

The Comparative Assessment of Curing Methods and Their Effect on the Strength Characteristics of Concrete

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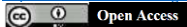
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ABSTRACT

This study comparatively evaluates the influence of water-submerged, polythene and air curing on selected strength characteristics of concrete. A nominal mix ratio of 1:2:4 with a water-cement ratio of 0.50 was adopted. A total of 36 concrete cubes and 36 beam specimens were produced using 150 × 150 × 150 mm cube moulds and 75 × 300 × 150 mm beam moulds, respectively. The specimens were cured under the three selected regimes and tested at 7, 14, 21 and 28 days. The investigated properties were compressive strength, flexural strength and density, while slump was used to assess the workability of the fresh concrete. The average slump was 63 mm, indicating a medium-workability mix. The experimental results show that water-submerged curing produced the highest compressive strength at 28 days (29.67 N/mm²), followed by polythene curing (20.74 N/mm²) and air curing (18.96 N/mm²). Water-submerged curing also produced the highest 28-day flexural strength (3.25 N/mm²). The results demonstrate that maintaining adequate moisture during the early stages of hydration is critical to strength development. The findings are consistent with previous experimental evidence showing that water curing generally provides superior strength development, while sealing methods such as polythene can perform better than unprotected air curing when they effectively reduce moisture loss (Safiuddin et al., 2007; Raheem et al., 2013). Overall, water-submerged curing was the most effective of the three methods investigated under the conditions of this study.

Introduction

Concrete is a heterogeneous composite material whose performance depends on the properties and proportions of its constituent materials, the water-cement ratio, mixing and compaction procedures, age, and the environmental conditions to which it is exposed. Among these factors, curing is particularly important because it controls the moisture and temperature conditions required for continued cement hydration and the development of the hardened cement paste structure. Neville (2011) describes curing as a set of procedures intended to promote hydration by controlling moisture movement and temperature. Adequate curing therefore provides the conditions under which the potential strength and durability of concrete can be developed.

When Portland cement is mixed with water, hydration reactions begin and progressively produce hydration products that bind the aggregate particles and develop the hardened cementitious matrix. Continued hydration requires sufficient internal moisture. If water is lost prematurely through evaporation, the relative humidity within the concrete falls and hydration becomes increasingly restricted. Experimental work by Safiuddin, Raman, and Zain (2007) showed that dry-air curing produced substantially poorer hardened properties than water and wrapped curing because of greater moisture loss. Their findings reinforce the fundamental principle that effective curing should either supply moisture to the concrete or prevent the loss of moisture already present.

The practical importance of curing is particularly relevant in regions such as Nigeria, where high temperatures, solar radiation, wind and periods of relatively low humidity can accelerate evaporation

from exposed concrete. Raheem, Aliu, and Amaka (2013), in an experimental investigation of six curing techniques, found substantial differences in compressive strength among curing regimes and reported the lowest 28-day strength for air-cured specimens. Such findings indicate that the selection of a curing method should not be treated as a secondary construction activity; rather, it is an essential part of quality control.

The present study investigates three curing methods—water-submerged curing (WSC), polythene curing (PC), and air curing (AC)—using the experimental results contained in the original study document. The objective is to clarify the relationship between curing method and the development of compressive and flexural strength while also examining the measured density of the concrete.

1.1 Aim of the Study

The aim of this study is to comparatively assess the effects of water-submerged, polythene and air curing on the strength characteristics of concrete.

1.2 Objectives of the Study

To produce concrete specimens using a nominal 1:2:4 mix proportion and a water-cement ratio of 0.50.

To investigate the compressive strength development of concrete cured by water submersion, polythene sheeting and exposure to air.

To determine the flexural strength of concrete under the three curing regimes at 7, 14, 21 and 28 days.

To compare the density of concrete specimens produced under the different curing conditions.

To identify the curing method that produced the most favourable strength performance under the conditions of the experiment.

