand).
2. Coarse aggregate (crushed gravel) 20 mm sizes.
3. Ordinary Portland cement (Ashaka cement).
4. Portable Water.

3.2. Preparation of test specimens

The dry constituents namely the aggregates (sand and gravel) and cement were mixed thoroughly, before water was added gradually to achieve a grey uniform color paste as mixing progressed. The mixed ratio was 1:2:4 with water/cement ratio of 0.5, which is a common mix used by most construction industries and the batch by weight method was used. The casting, curing and the concrete cube crushing were done in accordance with the guidelines specified by [10]; [11]; and [12] respectively. A cube mould size of (150mm×150mm×150mm) was used. The drying Shrinkage was carried out on 28-days cured cube in accordance to [13].

3.3. Methods of curing used

3.3.1. Ponding

The casted cubes were totally immersed inside water, throughout the curing period; the curing water was maintained at an average laboratory temperature of 28°C (82.4°F) to prevent thermal stresses that could result in cracking.

3.3.2. Sprinkling

The casted cubes were sprinkled with water periodically. Sprinkling with water is an excellent method of curing when the ambient temperature is well above freezing and the humidity is low.

3.3.3. Wet-covering

Hessian sac was used like a mulch to maintain water on the surface of the concrete cubes; also, it is important to ensure that the whole areas were covered. Wet covering material was placed as soon as the concrete cubes were hardened sufficiently to prevent surface damage. Through the curing period the sac is kept saturated with water.

3.3.4. Plastic sheet

Plastic sheet materials, such as polyethylene film, were used to cure the concrete cubes. Polyethylene is a lightweight, effective moisture retarder and was used easily applied to simple cubes shapes.

3.3.5. Totally uncured types (open air)

This method is the types where the cubes were left outside in the open air without any curing applied to it throughout the curing period, which tend to affect the cubes strength.

3.3.6. Cubes left uncured for two days before curing

This method is the type where the cubes were left uncured for two days before the cubes were subjected to curing.

4. Results and Discussion

4.1. Particle Size Distribution

Figure 1 is the plot of sieve analysis carried out in dividing the sample of aggregate into fractions which was prescribed in accordance with guidelines specified by [14]. As can be seen from the figure, the maximum and minimum grain size for gravel was 20 mm and 3 mm, while for sand it was 3 mm and 0.06 mm respectively. This corresponds to ranges for gravel and sand.

4.2. Compressive strength

Figures 2 and 3 shows a summary of the effect of curing method on the compressive strength with curing age for all the curing methods used. It could be seen that there was a significant increase in concrete strength with age depending on the curing method adopted. Compressive strength when arranged in descending order for all the curing methods, it could also be seen that ponding gave the highest result for the curing periods. This is due to improved pore structure and lower porosity resulting from greater degree of cement hydration and pozolanic reaction without any loss of moisture from the concrete cubes. Followed by wet covering, sprinkling, plastic sheeting, uncured for two days; the totally uncured method gave the lowest compressive strength. Since the concrete left total uncured gave the lowest result, this therefore suggests that curing is very important and necessary for all concrete structures.

4.3. Cube density

Figures 4 and 5, shows the variation of concrete cube densities with curing methods and age. From the figures it could be seen that the pattern of increase in concrete density was observed to be similar to that of the compressive strength, with few exceptional cases: 14 days for ponding as well as 21 days for wet covering where there was a decrease in the cube density. Of all the curing methods, only the totally uncured method of curing gave a continuous decrease in cube density with curing age. This therefore suggests that increase in both compressive strength and density of a concrete cube is a function of curing method.

4.4. Shrinkage

Table 1 shows results of the results of shrinkage limits for three curing methods, out of the six curing methods adopted, only Plastic sheeting, Uncured for two days and Totally uncured cubes indicated some level of shrinkage, while the other three: Ponding, Wet covering and Sprinkling did not record any shrinkage and it was for this that shrinkage results for only the three were shown in table 1. The results if arranged in descending order of severity, totally uncured gave the highest result of 0.23%, uncured for two days gave 0.20% and plastic sheeting gave 0.18% as the least shrinkage values. Evaluating this results suggest that, uncured concrete cubes shrinks faster when compared with the other two curing methods. It also suggests that proper curing methods when adopted will prevent shrinkage in concrete.

