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Comparative Analysis of The Strength of Concrete With Different Curing Methods In Ghana

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ABSTRACT : *Curing is one of the critical steps in concrete production but it is one of the most neglected and misunderstood procedures. The paper seeks to compare the compressive strengths of concrete cured using four different curing methods. The research work employed experimental and analytical study. A total number of 80 concrete cubes of size 150mm × 150mm× 150mm were cast and cured using four different methods of curing with constant water/cement ratio of 0.5. Data was collected and recorded on all 80 concrete specimen. The paper identified ponding as the curing method that yielded the highest compressive strength and was followed by jute bag. The least performing method was the wet sand method.*
KEYWORDS: *Curing methods, compressive strength, Portland cement, Ghana*

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I. INTRODUCTION

Curing of concrete is an essential step in concrete production. It is the treatment of newly placed concrete during the period in which it is hardening so that it retains enough moisture to immunize shrinkage and resist cracking (Lambert Corporation, 1999). Neville (1997) defined curing as the process of controlling the rate and extent of moisture loss from concrete during cement hydration. The use of appropriate mix ratio and the creation of a suitable environment for curing a concrete member during the hardening process are very critical to the overall strength gain. These two factors are among those that ensure the production of good quality concrete. The retention of moisture in concrete after it is placed is key because the hydration of the cement virtually ceases when the relative humidity within the capillaries drops below 80% (Neville, 1996). When hydration ceases, the resulting concrete may not possess the desirable strength and impermeability. The continuous pore structure formed on the near surface may allow the ingress of deleterious agents and which can durability problems. Moreover, due to early drying of the concrete, micro-cracks or shrinkage cracks may develop on surface of the concrete (Fauzi, 1995). Curing is a pre-requisite for cement hydration. For a given concrete, the amount and rate of hydration and the physical make-up of the hydration products are dependent on the time-moisture-temperature history (Jackson et al., 1996). The best method of curing concrete depends upon the conditions on site, or in a plant, or on the availability of curing materials, on the type of job, final appearance of the structure and the economics, and can be any one method or a combination of methods. Some of the previous investigators (Zhang et al., 1999; Oliveira et al., 2005; Safiuddin et al., 2007) in their studies on the effect of curing methods with and without the use of supplementary cementitious materials on the compressive strength and performance, found that conventional water curing is the most efficient method of curing compared to membrane curing, self-curing, wrapped curing and dry air curing methods. It was concluded that using membrane curing and self-curing methods, one can achieve 90% efficiency as compared to the conventional curing method. In their view, self-curing method is most suitable for high-rise buildings especially in columns and inaccessible areas. Whiting and Snyder (2003) undertook a study to examine the effectiveness of the different types of curing compounds in retaining water for hydration, promoting concrete strength, and reducing permeability, with and without supplementary materials. The outcome was that all compounds performed better than samples with no curing treatment.

1.1. Research Problem

Many concrete structures in Ghana are cured without artificial protection of any kind. They are allowed to harden in the full glare of the vagaries of the weather. This type of curing is unreliable, because water may evaporate from the surface. Concrete curing deserves special attention in practice because inadequate curing frequently causes lack of proper strength and durability. Excessive evaporation from an exposed horizontal surface within approximately 24 hours after casting will result in plastic shrinkage cracking and a weak, dusty surface. An excessive temperature difference through the cross-section of a concrete element will result in early thermal cracking due to restrain and contraction of the cooling outer layers from the warmer inner concrete.

Inadequate curing will result in the properties of the surface layer of concrete, up to 30-50 mm, not meeting the intentions of the designer in terms of durability, strength and abrasion resistance (Newman & Choo, 2003). Experience has shown that when the temperature difference between the inner and outer concrete exceeds, say, 20°C, cracking is likely to occur (Soroka, 2004). Ozyildirim (1993) said concrete exposed to the environment is subject to intrusion by water and aggressive solutions that may result in four major types of deterioration: corrosion of the reinforcement, alkali-aggregate reactivity, freeze-thaw deterioration, and attack by sulfates. According to Akinpelu (2002), "curing is probably the most abused aspect of the concrete construction process." In his view, concrete requires an adequate time to cure at a proper temperature and humidity; if not it may not develop the characteristics that are expected to provide the desired durability.