1.3 Scope of the Study

The investigation is limited to three curing methods: water-submerged curing, polythene curing and air curing. Concrete specimens were evaluated at 7, 14, 21 and 28 days. The principal hardened-concrete properties considered were compressive strength, flexural strength and density. Fresh-concrete workability was assessed using the slump test. The study does not evaluate durability indicators such as permeability, chloride penetration, sorptivity or shrinkage.

2. Literature Review

2.1 Concrete Curing and Cement Hydration

Curing is the deliberate control of moisture and temperature conditions around freshly placed concrete to allow cement hydration to proceed effectively. Neville (2011) emphasises that curing is closely connected with the movement of moisture into and out of concrete and with temperature control. The importance of curing arises because strength development is not simply a drying process. Rather, it is associated with continuing chemical and physical changes in the cementitious system.

During hydration, cement compounds react with water to form hydration products, principally calcium silicate hydrate, which is a major contributor to the strength and cohesion of hardened cement paste. Adequate curing supports continued hydration and refinement of the pore structure. Conversely, premature drying can restrict hydration and leave a more porous and weaker matrix (Safiuddin et al., 2007; Ramezani-pour & Malhotra, 1995).

2.2 Water-Submerged Curing

Water-submerged curing involves placing hardened specimens in water after demoulding so that the concrete remains continuously exposed to a moist environment. The method is particularly convenient for laboratory specimens because it can maintain a highly favourable moisture condition. Safiuddin et al. (2007) reported that water curing produced the highest compressive strength among the curing methods investigated for microsilica concrete. Raheem et al. (2013) likewise reported continuous strength development under water-submerged curing.

2.3 Polythene Curing

Polythene curing is a sealing technique in which the concrete surface is covered with an impervious polyethylene sheet. The principal purpose is to reduce evaporation and retain the mixing water within the concrete. When the sheet is properly sealed and remains in close contact with the surface, moisture loss can be substantially reduced. Safiuddin et al. (2007) found that wrapped curing performed better than dry-air curing, although water curing produced the best overall hardened properties in their study.

2.4 Air Curing

Air curing, as used in this study, involves exposing specimens to ambient laboratory conditions without active moisture supplementation or sealing. It provides a useful control condition because it represents a situation in which curing is inadequate or absent. The principal limitation is the loss of moisture from the concrete surface. Safiuddin et al. (2007) reported that dry-air curing resulted in greater moisture loss and lower compressive strength than water and wrapped curing. Raheem et al. (2013) similarly reported the lowest 28-day compressive strength for air-cured specimens among the curing regimes they investigated.

2.5 Factors Affecting Concrete Strength

Curing is only one of several variables affecting concrete strength. Other important factors include the water-cement ratio, cement type and content, aggregate grading and properties, degree of compaction, specimen geometry, age at testing, and testing procedure (Neville, 2011). Consequently, a meaningful comparison of curing methods requires the mix constituents, batching, mixing, moulding, compaction and testing conditions to be kept as consistent as practicable.

2.6 Review of Previous Experimental Evidence

Raheem et al. (2013) examined six curing methods using a 1:2:4 concrete mix with a water-cement ratio of 0.65. Their results showed that moist sand curing produced the highest 28-day compressive strength, while air curing produced the lowest. The authors also reported a weak positive relationship between density and compressive strength. Although the mix and curing conditions differed from those of the present study, the work provides useful evidence that curing regime can materially alter strength development.

Safiuddin et al. (2007) investigated water, wrapped and dry-air curing of microsilica concrete. Water curing produced the highest compressive strength, while dry-air curing produced the lowest. The authors attributed the poorer performance of dry-air curing to moisture movement out of the specimens, which restricted hydration and affected the development of the concrete microstructure. The agreement between that study and the present results strengthens the interpretation that moisture retention is a key mechanism governing curing effectiveness.

