Effect of Curing Techniques on the Strength of Washed Aggregate Concrete

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***Abstract:** The effect of curing techniques on the strength characteristic of washed aggregate concrete with a nominal mix ratio of 1:2:4 and a w/c ratio of 0.6 was examined. The fine and coarse aggregates were thoroughly washed and devoid of all impurities. Four curing techniques were considered: full water immersion, periodic water sprinkling, wet covering and open-air (uncured). A total of 48 concrete samples were produced and subjected to compressive strength test at ages 7, 14, 21 and 28 days. The 28-day compressive strength of samples cured by water immersion, sprinkling, wet covering and open-air methods were 20.01 N/mm^2, 13.95 N/mm^2, 11.16 N/mm^2 and 9.07 N/mm^2 respectively. The full water immersion technique was discovered to be the most effective. The difference in 28-day strength between samples cured by full water immersion and those exposed to the open-air (uncured) condition was obtained as 54.67%. Undesirable strength performances were recorded for concrete specimens that were allowed to harden without an intentional application of supplemental water or protective coverings.*

***Keywords:** Compressive Strength, Concrete, Curing Techniques, Washed Aggregate*

I. INTRODUCTION

Concrete is recognized as one of the most important composite material engineered by man. It is formed from the combination of cement (binder), sand (fine aggregate), stone (coarse aggregate) and water in specific proportions known as mix ratios to produce a physically robust, workable and durable material. A typical mix ratio of 1:2:4 denote a mixture proportion of 1 part of cement mixed with 2 parts of fine aggregate and 4 parts of coarse aggregate in a process called batching. Batching could be done by weight or by volume.

The binding of aggregates, cement and water is a result of the chemical reaction undergone by cement and water known as hydration. Hydration of concrete is necessary for the creation of a matrix that binds all its constituents together, ensuring that the concrete produced exhibits ideal characteristics such as strength, durability, crack resistance and hardening. However, for the optimal characteristic of concrete to be achieved, the hydration process must be deemed complete and this is obtained through a controlled production process where the concrete specimens are exposed to appropriate moisture and temperature levels. The curing process involves maintaining suitable moisture and temperature conditions to prevent moisture loss through evaporation. The duration for proper curing often last as long as 28 days, during which the concrete is expected to have attained at least 95% of its characteristic strength.

There are various methods of curing concrete documented in available literature; some of these include shading, water sprinkling, ponding, wet covering, steaming, moist sand covering, membrane covering etc. However, Padhi (2014) disclosed that the choice of curing method to be utilized is greatly influenced by the nature of work and prevailing climate conditions.

Osei et al. (2019) investigated the impact of different curing methods on the compressive strength of concrete. Concrete of mix ratio 1:2:4 (A) with water to cement (w/c) ratio of 0.5 and concrete of mix ratio 1:3:6 (B) with w/c ratio of 0.6 were examined. The study revealed that for concrete of mix ratio A, ponding curing technique recorded the highest 28-day compressive strength as 20.03 N/mm^2, while the least strength was obtained from samples cured by the sprinkling method as 16.7 N/mm^2. However for concrete samples of mix ratio B, the highest 28-day strength was obtained via the ponding method as 17.1 N/mm^2 and the least in this case was obtained by the open-air method as 14.5 N/mm^2. The study established that the ponding curing technique facilitated complete hydration of the concrete specimens.

Similar studies on concrete with a mix ratio of 1:2:4 were conducted by Jackson and Akomah (2018) and Orogbade et al. (2024). It was reported in Jackson and Akomah (2018) that concrete specimens cured by the ponding method performed better in compressive strength testing than all the other curing techniques considered, which included jute bag, polythene sheet and wet sand covering. However, Orogbade et al. (2024) found that the compressive strength of concrete specimens subjected to sand curing exceeded those of specimens cured by sawdust covering, polythene sheet covering, water sprinkling and ponding.

