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Impact of Curing Methods on the Porosity and Compressive Strength of Concrete

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Authors' contributions

This work was carried out in collaboration among all authors. Author FKNGW designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors KAB and FA managed the analyses of the study. Author KAB managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

An experimental investigation was conducted to evaluate the impact of different curing practices on the porosity and compressive strength of concrete. The targeted compressive strength of the concrete at 28-day of curing was 20 N/mm^2. Plain concrete cubes were prepared with a mix ratio 1:1.5:3 by weight and 0.6 water-cement ratio. A total of 120 concrete cubes were tested on 7th, 14th, 21st, 28th and 56th day curing periods for slump, porosity and compressive strength. The four curing methods used were immersion, jute sack, plastic sheet and sprinkling which were all carried out in the laboratory under the same average environmental conditions of 27 ± 20°C temperature and 75% relative humidity. The results from the study showed that slump values were within the range of 52mm to 58mm which is within the medium range of 25 to 100mm, hence a true slump was achieved. The porosity of all samples decreased with age (*i.e. at the dried state, immersion recorded the lowest 4.35%, followed by jute sack with 5.25%, plastic sheet 5.29% and sprinkling 5.55%*). Again, the pattern of increases in concrete density *(immersion curing produced concrete with the highest mean densities of 2369 kg/m^3, jute 2360 kg/m^3 ,plastic sheet 2277 kg/m^3, sprinkling 2229 kg/m^3 all for 56 days)* was similar to that of the compressive strength *(i.e immersion curing method yielded the highest compressive strength of 25.43 N/mm^2, jute method 23.90*

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N/mm^2, plastic method 23.47 N/mm^2, sprinkling method 22.33 N/mm^2 for 56 days curing ages respectively). Therefore, increases in both compressive strength and densities of concrete cube is a function of curing method. The study concludes that the immersion curing method has the greater effect on the properties of concrete since it yielded the highest strengths. The recommendation is made for further studies on the impact of curing methods on the porosity and compressive strength of concrete on the field since this study was done in the laboratory under control conditions.

Keywords: Curing methods; porosity; compressive strength and Concrete.

1. INTRODUCTION

The collapse of various building and other infrastructure projects in most developing countries is mostly caused by poor designs, project implementation, poor supervision and the use of sub-standard materials [1]. Recently, a five-storey church building had collapsed in the eastern part of Ghana in a town called Batabi a suburb of Oda killing 26 lives and properties [2]. The initial report indicated weak concrete being used for the structure. The strength of concrete is being influenced by several factors which include concrete mix design [3]. This study would look at the curing effect on concrete and porosity.

All cement products and concrete require curing so that cement hydration can proceed to allow for the development of strength, durability and other mechanical characteristics. This is because every concrete or concrete product is an aggregate of different materials. Olanitori [4] explained concrete as a product that constitutes a mixture of binding agent (cement), fine aggregate (sand), coarse aggregate (stone or gravel) and an appreciable amount of water. Surahyo [5] asserts that, in some instances, admixtures are added to the mixture to improve the concrete's properties such as colour, setting rate and workability.

Among all the major characteristics of concrete 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 factors that affect the strength of concrete. To obtain quality concrete, the placing of an appropriate mix must be followed by curing in a suitable environment, especially during 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 [5] [6]. Proper curing of concrete is requisite in developing its optimum properties. An adequate supply of moisture is necessary to ensure sufficient hydration for reducing the porosity of such a level that the desired strength and durability can be attained [7].