3. Materials and Methods

3.1 Materials

The coarse aggregate used in the original investigation was river gravel obtained from River Benue, while the fine aggregate was river sand obtained from the same source. Ordinary Portland cement manufactured by Dangote Cement was used as the binder. Water was obtained from the University of Agriculture waterworks. The materials were used consistently across the experimental batches.

3.2 Concrete Mix Proportion

A nominal mix ratio of 1:2:4 was adopted for cement, fine aggregate and coarse aggregate, respectively, with a water-cement ratio of 0.50. Batching was performed by weight using a 25-kg ELE weighing machine. The use of a constant mixture for all curing regimes ensured that curing condition was the principal variable being compared.

3.3 Specimen Preparation

Concrete was mixed manually by first blending the cement and fine aggregate, followed by the addition of coarse aggregate and then water. Concrete cubes measuring $150 \times 150 \times 150$ mm and beams measuring $75 \times 300 \times 150$ mm were used. The moulds were cleaned and oiled before casting. The fresh concrete was placed in the moulds and compacted in three layers using a tamping rod. After approximately 24 hours, the specimens were demoulded and assigned to their respective curing regimes.

A total of 36 cube specimens and 36 beam specimens were produced. The specimens were tested after curing periods of 7, 14, 21 and 28 days.

3.4 Preliminary Tests

Specific gravity tests were carried out on the fine and coarse aggregates using the pycnometer method. Sieve analysis was also conducted to determine particle-size distribution. The average specific gravity reported for the fine aggregate was 2.44, while that of the coarse aggregate was 2.60. The average slump of the fresh concrete was 63 mm, which falls within the medium-workability range reported in the original study.

Table 1

Summary of aggregate specific gravity results

Material	Test 1	Test 2	Test 3	Average
Fine aggregate	2.59	2.32	2.40	2.44
Coarse aggregate	2.59	2.62	2.58	2.60

3.5 Curing Regimes

The demoulded specimens were assigned to three curing regimes. In water-submerged curing, specimens were immersed in water. In polythene curing, specimens were covered with polythene membrane to reduce moisture loss. In air curing, specimens were exposed to ambient laboratory air without active curing. The same testing ages—7, 14, 21 and 28 days—were used for all regimes.

3.6 Testing Procedures

The slump test was used to assess the workability of fresh concrete. Density was determined from specimen mass and volume. Compressive strength was obtained by loading the 150-mm cubes to failure in a mechanically operated ELE compression-testing machine with a capacity of 1500 kN. Flexural strength was determined from the beam specimens under the four-point loading arrangement described in the original experimental procedure.

For compressive strength, the standard relationship is:

$$f_n = P / A$$

where f_n is the compressive strength, P is the maximum load at failure, and A is the loaded cross-sectional area. All reported strength values in this article are those recorded in the original study and represent the average values reported for each curing condition and age.

4. Results and Discussion

4.1 Workability

The average slump of the concrete was 63 mm. This value indicates medium workability and is consistent with the classification reported in the original study. Since the same concrete mixture was used for all curing regimes, differences in the hardened properties can reasonably be interpreted primarily in terms of the curing conditions rather than differences in initial workability.

4.2 Density and Compressive Strength

Table 2

Density and compressive strength of concrete cubes under different curing methods

Age (days)	WSC density (kg/m ³)	WSC strength (N/mm ²)	PC density (kg/m ³)	PC strength (N/mm ²)	AC density (kg/m ³)	AC strength (N/mm ²)
7	2439.8	23.29	2502.0	19.86	2453.4	19.5
14	2591.9	26.82	2388.25	25.48	2343.11	17.85
21	2389.8	27.55	2491.75	14.88	2605.53	18.37
28	2538.0	29.67	2425.15	20.74	2406.91	18.96