Alsadik et al. (2019) researched on the performance of cement mortar exposed to different temperature and curing methods. Mortar specimens of mix proportion 1:2.75 (cement: sand) with w/c ratio of 0.46 were produced using OPC (ordinary portland cement) and SRPC (sulfate resisting portland cement). The samples were tested under curing temperatures 25 ^{o}C and 45 ^{o}C. Ponding method was reported to have produced the maximum 28-day compressive strength. Specimens produced from OPC recorded a maximum strength at 25 ^{o}C as 31.31 N/mm^2. However, for samples made of SRPC, the maximum strength was obtained at 45 ^{o}C as 26.87N/mm^2. Alsadik et al., indicated that the increment in the compressive strength of mortar is significantly influenced by the curing method and the environmental conditions present.

The coarse and fine aggregates which are significant components of concrete occupy a large overall volume in concrete mixes and it can be argued that the quality of these aggregates significantly influences on the overall mechanical characteristics of concrete. Impurities like organic matter, salt, clay or dust, which are often found mixed-in with the extracted aggregates adversely affect the concrete production process. Impurities often restrict the bonding between the cement and aggregates, interfere with the hydration process, which can lead to crack formation, reduced durability, low wear and abrasive resistance and overall loss of strength. A way of separating these impurities from the aggregates is by washing the aggregates with fresh water, aggregate washing is an essential process undergone to maintain aggregate quality and integrity as well as improve adherence to specification standards.

Kolo et al. (2020) investigated the effect of aggregate washing on the compressive strength of concrete produced using Bida natural stone. The British standard mix design (DOE) method was used in the study. The results for the 28-day average compressive strength for the washed and unwashed aggregate concrete were obtained as 22.52 N/mm^2 and 19.94 N/mm^2 respectively, an 11.46% variation in strength was recorded, the washed aggregate concrete was found to outperform the unwashed aggregate concrete in strength and in all statistical confidence levels considered. The findings of this research were in agreement with Ode and Eluozo (2016) and Ogubiyi et al. (2017), it was recommended that aggregates should be washed thoroughly, freeing it from impurities prior to its utilization in concrete production.

The atmospheric condition of an environment is known to have a significant effect on the hydration of concrete; higher temperatures accelerates the drying out of concrete specimens due to evaporation, necessitating the need for a controlled environment to ensure complete hydration. In Calabar, Cross River State, Nigeria, some local contractors cure concrete by periodic water sprinkling. However, most of these contractors use the open-air curing technique, where no added water or protective coverings are introduced to create a suitable environment for complete hydration. Concrete specimens cured by open-air method are most often ignored after production, with curing relying solely on the prevailing environmental conditions, such as rainy or dry seasons. Local workmen remain ignorant of the true impact of their choice of curing method or the neglect of an intentional curing process, has on the probability of producing concrete specimens whose strength attains or exceeds the desired target compressive strength associated with its nominal mix ratio. This research is aimed at investigating the effect of curing techniques on the strength characteristics of washed aggregate concrete. It highlights how curing methods influences on the expected target compressive strength of concrete in relation to its nominal mix ratio (grade M15 - 1:2:4). The curing methods chosen for this study are those frequently used in local construction sites in Calabar.

II. MATERIALS AND METHODS

This paper reports on an investigation into the effect of curing techniques on the compressive strength of washed aggregate concrete. The aggregates used were thoroughly washed and devoid of impurities. All laboratory tests on the aggregates and concrete specimens were carried out at the University of Cross River State concrete and structures laboratory. The curing methods examined in this study include full water immersion, periodic water sprinkling, wet covering and open-air (uncured) method.

a. Materials

The materials used in this work were locally obtained and they include UNICEM Portland Limestone Cement: CEM II/B-L 32.5R, Coarse aggregate: 20mm nominal aggregate size of granite, Fine aggregate: sharp sand and fresh water. Details of the physical test conducted on the aggregates are presented in Table 1.

Table 1: Physical properties of aggregate

Properties	Aggregate	
	Sharp Sand	Granite
Specific gravity	2.5	2.56
Loose Bulk density (kg/m^3)	1412	1460
Water absorption (%)	2.6	1.5
Fineness modulus	3.38	6.4
Coefficient of uniformity C_U	3.16	1.66
Coefficient of curvature C_C	1.05	1

The uniformity coefficient C_u and curvature coefficient C_c obtained for the sharp sand from the grading curve are 3.16 and 1.05 respectively. This indicates that the sand is well graded since $1 < C_c < 3$, while the value of $C_u = 3.16$ suggests that the sand is uniformly or open graded. The fineness modulus of sand obtained as 3.38, indicates that the material is coarse sand and falls within the acceptable range for fine aggregates.

