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INVESTIGATING THE EFFECT OF CURING METHODS ON THE STRENGTH PROPERTIES OF CONCRETE

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In the hot humid climate, the method of curing used is critical in achieving the needed strength of concrete for construction application. This study sought to investigate how the different curing methods can influence the compressive and flexural strengths of concrete in the hot humid climate. The targeted compressive strength of the concrete at 28-day of curing was 20 N/mm2. Plain concrete cubes and beams were prepared with a mix ratio 1:1.5:3 by weight and 0.6 water-cement ratio. A total of 120 concrete specimens were prepared, comprising 60 each for cubes and beams. Four different curing methods (immersion, wet jute sack covering, plastic sheet covering and water sprinkling) were adopted. The concrete specimens were tested on 7, 14, 21, 28 and 56 days of curing. It emerged that the immersion curing method recorded the highest compressive values of 23.43 and 25.83 N/mm2, respectively for the 28 and 56 days curing at a significant difference of 16% increase strength over the sprinkling method. It was also found that the immersion curing method obtained the highest flexural strength of 2.81 and 3.49 N/mm2, respectively for the 28 and 56 days curing at 14% increase strength over the sprinkling method. The study, therefore, concludes that the use of appropriate method of curing can have an effect on the flexural and compressive strengths of the concrete, and therefore recommend the adoption of immersion curing method, especially in the hot humid climate for precast and laboratory-based concrete units 'production.

Keywords: compressive strength, concrete, curing method, flexural strength, slump tests

INTRODUCTION

Cement and concrete products require curing for development of strength, durability, and other properties. This is because cement and concrete products require hydration process in initially damp condition to allow for optimum development of their properties. Olanitori (2006) described concrete as a product which constitutes the mixture of binding agent, fine aggregate, coarse aggregate and an appreciable amount of water. In some instances, admixtures are added to

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the mixture to improve the concrete's properties such as colour, setting rate and workability (Surahyo, 2019). Among all the major characteristics of cement and concrete products namely, durability, workability, permeability and strength, the latter is considered the most valuable and desirable. This suggests that careful attention must be given to these factors that influence the concrete's strength. The curing of concrete in the right environment and condition, after the placement of concrete contributes to obtaining quality concrete, especially in the early stages of hardening.

The durability and quality of concrete depends on several factors. It is not limited to the characteristics or quality of the constituents of the concrete but also depends on factors such as the methods of preparation, placing, curing and environmental conditions to which it is exposed over its service life. Proper curing of concrete is requisite in developing its optimum properties. Sufficient supply of moisture during curing is essential in ensuring good hydration. This reduces the porosity of the concrete and helps attain the desired durability and strength (Federowicz et al., 2020; Rahman et al., 2012). According to a study of Mamlouk and Zaniewski (2006), concrete allowed to only dry in the air without proper curing can only gain up to 50% of its desired strength when adequately cured. The authors further stated that the concrete will attain 60% of the desired strength if cured for only three days and will gain 80% of its desired strength if cured for only seven days. Improper curing leads to insufficient moisture in the concrete, which results in the development of cracks, reduced strength as well as the long-term durability (Zain et al., 2000; Wojcik & Fitzgarrald, 2001; Rao et al., 2010).

According to Nurruddin et al. (2018) and Usman and Nura Isa (2015), curing has significant influence on the durability and properties of concrete and geopolymer since it contributes to the hydration of cement in the mix. Without moisture, the hydration of cement virtually ceases when the relative humidity of reduces below 80%. Nahata et al. (2014) also posited that, hardened concrete's properties are greatly affected by the method used in curing it. The sensitivity of concrete to curing is influenced by methods used in curing. There are several methods of curing concrete such as ponding (immersion), dry-air-curing, fogging (sprinkling), saturated wet covering, curing compound, plastic sheet, self-curing concrete and jute sack (wet covering), wrapped curing, wet gunny bags curing, etc. The different curing methods are employed based on the construction method and the nature of the project as well as the site conditions (Boakye et al., 2014). According to Liu et al. (2020) the effect of curing methods of on the properties of concrete have been relatively less studied. Despite these numerous methods used in curing to improve concrete properties, concrete structural failure and collapse is on the increase. Moreover, in spite of the extensive publications on the concrete curing methods and their effect on concrete strength properties in other countries, the topic has not been researched into detail in hot humid climate. This study therefore investigates the influence of the different curing methods on the strength properties of concrete in the hot humid climate, particularly in controlled environment for precast and laboratory-based concrete units.