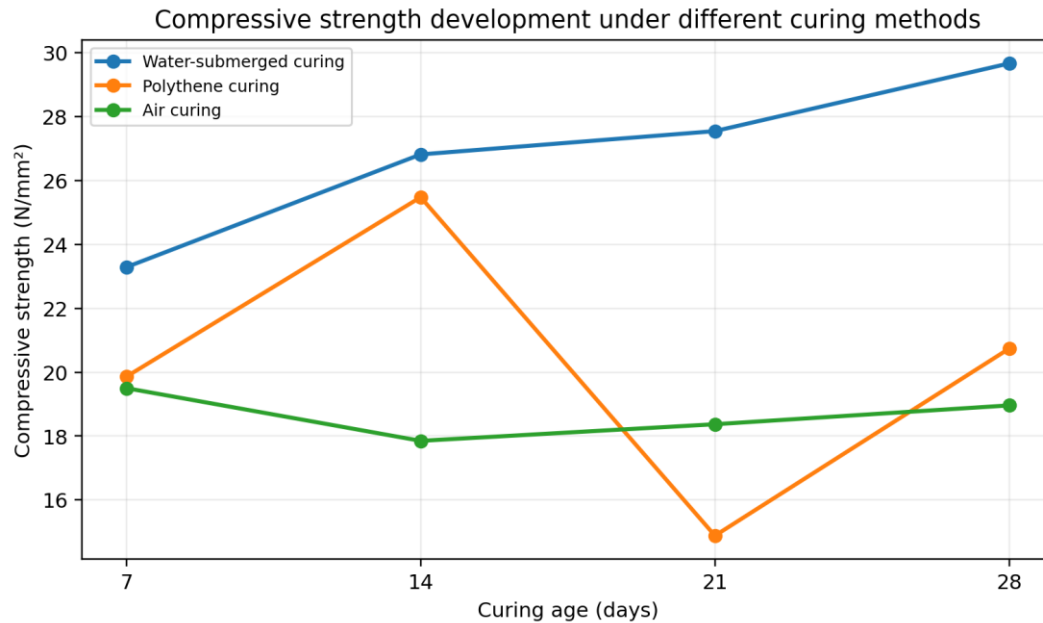


Figure 1. Compressive strength development under the three curing methods.

Water-submerged curing produced the highest compressive strength at every testing age except that the comparison should be interpreted in terms of the reported average values rather than a universal ranking for all concrete mixtures. Its strength increased from 23.29 N/mm² at 7 days to 29.67 N/mm² at 28 days. This progressive increase is consistent with continued hydration under sustained moisture availability.

Polythene curing produced 19.86 N/mm² at 7 days and reached 25.48 N/mm² at 14 days. However, the reported value declined to 14.88 N/mm² at 21 days before increasing to 20.74 N/mm² at 28 days. This non-monotonic trend is unusual for strength development and should be treated as an important experimental observation rather than smoothed or corrected. Possible contributors could include specimen-to-specimen variability, differences in moisture retention, compaction, handling or testing; however, the available dataset does not contain sufficient replicate-level information to identify the precise cause.

Air curing produced 19.50, 17.85, 18.37 and 18.96 N/mm² at 7, 14, 21 and 28 days, respectively. The comparatively low values are consistent with the mechanism identified by Safiuddin et al. (2007), whereby uncontrolled moisture loss restricts hydration. The results therefore demonstrate that simply allowing concrete to remain exposed to ambient air is less reliable for strength development than curing methods that actively maintain or retain moisture.

