Assessment of Compressive Strength in Ordinary Portland Cement Concrete: A Study of Curing Methods and Duration

Ram, Shobha
Department of Civil Engineering, Gautam Buddha University

Dengri, Abhinav
Department of Civil Engineering, Gautam Buddha University

Kumar, Rahul
Civil Engineering Department, GLA University

https://doi.org/10.5109/7183321

出版情報：Evergreen. 11 (2), pp.640-651, 2024-06. 九州大学グリーンテクノロジー研究教育センター
バージョン：

Assessment of Compressive Strength in Ordinary Portland Cement Concrete: A Study of Curing Methods and Duration

Shobha Ram[1], Abhinav Dengri[2], Rahul Kumar[3*]

[1]Department of Civil Engineering, Gautam Buddha University, U.P, India

[2]Department of Civil Engineering, Gautam Buddha University, U.P, India

[3]Civil Engineering Department, GLA University, Mathura, U.P, India

*Author to whom correspondence should be addressed:

E-mail: Rahulkardam124@gmail.com

(Received November 10, 2023; Revised March 23, 2024; Accepted April 10, 2024).

Abstract: Concrete's strength increases significantly throughout the curing process, and improper curing may reduce concrete's strength and durability. The development of compressive strength in ordinary Portland cement concrete is examined in this research in association with curing techniques and curing times. Six curing methods, wet rug covering, water curing, immersion in lime water solution (1:25), (1:50) and (1:75) curing and water-based curing compound were utilized. The 28-day compressive strength of the concrete was measured for each curing process and curing period and compared with a relative gain or loss during curing times of 3, 7, 14, and 28 days. Lime immersion curing (1:50) yielded the highest compressive strength after a 3-day curing period. After 7 days of curing, water immersion curing produced the concrete with the maximum strength. Wet rug curing produced the highest strength after 14 days of curing, and finally, lime immersion curing (1:50) again yielded the highest compressive strength when the cubes were cured for the full 28 days. The lime solution (1:50) curing method gives the best results compared to other lime solution curing methods i.e. (1:25) and (1:75). In case of time-constrained for construction, lime solution immersion curing (1:50) and (1:75) can be used for achieving target mean strength but curing should be at least 3 days.

Keywords: Curing methods; Curing duration; Hydration; Strength assessment; Mechanical properties

1. Introduction

Concrete's characteristics, such as strength, durability, and resistance to environmental parameters, develop through the curing process. Concrete's overall quality and performance are substantially impacted by the curing procedures used and the period of the curing time. In order to enable hydration and the appropriate development of concrete characteristics, curing is the process of maintaining suitable moisture and temperature levels. The ultimate strength of the concrete is substantially impacted by the technique of curing used and the period of the curing time. The hydration process fails to proceed in the absence of water, and the final concrete could not possess the desired strength and impermeability. In addition, the concrete's surface would experience microcracks or shrinkage cracks as a result of early drying [1]. Aggregate, $Ca(OH)_2$, C-S-H, hydrated and un-hydrated cement grains, and voids make up the microstructure of concrete. The pore spaces in concrete microstructure will retain water that is not used up in the hydration processes. Because the C-S-H bond cannot form sufficiently to give strength, these pores weaken the concrete and reduce its strength. So curing is very necessary for making strong concrete [2–6]. Engineers and researchers may optimize building procedures, improve the efficiency of concrete structures, and maintain their long-term durability by understanding the impacts of various curing processes and curing times on concrete. There are several methods for concrete curing and in this study, six types of curing methods and curing durations will be explored.

1.1 Literature review

According to Acarturk and Burris by increasing hydration, the wet curing process of concrete improves strength and durability, enhances microstructure, and reduces permeability. To assess the impacts of curing on the hydration of cement, strength development, and shrinkage, researchers looked at a range of curing periods and curing solution compositions. They discovered that three days of wet curing encourages sufficient strength growth, less shrinkage, and less cracking [7]. The air-entrained and fly ash concrete for cold regions was cured under four distinct curing situations: conventional, air, medium, and high temperature. After 28 days of curing, the freeze-thaw durability, sorptivity, air void system, and water absorption were all examined. Outcomes revealed that the Fly Ash concrete and OPC concrete were unable to generate strength after air curing. Compared to OPC concrete, Fly Ash concrete has more negative impacts from air curing in terms of both water absorption and sorptivity. By using high-temperature curing, Fly Ash concrete's compressive strength was enhanced both early on and later on [8–12]. The strength of soil-cement samples made from ball clay and soft clay was tested experimentally under a variety of curing circumstances, including water immersion, lime-water solution, plastic wrap, and ambient air. The samples that were cured in lime-saturated water had the maximum compressive strength, which may have been due to the lime water's ability to prevent $CaCO_3$ from cement from leaching during the hydration process [13]. In today's construction, steam-cured concrete is a good alternative, especially in metropolitan areas where construction progress is one of the most important factors in cost savings [14–16]. Geopolymer concrete is discovered to have improved compressive strength when it is cured in both open air and water. To save time, energy, and water and result in cost-effective building practices, more than 80% of 28 days' strength in geopolymer concrete was achieved at an early age of 7 days [17]. The best curing process for concrete's long-term performance is saturated limestone immersion [18]. For the curing of high-strength concrete samples, three different methods were used: wet coverage with a wet gunny, twice-daily water spraying for a week, and water immersion. The compressive strength of concrete was found maximum when had been immersed in water during curing [19]. Chen and Gao examine how Portland cement paste's compressive strength and microstructure are affected by pre-curing and the period of carbonation. They discovered that, especially in early-age cement mortar, the proper pre-curing and carbonation time might effectively enhance cement mortar's compressive strength [20]. The inclusion of lightweight aggregate in concrete can slow down the proportion of heat when temperatures rise in steam curing. This delay is very important because it prevents thermal damage of concrete due to steam-cured because of high temperatures during the first stages of curing. As a result, this delay contributes favourably towards increasing the concrete's compressive strength [21]. When the concrete is cast and cured outdoors, it will not obtain adequate moisture then the characteristics of concrete will decrease, according to the experimental results of previous research. The outdoor-cured slabs' flexural strengths were found 6–29% lower than those of the indoor-cured slabs [22]. Mortar specimens treated in lime-saturated water revealed better strength than those cured in fresh water at all curing stages [23]. Higher compressive, tensile, and flexural strengths than those of standard mixes are provided by using polyvinyl alcohol as a self-curing agent up to a specified limit [24]. Akinwumi and Gbadamosi investigate five concrete curing techniques: air drying, wet rug covering, lime water immersion, immersion in potable water, and covering with plastic sheets. They discovered that concrete that had been treated by immersion in lime water had the maximum compressive strength [25]. When compared to the standard water immersion approach, compressive strength may be increased by 80 to 90% using membrane curing and saturated wet coating. The saturated wet coating is appropriate for pavement structures but unsuitable for high-rise or vertical buildings. Construction should refrain from using dry-air curing since it is unable to provide the appropriate strength. From a strength viewpoint, wax-based compounds (Pradyuman Chemicals and Intermediates) have much greater strengths than any other chemical [26]. Maximum compressive strength was observed for concrete that was first water-cured for only four days and then evaluated at ages 28 and 90 days, indicating that water-treated concrete had greater mechanical characteristics than uncured specimens [27]. Raheem et al., state that the samples were aged 3 days, 7 days, 14 days, 21 days, and 28 days before being cured using six different techniques (air curing, wet sand curing, spray curing, burlap curing, water-submerged curing and polythene curing). They discovered that the concrete samples with the highest 28-day compressive strength were made using the wet sand curing procedure [28].

