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# THE EVALUATION OF THE EFFECTS OF DIFFERENT CURING METHODS ON CONCRETE

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## ABSTRACT

*This research explores the impact of various curing methods on the water absorption and compressive strength of concrete. To evaluate these properties, 45 cubes of mix ratio 1:2:4 were tested under different curing methods namely water ponding, sand, polythene sheet coverage, sawdust and water sprinkling. All the cubes were cured at an average laboratory temperature. Water absorption, compressive strength and SEM-EDX tests were conducted on the concrete cubes after curing for 7, 14 and 28 days. The study found that the water absorption and compressive strength values at 7, 14, and 28 curing days ranged from 1.53 to -1.12% and 21.30 to 31.40 N/mm$^2$, respectively and varied depending on the curing method used. All the cementitious compositions of the concrete cubes of all the curing methods showed an increase with the increase in curing age and ranged between 0.01 and 81.67, while their SEM images revealed heterogeneous microstructures consisting of aggregates, cement paste, and voids.Sand and sawdust curing produced the highest and lowest compressive strength values, respectively. Based on these findings, sand curing was identified as the most favourablemethod. Further investigation should be carried out.*

**Keywords:** Curing, compressive strength, polythene sheet, sawdust, sand, ponding, sprinkling.

## INTRODUCTION

Providing concrete with the right amount of moisture and temperature to promote cement hydration for a long enough time is referred to as "curing of concrete”. In particular, for concrete exposed to harsh climatic conditions at a young age, proper curing of concrete is essential to achieve design strength and maximum durability (Osama and Omar, 2019). Concrete won't reach its optimum compressive strength and may crack if the curing environment isn't kept sufficiently moist. Inadequate hydration of the cementitious material may also impair the durability of the concrete. When concrete is cast in cold weather, the formwork must be held in place for a longer period.Overall, Curing and application methods impact the strength, durability, and other physical attributes of concrete as they relate to the local meteorological conditions(Ahmad et al., 2022).

Hydration is the most significant part of the process of curing. It will not occur if there is inadequate water, and the resultant concrete may lack the desired strength and impermeability (Boukendakdji et al., 2021). Furthermore, due to the concrete's early drying, micro-cracks or shrinkage cracks would form on the surface. When concrete is exposed to the elements, water evaporates, reducing the initial water cement ratio and resulting in incomplete hydration of the cement, lowering the quality of the concrete. The compressive strength increase of concrete is influenced by wind velocity, relative humidity, air temperature, the water-cement ratio of the mix, and the kind of cement used in the mix (Osei et al., 2019; Ajay et al, 2023).

Curing temperature is one of the most important factors influencing the rate of strength development. Ordinary concrete loses strength at high temperatures due to the formation of cracks between two thermally incompatible ingredients, cement paste and aggregates. Concrete cured at high temperatures typically has greater early strength than concrete produced and cured at lower temperatures, but strength is generally reduced at 28 days and later stages. The qualities of hardened concrete are significantly affected by curing; effective curing increases strength, volume stability, durability, abrasion resistance, impermeability, and resistance to freezing and thawing. The material utilized, the building technique and the planned application of the hardened concrete - all affect how well the concrete cures. As soon as the concrete becomes sufficiently rigid to stop surface erosion, curing should start (Osama and Omar, 2019; Atoyebi et al., 2020; Boukendakdji et al., 2021; Liu et al., 2022).

If adequate curing is not performed, the effort required to control the quality of materials and the production of concrete can be discounted. The environment in which concrete is placed influences its sensitivity to curing. Hot dry environments hasten the drying of concrete and are thus far more dangerous than cool damp environments. A properly designed concrete mix that has been carefully placed, compacted, and cured will have adequate strength and durability. The effort put in to control the quality of the components and produce the concrete may be rendered ineffective if proper curing is not carried out. The environment in which concrete is placed influences its sensitivity to curing. Concrete dries out faster in hot, dry conditions (Basnayake et al., 2020; Yao et al., 2021; Hamzah et al., 2022).