4.3 Flexural Strength

Table 3

Flexural strength of concrete beams under different curing methods

Age (days)	Water-submerged curing (N/mm ²)	Polythene curing (N/mm ²)	Air curing (N/mm ²)
7	2.25	1.58	1.13
14	2.26	1.13	1.69
21	2.27	1.24	1.4
28	3.25	2.25	1.35

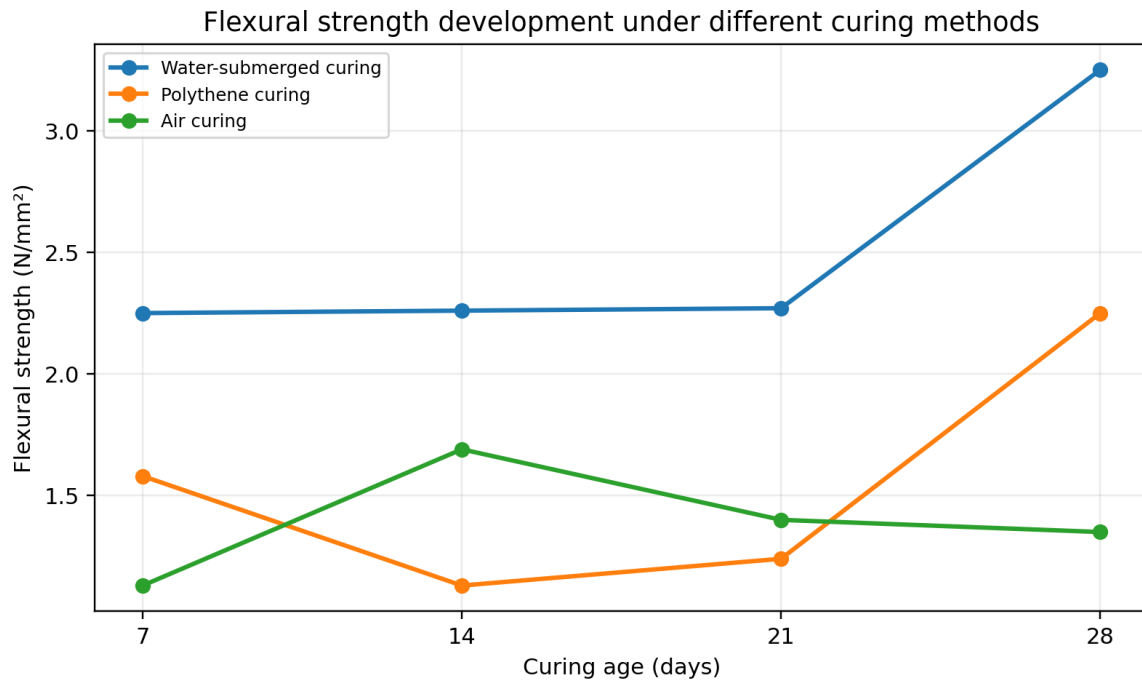


Figure 2. Flexural strength development under the three curing methods.

Water-submerged curing also produced the strongest overall flexural performance. The flexural strength increased from 2.25 N/mm² at 7 days to 3.25 N/mm² at 28 days. Polythene curing produced 1.58, 1.13, 1.24 and 2.25 N/mm² at 7, 14, 21 and 28 days, respectively, while air curing produced 1.13, 1.69, 1.40 and 1.35 N/mm². The 28-day result indicates a clear advantage for water-submerged curing in the present dataset.

The flexural-strength results also show that density alone cannot be used as a direct predictor of flexural performance. For example, the highest reported density among some individual observations does not consistently correspond to the highest flexural strength. This reinforces the importance of the internal cement paste structure, hydration degree, pore structure and interfacial characteristics rather than bulk density alone.

