Effect of Curing Methods on Density and Compressive Strength of Concrete

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Abstract

This study considered the effect of different methods of curing on density and compressive strength of concrete. Concrete cube specimens of mix 1:2:4 were prepared with water-cement ratio of 0.65. The cubes were cured using six methods (air curing, water-submerged curing, spray curing, polythene curing, moist sand curing and burlap curing) until testing ages of 3, 7, 14, 21 and 28 days when their densities and compressive strengths were determined. The results showed that densities of the specimens ranged from 2432.59 to 2502.72 Kg/m^3. Also, moist sand curing method produced concrete specimens with the highest 28-day compressive strength of 30.5N/mm^2 followed by the burlap curing method with a value of 24.4N/mm^2. Air curing method showed a 15% reduction in strength after 21-days thereby resulting in the lowest 28-day compressive strength of 17.8 N/mm^2. It was concluded that there exists a weak positive correlation between density and compressive strength of concrete specimens.

Keywords: Concrete, Curing methods, Density, Compressive strength.

1.0. Introduction

All concrete requires curing in order that cement hydration can proceed so as to allow for development of strength, durability and other mechanical characteristics. To obtain good concrete, the placing of an appropriate mix must be followed by curing in a suitable environment, especially during the early stages of hardening. According to Neville (1996), curing is the name given to procedures used for promoting hydration of cement, and consists of a control of temperature and moisture movement from and into the concrete. Price (1991) refers to curing as the process of protecting concrete for a specified period of time after placement, to provide moisture for hydration of the cement, to provide proper temperature and to protect the concrete from damage by loading or mechanical disturbance.

Curing is designed primarily to keep the concrete moist by preventing loss of moisture from it during the period in which it is gaining strength. Curing can be achieved by keeping the concrete element completely saturated or as much saturated as possible until the water-filled spaces are substantially reduced by hydration products (Gowripalan *et al.*, 1992). The chemical reaction which curing aims at continuing, termed hydration of cement, virtually ceases when the relative humidity within capillaries drops below 80% (Neville, 1996). This implies that if the humidity of the ambient air is at least that high, then there will be no need for active curing to ensure continuing hydration because there will be little movement of water between the concrete and ambient air. In many parts of the world including Nigeria, the relative humidity falls below 80 per cent at a certain time in a day which therefore would not permit voluntary curing but rather would necessitate active curing. If the concrete is not cured and is allowed to dry in air, it will gain only 50% of the strength of continuously cured concrete (Mamlouk and Zaniewski, 2006).

If concrete is cured for only three days, it will reach about 60% of the strength of continuously cured concrete; if it is cured for seven days, it will reach 80% of the strength of continuously cured concrete. If curing stops for some time and then resumes again, the strength gain will also stop and reactivate (Mamlouk and Zaniewski, 2006). If a concrete is not well cured, particularly at the early age, it will not gain the required properties at desired level due to a lower degree of hydration, and would suffer from irreparable loss (Ramezanianpour and Malhotra, 1995; Zain *et al*., 2000). Improper curing would entail insufficient moisture and this has been found to produce cracks, compromise strength, and reduce long-term durability (Wojcik and Fitzgarrald, 2001).

It is a known fact that many other factors affect the development of strength of concrete and consequently its durability other than curing or the curing technique applied. These factors include quality and quantity of cement used in a mix, grading of aggregates, maximum nominal size, shape and surface texture of aggregate (Arum and Alhassan, 2005) water/cement ratios, degree of compaction (Aluko, 2005) and the presence or otherwise of clayey particles and organic matter in the mix (Arum and Udoh, 2005). The scope of discussion in this study is methods of curing concrete.

A number of curing techniques can be applied depending on various factors considered on site or due to the construction method. They range from the most popular water-submerged curing to moist sand, water-spray curing, polythene membrane sealing and steam curing (autoclaving). Also, there has been the introduction of membrane-forming curing agents/compounds which are widely accepted in developed nations because they can be applied quicker than sheets and require least amount of curing protection. They work by sealing the surface of the concrete but do not prevent complete evaporation of mix water.

It is against this background that this study seeks to assess the effect of different curing methods on the density and compressive strength of concrete and to determine method(s) that is/are unsuitable which may impair the quality of the concrete.