In an attempt to evaluate the advantages associated with the various curing methods used in this study, that ponding method was ranked first, because water stored for curing can be used throughout the curing process, although this method can best be suitable for precast members. Wet-covering was ranked second, because the hessian sac retained water and this reduces the wastage of water. Sprinkling and plastic sheet method ranked third, because large volume of water was wasted during curing process. Uncured cube (Open air), although it remained the cheapest of all the curing methods used during this study was ranked fourth, because it gave a continuous decrease in both compressive strength and cube density with curing age.

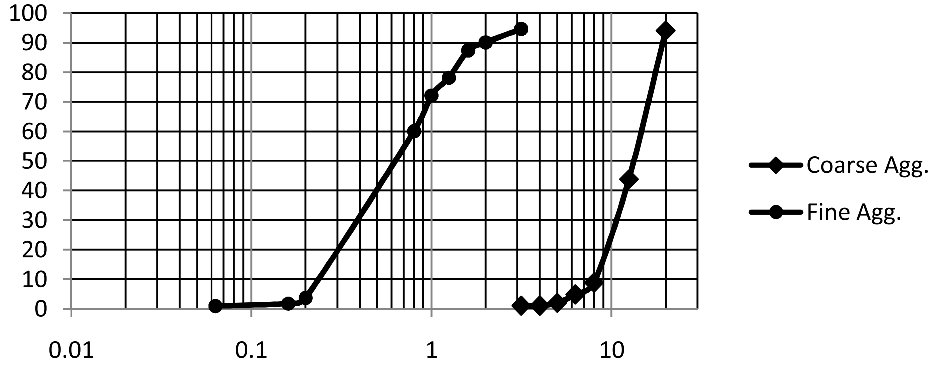

Figure 1: Particle Size Distribution for fine and coarse aggregates (sand and gravel).

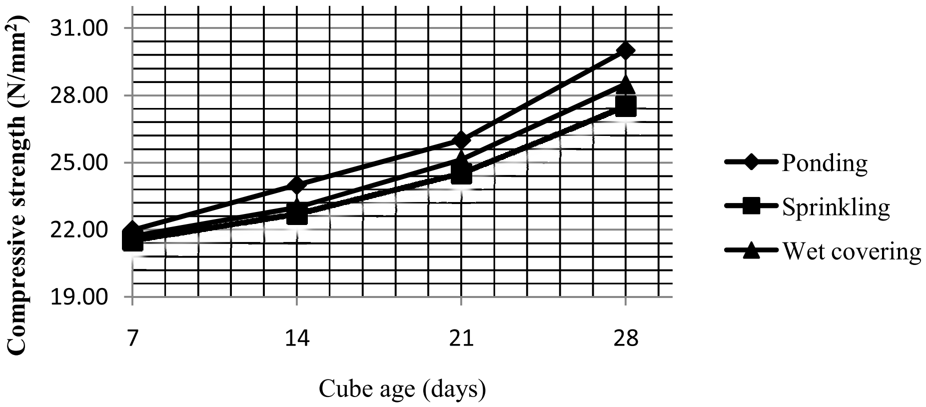

Figure 2: Variation of compressive strength with curing methods.