4.4 Density

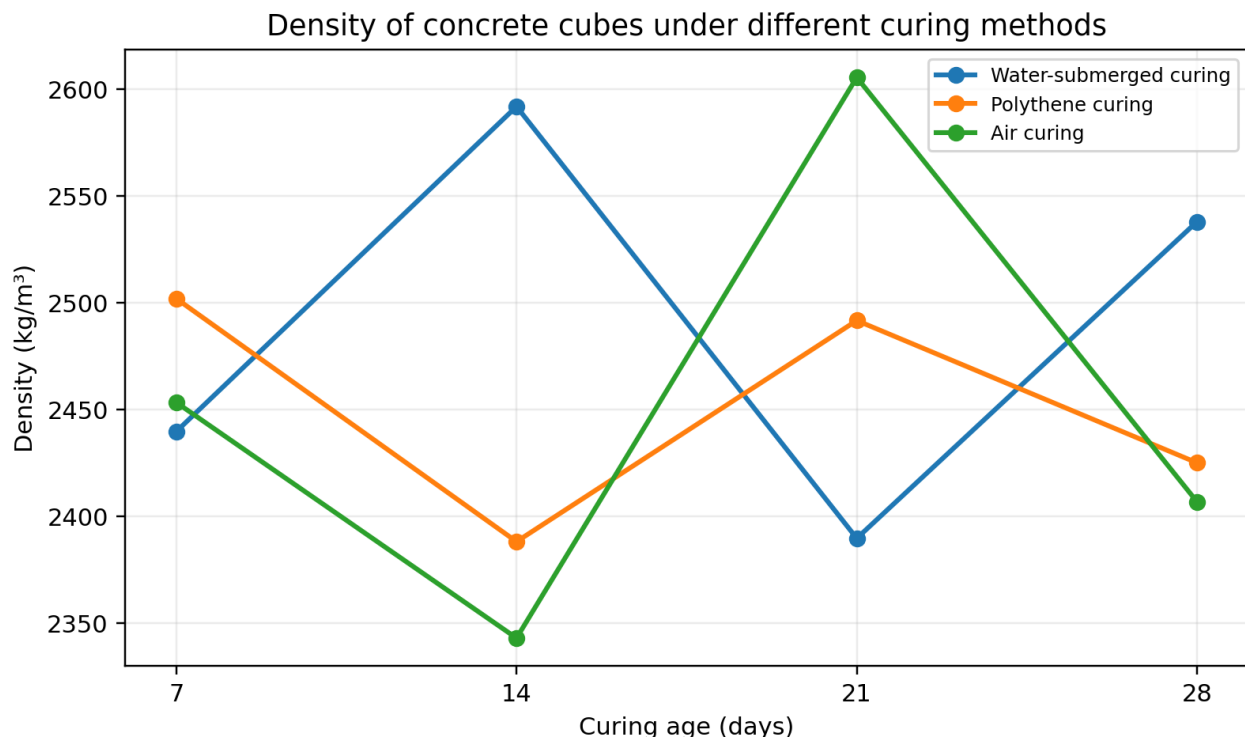


Figure 3. Density development of concrete cubes under different curing methods.

The cube densities reported in the study ranged from 2343.11 to 2605.53 kg/m³. These values are within the broad range generally associated with normal-weight concrete. However, density varied irregularly with curing age, particularly for the air- and polythene-cured specimens. This variation suggests that the strength differences cannot be explained by density alone.

4.5 Relationship Between Density and Compressive Strength

Reassessment of the twelve paired density and compressive-strength observations using the ordinary Pearson correlation gives $r \approx 0.105$, indicating a very weak positive linear relationship. The relationship is not statistically significant for this small dataset ($p \approx 0.746$). Thus, within the observations available in this experiment, increases in density do not provide a strong basis for predicting compressive strength.

4.6 Relationship Between Density and Flexural Strength

Using the twelve reported density-flexural-strength pairs, the Pearson correlation is approximately $r = 0.607$. This indicates a moderate positive linear association in the available dataset, although the small sample size and the experimental grouping mean that this relationship should not be interpreted as proof that density directly controls flexural strength. The earlier statement of 'no positive correlation' should therefore be revised because it does not follow from a standard Pearson correlation analysis of the reported numerical data.

4.7 Comparative Performance of the Curing Methods

At 28 days, water-submerged curing recorded the highest compressive strength of 29.67 N/mm², which was approximately 56.5% higher than air curing and 43.1% higher than polythene curing. Similarly, its 28-day flexural strength of 3.25 N/mm² was approximately 140.7% higher than air curing and 44.4% higher than polythene curing.