Many researchers have looked into the effects of different curing methods on concrete in the past. Osama and Omar (2019) used water curing, air curing and chemical curing compounds in curing of concrete. Water-soluble polymer was utilized by Udayabanu et al. (2020). Hot water, open air, earthing and sprinkling were applied by Atoyebi et al. (2020) in concrete curing. Boukendakdji et al. (2021) and Wang et al. (2023) used steam; while rice husk and strawwere utilized by Agustin et al. (2023) for curing of concrete under different mixed design.This study examines the effects of various curing methods (namely ponding, polythene sheet coverage, water sprinkling, sand and sawdust curing) on the compressive strength and water absorption of concrete produced with mixing design of 1:2:4, a water-cement ratio of 0.5 and cured for 7, 14, and 28 days. It helps in determining the most effective curing method that will give the highest result for the compressive strength of concrete. It provides a better understanding of the impact of curing on the strength and quality of concrete and aids in the selection of the most appropriate curing method for a given construction project. The results also help in corroborating past research works. This lies in its ability to improve concrete quality, aid in better decision-making, lead to cost savings, advance the concrete industry, and improve safety for the people and communities that use concrete structures (Agustin et al., 2023; Wang et al., 2023).

## MATERIAL AND METHODS

### *Materials, equipment and apparatus*

In this study, water, fine and coarse aggregates, and potable water were used in the production of concrete. Head pan, shovel, test

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moulds, curing tank, hand trowel, lubricants, weighing balance, compressive strength test machine, measuring cylinder and spannerwere among the tools and apparatuses utilized.

*Materials' collection*

The Cement used throughout the investigation is Ordinary Portland Cement (OPC) of G42.5N produced by Dangote Cement Plc and was sourced from the cement depot at Ibogun, Ogun state. The fine and coarse aggregatesutilized is river sand and granite (as shown in Plate 1). They were sourced from Ibogun quarry in Ogun state and free from impurities and possessed a sharp texture. To determine their particle size distribution, the fine and coarse aggregates were subjected to sieve analysis. This procedure involves dividing the aggregate sample into fractions according to the guidelines outlined in BS 1377 (1990). Clean water, devoid of impurities that may hinder the setting, hardening, and strength development of the concrete was used for both the mixing and curing processes. While the water used was potable and deemed fit for human consumption, and was ensured to be free from excessive amounts of minerals, acids, alkalis, salts, organic matter, and any other detrimental substances. It was sourced from Civil Engineering laboratory of OlabisiOnabanjo University, Ibogun campus.


**Plate 1:** Fine and coarse aggregates

*Preparation of test specimens*

Batch by weight method was used in measuring the cement, fine and coarse aggregates. A mixing ratio of 1:2:4 and a water-cement ratio of 0.5 was utilized in producing the concrete. The dry components of the mixture (the cement,fine and coarse aggregates) were thoroughly mixed after batching before gradually adding water. The mixture gradually turned into a uniform gray paste. The standards outlined in BS 8500:1 & 2 (2023) were followed for the concrete casting, curing and cube crushing. The cube moulds used have dimensions of 150x 150 x 150mm. A total number of 45 cubeswere cast.

*Slump test*

In order to measure the workability of freshly formed concrete and, consequently, the ease with which concrete flows, a slump test was conducted. The slump test determines the workability of concrete by measuring the difference in height between the top of the mould and the displaced centre of the concrete mass. The ASTM C143 (2020) guidelines were followed for the slump test.

*Curing of the test specimens (methods)*

Five (5) different curing methods were used in this study namely ponding, polythene sheet coverage, water sprinkling, sand and sawdust curing. A total of nine specimen cubes were used for each of the curing methods. For ponding curing (Figure 2), the cubes wereimmersed in water during the curing periods of 7, 14 and 28 days and to avoid thermal strains that could cause cracking of the concrete cubes, the curing water is maintained at the laboratory room temperature. For the polythene sheet coverage curing (Figure 2), the concrete cubes were wrapped around the polythene sheet to prevent moisture evaporation, which is important for maintaining the appropriate moisture level during the initial stages of the concrete's setting and hardening.


**Plate 2:** Curing of concrete cubes using ponding, polythene sheet coverage and sprinkling methods

The sprinkling method of curing (Plate 2) was used to cure the specified numbers (9) of cast concrete cubes by spraying water over the surface of the concrete at regular intervals during the curing periods to keep it moist during the early stages of setting and hardening. the sprinkling method help to maintain the required moisture content in the concrete and promote the development of the desired strength and durability. Clean, wet sand was used for curing and it was kept saturated throughout the entire period of curing. The sand layer was thick enough to evenly distribute water throughout the surface of the concrete samples as shown in Figure 3. In order to reduce the chance that undesirable materials would harm the concrete surface, sand will adhere to ASTM C33 (2018) regulations for deleterious materials in fine aggregate. Wet, clean sawdust was used for curing by keeping it saturated throughout the curing period (Figure 4). The sawdust coating was thick enough to evenly distribute water throughout the whole area to be treated.