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. Maximum curing can be attained by keeping the concrete element completely saturated or as much saturated as possible until the water-filled spaces are substantially reduced by hydration products [8] [9] Gowripalan et al., [10]

According to Piplewar et al. [11] concrete which is allowed to dry out without delay gain only 40% of the strength of the same concrete water cured for the full period of 180 days. Even three days of water curing increases to 60%, at the same time as 28 days water curing increases it to 95%. The need for adequate curing of concrete cannot be underestimated. However, the curing of concrete has often been overlooked by some contractors. They pay little attention to it and only budget a small amount of the total contract sum for it. Rahmanl et al. [6] citing Fauzi (1995) intimated that curing has a strong influence on the properties of hardened concrete. The sensitivity of concrete to curing is influenced by methods used in curing. A properly designed concrete mix, carefully placed, compacted and cured will have adequate strength and will be durable. Exposed slab surfaces are especially sensitive to curing as strength development and freeze-thaw resistance of the top surface of a slab can be reduced significantly when curing is defective. Further, advantages of proper curing include: a less permeable, more water-tight concrete; reduced permeability; prevents the formation of plastic shrinkage cracks caused by rapid surface drying; increases abrasion resistance as the surface concrete will have a higher strength and significant reduction in scaling problems [9].

The chemical reaction which curing aims at supporting-hydration of cement as it is called virtually ceases when the relative humidity within capillaries drop below 80% [12] [10]. 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% 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 the air, it will gain only 50% of the strength of continuously cured concrete [13]. 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 [13]. Improper curing would entail insufficient moisture and this has been found to produce cracks, compromise strength, and reduce long-term durability [14] [15] [16] Bushlaibi & Alshamsi, 2002). However, concrete properties and durability are significantly influenced by curing since it greatly affects the hydration of cement.

Many factors determine the quality of concrete and its strength properties. These include the type of cement used, wind velocity, relative humidity, atmospheric temperature, aggregate quality and grading, the degree of compaction, quality and quantity of water used in concreting, curing method, type of reinforcement used, given the sizes, arrangement and spacing [17] Miao & Liu,2002 [18].

The curing of the concrete is also governed by the moist-curing period: the longer the moist-curing period the higher strength of the concrete assuming that the hydration of the cement particles will go on. American Concrete Institute (ACI) Committee 301 recommends a minimum curing period corresponding to concrete attaining 70% of the specified compressive strength [19]. Loss of water from fresh and young concretes can result in detrimental effects or problems such as plastic shrinkage cracks and lack of durability and strength of concrete. 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 [20], water/cement ratios, degree of compaction [21] and the presence or otherwise of clayey particles and organic matter in the mix [22]. The scope of discussion in this study is methods of curing concrete.

A press statement released by the Ghana Institute of Safety and Environmental Professionals (GhISEP) gives statistics of some prominent building collapses in Ghana from the year 2000 to 2012. One of the questions the Institute was asked was: “Were they right and quality materials used for the construction?" Again, were the correct methods of curing concrete employed? [23]. Ghana has recorded many building collapses resulting in deaths, injuries and loss of properties which is indeed a worry (collapse of buildings in Ghana from the year 2002 to 2015).

It is worth noting that, the role of concrete in buildings and other construction members is so important that its structural performance cannot be overlooked. Ayedun et al. [24] and Ngugi et al. [24] assert that the quality of constituent materials used in the preparation of concrete plays a paramount role in the development of both physical and strength properties of concrete. To buttress this assertion, Danso and Boateng [25] opined that, poor quality materials are one of the major causes of building failures worldwide. However, the quality of concrete depends on both its constituent materials, mix proportions as well as its cure.

Several curing methods such as immersion, dry-air-curing, sprinkling, saturated wet covering, curing compound, plastic sheet, self-curing concrete and jute sack (wet covering), wrapped curing, wet gunny bags curing, etc. can be applied depending on various factors considered on-site or due to the construction method. Liu et al. [26] opined that the effect of curing methods on the properties of concrete have been relatively less studied. However, despite the numerous methods used in curing to improve concrete strength properties, concrete structural failure and collapse are on the ascendancy. If concrete is not well cured, particularly at an 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. [14]. Improper curing would entail insufficient moisture and this has been found to produce cracks, compromise strength, and reduce long-term durability [15] [26]. Usman and Nura Isa [10] however contend that proper curing greatly contributes to reducing the porosity and drying shrinkage of concrete, and thus to achieve higher strength and greater resistance to physical or chemical attacks in aggressive environments. Moreover, despite extensive publications on the concrete curing methods and their effect on concrete strength properties in other countries, the topic has not been researched in detail in Ghana. This study, therefore, sets out to investigate the impact of curing methods on the porosity and compressive strength of concrete. In order to achieve the purpose of the study the following specific objectives are examined: 1) to determine the impact of porosity on concrete strength; 2) to investigate the effect of curing methods on the compressive strength of concrete.