So there was limited work on comparative 28 days of compressive strength due to various curing methods. Only a little amount of research has been done on how concrete's strength and performance are affected by the curing process and time period. There hasn't been much research on the factors that contribute to the increase in concrete's compressive strength after various curing times. Objectives of this study are to study 28 days of concrete’s compressive strength that have been cured utilising various procedures and to study 28 days of concrete’s compressive strength cured for different curing regimes (3, 7, 14 and 28 days).

2. Material used

2.1 Cement

Ordinary Portland cement of 43 grade (J K Lakshmi) from a local material shop was used throughout the experiment. The colour of the cement was a uniform grey colour. It was smooth when rubbed between the fingers and was free from lumps that formed due to the absorption of moisture. Various laboratory test was done to see the physical properties of cement. The properties and specifications of the grade of cement used during the experimental study conforming to the IS code are given below.

Table 1. Properties of ordinary Portland cement

Description	Values Obtained	Method of test Reference
Colour	Uniform Grey colour	-
Sieve test	4%	IS 4031-1-1996 [29]
Specific Gravity	2.86	IS 4031-11-1988 [30]
Standard Consistency	28%	IS 4031-1-1996 [29]
Initial/Final Setting Time	75 min, 220 min	IS 4031-5-1988 [31]
Soundness	5mm	IS 4031-3-1988 [32]

Table 2. Chemical Composition of Ordinary Portland Cement

Chemical Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LOI
(%)	19.71	5.41	3.34	61.92	2.58	3.22	2.71

2.2 Aggregate

The aggregate used throughout the research was quartzite in origin and their source of location was the bazpur quarry pit in bazpur, Uttarakhand. There are two types of aggregates are used according to their sizes, one is the fine aggregate (FA) and another is the coarse aggregate (CA).

2.3 Fine aggregate

The material which passes through a 4.75 mm sieve is termed as FA. It consists of small angular or rounded grains of silica. The FA was free from silt and clay particles. Sieve analysis is done by using different sizes of sieves and shaking them with the mechanical shaker. The physical properties are provided in Table 3.

Table 3. Physical Properties of FA

S.No.	Properties	Results
1.	Nature	Bazpur Sand
2.	Specific Gravity [33]	2.39
3.	Finesse Modulus [34]	2.33
4.	Grading Zone [34]	II

2.4 Coarse aggregate

The aggregates that are retained over IS sieve 4.75mm are termed as CA. The size of CA is between 10 mm to 20 mm. The CA used in the present study was in the form of crushed rock. Specific Gravity and other physical properties of CA are provided in Table 4.

Table 4. Physical Properties of CA

S.No.	Properties	Value
1.	Shape	Angular
2.	Colour	Grey
3.	Specific Gravity [33]	2.67
4.	Maximum size	20 mm

2.5 Lime

The selection of lime for the study was made referring to IS code 712:1984. In the study lime Fig. 1 has been used for making a different percentage of the solution with water for curing of the concrete. The solutions made are 1:25, 1:50 and 1:75 (1 part is lime and the other part is water). Lime was added to the cylindrical tank and was stirred continuously till a milky white colour appeared, then concrete cubes were placed in the cylindrical tank for specified days for curing.

Fig. 1: Physical appearance of Lime

2.6 Curing Compound

In this study, the Fosroc Water-based curing compound was used for application on concrete cubes.

3. Methodology

In the present experimental study, the M35 grade concrete design mix is prepared using IS 10262: 2009 [35]. Concrete is divided into six groups to study the effect according to the various curing procedures adopted. Six different types of curing methods studied are-

1. Wet Rug Covering
2. Immersion In Water
3. Immersion In Lime Water Solution 1:25
4. Immersion In Lime Water Solution 1:50
5. Immersion In Lime Water Solution 1:75
6. Water-based Curing Compound

The concrete samples were properly labelled with references to the curing techniques employed following the removal of the concrete cube samples from moulds after 24 hours of casting. Every cube followed the prescribed curing process, for the prescribed amount of time. Apart from concrete cubes that were covered by a wet rug to cure, entire curing processes were carried out inside. Concrete cubes were cured for 3, 7, 14, and 28 days using various curing procedures. At a test age of 28 days, the compressive strength of concrete cubes was evaluated. A total of 60 cubes (3 for each different curing day (3, 7, 14 and 28 days) of different curing methods) were cast for wet rug curing, immersion in water and immersion in lime water solution (1:50), lime water solution (1:25) and lime water solution (1:75) for analyse of compressive strength at 28 days. 3 cubes were cast for a water-based curing compound for determination of 28 days compressive strength because the curing compound is applied once on concrete. Concrete cubes that were cured for 3, 7, 14 and 28 days were kept in a moderately bright room where they air-cured for 25, 21 and 14 days for a test age of 28 days compressive strength. A comparative study was done to draw out the conclusion for the most optimum curing method according to various site situations, optimum curing periods and curing methods.

4. Mix proportion

The concrete mixture (Design mix) in the batch is prepared with grade 43 OPC content according to IS 10262-2009.