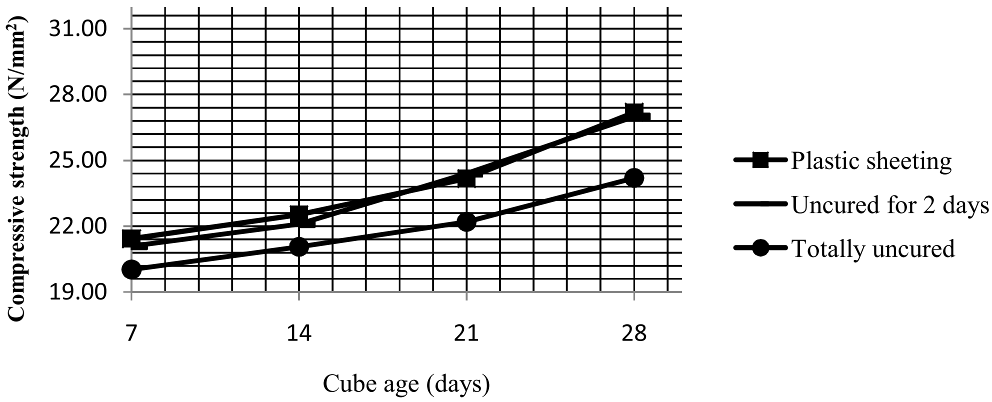

Figure 3: Variation of compressive strength with curing methods.

Table 1: Variation of shrinkage with curing methods.

Curing methods	**Cube age (days)**	**Cube length (mm)**		**Shrinkage (%)**
		Initial	Final	
Plastic sheeting	28	150	149.73	0.18
Uncured for 2 days	28	150	149.67	0.20
Totally uncured	28	150	149.65	0.23

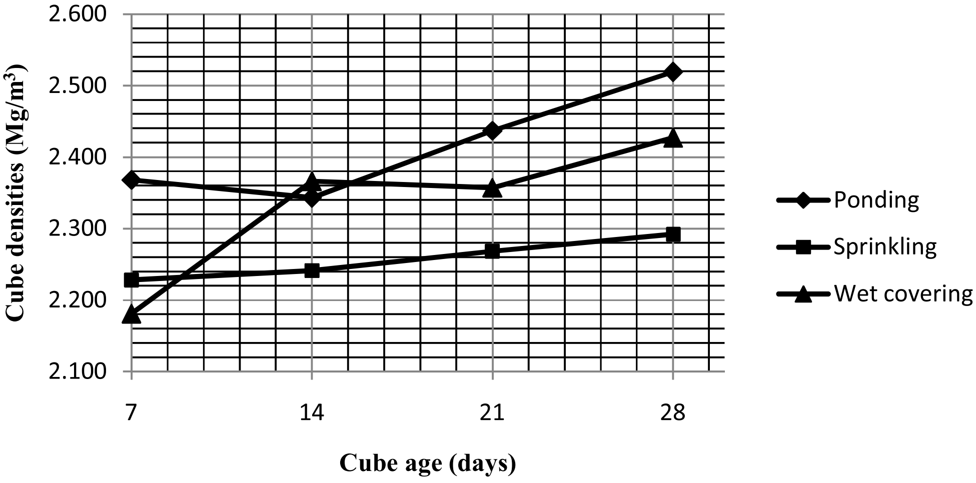

Figure 4: Variation of cube densities with curing methods and age.

5. Conclusions and Recommendations

5.1. Conclusions

Based on the results and discussion of this study, the following conclusions can be drawn:

1. Ponding was the most effective method of curing. It produced the highest level in compressive strength and cube densities.
2. Increase in both compressive strength and cube densities is a function of curing method.
3. Totally uncured method of curing produced the least compressive strength as well cube densities.
4. Totally uncured concrete shrinks faster when compared to other curing methods.

5.2. Recommendations

Based on the results and discussion of this study, the following recommendations are made:

1. Ponding method of curing is recommended to be the best of all the curing methods.
2. Sprinkling methods of curing is recommended to be used for areas where there is plenty of water, since large volume of water is needed.

References

1. James K. Cable, kejin Wang and Zhi. *Investigation into improved pavement curing materials and Techniques, part 1 (phase I and II).* Iowa DOT TR-451. Iowa Highway Research Board 800 Lincoln way. 2002.

2. ACI Committee 308. *Standard Practice for Curing Concrete.* ACI 308-92. American Concrete Institute, Detroit. 2000.

3. Samir H. Al-Ani, Mokdad A. and K. Al-Zaiwary. The effect of Curing delay on concrete in hot weather. *Materials and Structures*, Vol. 21 Number 3, 1988, pp 205-212.