2. MATERIALS AND METHODS

2.1 Materials

Aggregates: Crushed granite rock (coarse) and quarry sand (fine) aggregates were procured from a commercial quarry company at Ntensere in the Ashanti Region of Ghana were used for the study which had 20mm maximum size of aggregate. The quarry sand was sieved using a BS 3.75mm sieve to obtain sieve analysis and to also remove any foreign materials affecting concrete properties.

Cement: Super Rapid cement (Class 32.5 R) produced by Ghana cement (GHACEM) that conformed to BS EN 197-1 was employed in the experiment.

Water: Potable drinking water from Ghana Water Company supplied to the College of Technology Education, Kumasi, and laboratory of the Department of Construction Technology was used for the study. The selection of potable water was premised on the fact that water meant for concrete and construction works must be free from harmful chemicals, impurities and contamination was used throughout this study as specified [27] [28][29].

Plastic/Polythene Sheet: The plastic sheet used for the curing purposes was purchased from suppliers in the Tanoso commercial market in Kumasi. Safuddin et al., [30] contend that wrapping curing is more efficient than dry-air curing as it results in greater compressive strength, ultrasonic pulse velocity and dynamic modulus of elasticity and lower surface absorption.

Jute sack: Jute sack materials were obtained from the Cocoa Research Centre at Tanoso in Kumasi, Ghana. Jute sack method is moisture-retaining fabrics such as burlap cotton mats and rugs used as a wet covering to keep the concrete in a wet condition during the curing period, for if the drying is permitted, the cover will itself absorb the water from the concrete.

2.2 Testing Methods and Procedures

In this study, the following tests were conducted: slump, porosity and compressive strength. Table 1 shows the type of test conducted and the number of specimens prepared.

2.3 Mix Proportioning of Concrete Ingredients

Mix design of concrete was done according to BS 10262:2009. Estimated water content was also calculated for the desired workability and a 0.60 w/c ratio was selected based on concrete targeted strength. Aggregate grading for 20mm nominal size aggregate as the requirements given in BIS 383:1970 was used as the proportion of aggregate in concrete. To ensure reliability and consistency of results, all the materials, coarse aggregate, fine aggregate, cement and water were weighed with an electronic weighing balance machine for accuracy in the proportion of material mix.

Again, the research adopted the machine mixing (pan mixer) procedure since the mix was in large quantity. M20 as the targeted strength for the concrete and with the mixed proportion 1:1.5:3 ratio for the study.

Table 1. Specimens test

Test Type	Curing Methods	Curing Periods (Days)					Total
		7	14	21	28	56	
1.Porosity (Cubes)	Immersion	3	3	3	3	3	15
	Sprinkling	3	3	3	3	3	15
	Plastic Sheet	3	3	3	3	3	15
	Jute Sack	3	3	3	3	3	15
2.Compressive (Cubes)	Immersion	3	3	3	3	3	15
	Sprinkling	3	3	3	3	3	15
	Plastic Sheet	3	3	3	3	3	15
	Jute Sack	3	3	3	3	3	15
Total specimens							120

2.4 Specimens Preparation

The concrete was placed in a metallic mould of size (100 × 100 × 100mm) for cube mould boxes which were per the ASTM and British Standard (BS EN 12390-2:2000, [28]

All the concrete specimens (a total of 120 cubes) were cast in steel moulds. Concrete specimens were compacted using a vibrating table. While placing, a sample of concrete was taken for slump test following BS EN 12350:200 to ascertain concrete workability. Fig. 1 shows concrete cubes in a mould.