Table 5. Mix design for M35 grade concrete

Cement (grade 43 OPC) (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)		W/C	Superplasticiser (%)
		(10 mm)	(20 mm)		
360	697	465	698	0.42	0.3

4.1 Mixing and casting and curing

According to the design mix, all the materials were weighed on the weighing machine. Before loading concrete materials into a mixer any water retained in the mixing drum for washing-out purposes is completely removed. After that, all materials are put into the mixer. All mixing is conducted in a mechanical concrete mixer under laboratory conditions. The cement, FA and CA are placed and dry mixed for about a minute before adding water with admixture in it. After 3 minutes of mixing fresh concrete is checked for workability. After the workability test cubes were cast in 150mm X 150mm X 150mm moulds size. The specimens are cured in the air inside the laboratory for a period of 24 hours before they are de-moulded. After de-moulding, cubes are immediately cured according to assigned curing practices and curing period [36–40].

5. Different curing procedures

5.1 Wet rug curing

A total of 12 cubes were cast for wet rug curing analysis. After de-moulding of cubes, they were immediately wrapped in hessian cloth Fig. 2 and cured with water every 6-8 hours Fig. 3. An attempt was made to not allow alternate wetting and drying of concrete cubes as it may lead to shrinkage cracks and reduction in strength. Cubes were cured for 3, 7, 14, 28 days and 28 days compressive strength was checked.

Fig. 2: Hessian cloth for wet rug curing

Fig. 3: Wet Rug Curing

5.2 Immersion in portable water

A total of 12 cubes were cast for immersion in a portable water curing analysis. After the de-moulding of cubes, they were immediately placed in a water curing tank. Water used in curing was tap water which was free from impurities and oils. The curing water was replaced after every 7 days to prevent impurities in the water. Cubes were cured for 3, 7, 14, 28 days and 28 days compressive strength was checked.

5.3 Immersion in lime water

Three kinds of lime water solutions were made using (1:25), (1:50) and (1:75) ratios. A solution of (1:25) was prepared by mixing 1 Kg of hydrated lime in 25 litres of water. Continuous steering with the help of a long wooden plank to form a uniform mixture. Steering was done after every 3-4 hours and a new solution for curing was made after every 7 days. After de-moulding of cubes, they were immediately placed in the cylindrical tank of (1:25) lime water solution. Other solutions (1:50) and (1:75) were made using the above proportion method. Cubes were cured for 3, 7, 14, 28 days and 28 days compressive strength was checked. The prepared solutions are shown in Fig. 4.

Fig. 4: Different solutions of lime water

5.4 Water-based curing compound

A total of 3 cubes were cast for water-based curing compound curing analysis because the curing compound is applied once on concrete. After de-moulding of cubes, they were placed in the local atmosphere to allow the excess water to drain off. The surface of the cubes was cleaned with a dry cloth and a single coat of water-based curing compound was applied to all the faces with the help of a brush. The compressive strength of the concrete of the water-based curing compound was checked after 28 days. The physical appearance of a cube after applying the curing compound is shown in Fig. 5.

Fig. 5: Physical appearance of a cube after applying the curing compound

6. Result and discussion

6.1 Compressive strength

The compressive strength of concrete is tested according to IS code [41,42]. The result of the compressive strength of concrete cubes at 28 days and curing ages of 3, 7, 14 and 28 days for each curing method, is presented in Fig. 6. The 28-day compressive strength of concrete cubes cured using the following methods is shown in Fig. 6 wet rug curing, immersion in water, immersion in lime water (1:25), (1:50), and (1:75), and WBCC. Here it can be seen the lime solution (1:25) curing and lime solution (1:50) curing have a proportional gain of 28 days of compressive strength with a curing period. Results show that 28 days of compressive strength is increasing w.r.t to curing days for lime solution (1:75) curing, wet rug curing, and water immersion curing when cured till 14 days, but after 14 days of curing the 28 days of compressive strength for all three curing methods are decreasing. 14 days of curing gives the best results for all three curing methods after that the 28 days of compressive strength decreases. 28 days compressive strength is maximum for lime (1:50) and minimum for WBCC i.e., 50 MPa and 43.47 MPa respectively when cured for 28 days. The lime solution (1:50) curing method gives the best results compared to other lime solution curing methods i.e. (1:25) and (1:75). All the curing methods acquire their target mean strength (43.25 MPa) when cured for 28 days. Concrete cubes that have been cured for three days using wet rugs, water immersion, and lime solution curing (1:25) do not reach the desired mean compressive strength. The WBCC method's concrete's 28-day compressive strength is slightly less than all other methods but it passed to achieve the target compressive strength. A similar pattern of Compressive strength has been found in past studies [26,43,44].

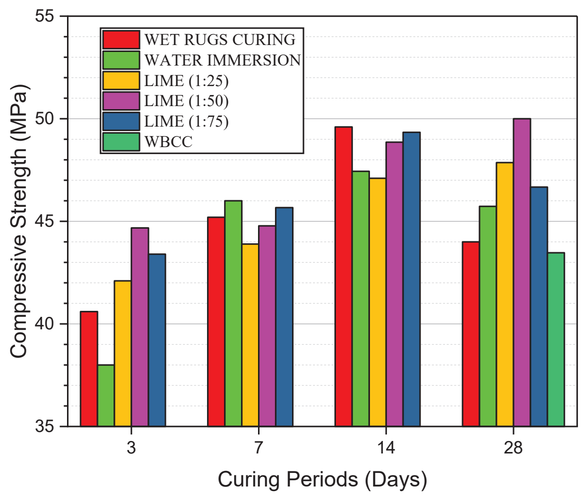

Fig. 6: Compressive strength at 28 days of all curing methods w.r.t their curing days

6.2 Relative comparison of 28 days compressive strength versus curing period of 3 day

The 28-day compressive strength of concrete that has been cured for three days utilising a variety of curing techniques is shown in Fig. 7 in comparison to the concrete's compressive strength that has been limewater (1:50) solution cured. The concrete cubes cured in lime water (1:50) solution for 3 days developed the highest 28 days compressive strength when tested and compared to another method. Concrete cubes cured for 3 days with a lime water (1:75) solution developed strength just equal to the lime water (1:50) solution and there is only a 3% reduction in strength. The least 28-day compressive strength was produced by concrete cubes that were cured for three days by submerging them in water. The 28 days compressive strength developed after 3 days of curing is less than the target mean strength (43.25 N/mm^2) of concrete for wet rugs curing (40.6 N/mm^2), water immersion curing (38 N/mm^2) and lime water solution (1:25) immersion curing (42.1 N/mm^2). After evaluating the compressive strength of concrete cubes that had been air-cured, sandpit-cured, and lime-immersed-cured over the course of three days, Newbold [25,45] also discovered the limewater-cured concrete had produced the maximum compressive strength result. The least strong concrete cubes were those that underwent water immersion curing. A similar pattern of Compressive strength has been found in past studies [26,43,44].