*Water absorption test*

By evaluating the increase in mass of a specimen brought on by water absorption as a function of time, the rate of water absorption (sorptivity) by the produced concrete was estimated. The specimen is conditioned in an environment with a specified relative humidity to establish a continuous moisture state in the capillary pore system. This test was conducted in accordance with ASTM C1585 (2020). Water Absorption (WA) was calculated using Equation (1).

$$\mathrm{WA} = \frac{(\mathrm{Ww} - \mathrm{Wd})}{Wd}\ X\ 100\% \qquad (1)$$

Where Ww and Wd is weight of wet and dry concrete, respectively.

*Compressive strength test*

To ascertain the average strength of each concrete cube specimen, a compressive strength test was performed by ASTM C39 (2023) using a Compressive Strength Testing Machine (CTM). The load result is recorded and the concrete compressive strength is calculated by dividing the maximum load at failure by the average cross-sectional area of the sample as shown in Equation (2).

$$\text{Compressive strength} = \frac{\mathrm{P}}{A} \qquad (2)$$

where P and A are loads applied by testing machine and the area of the concrete cube, respectively.

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**Plate 3:** Curing of concrete cubes using sand curing method

**Plate4:** Curing of concrete cubes using sawdust curing method

*Scanning Electron Machine (SEM) and Energy Dispersive X-ray (EDX) Spectroscopy test*

The concrete cube specimens were smashed when the compression testing was over, and the hydrated cement was extracted from the centres of the cubes that is/are the deepest. The samples that were gathered were sieved. To reduce the sample size, the test was set up using the cone and quartering approach. The test was administered on a flat area and took the shape of a cone. The conical shape's top was flattened and then cut the cone into quarters. The other two quarters were combined, and two opposite quarters were thrown away. Up until a sufficient sample size is obtained, the process was repeated. The test was carried out at Covenant University laboratory, Ota, Ogun State.

## RESULTS AND DISCUSSION

*Sieve analysis tests' results for the fine and coarse aggregates*

Figure 5 depicts the graphical representation of the sieve analysis performed on the fine and coarse aggregates.It is evident that the fine and coarse aggregates exhibit a maximum grain size of 4.75 mm and a minimum grain size of 0.09 mm. These values fall within the specified sieve sizes and grading curve, indicating that the aggregates conformed to BS 882 (1992) requirements.It should be noted that smaller-sized coarse aggregate may result in a more workable mixture and a smoother surface finish. However, it may also lead to lower compressive strength and reduced durability, especially if the proportion of fine aggregate is increased to compensate for the smaller coarse aggregate size (Rumsys et al., 2018).