The uniformity coefficient C_u and curvature coefficient C_c for granite, derived from the grading curve, are 1.66 and 1.05 respectively. This indicates that the granite is well graded since $1 < C_c < 3$, while the value of $C_u = 1.66$ suggests the granite is narrowly graded, as $C_u < 4$. The fineness modulus of granite obtained as 6.4, indicates that the material is coarse.

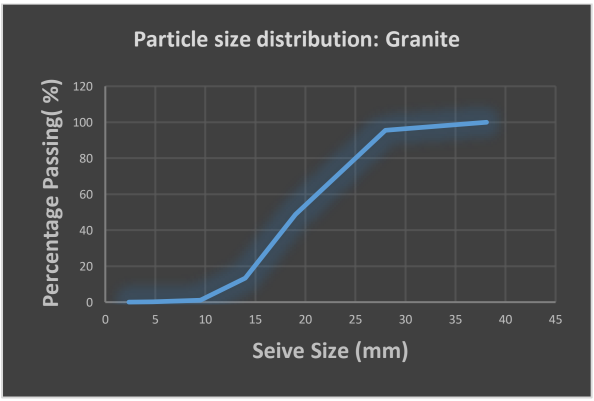

Figure 1: Aggregate grading curve: granite

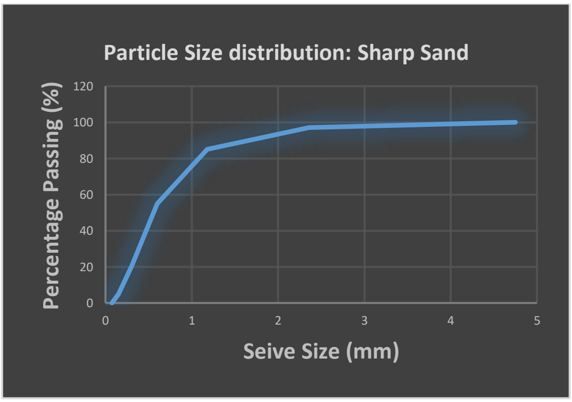

Figure 2: Aggregate grading curve: sharp sand

The results of the particle size distribution test performed in accordance with BS 812-103: (1985) indicates that the particle sizes of sharp sand (figure 2) and granite (figure 1) fall within the grading limits for sand and gravel, respectively, as specified in BS 1199 and 1200.

b. Methods

The fresh concrete was prepared using a nominal mix ratio of 1:2:4 and w/c ratio of 0.6. Batching of materials was done by weight. A slump test was performed to measure the workability of the freshly mixed concrete. The concrete mix was then transferred to a slump cone which was oiled and cleaned in four equal layers with each layer tapped 25 times with a tamping rod, after compaction, the top surface was leveled and the cone gently lifted in an upward direction. The cone was placed by the side of the sample and at the end of the concrete settlement, the difference in height between the concrete sample and cone (slump value) was measured in millimeters (mm). The reduction in height of the cone was considered a measure of workability (Ibiang, 2025).

To perform a compressive strength test on the hardened concrete, a cubical metal mould measuring 100mm x 100mm x 100mm in dimension was used to cast the specimens. The moulds were cleaned and greased to avoid the concrete paste sticking to its sides during removal. The cement and aggregates were thoroughly mixed with gradual addition of water to avoid coagulation. The fresh concrete was poured into each mould in three layers with each layer compacted with a tamping bar by 35 blows. The samples were separated into four categories representing each curing conditions: full water immersion, periodic water sprinkling, wet covering and open-air (uncured). They were cured for 7, 14, 21 and 28days, with three cubes cast for each curing period and method, resulting in a total of 48 specimens. In full water immersion method, the concrete samples were fully immersed in a tank filled with fresh water. In periodic sprinkling method, the specimens were sprinkled with water for a duration of 2 – 3 minutes in every 12±1 hours. In wet covering method, the specimens were covered with a wet blanket which was regularly kept moist to prevent it from drying out. In open-air (uncured) method, the samples were not subjected to any intentional curing process and were left out in the open air.