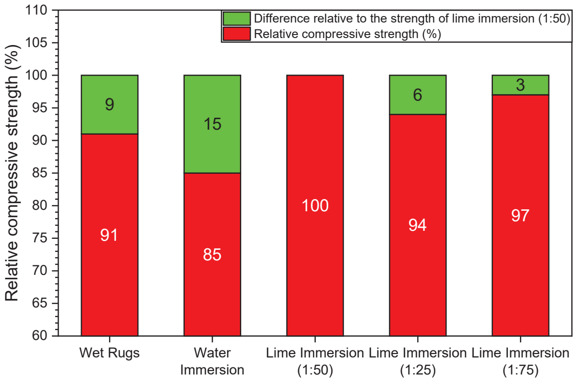

Fig. 7: Relative comparison of 28 days compressive strength versus curing period of 3 days

6.3 Relative comparison of 28 days compressive strength versus curing period of 7 days

In comparison to concrete cured in a lime water (1:50) solution, Fig. 8 illustrates the compressive strength of concrete after 28 days, at 7 days of curing using different curing procedures. It can see that concrete cured for 7 days by immersion in water, lime water immersion (1:75) solution and wet rugs have 3%, 2% and 1% more 28 days compressive strength respectively than cubes cured in lime water solution (1:50). When concrete is cured by lime water solution (1:25), there is 2% less 28 days compressive strength than the concrete when cured in lime water (1:50) solution. So after 7 days of the curing period, the water immersion technique gives the best compressive strength results. The outcomes are consistent with the work stated by Mohamed et. al. [28].

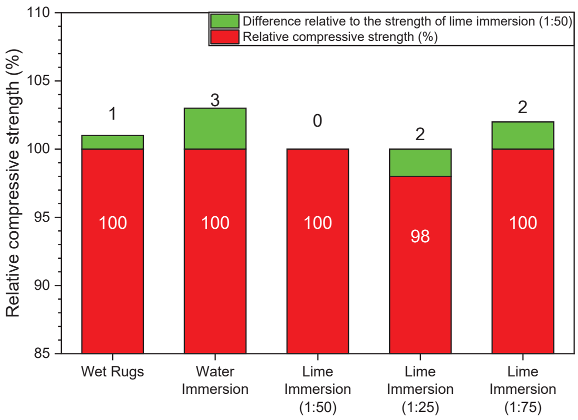

Fig. 8: Relative comparisons of 28 days compressive strength versus curing period for the 7 days.

6.4 Relative comparison of 28 days compressive strength versus curing period of 14 days

The 28-day compressive strength of concrete that has been cured for 14 days utilising a variety of curing techniques is shown in Fig. 9 in comparison to the concrete's compressive strength that has been limewater (1:50) solution cured. It can be seen that concrete cured for 14 days by wet rugs and lime water solution (1:75) develops 2% and 1% more strength compared to concrete cured in lime water solution (1:50) respectively. The relative compressive strength compared to the lime (1:50) solution is 3% and 4% is less when cured by water immersion and lime immersion curing (1:25). Results show that as the curing period increases (7 days to 14 days) 28 days compressive strength also increases. Percentage increase of 28 days compressive strength is 9.73%, 3.13%, 8.35%, 7.31% and 8% for wet rug curing, water immersion curing, lime solution (1:50) immersion curing, lime solution (1:25) immersion curing, lime solution (1:75) immersion curing when concrete is cured for 7-14 days. According to past studies, the relative compressive strength of concrete increases and they show the same pattern as found in the present study [19,46,47].

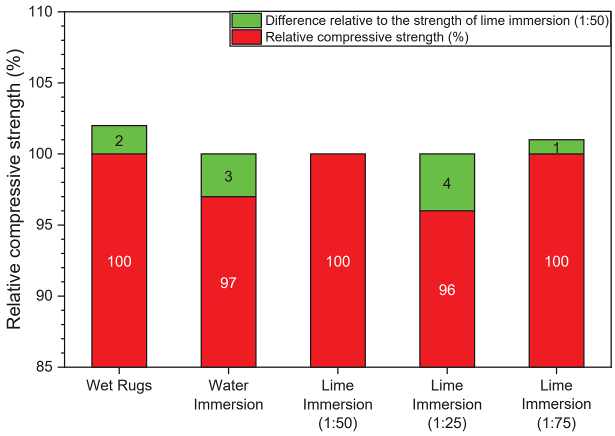

Fig. 9: Relative comparisons of 28 days compressive strength versus curing period for the 14 days.

6.5 Relative comparison of 28 days compressive strength versus curing period of 28 days

The 28-day compressive strength of concrete that has been cured for 28 days utilising a variety of curing techniques is shown in Fig. 10 in comparison to the concrete's compressive strength that has been limewater (1:50) solution cured. Lime immersion curing (1:50) has a maximum compressive strength of 50 N/mm^2. WBCC curing developed a minimum 28-day compressive strength of 43.47 N/mm^2 among all curing methods. But all the curing methods are able to achieve their target 28 days compressive strength i.e., 43.35 N/mm^2. Wet rug curing, water immersion, lime water solution (1:25) immersion, lime water solution (1:75) immersion and WBCC curing have developed 92%, 96%, 96%, 98% and 87% strength compared to concrete cured in lime water solution (1:50) curing. In all curing methods cured for 28 days, the lime water solution (1:50) curing gained a maximum 28 days compressive strength (50 N/mm^2). According to past studies, the relative compressive strength of concrete increases and they show the same pattern as found in the present study [47–49].