2.5 Curing of Concrete Specimens

Although there are varied methods of curing concrete, this study was confined to immersion/ ponding, sprinkling/ fogging, plastic sheet and jute sack/saturated wet covering curing until their porosity and compressive strength was determined at ages 7, 14, 21, 28 and 56 days respectively.

After an overnight setting, the de-moulding and labelling of the specimens for immersion/ ponding curing were then immersed in water per BS EN 12390. The specimens were subjected to 7, 14, 21, 28 and 56 curing before testing. The water for curing was tested every 7 days and the temperature of the water was on average at 27 ± 20°C. The specimens were kept in the same water sources that were used in the production of the cubes for immersion curing.

Second, plastic sheet/ polythene film was used to cure the concrete cubes. Polythene is a lightweight, effective moisture retarder and was used easily applied to simple cubes shapes. The specimens were tested after the first 7, 14, 21, 28 days and 56 days respectively. Polythene specimens were covered with at least two layers of polythene membrane to prevent moisture movement from the concrete specimens.

Jute sack was used in a form of a mulch to maintain water on the surface of the concrete cubes; also, it was important to ensure that the whole areas were covered. A wet jute sack was placed as soon as the concrete cubes were set sufficiently to prevent surface damage. The samples were tested after the first 7, 14, 21, 28 days and 56 days respectively. Throughout the curing period, the jute sack was kept saturated with water.

Finally, specimens for the sprinkling method of curing were sprinkled with water periodically. The specimens, both cubes were tested after the first 7, 14, 21, 28 days and 56 days respectively. Water sprinkling is an excellent method of curing when the ambient temperature is well above freezing and the humidity is low.

2.6 Concrete Slump Test

The slump test was performed per BS EN 12350:200. A slump cone was filled in three layers of equal volume. Each layer was rodded 25 times with a tamping rod of length 600mm long and 16mm diameter with a hemispherical tip. The cone was lifted upright after levelling the concrete at the top of the cone. The slump cone was then set next to the concrete and the difference in height between the slump cone and the original centre of the specimen was recorded.

2.7 Porosity Test

Porosity is a ratio of the volume of the pores to the total volume of the particle [31]. As per the standard procedure, there are no specifications given regarding the shape and size of the specimens for porosity test, except that the volume of each specimen shall not be less than 350 cm^3, with the weight of more than 800g and each portion shall be free from observable cracks, fissures and shattered edges.

Concrete cube specimens were dried for 14 days in the open sun. The concrete specimens were weighed on an electronic weighing balance before being cured. The samples were then cured in a water tank for three days. Oven dry mass and saturated mass of the concrete specimens were determined as per the ASTM C 642-13. The porosity of concrete was calculated using the formula:

W2-W1/W2×100%.

Where W1 is the weight of sample/ specimen before immersion. W2 is the weight of the sample/ specimen after immersion.

2.8 Compressive Strength test

This test was per (BS EN 12390-2:2000; [28] specifications. Cubes were tested on the 7, 14, 21, 28 and 56 days of curing respectively. The cubes were first weighed to ascertain their weights. Cubes were loaded into the machine. To determine the unconfined compressive strength, one hundred and twenty concrete cubes of size 100 mm × 100 mm ×100 mm was cast from the mixture. For all four curing methods used for this experiment, the specimens were kept for 7, 14, 21, 28 and 56 days before the compressive strength test was conducted. An average of three specimens (replicates) was tested at a constant loading rate, at each required curing age using the universal testing machine.

An increasing compressive load was applied to the specimen until failure occurred to obtain the maximum compressive load. Before applying compressive loads on specimens in the machine, the following parameters were captured by the machine to help the machine calculate the appropriate strength: a dimension of the cubes, weight of specimens and the number of days of curing.

2.9 Density Test

The dry density of the specimens was determined per BS EN 12390. The specimens were weighed to obtain their weights and the volumes calculated to determine the density. Three replicates from each mix design were used and their averages computed to determine the density of the concrete.