4. M. Safiuddin, S.N. Raman and M.F.M Zain. Effect of different curing methods on the properties microsillica concrete, *Australian Journal of basic and applied sciences*, vol. 1 Number. 2, 2007, pp 87-95.

5. M.F.M Zain, M. Safiuddin and K.M. Yusof. Influence of different curing conditions on the strength and durability of high performance concrete. In *proceedings of the fourth ACI international conference on Repair, Rehabilitation and Maintenance*, ACI sp-193, American Concrete Institute Farmington Hills, Michigan, USA. 2000, pp 275-292.

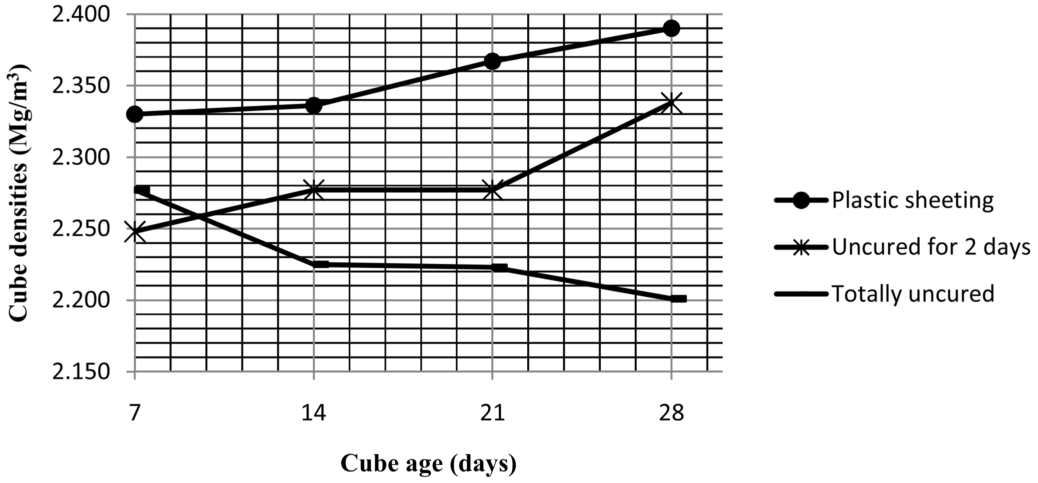

Figure 5: Variation of cube densities with curing methods and age.

6. Ragai, S.M., and T.M. Salem. Electrical Conductivity of Granulated Slag Cement Kiln Dust-Silica Fume Pastes at Different Porosities, *Concrete and Concrete Research*, Vol. 31, 2001, pp. 781-787.

7. Yahia A. Abdel-Jawal, Estimating concrete using a modified maturity model. In proceedings of the Institution of civil Engineers. *Construction Materials* 159. Issue CMI, 2006, pp 33-37.

8. P.C. Taylor, SH Kosmatka, G.F Voight, M.E Ayers, A Davis, G.J Fick, J.Gajada, J. Groove, D. Harrington, B Kerkhoff, C. Ozyildirim, J.M. Shiltone, K. Smith, S.M. Tarr, P.D Tennis, T.J Van Dam, and S. Waalkes. *Integrated materials and construction practices for concrete pavement: A state of the Practice manual*. FHWA HIF-07-004. Federal Highway Administration, Washington D.C, 2006.

9. S.H. Kosmatka, B. Kerkhoff and W. C. Panarese Design and Control of Concrete Mixtures. *Engineering Bulletin 001*. Portland cement Association, Skokie, IL, 2002.

10. BS 1881; part 108, *Method for making test cubes from fresh concrete*, British Standards Institution. 1983.

11. BS 1881; part 3, *Method for determination of density of partially compacted semi-dry fresh concrete*, British Standards Institution. 1992.

12. BS 8110: part 1. *Methods of Curing*, British Standard Institution. 1985.

13. BS 812: part 120. *Method for Testing and Classifying Shrinkage of Aggregate in Concrete*, British Standard Institution. 1989.

14. BS 1377; part 2. *Methods for test of soils for civil Engineering purposes*, British Standard Institution. 1990.