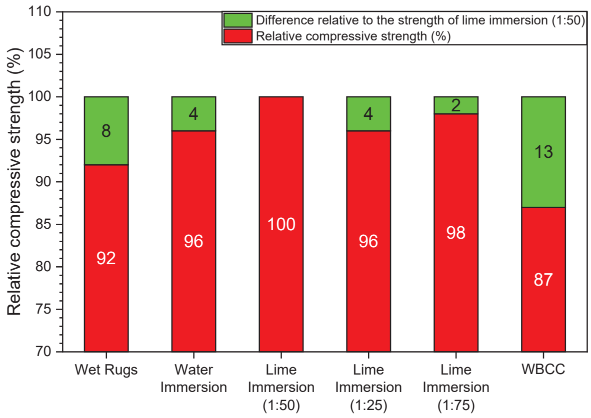

Fig. 10: Relative comparisons of 28 days compressive strength versus curing period for the 28 days

6.6 Relative comparison of compressive strength per curing method

6.6.1 Relative comparison of 28th day compressive strength for water immersion curing for different periods

The relative compressive strength for each 3, 7 and 14-day curing period is shown in Fig. 11 (compared to the 28-day water immersion cure concrete cube's compressive strength). Each 3, 7 and 14-day curing period's corresponding relative compressive strength is 83%, 101%, and 104%, respectively. At 3 days of water curing the compressive strength is 17% less, at 7 days of water curing the compressive strength is 1% more and at 14 days of water curing the compressive strength is 4% more than the compressive strength of 28 days of water curing. According to Raheem et al. [28] water immersion cure concrete's results are quite similar compared to this study. However, according to this study, the results were better than those in the previous literature. Both studies demonstrated that the concrete cube's compressive strength that had been water immersion cured increased gradually throughout the duration of the curing process. The findings indicate that 3 days of curing are insufficient since the mean target of 28 days for compressive strength development (43.25 N/mm^2) is not reached. 28 days of compressive strength for 14 days of curing was the maximum recorded as 47.44 N/mm^2.

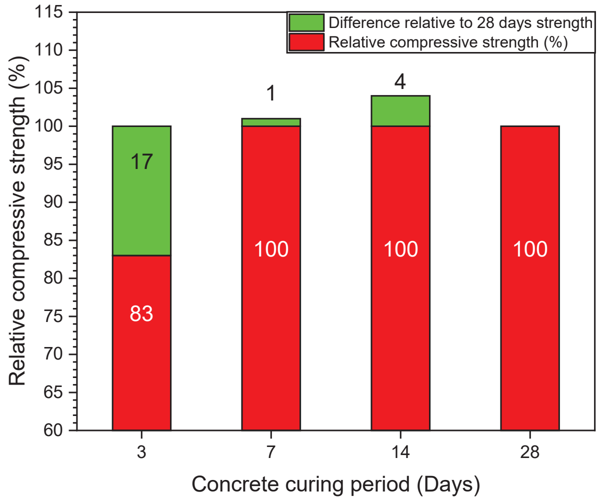

Fig.11: Relative 28 days compressive strength versus curing periods for the concrete immersed in water.

6.6.2 Relative comparison of 28th day compressive strength for wet rug curing for different periods

The relative compressive strength for each 3, 7 and 14-day curing period is shown in Fig. 12 (compared to the 28-day wet rug cure concrete cube's compressive strength). Each 3, 7 and 14-day curing period's corresponding relative compressive strength is 92%, 103%, and 113%, respectively. "According to Akinwumi et al. [25] for concrete cured by wet rugs, the results show that the differences in the relative compressive strength (relative to the 28 days strength of concrete) for each of the 3, 7 and 14-day curing periods are 55%, 47%, and 23%, respectively." The results of this study are better than the study by Akinwumi et al., [25]. The findings indicate that 3 days of curing are insufficient since the mean target of 28 days for compressive strength development (43.25 N/mm^2) is not reached. 28 days of compressive strength for 14 days of curing was the maximum recorded as 49.6 N/mm^2.

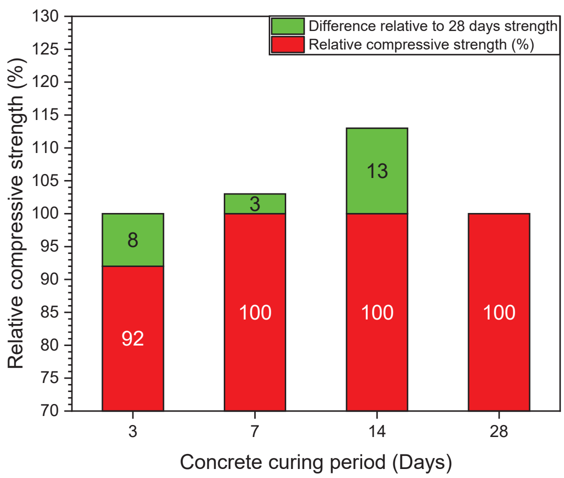

Fig. 12: Relative 28 days compressive strength versus curing periods for the concrete cured in wet rugs.

6.6.3 Relative comparison of 28th day compressive strength for lime immersion solution (1:25) curing for different periods

The relative compressive strength for each 3, 7 and 14-day curing period is shown in Fig. 13 (compared to the 28-day lime immersion (1:25) cure concrete cube's compressive strength). Each 3, 7 and 14-day curing period's corresponding relative compressive strength is 88%, 92%, and 98%, respectively. 28 days compressive strength for 28 days curing was recorded the maximum as 47.86 N/mm^2 and for 3 days curing was recorded minimum 42.1 N/mm^2. For each 3, 7 and 14-day curing period 28 days of compressive strength increase with an increase in the curing period. For 3 days of curing 28 days compressive strength developed is only 42.1 N/mm^2 which is 12% less than the 28 days compressive strength for 28 days of curing. For 7 days of curing 28 days compressive strength developed is 43.89 N/mm^2 which is 8% less than the 28 days compressive strength for 28 days of curing. The 28 days compressive strength results of 14 days of curing and 28 days of curing are quite similar, only 2% is less in 14 days of curing. So, we can use the lime immersion (1:25) curing method for concrete for 14 days because it gives an almost similar result to the 28 days of curing.