1.2. Aim

The paper aims at comparing and analyzing the strengths of concrete cured with four different curing methods.

II. LITERATURE REVIEW

2.1. Curing

Concrete curing is necessary for one reason: cement hydration. Cement hydration is a series of chemical reaction that requires adequate water supply and proper temperature over an extended period of time (Taylor, 2014). It is the name given to the procedures used for promoting the hydration of cement, and consists of the control of temperature and moisture movement from and into concrete. Curing allows continuous hydration of cement and consequently continuous gain in strength. Once it stops, strength gain of concrete also stops. The term has been the subject of variety of definitions. Shetty (1997), defines it as the prevention of moisture loss from concrete during cement hydration. Meanwhile, the American Concrete Institute [ACI] (2007) defines it as the process by which hydraulic-cement based materials develop strength hardening over time. ACI (2013) redefined the term as "action taken to maintain moisture and temperature conditions in a freshly placed cementitious mixture to allow hydraulic cement hydration and (if applicable) pozzolanic reactions to occur so that the potential properties of the mixture may develop."

2.2 Curing Methods

Broadly, concrete curing processes can be classified into three categories. The first is the method in which the moisture loss can be prevented by continuously wetting the exposed surface of concrete; this in turn maintains the requisite quantity of water in concrete during the early hardening period. This is known as the conventional curing. The second method minimizes moisture loss from concrete, thus preventing the loss of mixing water from concrete, for example, by covering it with a relatively impermeable membrane. This is referred to as membrane curing using curing compounds. The third method keeps the surface of a concrete member moist and raises the temperature of concrete by increasing the rate of strength gain. This method is typically convenient for pre-cast concrete products, called accelerated curing.

2.3 Effect of Curing on the Strength of Concrete

Curing temperatures affect the degree of hydration and thus the pore size distribution. According to maturity theory, the hydration of cement is accelerated if elevated temperature is applied and water is available for the process of hydration (Wilby, 1983). In the precast concrete industry, the use of elevated temperature curing techniques to accelerate early strength development has been adopted as one of the standard methods for high volume production of concrete units. Curing temperature affects the degree of hydration and the pore size distribution. Micro-structural examination of two months old concrete cured at 16°C, 42°C and 46°C revealed no much difference in the spatial distribution, morphology, and volume of hydrates and other micro-structural features present. However, a network of micro-cracks was evident within the matrix of all the concrete, when cured at 80°C. After setting, concrete increases in strength with age. Suitable curing of the concrete whilst it is maturing can further increase the strength at a particular age. Curing can be affected by the application of heat and/or the preservation of moisture within concrete. In the temperature range 5°C to 46°C, when concrete is cast and cured at a specific constant temperature, if it is generally observed up to 28 days, the higher the temperature, the more rapid the cement hydration and the strength gain (Mehta and Monteiro, 2006). Recently poured concrete must be protected from rain and fast drying as a result of warm or dry air or severe storms. The protection is achieved by covering the cast concrete with suitable coating system after finishing the pouring process until the final hardening, after which the curing process may proceed. The purpose of the curing process is to maintain wetness for not less than seven days in the case of ordinary Portland cement and not less than four days in the case of fast-hardening concrete or when additives are added to accelerate the setting time. According to El-Reedy (2009), there are many ways of executing the curing process:

1. Spraying water free from salt and any harmful substances.
2. Covering the concrete surface with rough sand or wood wastes and keeping it wet by spraying water on it

regularly.
3. Covering the concrete surface with high-density polyethylene sheets.
4. Using steam for curing in some special structures.