2.10 Data Analysis

The slump results obtained were tabulated and compared to various forms of slump such as shear, collapse, true and conclusions were drawn descriptively. Porosity results were tabulated, analysed and used to draw a bar chart. An Engineering software- Sigma Plot 12 was used to process research data. With regards to compressive strength analyses, the mean strength of concrete specimens was computed and presented in tables using Microsoft excel. Data were subjected to one-way ANOVA tests to determine significant difference and variation between results.

Fig. 1. Concrete cubes in a mould

3. RESULTS AND DISCUSSIONS

3.1 Workability/ Slump Test

Workability relates to the ability of a fresh (plastic) concrete mix to fill the form/mould properly with the desired work (vibration) and without reducing the concrete's quality [3]. The degree of workability ranges from very low to high: 0-25 very low, 25-50 low, 25-100 medium, and 100-172 high [3] [32]. The slump was measured in millimetres (mm).

The highest slump test result is 58, followed by 57, 55 and finally, the lowest slump measured 52. Table 2 showed the slump values as measured for the various batches of concrete used for the study. It can be observed from the Table that the slump results were within the range of 52 to 58 which fall within the medium range of 25 to 100 [3]. The slump results depicted a true slump which indicated that concrete was workable and as such there was the right quantity of water which did not affect the strength.

In the schemes of concrete technology, the lower the slump values, the higher the strength of concrete, and the higher the slump values, the weaker the concrete strength. Therefore, from table 2, the slump test result of 52mm had the highest concrete strength. The slump of the samples may be due to the grading of the aggregate. This is in line with what Neville and Brooks [3] reported that grading affects the workability of concrete. The differences in the slump samples may be due to operational error such as measuring of the water and the inclusion of quarry sand as a substitute for natural sand leads to an increase in water demand of concrete. Supporting this assertion, Salema and Pandey [33] said that the strength of concrete mixes increases with cement-water ratios.

3.2 Impact of Porosity on Strength of Concrete

The study, as one of its main objectives, sought to find out how concrete porosity impacts its strength. The porosity test for the 28 days cured concrete specimens as presented in Fig. 1A had the following results. At the dried state, immersion recorded the lowest 4.35%, followed by jute sack with 5.25%, then plastic sheet ranking the next highest 5.29% and sprinkling ranked highest with 5.55%.

Table 2. Measurement of slump for workability test

Water/Cement Ratio (w/c)	Slump (mm)	Degree of Workability
0.60	58	Medium
	57	Medium
	55	Medium
	52	Medium
Average	55.5	Medium

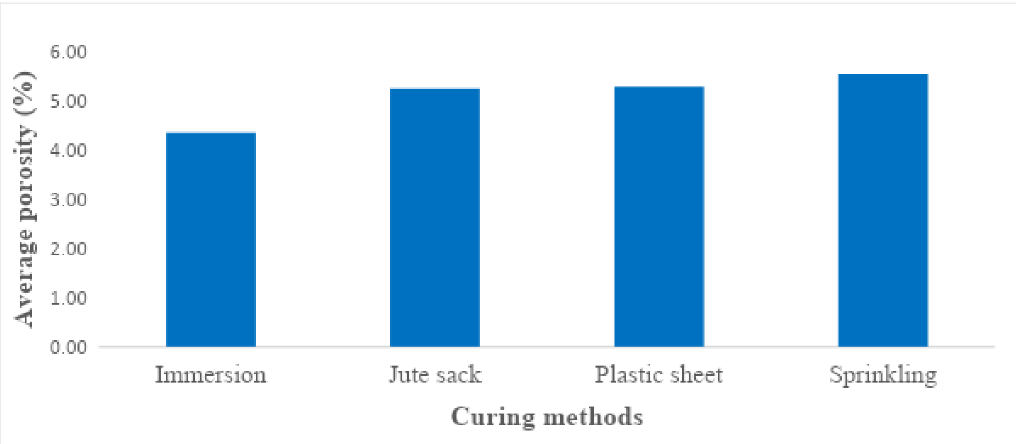

Fig. 1A. Average porosity of concrete at 28 days and curing methods

From the results, immersion recorded the lowest porosity of 4.35%, which implies this method of curing concrete gain the maximum strength. This is because the lower the w/c ratio which mean lower porosity (4.35%), the higher the strength of concrete. The water-cement ratio is vital in determining the porosity in the strength of concrete [34]. Affirming that Ishida, et al., [35] and Song, et al. [36] assert that pore structure is developed with hydration reaction and porosity generally decreases with age in curing condition.