MATERIALS AND METHODS

Materials

Crushed granite rock aggregate procured from a commercial quarry company at Ntensere in the Ashanti Region, Ghana was used for the study which had 20mm maximum size of aggregate. The coarse aggregates used was clean, free from waste and impurities. Natural sand is usually used as a fine aggregate in a concrete mix, however, in this study quarry sand was used as a replacement of natural sand. The quarry sand was air-dried to remove the moisture, in order not to change the chosen water cement ratio. The drying of the quarry sand was done at room temperature condition. The quarry sand was sieved using BS 3.75mm sieve to obtain the required sizes and to also remove any foreign materials that can influence the quality of the concrete.

Super Rapid Ordinary Portland Cement (class 32.5 R) produced by Ghana Cement Company Limited (GHACEM) that conformed to BS EN 197-1 (2011) was used in the study. It was procured from a retailing outlet prior to the experimental work and was kept in the laboratory, in a dry place to prevent premature hydration that could lead to caking of the cement. Tap water from Ghana Water Company supplied to the College of Technology Education, Kumasi, laboratory of the Construction Technology was used for the study. The use of tap water was premised on the fact that, water meant for concrete and construction works must be free from harmful chemicals (salts and oil) and impurities (suspended particles). The plastic sheet used for the curing purposes was purchased from suppliers in the commercial market in Kumasi. The specimens were covered with plastic (polyethylene) sheets in two layers to retain moisture in the concrete specimens. Jute sack materials were obtained from the commercial market in Kumasi, Ghana. The jute sacks were used to cover the concrete specimens and kept wet during the curing period.

Preparation of concrete specimens

The concrete was prepared in the controlled laboratory setting. A laboratory pan mixer was used for the mixing of the concrete. A concrete grade of M20 with the targeted compressive strength of 20 N/mm2 was used for the study. The mix proportion adopted for the experiment was a ratio of 1:1.5:3 with 0.6 water-cement ratio. The concrete beams and cubes were produced following BS EN 12390-1 (2012) and BS EN 12390-2 (2019) respectively. Steel mould of size 100 × 100 × 100 mm was used for casting concrete cubes and 100 × 100 × 500 mm for casting beams. A total of 180 specimens (120 cubes & 60 beams) were prepared for experiment. The curing was following BS EN 12390-2 (2019). After an overnight setting of the, the concrete specimens (cubes and beams) were de-moulded and were labelled for easy identification. The specimens were subjected to 7, 14, 21, 28 and 56 days of curing before testing. Four different curing methods were adopted for the curing of the specimens. The methods were immersion (ponding), plastic (polyethylene) sheet covering, Jute (hessian) sack covering, and sprinkling.

Immersion curing

The specimens were put in water in a curing tank in the laboratory (see Figure 1a). The water for curing was tested every 7 days and the temperature of water was on the average at 27 ±2°C. The same tap water used in the production of the concrete was used for the immersion curing.

Plastic sheets curing

Specimens were covered with the plastic sheets. They were covered in two layers to ensure that moisture was retained in the concrete specimens (see Figure 1b). The surface area of the cubes and beams were completely covered by the sheets.

Wet jute sack curing

Wet jute sacks were to cover the specimens in a form of a mulch. The wetness of the sacks ensured that the surface of the specimens was kept moist (see Figure 1c). The whole surface area of the specimens was covered with the wet jute sacks. The sacks were kept saturated with water throughout the curing period.

Sprinkling

Specimens were arranged on the floor of the laboratory and sprinkled with water periodically (see Figure 1d). The specimens were kept wet all the time.

a. Immersion

b. Plastic sheet covering

c. Wet jute sack

d. Sprinkling

Figure 1: Curing methods of concrete specimens

Testing of concrete specimens

Compressive strength

The test was carried out following BS EN 12390-3 (2019) specifications. Cubes were tested on the 7, 14, 21, 28 and 56 days of curing for compressive strength. The compressive test was carried out using ELE Universal Testing Machine (ADR 1500/200) with a maximum capacity of 2000 kN (see Figure 2a). The cubes were first weighed to ascertain their weights and then place on the test machine. Three replicates were tested for each test point. A constant load was applied until failure occurred. The maximum load at failure was recorded. The compressive strength was computed using Equation 1:

$$f_{cu} = F/A_c \qquad \text{(Eqn. 1)}$$

Where:
fcu = compressive strength (N/mm2)