2.0. Experimental Procedure

2.1. Materials

The materials used for the production of concrete test specimens are ordinary Portland cement, sharp sand, granite and tap water. Locally available crushed granite was used as coarse aggregates and sharp sand as fine aggregate. All aggregates were ensured to be free from deleterious substances such as organic impurities, clay and other unsound particles. Burham brand of ordinary Portland cement was used as binder in this study.

2.2. Preliminary Tests

The grading of fine and coarse aggregates was determined in accordance with procedure in BS 1377 (1990), Part 2:9.2. The specific gravity and moisture content of the fine aggregates were also determined according to procedure in B.S. 1377 (1990).

2.3. Preparation of Concrete and Test Specimens

A standard mix ratio of 1:2:4 was used. This is due to the fact that it is the commonly used ratio on construction sites for reinforced concrete. Batching by weight was adopted. Casting of all specimens was carried out under same ambient conditions of average temperature 27°C and 75% relative humidity. The water-cement ratio used for the mix was 0.65 and maintained for all subsequent mixes. Appropriate calculations and subsequent reduction of water to be used was made upon the determination of the moisture content of the fine aggregate. The concrete was prepared by hand mixing.

The steel cube moulds for the test specimens were cleaned thoroughly and the interior faces oiled. The mixed concrete was placed into the mould in three layers. Each layer of concrete was compacted by not fewer than 35 strokes of a 25mm diameter steel rod until full compaction without segregation was achieved. After compaction of the final layer, the top surface was finished by means of a hand trowel. The cubes were left undisturbed for about 24 hours in the laboratory to set and harden. At the end of this period, the concrete cubes specimens were stripped of the moulds and placed in their respective curing environments.

2.4. Curing Methods

The concrete specimens were cured using six different techniques until when their compressive strengths were determined at ages 3, 7, 14, 21 and 28 days. The curing techniques that were applied are:

1. Water Submerged Curing (WSC): This involved the submersion of the concrete cube specimens in water.
2. Spray Curing (SC): This involved the spraying of water on the concrete cube specimens twice daily.
3. Polythene Curing (PC): The specimens were covered with at least two layers of polythene membrane to prevent moisture movement from the concrete specimens.
4. Burlap Curing (BC): This involved covering the concrete cube specimens underneath burlap which was kept wet periodically.
5. Moist Sand Curing (MSC): This involved burying the entire concrete cube specimens in wet sand which was kept moist by wetting with water on a daily basis.
6. Air Curing (AC): This served as the control. It involved no form of active curing by just exposing the specimens to ambient air in the Laboratory.

All the curing methods, except that of moist sand were carried out in the laboratory under the same environmental conditions of 27°C temperature and 75% relative humidity. Moist sand curing was done outside the laboratory and exposed to varying environmental condition.

3.0. Results and Discussion

3.1. Sieve Analysis

The results of the sieve analysis for fine and coarse aggregates used are presented in Figure 1. It could be observed from the grading curves that the Coefficient of uniformity (Cu) and Coefficient of curvature (Cc) for the fine aggregates are 2.58 and 0.82 respectively. Thus, the sand can be said to be well graded. For the coarse aggregates, Cu and Cc are 2.1 and 1.1 respectively. According to Smith (1970), the coarse aggregate is well graded since it has a coefficient of curvature, Cc that falls between 1 and 3. The coarse aggregate falls under the category of nominal size of graded aggregates ranging from 20 to 5mm. The specific gravity of the sand is 2.66 while the moisture content is 16.8%.

3.2. Density of Concrete Specimens

Table 1 showed the mean density recorded by each curing method, the range and standard deviation. The density of the specimens ranged from 2432.59 to 2502.72 Kg/m^3. This lies within the range of 2200 to 2600 Kg/m^3 specified as the density of normal weight concrete (Neville, 2000). The moist sand curing method produced concrete specimen with the highest mean density of 2502.72 Kg/m^3, followed by the polythene and water submerged methods with mean values of 2484.94 Kg/m^3 and 2461.23 Kg/m^3 respectively. The polythene curing method produced the highest range of density and standard deviation indicating that the method is highly unreliable. The specimens cured by burlap method produced the lowest range of density and standard deviation indicating that the method is reliable.

3.3. Compressive Strength of Concrete Specimens

Figure 4.2 showed the compressive strength of air-cured concrete specimens. The air cured specimens showed an average compressive strength of 11.9, 16.6, 20.0, 20.9 and 17.8 N/mm^2 after 3, 7, 14 21 and 28 days of curing.