This result has been corroborated by Li, et al., [37] in their study which concluded that the porosity of concrete decreases with age. The reason is that the hydration of cement is low at the early stages, which leads to higher porosity. While hydration increases, the hydration products fill some of the pores and this leads to the decrease of porosity. There is therefore a good linear relationship between porosity and w/c. Also, in the same study, the influence of age on porosity was concluded that the porosity of all concrete samples decreases with age. This is because porosity reduces with the increasing ages while it increases largely as the w/c increases [38]. Similarly, Kabashi, et al., [34] confirmed that the basic relationship between porosity and strength of concrete is on the function of contents of concrete: aggregate; cement paste matrix and the interfacial zone between the matrix and coarse aggregate.

Concrete porosity is inversely proportional to its density. Concrete porosity is affected by several parameters, including water to cementitious materials ratio, degree of hydration, air content, consolidation, admixtures, aggregates, the reaction between aggregate and the hydrated cement paste, mixture proportioning, etc. Of these, the water to cementitious materials ratio and degrees of hydration are the most important parameters that affect concrete porosity and thus concrete density. An increase in the water to cementitious materials ratio increases porosity [39]. Also, to produce a low porosity in concrete, low water to cementitious materials ratio with optimum curing is used. For achieving high durability, concrete porosity should be kept low to reduce its permeability [39].

In conclusion, the porosity of concrete decreases as the curing ages increase, and increases with the w/c increasing, hence, a good linear relationship between the porosity and w/c. Immersion curing recorded the lowest porosity of 4.35%, at the highest curing age of 56 days which implies that the immersion method of curing concrete gained the maximum strength. However, with an increasing w/c ratio, porosity goes up and compressive strength is reduced [40].

3.3 Impact of Curing Methods on Compressive Strength of Concrete

The study also sought to find out the impact of curing methods on the compressive strength of concrete.

It can be observed from Fig. 2 that the immersion curing method yielded the highest compressive strength of 24.43 N/mm^2 for the 28 days curing period and 25.43 N/mm^2 for the 56 days, whereas the sprinkling method recoded the lowest strength of 18.00N/mm^2 for the 28 days and 22.33 N/mm^2 for 56 days curing ages respectively. This result is similar to those obtained by Raheem and Abimbola [41], Raheem et al., [42] and Usman and Nura Isa [10].