F = peak load at failure (N)
Ac = cross-sectional area (mm2)

a. Compressive strength test b. Flexural strength test
Figure 2: Test setup of specimens

Flexural strength

The test was carried out following BS EN 12390-5 (2019) with centre-point loading method. The test was carried out with the beam specimens at the end of 7, 14, 21, 28 and 56 days of curing using the flexural testing machine. Each beam was loaded with a central-point loading at mid-span of the beam (see Figure 2b). Three replicates were tested at each test point. The beams were placed in the test machine and constant load applied gradually until the specimen failed. The peak load which split the specimen was recorded. The flexural strength of the beam (fcf) was computed using Equation 2:

$$fcf = 3Fl/2bd2 \qquad \text{(Eqn. 2)}$$

Where:
F = peak load at failure (N)
l = distance between supporting rollers (mm)
b = width of the beam (mm)
d = depth of the beam (mm).

RESULTS AND DISCUSSIONS

Compressive strength

The result obtained from the compressive strength test is shown in Figure 3. It can be observed that the compressive strength of all the specimens from the four curing methods increased in from 7 to 56 days curing periods. This was expected as concrete develop strength by age. The trend of results is similar to those obtained by Raheem and Abimbola (2006), Raheem et al. (2013) and Usman and Nura Isa (2015) which also recorded increase compressive strength development by increase age of curing. It emerged from the result that immersion method of curing yielded the highest compressive strength for all the curing days and recorded strength values of 24.43 and 25.43 N/mm2, respectively for 28 and 56 days of curing. This can be ascribed to improved pore structure and lower porosity of the immersion curing method which propels increased cement hydration and pozzolanic reaction in the concrete (James et al., 2011). Conversely, the specimens cured with the sprinkling method recorded the lowest compressive strength for all the curing days and obtained strength values of 18.00 and 22.33 N/mm2, respectively for 28 and 56 days of curing. The low strength obtained for the sprinkling method of curing can be attributed to high moisture movement and evaporation in the concrete specimens as the specimens are uncovered and unprotected against early drying out of the concrete (Rahman et al., 2012).

The finding corroborates the assertion that concrete curing age has an influence on strength (James et al., 2011). The result therefore confirms the claim that appropriate curing method is critical and necessary for all concrete structures. For the targeted concrete grade of M20, it was expected that on the 28-day of curing the compressive strength should attain strength value of 20 N/mm2. It can be observed from Table 1 that all curing methods attained more than the of 20 N/mm2, except the sprinkling method (19.80 N/mm2) which was even closed to the targeted strength. The immersion method recorded an average compressive strength of 23.43 N/mm2 as compared to the sprinkling method of 19.80 N/mm2 which translates to about 16% increase of the immersion method over the sprinkling method. This therefore implies that the appropriate curing method use for curing concrete can have a significant effect on the compressive strength of the concrete, especially in the controlled environment for precast and laboratory-based concrete units.