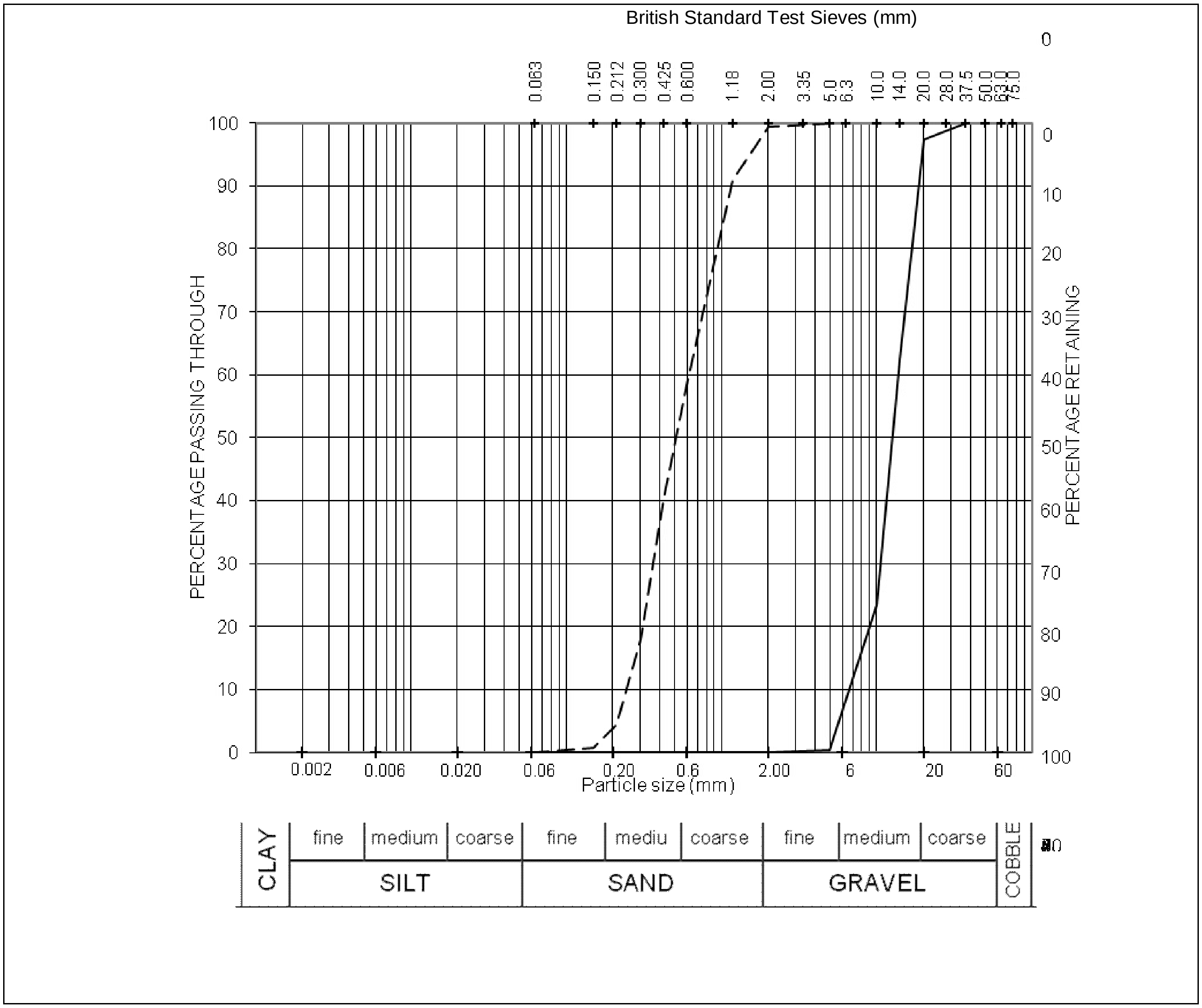

Figure 1: Particle Size distribution curve for the Sand and Granite used

Table 1: Relationship between Curing Methods and Density of Specimens

Curing method	*Curing period (days)*	*Density (Kg/m^3)*	*Mean (Kg/m^3)*	*Range (Kg/m^3)*	*Standard Deviation*
Air Curing (Control)	3	2469.14	2442.47	69.14	29.13
	7	2424.69			
	14	2459.26			
	21	2459.26			
	28	2400.00			
Water Submerged Curing	3	2459.26	2461.23	118.52	42.13
	7	2459.26			
	14	2469.14			
	21	2400.00			
	28	2518.52			
Polythene Curing	3	2469.14	2484.94	207.41	83.40
	7	2390.12			
	14	2429.63			
	21	2597.53			
	28	2538.27			
Moist Sand Curing	3	2518.52	2502.72	79.01	35.34
	7	2518.52			
	14	2439.51			
	21	2518.52			
	28	2518.52			
Burlap Curing	3	2459.26	2432.59	39.51	16.23
	7	2419.75			
	14	2434.57			
	21	2429.63			
	28	2419.75			
Spray Curing	3	2404.94	2450.37	93.83	38.00
	7	2439.51			
	14	2498.77			
	21	2479.01			
	28	2429.63			

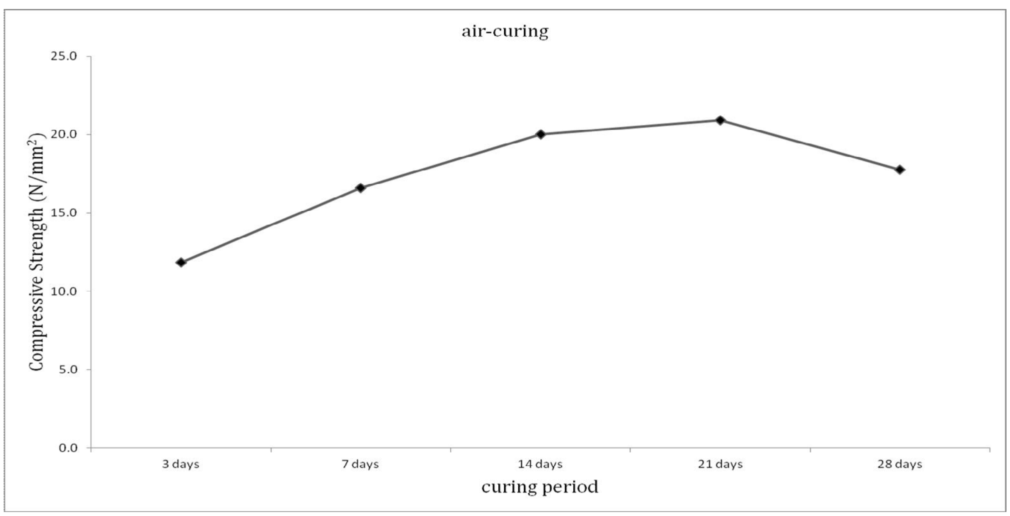