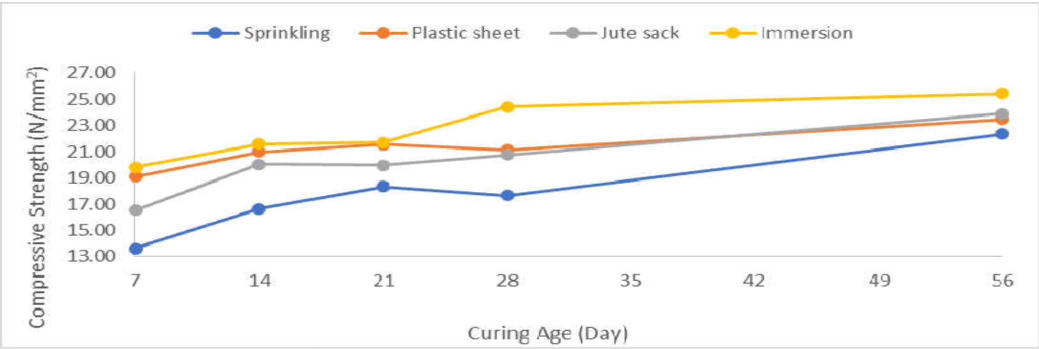

Fig. 2. Graph of average compressive strength against ages of concrete cubes

The entire specimens for the four curing methods increased in strength from the 7th to the 56th day curing periods. In ranking the four curing methods in terms of strength, the sprinkling methods were ranked last. Inferring from the results, the strength of the specimens continually increased during the 56 days of curing as water, which allows continuous cement hydration was present in abundance thereby ensuring 100% relative humidity. Sprinkling curing recorded lower compressive strengths of curing at all ages. This is because the moisture movement from the concrete specimen is higher in the sprinkling method, which did not provide any protection against early drying out of concrete [6].

In summary, the mean compressive strength results showed that at all ages, immersion curing recorded the highest compressive strength of all the other curing methods with sprinkling having the lowest compressive strength. It could be seen that there was a significant increase in concrete strength with age depending on the curing method used. Since the concrete curing age gave an increase in strength, this, therefore, suggests that curing is very important and necessary for all concrete structures [2].

3.4 ANOVA Test of Significance

Following the results obtained from the descriptive statistics, a one-way ANOVA test at a significance level of 5% was also conducted as shown in Table 3 to test if the difference in group means is attributed to chance or error. Deducing from the table, differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001) in the strength of concrete. This means that the treatment method for curing concrete produce a significant difference in the compressive strength of concrete. It can therefore be concluded from the results that the immersion curing method produces significantly higher compressive strength than all the other methods used for the study.

Also, to isolate the group or groups that differ from the others, a multiple comparison procedure was used and the result is as shown in Table 4 below.

Pairwise comparison between the treatment methods indicated a significant difference in the use of immersion and sprinkling method of curing concrete and ranked highest (T=8.433, p<0.001) followed by plastic sheets and sprinkling method (T=6.114, p<0.001). The lowest-ranked significant difference in the means was found in the jute sack and sprinkling method of curing concrete (T=4.351, p<0.05). And the next lowest significant difference in the means was in the immersion and jute sack method of curing concrete (T=4.081, p<0.05).

Table 3. Difference between the compressive strength of the curing methods

Descriptive statistics				One Way RM ANOVA					
Treatment Name	**Mean**	**Std Dev**	**SEM**	**Source of Variation**	**DF**	**SS**	**MS**	**F**	**P**
Sprinkling	17.720	3.144	1.406	Between Subjects	4	87.778			
Plastic Sheet	21.253	1.558	0.697	Between Treatments	3	63.692	21.231	25.428	<0.001
Jute sack	20.235	2.622	1.173	Residual	12	10.019	0.835		
Immersion	22.593	2.293	1.026	Total	19	161.489			

Table 4. Pairwise Comparison between P-values

Comparison	Diff of Means	T	P	P<0.050
Immersion vs. Sprinkling	4.873	8.433	<0.001	Yes
Plastic sheet vs. Sprinkling	3.533	6.114	<0.001	Yes
Jute sack vs. Sprinkling	2.515	4.351	0.004	Yes
Immersion vs. Jute sack	2.359	4.081	0.004	Yes
Immersion vs. Plastic sheet	1.340	2.319	0.076	No
Plastic sheet vs. Jute sack	1.019	1.763	0.103	No

On the contrarily, immersion and plastic sheet method of curing concrete were found not to have any significant difference (T=2.319, p>0.05) just as plastic sheet and jute sack methods of curing concrete (T=1.019, p>0.05).

3.5 Relationship between Porosity and Compressive Strength

Table 5 below showed porosity versus compressive strength. Pearson correlation coefficient computed for the relationship between porosity and compressive strength of concrete at the 28th day curing age indicates that porosity has a significant negative effect on the compressive strength of concrete (r = 0.497, p = 0.05). This implied an increase in the percentage of concrete porosity will lead to a decrease in concrete compressive strength. The results show that there is an inverse relationship, i.e., the higher the strength the lower the porosity. This confirms the findings of other researchers [43] [44].