2.4 Compressive Strength

As cement hydrates, strength increases and permeability decreases. When hydration stops, strength gain ceases. Therefore, proper hydration of the cement is significant in the development of strong durable concrete. Most concrete mixes contain adequate amount of mixing water for complete cement hydration. One of the factors designers, contractors, and owners are concerned about concrete is compressive strength. Test data from Cusson and Hoogeveen (2008) showed that internally cured concrete using varying amounts of saturated LWA significantly reduced autogenous shrinkage without affecting the strength or elastic modulus of the concrete. This was accomplished using a total w/cm ratio of 0.34 for all four mixtures and reducing the amount of mix water by the amount of water supplied by the LWA to reduce the effective w/cm ratio. Compressive strength criterion may involve one of two approaches. The first concept (R_1), concrete is cured until it attains a specified minimum strength. As an example, a suggested minimum strength is the strength after 7 days of moist curing that would be obtained by a reference concrete with a water-cement ratio of 0.6 and made with the same materials as the concrete to be cured (Hilsdorf, 1995). A water cement ratio of 0.6 corresponds closely to the highest value for which capillary pores can become segmented with good curing. The second approach (R_2), is concrete cured till the in-place compressive strength touches an approved segment of the 28-days specified compressive strength so that at 28 days concrete at an agreed depth will reach the stated strength. The R_1 approach offers improvement that the use of mixtures with low water-cement ratios or having rapid early strength development can decrease the curing period. This criterion may be applicable when durability is of concern, because it has been established that, for a given concrete, there is a “reasonably reliable" correlation between compressive strength and other durability-related characteristics (Hilsdorf and Burieke, 1992; Ho and Lewis, 1988). In the R_2 approach, the curing duration is liberated of water-cement ratio but subject to the rate of strength development. The R_2 - concept is appropriate when structural strength is of concern. The basic notion is that the concrete should be cured long enough so that the in-place strength at some depth below the surface attains the specified strength used to design the structure. When curing is terminated, drying of the surface occurs and hydration ceases when the moisture content in the surface layer falls below a critical value. However, it will take time for the drying front to penetrate into concrete. As result, the interior concrete continues to gain strength after curing is terminated. When the drying front stretches the agreed depth, two things happen: (1) the strength rises due to drying and (2) the rate of hydration is reduced. Later, concrete at approved depth dries below a serious level and strength progress stops. The objective is to ensure that the two strength development curves cross at an age of 28 days or later.

III. METHODOLOGY AND DATA ANALYSIS

Quarry chippings and pit sand were used as coarse and fine aggregates respectively. Portland cement was used as the main binder. The cement required was collected from the same batch of production to avoid additional variables. The concrete mix ratio was 1:2:4. Normal tap water was used for preparing the concrete and for curing. The test specimens were cured under four types of curing conditions until the days of testing. These were water curing (ponding), the use of polythene sheet, the use of jute bag and the use of wet sand. In the water curing, the specimen were weighed and immersed in water. In the wrapped curing, polythene and jute bags were wrapped around specimen separately after weighing them. At least three layers of wrapping were used to prevent moisture movement from the concrete member. In the case of wet sand curing, the specimen were weighed and covered with wet sand. The curing temperature was tempered with in all curing methods. The silt test for the sand was carried out to determine the quantity of silt and clay content in the fine aggregate at the laboratory. The performance of concrete is influenced by mixing and a proper and good practice of mixing can lead to better performance and quality of concrete. In the present study, standard concrete cubes of size 150mm x 150mm x 150mm were cast and a water-cement ratio of 0.50 was used. The cast specimen were demoulded at the end of 24±3 hours and cured for the required number of days with different curing methods. All cubes specimen of size mentioned earlier were used to determine the compressive strengths at the end of 7, 14, 21 and 28 days taking the average compressive strengths of the three specimen for each test. The test was conducted in the laboratory; on digital compressive strength test machine of 1500 KN capacity. The load at the time of failure of specimen was recorded to compute the compressive strength.

3.2 Data Presentation and Analysis

The results obtained from the experimental investigations were presented using scatter with smooth lines format. The compressive strength comparisons and percentage differences are presented in a table and was analyzed quantitatively using the compressive strength test results.

IV. RESULTS AND DISCUSSION

The compressive strengths of concrete cured with different methods in 7, 14, 21 and 28days were analyzed based on their curing methods with results presented in Fig. 1 and Table 1 below.