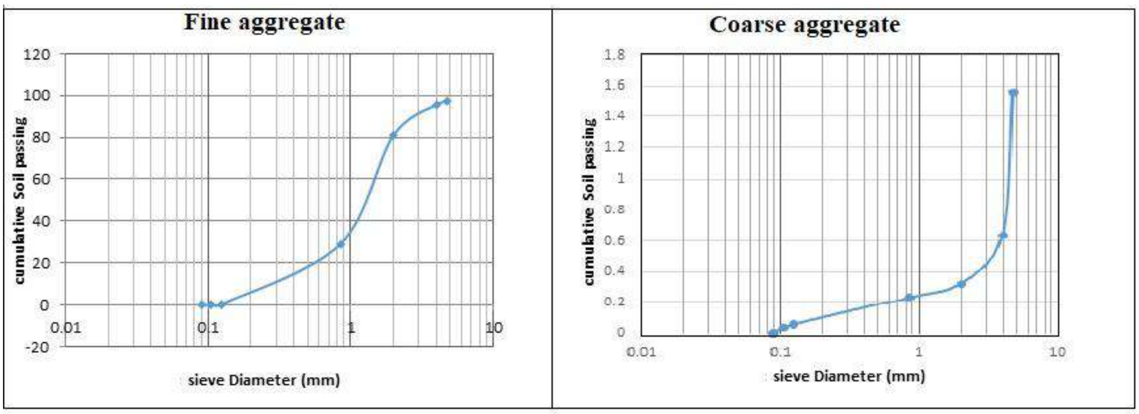


**Fig.5**.Sieve analysis for the aggregates

*Result of Slump test*

The concrete mix exhibited a true slump, as the measured slump value was 10mm, falling within the acceptable range of 10mm to 50mm (ASTM C143, 2020). It is important to note that the workability of concrete can indirectly affect its compressive strength. Concrete that is excessively dry or wet can lead to poor compaction and ultimately result in lower compressive strength. Therefore, it is crucial to ensure consistent workability across all batches of concrete before conducting compressive strength testing (Ahmad et al., 2022; Agustin et al., 2023).

*Result of Water absorption test*

Based on the water absorption tests conducted on the concrete cubes using different curing methods, namely ponding, sawdust, sand curing, water sprinkler, and polythene sheet, the results, whichindicate varying percentages of water absorbed are shown in Figure 6 - 1.53%, 0.61%, 1.29%, -1.12%, and 0%, respectively.

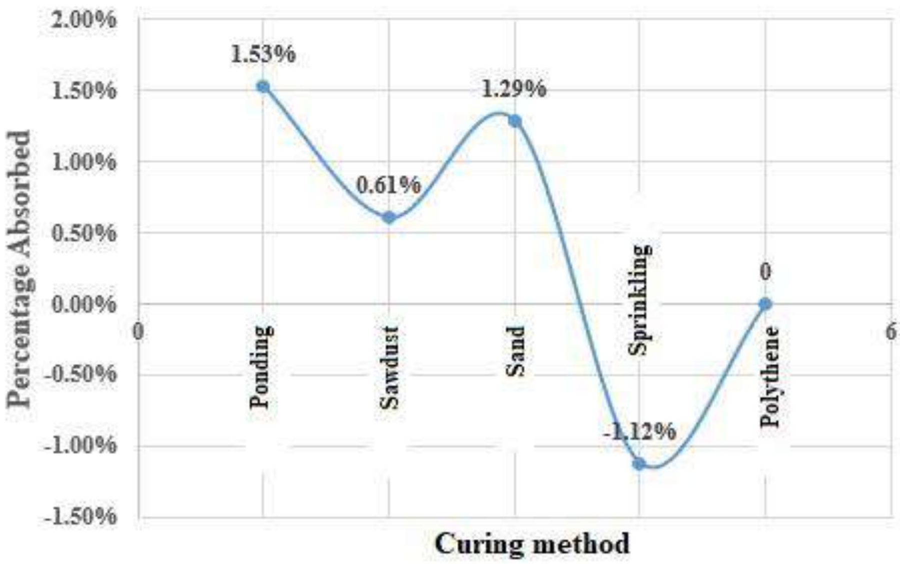


**Fig. 6**: Water absorption for different curing methods

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The ponding method resulted in a water absorption percentage of 1.53%. This suggests that the concrete cubes cured through this method absorbed highest amount of water. The presence of a continuous water supply surrounding the cubes might have facilitated the penetration of water into the concrete matrix, leading to increased water absorption. Zeyad (2019) and Atoyebi et al. (2020) adjudged this method to be effective in long term curing of concrete. Similarly, the Sand curing method yielded a water absorption percentage of 1.29%. In contrast, the sawdust curing method resulted in a lower water absorption percentage of 0.61%. Sawdust and sand act as moisture-retaining media, potentially reducing the rate of water absorption by the concrete cubes. Their layer might have created a barrier that limited the water's contact with the cubes, thereby reducing the overall absorption (Zeyad, 2019; Agustin et al., 2023).

The Polythene sheet curing method exhibited a water absorption percentage of 0%. The impermeable nature of the polythene sheet may have prevented the ingress of water into the cubes, resulting in minimal or no water absorption (Atoyebi et al., 2020). Surprisingly, the Water sprinkler method resulted in a negative water absorption percentage of -1.12%. Negative water absorption suggests that the concrete cubes released moisture during the curing process instead of absorbing it. This unexpected outcome may be attributed to factors such as evaporation or the specific characteristics of the concrete mixture used (Zeyad, 2019; Atoyebi et al., 2020).