Figure 2: Effect of air-curing on the compressive strength of concrete

The 28-day strength recorded a 15% decrease in strength relative to the 21-day strength. This is similar to the results obtained by Safan and Kohoutková (2001) in which the specimens were exposed to outside environmental conditions and 15% reduction in strength was recorded between the 7 and 28-day strength. The reduction in strength recorded between the 21st and 28th day of curing can be attributed to the total consumption of all the mix water in the concrete specimen which halted the cement hydration process.

The compressive strength of concrete specimens cured by submersion in water is presented in Figure 3. It could be observed from the figure that an average compressive strength of 16.6, 17.3, 19.0, 20.3 and 23.6 N/mm^2 were recorded after 3, 7, 14, 21 and 28 days of curing respectively.

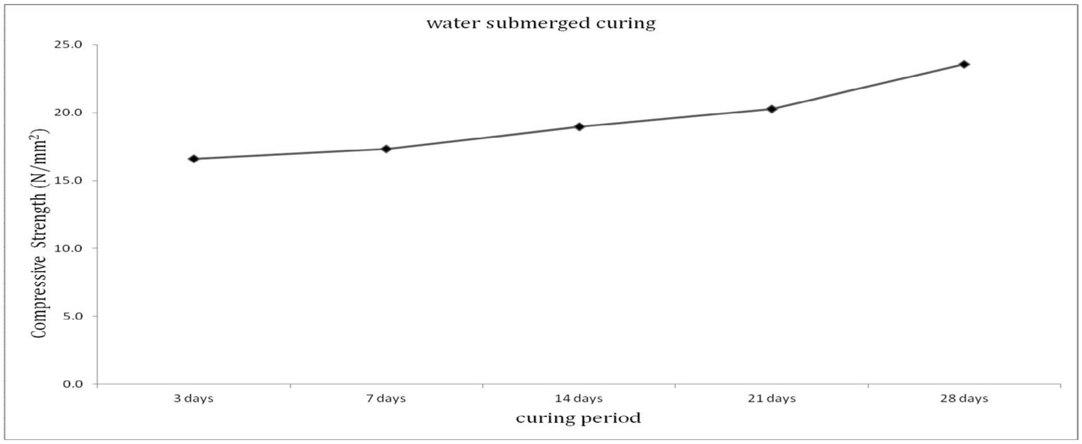

Figure 3: Effect of Water-submerged curing on the compressive strength of concrete