4.1. Compressive Strength Test

Figure 1 depicts the various compressive strengths of the tested specimen against the four different methods of curing and their corresponding ages. From the scatter chart, it was revealed that water curing produced the highest compressive strength at all ages. The compressive strengths were recorded as 16.03, 16.48, 18.45, and 25.78KN/mm^2 at ages 7, 14, 21, and 28 days respectively. Jute bag curing recorded the second highest and was captured as 15.17, 16.13, 18.16 and 23.46KN/mm^2 at 7, 14, 21 and 28 days respectively. Polythene sheet curing produced the third highest: 14.28, 14.50, 16.23 and 20.65 KN/mm^2 at 7, 14, 21, and 28 days respectively. Wet sand curing produced the lowest recorded compressive strength at all ages. The recorded compressive strengths were 14.11, 14.18, 16.06, and 18.97 KN/mm^2 at 7, 14, 21, and 28 days respectively, as compared to water curing, jute bag curing and polythene sheet curing.

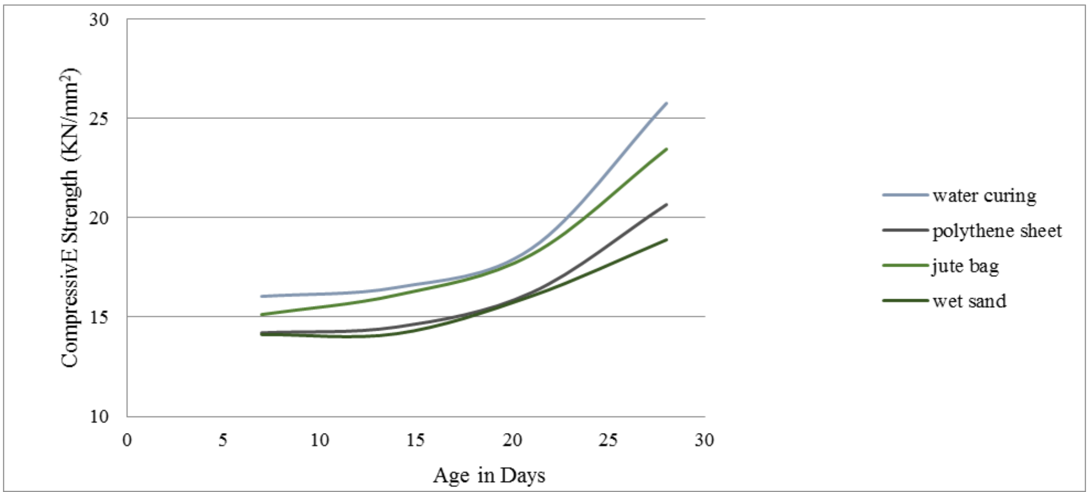

Fig 1 Compressive strength comparison of concrete cured under four different curing techniques at ages: 7, 14, 21 and 28 days