The overall ranking observed in this experiment water-submerged curing followed by polythene curing and air curing for the 28-day compressive strength is consistent with the broader experimental evidence reported by Safiuddin et al. (2007). The result also supports the practical recommendation that curing should focus on maintaining adequate moisture during the early period of hydration.

5. Conclusions

1. Water-submerged curing was the most effective of the three curing methods investigated, producing the highest reported compressive and flexural strengths at 28 days.
2. At 28 days, the compressive strengths were 29.67 N/mm² for water-submerged curing, 20.74 N/mm² for polythene curing and 18.96 N/mm² for air curing.
3. Water-submerged curing produced a 28-day flexural strength of 3.25 N/mm², compared with 2.25 N/mm² for polythene curing and 1.35 N/mm² for air curing.
4. The results support the established mechanism that maintaining moisture availability promotes continued cement hydration and strength development.
5. The density of the specimens varied with curing method and age, but density showed only a very weak linear relationship with compressive strength in the reported dataset.
6. The non-monotonic strength development observed for some polythene- and air-cured specimens indicates experimental variability and demonstrates the importance of replicate-level results in interpreting curing experiments.
7. The results are consistent with previous studies showing that water curing generally provides favourable strength development, while moisture-retaining wrapping performs better than unprotected dry-air curing (Safiuddin et al., 2007; Raheem et al., 2013).

6. Recommendations

1. Water curing or another reliable moisture-preserving curing method should be adopted whenever site conditions permit.
2. Where continuous water curing is impractical, properly installed polythene sheeting may be used to reduce evaporation and retain moisture.
3. Air curing should not be relied upon for structural concrete where the objective is to achieve the designed strength, particularly under hot, dry or windy conditions.
4. Concrete curing should be planned as part of the construction quality-control procedure rather than treated as an optional finishing activity.

5. Future investigations should use multiple replicate specimens for every curing method and testing age and should report standard deviation and coefficient of variation.
6. Further research should examine additional curing methods commonly used in Nigeria, including wet burlap, spray curing and moist-sand curing, and should include durability indicators such as water absorption, sorptivity and permeability.
7. Future studies should also record curing temperature, relative humidity and specimen mass change so that the mechanisms responsible for differences in strength can be evaluated more rigorously.

References

1. American Concrete Institute. (2019). ACI 308R-16: Guide to external curing of concrete. American Concrete Institute.
2. ASTM International. (2021a). ASTM C31/C31M-21a: Standard practice for making and curing concrete test specimens in the field. ASTM International.
3. ASTM International. (2020). ASTM C143/C143M-20: Standard test method for slump of hydraulic-cement concrete. ASTM International.
4. ASTM International. (2021b). ASTM C39/C39M-21: Standard test method for compressive strength of cylindrical concrete specimens. ASTM International.
5. Neville, A. M. (2011). Properties of concrete (5th ed.). Pearson.
6. Price, W. H. (1950). Factors influencing concrete strength. *Materiales de Construcción*, (19), 40–43. <https://doi.org/10.3989/mc.1950.i019.3244>
7. Raheem, A. A., Aliu, A. S., & Amaka, J. E. (2013). Effect of curing methods on density and compressive strength of concrete. *International Journal of Applied Science and Technology*, 3(4), 55–64.
8. Ramezaniapour, A. A., & Malhotra, V. M. (1995). Effect of curing on the compressive strength, resistance to chloride-ion penetration and porosity of concretes incorporating slag, fly ash or silica fume. *Cement and Concrete Composites*, 17(2), 125–133.
9. Safiuddin, M., Raman, S. N., & Zain, M. F. M. (2007). Effect of different curing methods on the properties of microsilica concrete. *Australian Journal of Basic and Applied Sciences*, 1(2), 87–95.