The compressive strength test was performed to determine the maximum axial load the hardened concrete cubes can resist before failure, in accordance with BS 1881 – 116 (1983). After the desired curing age was attained, the cubes were wiped, left to dry, and their dimensions and weight were measured. The specimens were then placed in a digital compressive machine aligned centrally to the base plate; the load was gradually applied until specimen failure was observed, the failure load was recorded and the compressive strength was determined from equation (1).

$$Compressive\ strength\ (N/mm^2) = \frac{Failure\ load\ (N)}{Cross\ Sectional\ area\ of\ concrete\ cube\ (mm^2)} \quad (1)$$

III. RESULTS AND DISCUSSION

The test for workability of fresh concrete measures the ease at which concrete can be poured, placed, cured and compacted without excessive bleeding or segregation. The slump test is one of the more renowned method of assessing concrete workability; its value signifies the consistency, fluidity, and workability of fresh concrete. The compressive strength of the hardened concrete specimens measures it resistance to direct axial loading prior to failure.

b. Slump Value

The concrete with nominal mix ratio of 1:2:4 and w/c ratio of 0.6 produced a true slump value of 85mm, indicating medium workability (slump class: S2) and suitability for application in concrete slabs, footings, mass concrete, retaining walls and columns. The sump test was done in accordance with BS 1881- 103 (1993).

c. Compressive Strength

The results of the compressive strength test on the hardened concrete specimens under the various curing conditions and ages are presented in Figure 3. Table 2 provides a detailed comparative overview of all the curing conditions examined as they impact on the strength of concrete over time. The mean compression strength represents the average strength of the 3 specimens crushed for each age and curing method.