3.6 Cube Density

Table 6 below showed the mean density recorded by each curing method and the range. The density of the specimens ranged from 2229 to 2398.33 kg/m3. This lies within the range of 2200 to 2600 kg/m3 specified as the density of normal weight concrete [24]. The immersion curing produced concrete with the highest mean densities of 2369 kg/m3, followed by jute 2360 kg/m3 for 56th days, then plastic sheet method with mean density values of 2277 kg/m3. The specimens cured with the sprinkling method produced the lowest range of density of 2229 kg/m3 for 56 days. The immersion curing method produced the highest range of density and standard deviation indicating that the method is highly unreliable. The specimens cured by the sprinkling method produced the lowest range of density and standard deviation indicating that the method is reliable. This is similar to study results obtained by James et al. [2].

The mean compressive strength results showed that at all ages, curing with immersion recorded the highest compressive strength of all the other curing methods, while the sprinkling curing method has the lowest mean compressive strength. It could be seen that there was a significant increase in concrete strength with age depending on the curing method used. Since the concrete curing age gave an increased strength, this, therefore, suggests that curing is very important and necessary for all concrete structures [2].

The pattern of increase in concrete density was observed to be similar to that of the compressive strength. This, therefore, suggests that an increase in both compressive strength and density of a concrete cube was a function

Table 5. Correlation between porosity and compressive strength

	Porosity y	Compressive strength
Porosity	1	-0.497'
Compressive e strength		1

'P = 0.05 (1-tailed significance)

Table 6. Average density of concrete

		Curing Method			
Curing Days	**Test type**	**Sprinkling**	**Plastic sheet**	**Jute sack**	**Immersion**
7	Density kg/m^3	2303.67	2320.33	2340.00	2398.33
14	Density kg/m^3	2332.33	2323.67	2325.33	2341.00
21	Density kg/m^3	2281.00	2310.33	2342.67	2397.00
28	Density kg/m^3	2327.33	2316.00	2321.00	2352.00
56	Density kg/m^3	2229.00	2277.00	2360.00	2369.00

of the curing method. Immersion is thus the most effective method of curing. It produced the highest level in compressive strength and cube densities. Compressive strength when arranged in descending order for all the curing methods, it could also be seen that immersion gave the highest result for the curing periods. Affirming this assertion, James et al. [2] assert that this is due to improved pore structure and lower porosity resulting from a greater degree of cement hydration and cement reaction without any loss of moisture from the concrete cubes.

4. CONCLUSIONS

Based on the results and discussions, the following conclusions can be drawn:

- Slump valves were within the range of 52 to 58 which is within the medium range of 25 to 100, hence true slump was achieved.
- The porosity of all samples decreased with age (i.e at the dried state, immersion recorded the lowest 4.35%, followed by jute sack with 5.25%, plastic sheet 5.29% and sprinkling 5.55%). The lower the w/c ratio the lower porosity and the higher the strength of concrete. Therefore, immersion with the lowest valve (4.35%) is the best curing method with high strength.
- The pattern of increases in concrete density (immersion curing produced concrete with the highest mean densities of 2369 kg/m^3, jute 2360 kg/m^{3,} plastic sheet 2277 kg/m^3. sprinkling 2229 kg/m^3 all for 56 days) was similar to that of the compressive strength (immersion curing method yielded the highest compressive strength of 25.43 N/mm^2, jute method 23.90 N/mm^2, plastic method 23.47 N/mm^{2,} sprinkling method 22.33 N/mm^2 for 56 days curing ages respectively). Therefore, increases in both compressive strength and densities of concrete cube is a function of curing method.

5. RECOMMENDATIONS

Based on the results and discussions, the study recommends the following:

- The immersion method of curing is recommended to be the best of all the curing methods. For early strength development, immersion curing is the most effective method. Immersion curing produces higher compressive strength than the sprinkling method.
- Concrete designers and manufacturers are advised to pay attention to curing methods that are good for our hot climate.
- A recommendation is made for further studies on the effect of curing methods on porosity and compressive strength of concrete on the field since this study was done in the laboratory under control conditions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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