The specimens recorded 70% of its 28-day strength just after 3 days of curing. The strength of the specimens continually increased during the 28 days of curing as water, which allows continuous cement hydration was present in abundance thereby ensuring 100% relative humidity. This result is similar to those obtained by Raheem and Aderounmu (2002), Adesanya and Raheem (2002) and Raheem and Abimbola (2006).

Figure 4 showed the compressive strength of concrete specimens cured using the polythene curing method. The figure indicated that the average compressive strength of the specimens at 3, 7, 14, 21 and 28 days of curing are 15.0, 16.1, 18.5, 19.3 and 23.0 N/mm^{2}respectively. The specimens attained 70% of their 28th day strength after 7 days of curing.

The compressive strength of concrete specimens cured using the moist sand method is presented in Figure 5. The average compressive strength recorded are 18.1, 18.2, 19.6, 22.5 and 30.5N/mm^2 at 3, 7, 14, 21 and 28 days respectively.

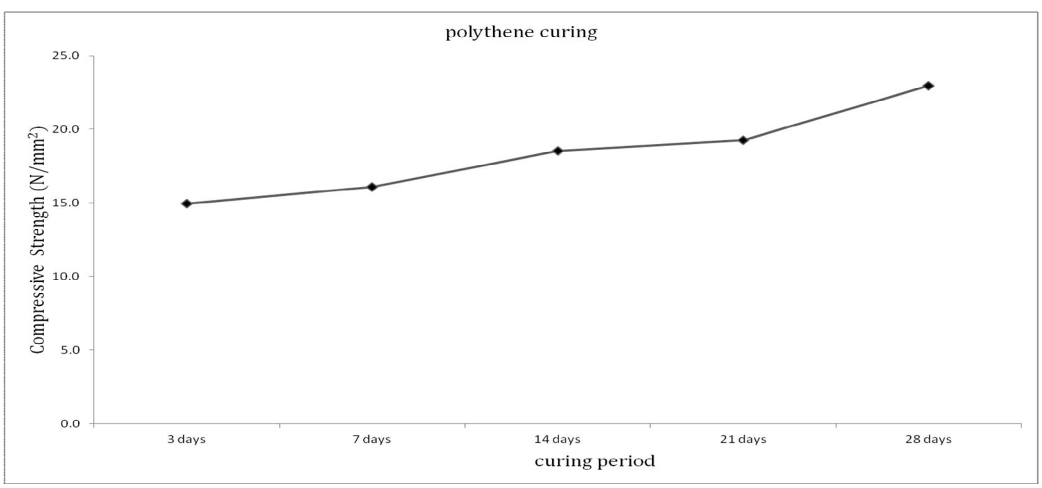

Figure 4: Effect of polythene curing on the compressive strength of concrete

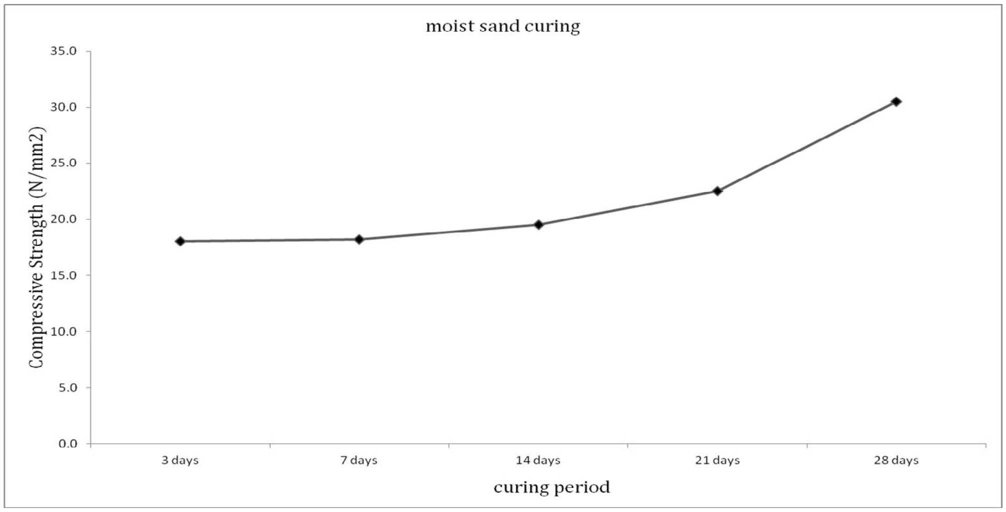

Figure 5: Effect of moist sand curing on the compressive strength of concrete.

This method was the only one executed outside the laboratory and was prone to varying environmental conditions. The high compressive strength recorded at the 28th day can be attributed to the suitable weather condition(average daily ambient temperature of 32°C which was higher than that of the laboratory of 27°C) witnessed throughout the curing period. However, the concrete cube specimens cured by this method had their entire surface marred by the colour of the sand grains. The discolouration of the concrete surface makes the method unsuitable for pre-cast concrete members which usually do not require any finishing.

Figure 6 showed the compressive strength of concrete specimens cured using the burlap curing method. After 3 days of curing, the specimens recorded average compressive strength of 14.5 N/mm^2. This increased to 15.7 N/mm^2 at 7 days, 17.3 N/mm^2 at 14 days, 18.7 N/mm^2 at 21 days and 24.4 N/mm^2 at 28 days.

The compressive strength of concrete specimens cured using the water spray curing method is presented in Figure 7. It could be observed from the figure that an average compressive strength of 13.6, 15.0, 17.2, 19.7 and 23.6 N/mm^2 were recorded after 3, 7, 14, 21 and 28 days of curing respectively. All the methods of curing, except air curing (the control) produced concrete specimens that met the minimum compressive strength of 21 N/mm^2 at 28 days specified by National Building Code (2006). Air curing with compressive strength of 17.8N/mm^2 has the lowest strength while Moist sand curing recorded the highest strength of 30.5 N/mm^2.

3.4. Relationship between Density and Compressive Strength of Specimens

Table 2 seeks to establish the relationship between average densities of specimens cured via different curing methods and their respective compressive strength. This was done through the determination of Pearson's Correlation Coefficient.