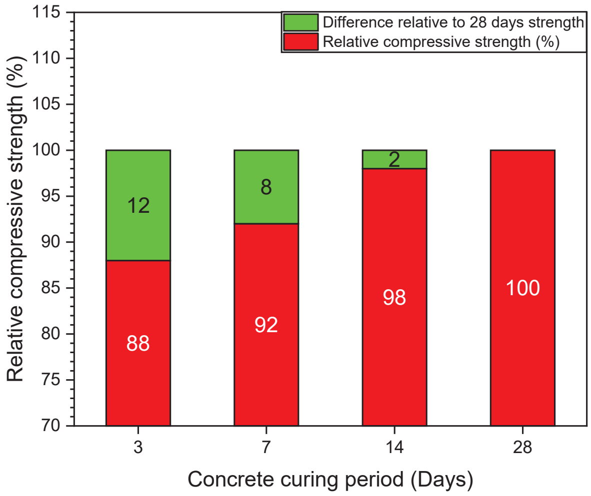

Fig. 13: Relative 28 days compressive strength versus curing periods for the concrete immersed in lime (1:25)

6.6.4 Relative comparison of 28th day compressive strength for lime immersion solution (1:50) curing for different periods

The relative compressive strength for each 3, 7 and 14-day curing period is shown in Fig. 14 (compared to the 28-day lime immersion (1:50) cure concrete cube's compressive strength). Each 3, 7 and 14-day curing period's corresponding relative compressive strength is 89%, 90%, and 98%, respectively. 28 days compressive strength for concrete cubes cured increases with an increase in curing periods. Concrete cubes cured for 28 days develop a maximum of 28 days of compressive strength (50 N/mm^2). For each 3, 7, and 14-day curing period all develop their 28-day mean target compressive strength (43.25 N/mm^2). After analysing the all results it was found that the lime immersion curing (1:50) gives the best results among all curing methods. Adopting this method 3 days of curing is sufficient to achieve target strength for M35 grade of concrete. For 3 days of curing 28 days compressive strength developed is 44.68 N/mm^2 which is 11% less than the 28 days compressive strength for 28 days of curing. For 7 days of curing 28 days compressive strength developed is 44.78 N/mm^2 which is 10% less than the 28 days compressive strength for 28 days of curing. The 28 days compressive strength results of 14 days of curing and 28 days of curing are quite similar, only 2% is less in 14 days of curing. So, the lime immersion (1:50) curing method can be used for concrete for up to 14 days because it gives an almost similar result to the 28 days of curing. The lime solution (1:50) curing method gives the best results compared to other lime solution curing methods i.e. (1:25) and (1:75).

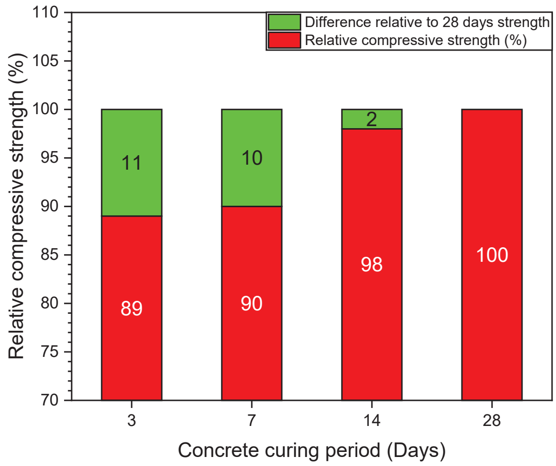

Fig. 14: Relative 28 days compressive strength versus curing periods for the concrete immersed in lime (1:50)

6.6.5 Relative comparison of 28th day compressive strength for lime immersion solution (1:75) curing for different periods

The relative compressive strength for each 3, 7 and 14-day curing period is shown in Fig. 14 (compared to the 28-day lime immersion (1:75) cure concrete cube's compressive strength). Each 3, 7 and 14-day curing period's corresponding relative compressive strength is 93%, 98%, and 106%, respectively. 28 days compressive strength for 14 days curing was the maximum recorded as 49.34 N/mm^2. For each 3, 7 and 14-day curing period, all develop their mean target compressive strength (43.25 N/mm^2). This comparison shows the increase in curing period increases the compressive strength of concrete, till concrete cubes are cured for 14 days. That means 14 days curing of lime immersion curing (1:75) is sufficient to gain the maximum strength and there is no need to go beyond 14 days of curing. Adopting this method 3 days of curing is sufficient to achieve target strength for M35 grade of concrete. So this method and 3 days curing can be used where regular curing is impossible. For 3 days of curing 28 days compressive strength developed is 43.4 N/mm^2 which is 7% less than the 28 days compressive strength for 28 days of curing. For 7 days of curing 28 days compressive strength developed is 45.67 N/mm^2 which is 2% less than the 28 days compressive strength for 28 days of curing. For 14 days of curing 28 days compressive strength developed is 49.34 N/mm^2 which is 6% more than the 28 days compressive strength for 28 days of curing. So the lime immersion (1:75) curing method can be used for concrete for up to 14 days of curing because it gives the best result of compressive strength. After analysing the all results it was found that the lime immersion curing (1:50) gives the best results among all lime immersion curing methods i.e. (1:25) (1:50) (1:75).

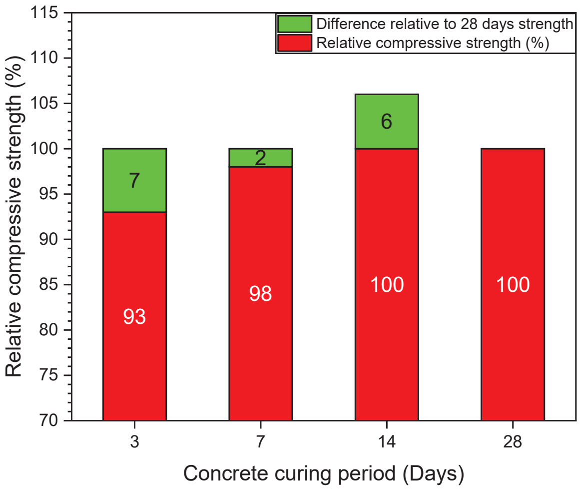

Fig. 15 Relative 28 days compressive strength versus curing periods for the concrete immersed in lime (1:75)