4.2 Compressive strength differences and percentage deviations for the four methods of curing

Specimen cured using water curing performed better in terms of compressive strength than all other methods. The strength decrease between the water cured and the jute bag cured specimen at 7days, 14days, 21days and 28days were 0.86KN/mm^2, 0.35KN/mm^2, 0.29KN/mm^2, 2.82 KN/mm^2 respectively. The highest strength differences occurred at 7days and 28days. Strength difference at 7days was higher than 14days and 21days. The percentage strength difference between the two methods at 28days was more than two times what was achieved at 7days. The strength difference between the water curing and polythene sheet method were recorded as 1.75KN/mm^2, 1.98KN/mm^2, 2.22KN/mm^2 and 5.13KN/mm^2 for 7days, 14days, 21days and 28days respectively. The two methods recorded 10.92% strength difference at 7days. Though the percentage strength difference rose at 14days and 21days, the rise from 14days to 21days was gradual. The difference at 28days was very high compared to other ages. There was a recorded difference of 8.98%. The performance of the water curing method was even better against the wet sand method than other methods. The strength difference at 7days was lower than 14days and 21days. Meanwhile, the increase from 14days to 21days was gradual but there was a huge increase of 4.42 KN/mm^2 from 21 to 28days. The performance of the jute bag in terms of its compressive strength was better than polythene sheet and wet sand. The strength differences between the jute bag and the polythene sheet curing were 0.89KN/mm^2, 1.6 KN/mm^2, 1.93KN/mm^2, 2.81 KN/mm^2 at 7days, 14days, 21days and 28days in that order. The increase at 28days was higher than all other ages. Between the jute bag and the wet sand, the strength differences were a little higher compared to its recordings against the polythene sheet method of curing. There was a gradual increase in strength difference from 14days to 21days but a significant increase from 21days to 28days. The difference between early strength (7days) and the later strength (28days) was 3.43KN/mm^2. The compressive strengths recorded by the polythene sheet were better than the wet sand. The two samples all recorded gradual increase in compressive strength at 7days and 14days. Though the increases were gradual, the polythene sheet recorded a significant strength increase than the wet sand method. The increase in compressive strength of the two samples was more significant at 21days than it was previously recorded by the same. The increase at 28days was even more significant with the polythene sheet and wet sand methods recording strength increase of 4.42KN/mm^2 and 2.91KN/mm^2 respectively. The percentage strength difference between the two methods occurred at 14days and 28days.

Table 1 Strength differences and corresponding percentage deviations

Curing methods	**Compressive strengths for the different ages in KN/mm^2**			
	7days	**14days**	**21days**	**28days**
Water curing	16.03	16.48	18.45	25.78
Jute bag	15.17	16.13	18.16	23.46
Difference in compressive strength (KN/ mm^2)	0.86	0.35	0.29	2.82
Percentage deviation (%)	5.36	2.12	1.57	10.94
Water curing	16.03	16.48	18.45	25.78
Polythene sheet	14.28	14.50	16.23	20.65
Difference in compressive strength (KN/ mm^2)	1.75	1.98	2.22	5.13
Percentage deviation (%)	10.92	12.01	12.03	19.90
Water curing	16.03	16.48	18.45	25.78
Wet sand	14.11	14.18	16.06	18.97
Difference in compressive strength (KN/ mm^2)	1.92	2.30	2.39	6.81
Percentage deviation (%)	11.98	13.96	12.95	26.42
Jute bag	15.17	16.13	18.16	23.46
Polythene sheet	14.28	14.50	16.23	20.65
Difference in compressive strength (KN/ mm^2)	0.89	1.63	1.93	2.81
Percentage deviation (%)	5.87	10.11	10.63	11.98
Jute bag	15.17	16.13	18.16	23.46
Wet sand	14.11	14.18	16.06	18.97
Difference in compressive strength (KN/ mm^2)	1.06	1.95	2.10	4.49
Percentage deviation (%)	6.99	12.09	11.56	19.14
Polythene sheet	14.28	14.50	16.23	20.65
Wet sand	14.11	14.18	16.06	18.97
Difference in compressive strength (KN/ mm^2)	0.17	0.32	0.17	1.68
Percentage deviation (%)	1.19	2.21	1.05	8.13

V. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

There was no controlled temperature for any of the curing techniques. All the samples under the four different methods were cured under the same temperature. Based on the uniform platform that was created for all the samples, the study concludes that the water curing and jute bag methods are the most efficient methods of curing. This is because the two yielded better compressive strength than the other two. The wet sand method was however, the least performing curing method. Its compressive strength recordings were lower at all ages than the other methods.

5.2 Recommendations

Generally, every concrete needs to be cured for a maximum number of days to attain the maximum strength required. The study recommends that;

- Since total immersion or ponding was considered the most effective curing method, it should be adopted on construction sites in the country to help concrete members achieve their desired strength.
- Jute bag curing method should be considered as a replacement for the total immersion on construction sites. The surface of concrete should be moistened by spraying with water prior to the application of the covering to minimize the effect of any initial loss of water into air spaces between the concrete and the covering.
- Further experiments or research work be conducted with different water cement-ratio with the four curing techniques used in this research work to compare the strength.
- Curing techniques aside the ones used in this research work should be used so that their compressive strengths can be compared to the ones here to help make inform decisions on site.

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