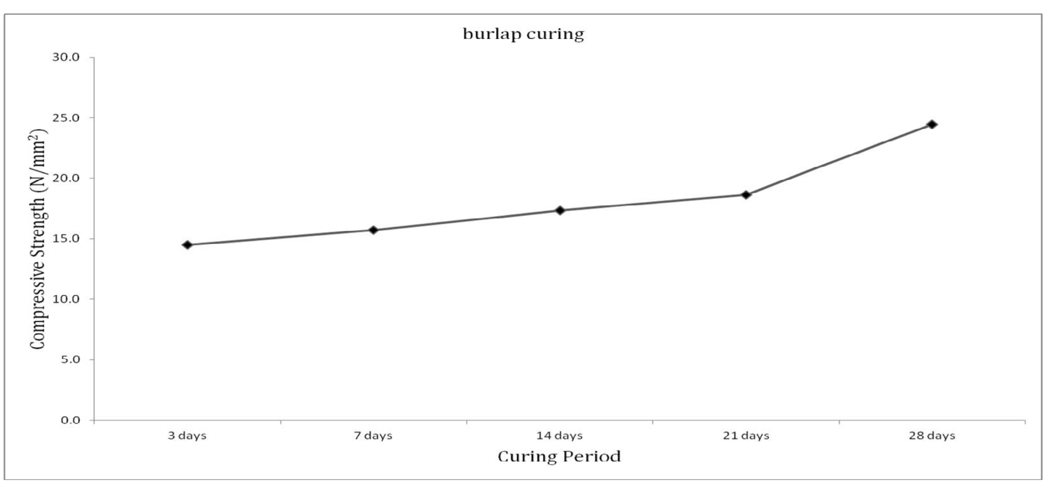

Figure 6: Effect of burlap curing on the compressive strength of concrete

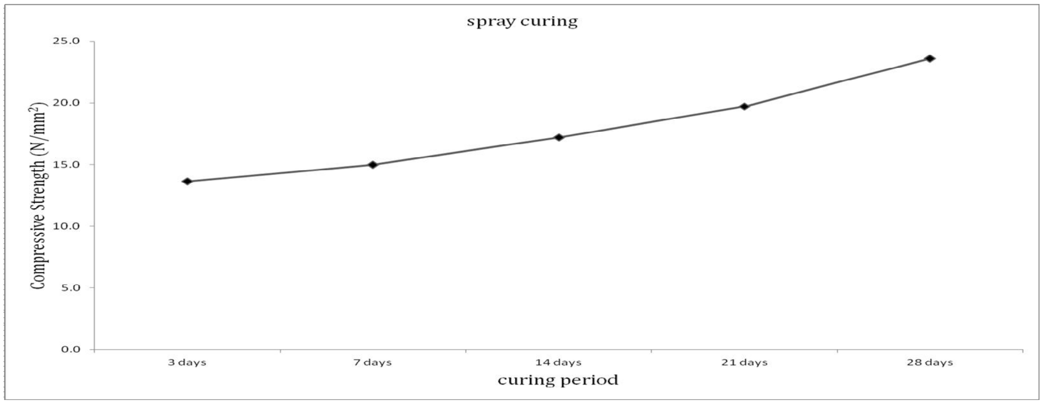

Figure 7: Effect of spray curing on the compressive strength of concrete

Table 2: Relationship between Density and Compressive Strength

Curing Method	*Curing Period*	*Average Density (Kg/m³)*	*Compressive strength (N/mm²)*	$rank\ A = x_i$	$rank\ B = y_i$	$x_i y_i$	x_i^2	y_i^2
Air- Curing	3	2469.1	11.9	11	29	319	121	841
	7	2424.7	16.6	24	22.5	540	576	506.25
	14	2459.3	20.0	15	9	135	225	81
	21	2459.3	20.9	15	7	105	225	49
	28	2400.0	17.8	28.5	18	513	812.25	324
Water Submerged curing	3	2459.3	16.6	15	22.5	337.5	225	506.25
	7	2459.3	17.3	15	19.5	292.5	225	380.25
	14	2469.1	19.0	11	13	143	121	169
	21	2400.0	20.3	28.5	8	228	812.25	64
	28	2518.5	23.6	5	3.5	17.5	25	12.25
Polythene curing	3	2469.1	15.0	11	26.5	291.5	121	702.25
	7	2390.1	16.1	30	24	720	900	576
	14	2429.6	18.5	22	15	330	484	225
	21	2597.5	19.3	1	12	12	1	144
	28	2538.3	23.0	2	5	10	4	25
Moist sand curing	3	2518.5	18.1	5	17	85	25	289
	7	2518.5	18.2	5	16	80	25	256
	14	2439.5	19.6	18.5	11	203.5	342.25	121
	21	2518.5	22.5	5	6	30	25	36
	28	2518.5	30.5	5	1	5	25	1
Burlap curing	3	2459.3	14.5	15	27	405	225	729
	7	2419.8	15.7	25.5	25	637.5	650.25	625
	14	2434.6	17.3	20	19.5	390	400	380.25
	21	2429.6	18.7	22	14	308	484	196
	28	2419.8	24.4	25.5	2	51	650.25	4