Overall, the results of the water absorption test indicate that different curing methods can significantly influence the amount of water absorbed by concrete cubes. Factors such as the curing environment, the presence of moisture-retaining materials, and the use of barriers play a vital role in determining the water absorption characteristics of concrete. These findings highlight the importance of carefully selecting an appropriate curing method based on the desired moisture conditions and long-term durability of the concrete structures.

*Result of compressive strength test*

Figure 7 shows theresults of compressive strength for the different curing methods. The compressive strength values of the concrete cubes at 7, 14, and 28 days for sand curing method are 23.7, 28, and 31.4, respectively. Past research works of Afaf et al. (2019) and Atoyebi et al. (2020) have also investigated the use of sand in curing concrete and its impact on compressive strength. Afaf et al. (2019) obtained the compressive strength values of 11.27, 15.0, and 24.37 N/mm² for 7, 21, and 28 days, respectively for cubes with a mix ratio of 1:3:6. In comparison, this research yielded higher compressive strength values at both 7 and 28 days of curing. It is important to note that the difference in compressive strength could be attributed to variations in the mix ratio and water-cement ratio used in the concrete mixture.

The compressive strength values of the concrete cubes cured with sawdustfor 7, 14, and 28 days are 21.5, 25.9, and 27.1, respectively as shown in Figure 7.Obhielo et al. (2020) also investigated the use of sawdust for curing concrete and its impact on compressive strength. Compressive strength values for concrete cubes are 16.1, 19.7, and 20.8 N/mm² when cured for 7, 14, and 28 days, respectively, using a water-to-cement ratio of 0.60. In comparison, this research yielded higher compressive strength values at both 7, 14, and 28 days of curing. This difference in compressive strength could be attributed to variations in the water-to-cement ratio used during the concrete mixing process.

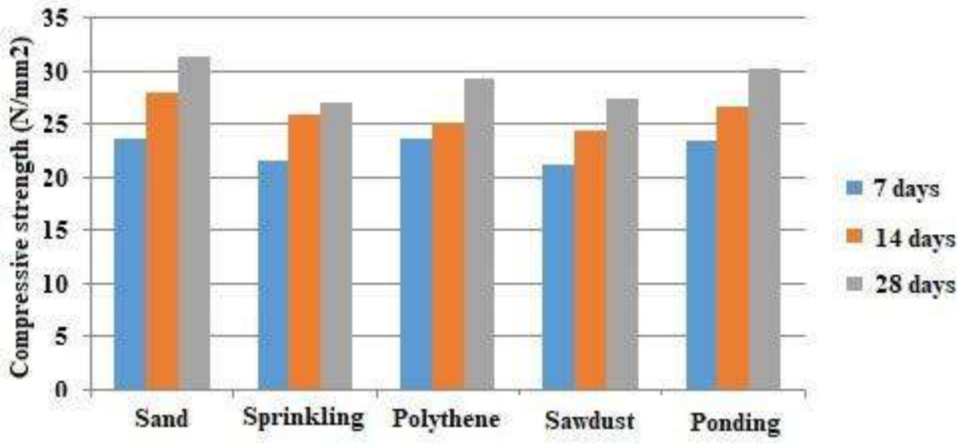


**Fig. 7**: Compressive strength for different curing methods

The compressive strength values of the concrete cubes cured polythene sheet coverage at 7, 14, and 28 days are 23.6, 25.2, and 29.3 N/mm$^2$, respectively (Figure 7). In comparison of this study with past research work of Atoyebi et al. (2020) among others, there is notable difference in higher compressive strength values at 7 and 14 days, but the same compressive strength value at 28 days. The compressive strength values of the concrete cubes cured using water sprinkling method for 7, 14, and 28 days are 21.3, 24.4, and 27.5 N/mm$^2$, respectively as depicted in Figure 7. From Figure 7, the compressive strength values of the concrete cubes of water immersion (i.e. ponding) curing method at 7, 14, and 28 days are 23.5, 26.7, and 30.2, respectively. The compressive strength values from this study showed to be higher for the curing days when compared with past research works of Osama and Omar (2019) and Atoyebi et al. (2020) among others. This difference in higher compressive strength values may be attributed to various factors, including the curing conditions, presence of voids or cracks on the cubes, and other influencing variables. It could also indicate that the concrete produced through ponding method exhibits enhanced durability and is safe for use (Boukendakdji et al., 2021).