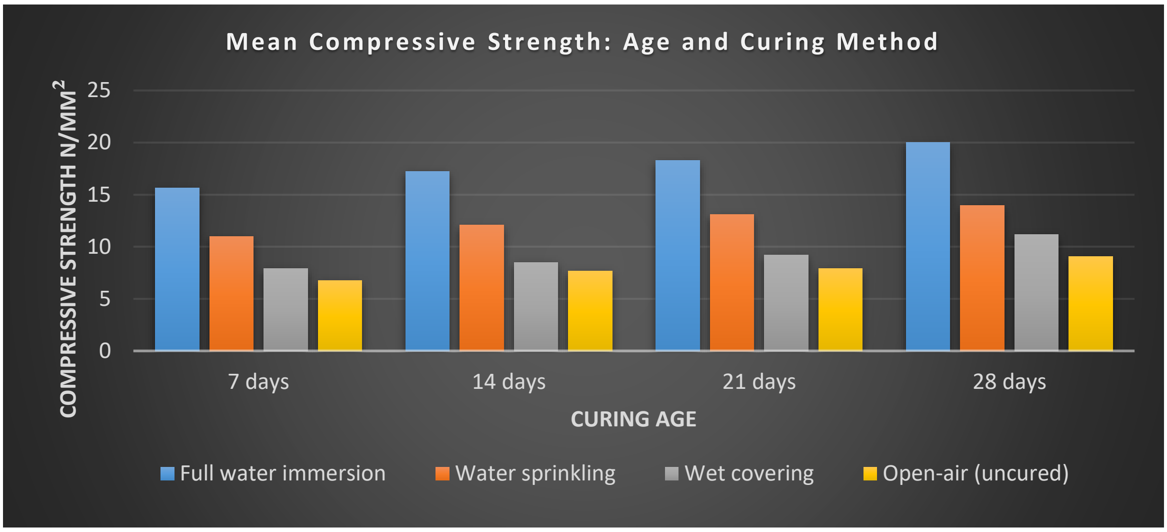

Figure 3: Compressive strength: Age and Curing Methods

Table 2: Deviations in mean compressive strength

S/N	Curing methods	Mean Compressive strength (N/mm^2)			
		7 days	14 days	21 days	28days
1	Full water immersion	15.63	17.22	18.29	20.01
	Periodic water sprinkling	10.97	12.08	13.08	13.95
	Difference in comp. strength	4.66	5.14	5.21	6.06
	% Difference	29.81	29.85	28.49	30.28
2	Full water immersion	15.63	17.22	18.29	20.01
	Wet covering	7.92	8.51	9.19	11.16
	Difference in comp. strength	7.71	8.71	9.1	8.85
	% Difference	49.33	50.58	49.75	44.23
3	Full water immersion	15.63	17.22	18.29	20.01
	Open-air (Uncured)	6.75	7.66	7.91	9.07
	Difference in comp. strength	8.88	9.56	10.38	10.94
	% Difference	56.81	55.52	56.75	54.67
4	Periodic water sprinkling	10.97	12.08	13.08	13.95
	Wet covering	7.92	8.51	9.19	11.16
	Difference in comp. strength	3.05	3.57	3.89	2.79
	% Difference	27.8	29.55	29.74	20
5	Periodic water sprinkling	10.97	12.08	13.08	13.95
	Open-air (uncured)	6.75	7.66	7.91	9.07
	Difference in comp. strength	4.22	4.42	5.17	4.88
	% Difference	38.47	36.59	39.53	34.98
6	Wet covering	7.92	8.51	9.19	11.16
	Open-air (uncured)	6.75	7.66	7.91	9.07
	Difference in comp. strength	1.17	0.85	1.28	2.09
	% Difference	14.77	9.99	13.93	18.73

As shown in figure 3, it evident that specimens subjected to full water immersion outperformed those cured by periodic water sprinkling, wet covering and open-air curing methods. It is also evident that the concrete cubes which were not intentionally cured (open-air method) exhibited poor strength performances when compared to concrete samples which were intentionally cured by application of supplemental water or protective covering. The compressive strength of concrete was observed to gradually increase with age across all specimens. The highest strengths were recorded from specimens cured by full water immersion with values of 15. 63 N/mm^2, 17.22 N/mm^2, 18.29 N/mm^2 and 20.01 N/mm^2 at ages 7, 14, 21 and 28 days respectively. Those cured by periodic water sprinkling were next, with strengths obtained as 10. 97 N/mm^2, 12.08 N/mm^2, 13.08 N/mm^2 and 13.95 N/mm^2 at ages 7, 14, 21 and 28 days respectively. Specimens cured by wet covering followed, recording strengths of 7.92 N/mm^2, 8.51 N/mm^2, 9.19 N/mm^2, and 11.16 N/mm^2 at ages 7, 14, 21 and 28 days respectively. The least strength was observed in the untreated samples (open-air method), with values of 6.75 N/mm^2, 7.66 N/mm^2, 7.91 N/mm^2 and 9.07 N/mm^2 at ages 7, 14, 21 and 28 days respectively. Table 2 illustrates the degree at which the choice of curing method adopted impacts on the strength of the concrete samples. It can be observed that the 28-day strength deviation between samples cured by full water immersion and those cured by periodic sprinkling and wet covering are 30.28% and 44.23% respectively. The difference is more pronounced when comparing samples cured by full water immersion with those left uncured (open-air), the deviation was obtained as 54.67%.

The target compressive strength (approximately 15 N/mm^2) based on the nominal mix ratio 1:2:4 M15 grade was attained and exceeded by specimens cured by full water immersion at 28 days (20.01 N/mm^2). Specimens cured by water sprinkling recorded a maximum strength of 13.95 N/mm^2 which fell short of the target compressive strength. Worse strength performances were observed with samples of the wet curing method (11.16 N/mm^2) and the open-air (uncured) method (9.07N/mm^2). The overall results highlights the significant impact that the choice of curing method has on the strength performance of washed aggregate concrete. Aggregate washing and an appropriate curing technique must be adopted to ensure adequate quality levels are maintained in concrete production.

IV. CONCLUSION

In this study, it was shown that proper curing of concrete can improve strength gains by up to 50% when compared to concrete that underwent no intentional curing process. The full water immersion curing method was found to be the most effective in promoting complete cement-water hydration. Concrete samples cured by this technique recorded the highest compressive strength among all concrete ages with variation in 28-day compressive strength obtained as 30.28%, 44.23% and 54.67% when compared to samples cured by periodic water sprinkling, wet covering and open-air (uncured) methods respectively. Undesirable strength performances were recorded for concrete that were subjected to the open-air curing technique, this technique by its nature is solely dependent on the existing environmental conditions and must be discontinued due to its unreliability.

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