Spray curing	3	2404.9	13.6	27	28	756	729	784
	7	2439.5	15.0	18.5	26.5	490.25	342.25	702.25
	14	2498.8	17.2	8	21	168	64	441
	21	2479.0	19.7	9	10	90	81	100
	28	2429.6	23.6	22	3.5	77	484	12.25
			$\sum =$	465	462	7770.25	9429.5	9282

The Pearson's correlation was used to determine the relationship between the set of data. The rank assigned each member of the set (i.e. average density and compressive strength) are from the highest to the lowest. Where equal values in a set of data exist, the same rank has been assigned to each of the equal value which is the average of their positions in the ascending order of the values.

$$\rho = \frac{n(\sum x_i y_i) - (\sum x_i)(\sum y_i)}{\sqrt{n(\sum x_i^2) - (\sum x_i)^2}\sqrt{n(\sum y_i^2) - (\sum y_i)^2}} \text{..........} (v)$$

$$\rho = \frac{30(7770.25) - (465)(462)}{\sqrt{30(9429.5) - (465)^2}\sqrt{30(9282) - (462)^2}}$$

$$\rho = \frac{233107.5 - 214830}{\sqrt{282885 - 216225}\sqrt{278460 - 213444}}$$

$$\rho = \frac{18277.5}{\sqrt{66660}\sqrt{65016}}$$

$$\rho = \frac{18277.5}{258.186 \times 254.982}$$

$$\rho = +0.278$$

Since the value of ρ falls between 0 and +0.5, it implies that there exists a weak positive correlation between the densities and compressive strengths of the concrete specimens. This means that as the density of the concrete specimen increases, there is a tendency for the compressive strength to also increase.