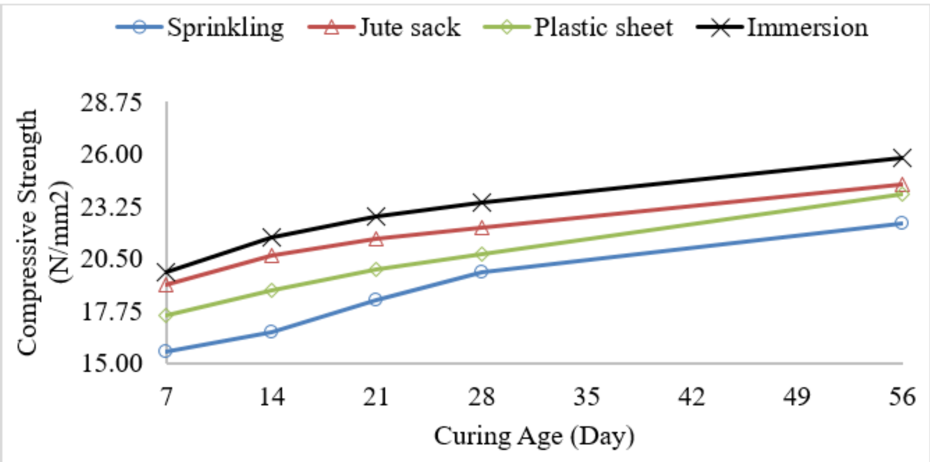

Figure 3: Compressive strength of concrete cube specimens

Table 1: Average test results

Curing day	Compressive strength (N/mm^2)				Flexural strength (N/mm^2)			
	Sprink-ling	Plastic sheet	Jute sack	Immer-sion	Sprink-ling	Plastic sheet	Jute sack	Immer-sion
7	15.63	17.53	19.10	19.80	1.82	2.02	2.15	2.44
14	16.63	18.80	20.68	21.60	2.01	2.12	2.22	2.54
21	18.33	19.97	21.57	22.70	2.24	2.31	2.43	2.65
28	19.80	20.74	22.10	23.43	2.40	2.50	2.61	2.81
56	22.33	23.90	24.43	25.83	3.01	3.16	3.39	3.49

Flexural strength of concrete beams

The result of the flexural strength test of the concrete specimens are shown in Figure 4. The flexural strength result followed the pattern of the compressive strength result. As was also expected, the flexural strength of the concrete specimens increased with increase age of curing. This result is consistent with Elinwa and Kabir (2019) findings that flexural strength of concrete increased as the curing age increased. It can be observed that the specimens cured by immersion method recorded the highest flexural strength for all the curing days with strength values of 2.81 and 3.49 N/mm2, respectively on 28 and 56 days of curing. Nahata et al. (2014) attributes the high strength to low water loss from the concrete specimens during curing. Wet jute sack covering method followed with average values of 2.61 and 3.39 N/mm2, respectively on 28 and 56 days of curing. The specimens cured by sprinkling method recorded the lowest flexural strength values of 2.4 and 3.01 N/mm2 on the 28th and 56th days of curing respectively. In general, it was observed that there was increase in flexural strength with respect to curing age. This is similar to what Neville (1996) reported that flexural test results may be influenced by the specimen's preparation and size; moisture conditions, curing; and the type and volume of coarse aggregates used for specimen preparation.

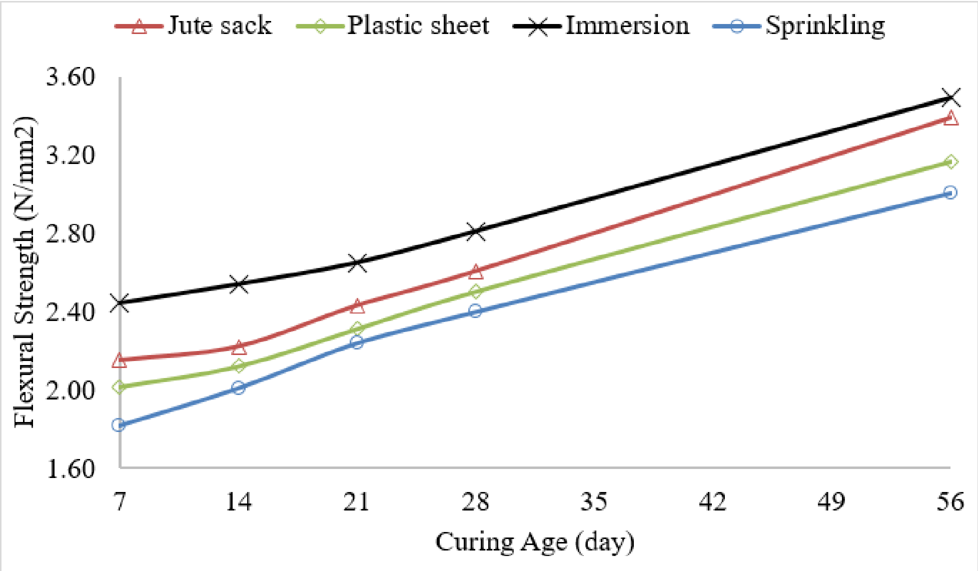

Figure 4: Average flexural strength of concrete beam specimens

CONCLUSION

The study investigated the effect of curing methods on the strength properties of concrete in the hot humid climate, particularly in the hot humid climate for precast and laboratory-based concrete units. The study found that the immersion method of curing obtained the highest compressive and flexural strength of the concrete specimens with about 16 strength improvement. The study, therefore, concludes that the use of appropriate method of curing can have an effect on the compressive and flexural strengths of the concrete, and therefore recommend the adoption of immersion curing method to concrete producers, especially in the hot humid climate for precast and laboratory-based concrete units 'production. This study only focused on the strength properties of concrete cured under different methods, and therefore recommend further studies to investigate the effect of curing methods on the physical and durability properties of concrete produced in the hot humid climate.

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