7. Conclusions

1. 28 days compressive strength was obtained maximum in lime immersion curing (1:50) method as 44.68 N/mm^2 when the concrete is cured in all curing methods for 3 days, in water immersion curing as 46 N/mm^2 when the concrete is cured in all curing methods for 7 days, in wet rug curing as 49.6 N/mm^2 when the concrete is cured in all curing methods for 14 days, lime immersion curing (1:50) as 50 N/mm^2 when the concrete is cured in all curing methods for 28 days.
2. Concrete cubes cured by lime immersion curing (1:25) have lesser 28 days compressive strength compared to lime immersion curing (1:75) and (1:50) for 3, 7 and 14- days of curing. Concrete cubes cured by lime immersion curing (1:50) give a maximum of 28 days of compressive strength among all the lime immersion curing i.e. (1:25), (1:50) and (1:75). Higher concentration of lime solution (1:50) does not significantly improve the 28 days compressive strength but only leads addition in cost. In these 3 lime solution immersion curing, (1:50) is the optimum dosage for making lime solution. Concrete cured by the concentration of lime immersion (1:50) shows more 28 days of compressive strength than potable water immersion and wet rugs curing after 3 days and 28 days of curing.
3. Concrete cubes cured for 3 days by potable water immersion, lime immersion (1:25) and wet rug curing do not achieve the target mean 28 days characteristic compressive strength. But all the curing methods cured for 14 days are able to achieve the target mean 28 days characteristic compressive strength. In case of time-constrained for construction, we can use lime solution immersion curing (1:50) and (1:75) for at least 3 days of curing. All the curing methods cured can be used for in-situ construction purposes to achieve the target 28 days of compressive strength but curing should be done at least 7 days.
4. Wet rug curing is better than water immersion curing because it does not lead to stagnation of water which may lead to fly nuisance. It can be used in columns and high-rise buildings where water immersion is not appropriate. It shows more 28 days of compressive strength than water immersion. But if there is no constraint for curing methods like floor or slab then water immersion curing is good from the economical point of view.
5. The lime immersion (1:75) curing method is recommended for small-scale works and quick strength gain in construction (3 days curing) where time is constrained. But this method should be used only when there is no economic factor because this method is a little more costly than other methods, otherwise, we should go towards wet rug curing.
6. WBCC curing method is recommended where other curing methods are difficult such as beams, columns and high-rise buildings. This method is able to achieve the target 28 days of compressive strength but in this method, the compressive strength is slightly less than the other methods. This method is being used a lot these days because it does not require repeated curing, just once the compound has to be applied to the concrete for curing, which saves a lot of time.

Acknowledgement

This work is supported by the Civil Engineering Department, Gautam Buddha University, U.P, India.

Funding

Gautam Buddha University, U.P India has funded this work.

References

1) M. Fauzi, "The study on the physical properties of surface layer concrete under the influence of medium temperature environments, Ph.D. Thesis, Kyushu University, Fukuoka, Japan," Kyushu University Fukuoka, Japan, 1995.

2) G. Zhakypova, S. Uderbayev, N. Saktaganova, G. Abyieva, A. Budikova, and A. Zhapakhova, "Properties of fine-grained concrete using ash of kazakhstan," *Evergr. Jt. J. Nov. Carbon Resour. Sci. Green Asia Strateg.*, 10 (*02*) 830–841 (2023). https://doi.org/10.5109/6792835

3) S. Singh, S.K. Singh, R. Kumar, A. Shrama, and S. Kanga, "Finding alternative to river sand in building construction," *Evergr. Jt. J. Nov. Carbon Resour. Sci. Green Asia Strateg.*, 9 (*4*) 973–992 (2022). https://doi.org/10.5109/6625713

4) L. Yadav, A.K. Verma, V. Dabra, and A. Yadav, "Performance comparison of different desiccant material based wheels for air conditioning application," *Evergr. Jt. J. Nov. Carbon Resour. Sci. Green Asia Strateg.*, 10 (*02*) 912–923 (2023). https://doi.org/10.5109/6792886

5) M.S. Shetty, "Concrete Technology by M S Shetty," Eighth rev, s chand, New Delhi, 2019.

6) A.M. Neville, and J.J. Brooks, "concrete technology," Second Edi, Pearson Education Limited, London, 2013.

7) B.C. Acarturk, and L.E. Burris, "Investigations of the optimal requirements for curing of calcium sulfoaluminate cement systems," *Cement*, 12 100072 (2023). doi:10.1016/j.cement.2023.100072.

8) M. Verma, and N. Dev, "Sodium hydroxide effect on the mechanical properties of fly ash-slag based geopolymer concrete," *Struct. Concr.*, 22 (*S1*) E368–E379 (2021). doi:10.1002/suco.202000068.

9) M. Verma, and N. Dev, "Effect of liquid to binder ratio and curing temperature on the engineering properties of the geopolymer concrete," *Silicon*, (2021). doi:10.1007/s12633-021-00985-w.

10) M. Verma, and N. Dev, "Effect of ground granulated blast furnace slag and fly ash ratio and the curing conditions on the mechanical properties of geopolymer concrete," *Struct. Concr.*, (*February*) (2021). doi:10.1002/suco.202000536.

11) M. Verma, and N. Dev, "Effect of snf-based superplasticizer on physical, mechanical and thermal properties of the geopolymer concrete," *Silicon*, (2021). doi:10.1007/s12633-020-00840-4.

12) Y. Wang, R. Xiao, H. Lu, W. Hu, X. Jiang, and B. Huang, "Effect of curing conditions on the strength and durability of air entrained concrete with and without fly ash," *Clean. Mater.*, 7 100170 (2023). doi:10.1016/j.clema.2023.100170.

13) S. Chaiyaput, N. Arwaedo, N. Kingnoi, T. Nghia-Nguyen, and J. Ayawanna, "Effect of curing conditions on the strength of soil cement," *Case Stud. Constr. Mater.*, 16 e01082 (2022). doi:10.1016/j.cscm.2022.e01082.

14) M. Verma, K. Upreti, P. Vats, S. Singh, P. Singh, N. Dev, D.K. Mishra, and B. Tiwari, "Experimental analysis of geopolymer concrete : a sustainable and economic concrete using the cost estimation model," *Adv. Mater. Sci. Eng.*, 2022 1–16 (2022). doi:10.1155/2022/7488254.

15) V.M. Tran, L.T. Nguyen, and T.H.Y. Nguyen, "Enhancing the effectiveness of steam curing for cement paste incorporating fly ash based on long-term compressive strength and reaction degree of fly ash," *Case Stud. Constr. Mater.*, 16 e01146 (2022). doi:10.1016/j.cscm.2022.e01146.

16) Z. Mo, Y. Han, L. Jiang, J. Wang, and X. Gao, "Strength properties and hydration of ultra-high performance concrete incorporating calcined clay and limestone with steam curing regimes," *Case Stud. Constr. Mater.*, 17 e01658 (2022). doi:10.1016/j.cscm.2022.e01658.