*Results of SEM – EDX test*

The SEM images for all the curing methods of the concrete specimens are shown in Figure 8. It revealed a heterogeneous microstructure consisting of aggregates, cement paste, and voids. Aggregates appeared as coarse, irregular particles with varying shapes and sizes, contributing to the overall strength and durability of the concrete. The cement paste, surrounding the aggregates, exhibited a dense and compact morphology, indicating good hydration and adequate cementitious materials. The presence of voids, ranging from isolated pores to interconnected networks, was observed throughout the concrete matrix, which could potentially impact its mechanical properties, such as strength and permeability.

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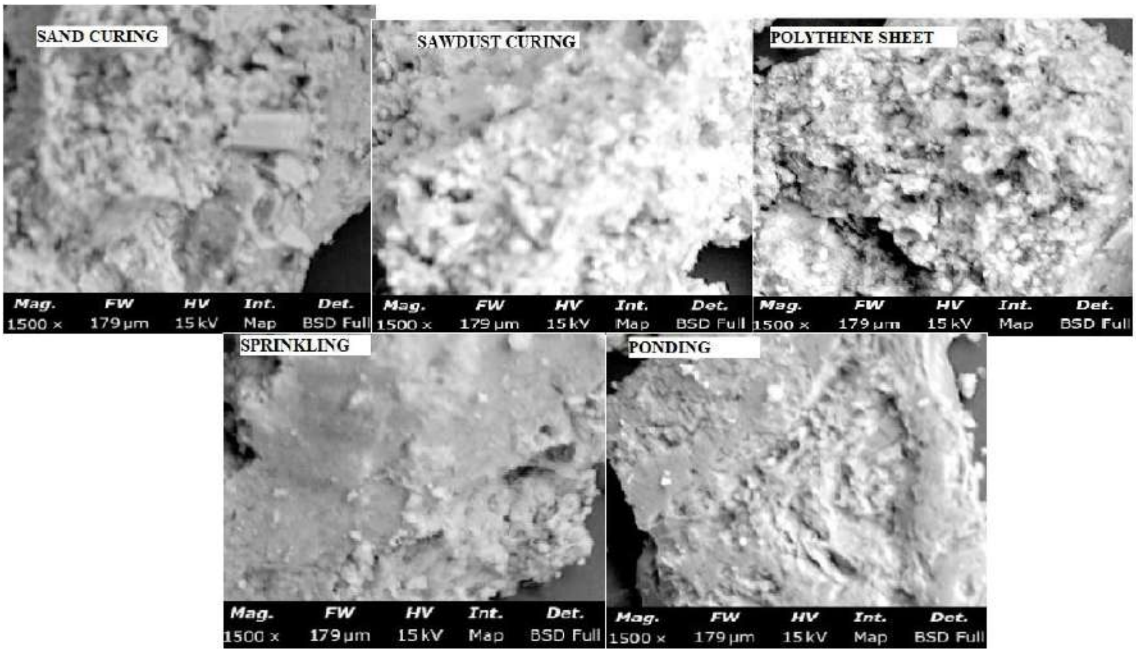


**Plate 8:** SEM images for all the curing methods of the concrete specimens

The EDX analysis provided elemental composition data by detecting characteristic X-ray emissions from the sample. The major elements identified within the concrete matrix were Calcium (Ca), Silicon (Si), Aluminium (Al), and Oxygen (O)consistent with the typical composition of Portland cement-based concrete. These elements are primary constituents of cementitious materials, namely calcium silicates, calcium hydroxide, and calcium aluminate hydrates, which contribute to the overall binding and strength of the concrete (Yaseen et al., 2024). All the concrete weight composition for all the curing methods increased with an increase in curing days as shown in Table 1. Ponding curing method has the highest elemental increase of the cementitious materials, while sawdust has the lowest. Their increments are in descending order of Ponding > Sand > Polythene > Sprinkling > Sawdust. This order differs a little from the compressive strength values order because sand curing method has the highest compressive strength value. This highest elemental composition in ponding method could be adduced to the continuous presence of water for the concrete cubes, whichenhances availability of water reaction among the cementitious materials (Atoyebi et al., 2020; Yaseen et al., 2024).