4.0. Conclusion

The following conclusions are drawn based on the results obtained from the various tests and discussion of findings:

1. Based on the density, the specimens fall into the category of normal weight concrete.

2. Moist sand curing method produced specimens with the highest compressive strength while Air curing produced the lowest.

3. All the methods of curing considered, except air curing (the control) produced concrete specimens that met the minimum compressive strength specified by the available code.

4. There exists a weak positive correlation between density and compressive strength of concrete.

References

Adesanya, D. A. and Raheem, A. A. (2002). The Effect of Different Brands of Ordinary Portland Cement on the Compressive Strength of Concrete. Journal of Civil Engineering, Second Edition, November, 37-43.

Aluko, O.S.(2005). Comparative Assessment of Concrete Curing Methods. Unpublished Post Graduate Diploma Thesis, Federal University of Technology, Akure, Nigeria.

Arum, C. and Alhassan, Y.A. (2005). Combined Effect of Aggregate Shape, Texture and Size on Concrete Strength. Journal of Science, Engineering and Technology.13(2), 6876-6887.

Arum, C. and Udoh, I.(2005). Effect of dust inclusion in aggregate on the compressive strength of concrete. Journal of Science, Engineering and Technology. 12(2), 6170-6184.

British Standard Institution (1990) *Methods of Testing of Soils for Civil Engineering Purposes,* BS 1377, London, British Standard Institution

Gowripalan, N., Cabrera, J.G.; A.R, Cusens and Wainwright, P.J. (1992) Effect of Curing on Durability, Durable Concrete, ACI Compilation 24. American Concrete Institute, Farmington Hills, Michigan, USA, 47-54.

Mamlouk, M.S. and Zaniewski, J.P (2006). *Materials for Civil and Construction Engineers.* 2nd ed., New Jersey: Pearson Prentice Hall.

Neville, A. M. (1996). *Properties of Concrete,* 4th ed., USA, New York: John Wiley and Sons

Neville, A. M. (2000). *Properties of* Concrete, 4th ed., England: Longman.

Price, W. H. (1991) Factors influencing Concrete Strength. *J. Am. Concrete Institute.*

Raheem, A. A. and Abimbola, S. A. A. (2006). Effect of Specimen Size on the Compressive Strength of Concrete. USEP, Journal of Research Information in Civil Engineering (RICE), 3 (1), 55-64.

Raheem A. A. and Aderounmu O. M. (2002). The Effect of Aggregate Sizes on the Strength of Concrete. Journal of Science, Engineering and Technology (JSET), 9 (2), 4041-4051.

Ramezanianpour, A.A. and V.M. Malhotra,(1995). Effect of Curing on the Compressive Strength, Resistance to Chloride-Ion Penetration and Porosity of Concretes Incorporating Slag, Fly Ash or Silica Fume. Cement and Concrete Composites. 17(2), 125-133.

Safan, M. and Kohoutková, A. (2001). Influence of Different Drying Conditions on High Strength Concrete, *Acta Polytechnica*. 41(3), 24-28.

Safiuddin, M.D.,Raman, S.N. and Zain, M.F.M. (2007). Effect of Different Curing Methods on the properties of Microsilica Concrete. Australian Journal of Basic and Applied Sciences. 1(2), 87-95.

Wojcik, G.S., and Fitzjarrald, D.R. (2001). Energy Balances of Curing Concrete Bridge Decks. Journal of Applied Meteorology, 40(11).

Zain, M.F.M., M. Safiuddin and K.M. Yusof, (2000). Influence of Different Curing Conditions on the Strength and Durability of High Performance Concrete. In the Proceedings of the Fourth ACI International Conference on Repair, Rehabilitation and Maintenance, ACI SP-193, American Concrete Institute. Farmington Hills, Michigan, USA. 275-292.