**Table 2:** Weight of elemental compositions of concrete produced for different curing methods

| S/No. | Element | Element | Sawdust | | | Sand | | | Polythene | | | Sprinkler | | | Ponding | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Symbol | Name | 7 days | 14 days | 28 days | 7 days | 14 days | 28 days | 7 days | 14 days | 28 days | 7 days | 14 days | 28 days | 7 days | 14 days | 28 days |
| 1 | O | Oxygen | 18.24 | 49.88 | 51.08 | 13.3 | 51.7 | 55.57 | 16.84 | 39.94 | 50.27 | 39.3 | 43.06 | 54.2 | 16.67 | 54.21 | 55.95 |
| 2 | Ca | Calcium | 2.64 | 11.62 | 20.42 | 3.52 | 14.05 | 44.61 | 3.47 | 12 | 43.89 | 1.59 | 21.58 | 24.6 | 5.93 | 24.35 | 81.67 |
| 3 | N | Aluminium | 6.08 | 6.44 | 6.56 | 10.68 | 14.38 | 21.97 | 5.38 | 7.73 | 17.14 | 0.01 | 4.97 | 6.63 | 2.59 | 5.66 | 31.99 |
| 4 | Si | Silicon | 8.77 | 18.35 | 21.96 | 6.54 | 23.18 | 34.89 | 2.18 | 22.42 | 25.85 | 1.67 | 9.89 | 19.24 | 7.57 | 34.81 | 35.14 |

*Summary: Results of curing of concrete using different methods*

The measured slump value was within the acceptable range in accordance with ASTM C143(2020). The water absorption for the selected curing methods followed the trend of Ponding (1.53%) > Sand (1.29%) > Sawdust (0.61%) > Polythene sheet (0.00%) > Sprinkling (-1.12%). The results of the water absorption test indicate that different curing methods can significantly influence the amount of water absorbed by concrete cubes. It can be observed that the sawdust curing method resulted in the lowest compressive strength values at both 7 and 28 days of curing. On the other hand, the sand curing method exhibited the highest compressive strength values at 7, 14, and 28 days. This can be attributed to several advantages associated with using sand for curing. These advantages include moisture retention, protection against temperature fluctuations, and prevention of cracking, among others.

In summary, the observed lower compressive strength values in the sawdust curing method may be attributed to the ability of sawdust particles to absorb and retain moisture from the concrete, leading to rapid drying of the concrete surface and subsequent cracking. while the higher compressive strength values in the sand curing method may be due to the beneficial properties of sand in moisture retention and providing protection against adverse conditions, thereby promoting the development of stronger concrete (Atoyebi et al., 2020; Obhielo et al., 2020). Polythene and sprinkling methods proved to be worthy in hot environment and where there is water scarcity, respectively. Atoyebi et al. (2020) advocated long term strength and occasion for ponding curing method of concrete.

Ponding also requires continuous monitoring and maintenance to ensure that the water level remains constant and the concrete is adequately saturated; thus, may not be suitable for certain construction scenarios where the presence of water could interfere with other processes or materials. Water sprinkling curing method has the third highest value of compressive strength, while polythene sheet curing method has the fourth highest value of compressive strength. This is due to the fact that concrete cured with polythene sheet method does not have enough air penetration for process of hydration to be completed. Their EDX analyses results showed the presence of required cementitious materials (i.e. Silicon, Calcium, Aluminium) in all the concrete cubes of different curing methods and increment with curing age. Ponding curing method overtook sand one in this respect.

## CONCLUSIONS

The findings from this study provide valuable insights into the effects of different curing methods on the compressive strength of concrete. Through a comprehensive experimental investigation, it was observed that the curing method has a significant impact on the strength development of concrete. In other to enhance the level of hydration, it is essential to maintain a constant saturation or close to it for freshly prepared concrete. Continuous curing of concrete is necessary not just to achieve its maximum strength and durability but also to minimize the occurrence of shrinkage cracks and surface damage. Out of all the curing techniques, sand curing method is the most effective method of curing. It produced the highest level of compressive strength.Sawdust curing method produced the least compressive strength. Saw dust curing cannot be preferred on field as it is time consuming and preferableresults cannot be achieved by this method.Further investigation is required to examine the structural integrity of concrete under various environmental conditions, including high temperature and humidity as well as low temperature.Utilizing a variety of cement types and grades and the influence of using different grades of concrete should be looked into.

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