17) N. Poornima, D. Katyal, T. Revathi, M. Sivasakthi, and R. Jeyalakshmi, "Effect of curing on mechanical strength and microstructure of fly ash blend ggbs geopolymer, portland cement mortar and its behavior at elevated temperature," *Mater. Today Proc.*, 47 (*4*) 863–870 (2021). doi:10.1016/j.matpr.2021.04.087.

18) J. Shi, B. Liu, S. Shen, J. Tan, J. Dai, and R. Ji, "Effect of curing regime on long-term mechanical strength and transport properties of steam-cured concrete," *Constr. Build. Mater.*, 255 119407 (2020). doi:10.1016/j.conbuildmat.2020.119407.

19) A.M. Zeyad, "Effect of curing methods in hot weather on the properties of high-strength concretes," *J. King Saud Univ. - Eng. Sci.*, 31 (*3*) 218–223 (2019). doi:10.1016/j.jksues.2017.04.004.

20) T. Chen, and X. Gao, "Effect of carbonation curing regime on strength and microstructure of portland cement paste," *J. CO2 Util.*, 34 (*May*) 74–86 (2019). doi:10.1016/j.jcou.2019.05.034.

21) G. Long, J. Yang, and Y. Xie, "The mechanical characteristics of steam-cured high strength concrete incorporating with lightweight aggregate," *Constr. Build. Mater.*, 136 456–464 (2017). doi:10.1016/j.conbuildmat.2016.12.171.

22) K.N. Rahal, "Effects of improper moist curing on flexural strength of slabs cast under hot weather conditions," *Constr. Build. Mater.*, 110 337–345 (2016). doi:10.1016/j.conbuildmat.2016.02.040.

23) M. Bediako, J.T. Kevern, and E.O. Amankwah, "Effect of curing environment on the strength properties of cement and cement extenders," *Mater. Sci. Appl.*, 06 33–39 (2015).

doi:10.4236/msa.2015.61005.

24) E.M.B. Stella, M. Tech, and A. Professor, "Self curing concrete and its inherentproperties," *J. Eng. Res. Appl. Www.Ijera.Com*, 4 (*8*) 66–71 (2014). www.ijera.com.

25) I.I. Akinwumi, and Z.O. Gbadamosi, "Effects of curing condition and curing period on the compressive strength development of plain concrete," *Int. J. Civ. Environ. Res.*, 1 (*2*) 83–99 (2014). https://www.researchgate.net/publication/264276085.

26) Y. Nahata, N. Kholia, and T.G. Tank, "Effect of curing methods on efficiency of curing of cement mortar," *APCBEE Procedia*, 9 (*Icbee 2013*) 222–229 (2014). doi:10.1016/j.apcbee.2014.01.040.

27) A.E. Abalaka, and O.G. Okoli, "Effects of limited initial curing durations on mechanical properties of concrete," *J. Civ. Eng. Constr. Technol. Vol.*, 4 (*3*) 104–109 (2013).

28) O. Mohamed, and O. Najm, "Effect of curing methods on compressive strength of sustainable self-consolidated concrete," *IOP Conf. Ser. Mater. Sci. Eng.*, 471 (*4*) 032059 (2019). doi:10.1088/1757-899X/471/3/032059.

29) Bureau of Indian Standards (BIS), "Method of physical tests for hydraulic cement: determination of fineness by dry sieving," *IS 4031 Part 1, New Delhi*, Reaffirmed in 2005 (1996).

30) Bureau of Indian Standards (BIS), "Methods of physical tests for hydraulic cement 4031 (part 11) - 1988," *Bur. Indian Stand. New Delhi*, (2005).

31) IS 4031- Part V, "Methods of physical tests for hydraulic cement. part v- determination of initial and final setting times," *Bur. Indian Stand. New Delhi*, Reaffirmed in 2005 (1988).

32) IS 4031 - 3 (1988) (Reaffirmed 2005), "Methods of physical tests for hydraulic cement, part 3: determination of soundness [ced 2: civil engineering]," *Bur. Indian Stand. New Delhi*, 1–10 (2005).

33) Bureau of Indian Standards (BIS), "Method of test for aggregate for concrete. is 2386- part iii- 1963 (reaffirmed 2002) specific gravity, density, voids, absorption and bulking," *Bur. Indian Stand. New Delhi*, (1963).

34) Bureau of Indian Standards, "Specification for coarse and fine aggregates from natural sources for concrete is 383: 1970," *IS 383 1970(Reaffirmed 2002)*, 1–24 (1970).

35) Bureau of Indian Standards, "Indian standard guidelines for concrete mix design proportioning is:10262- 2009," *Bur. Indian Stand. New Delhi*, New Delhi,India (2009).

36) R. Kumar, and N. Dev, "Effect of acids and freeze–thaw on the durability of modified rubberized concrete with optimum rubber crumb content," *J. Appl. Polym. Sci.*, 139 (*21*) 52191 (2022). doi:10.1002/app.52191.

37) R. Kumar, N. Dev, S. Ram, and M. Verma, "Investigation of dry-wet cycles effect on the durability of modified rubberised concrete," *Forces Mech.*, 10 (*December 2022*) 100168 (2023). doi:10.1016/j.finmec.2023.100168.

38) R. Kumar, and N. Dev, "Mechanical and microstructural properties of rubberized concrete after surface modification of waste tire rubber crumb," *Arab. J. Sci. Eng.*, 47 (*4*) 4571–4587 (2022). doi:10.1007/s13369-021-06154-w.

39) R. Kumar, and N. Dev, "Assessment of mechanical and impact resistance properties of rubberized concrete after surface modification of rubber crumb," *Iran. J. Sci. Technol. Trans. Civ. Eng.*, 46 (*4*) 2855–2871 (2022). doi:10.1007/s40996-021-00784-8.

40) R. Kumar, M. Verma, N. Dev, and N. Lamba, "Influence of chloride and sulfate solution on the long-term durability of modified rubberized concrete," *J. Appl. Polym. Sci.*, 139 (*37*) 1–15 (2022). doi:10.1002/app.52880.

41) V. Ordonez, H. Baykara, A. Riofrio, M. Cornejo, R. Rodríguez, F. De Ciencias, E. Superior, C. Gustavo, G. Km, and V. Perimetral, "Preparation and characterization of ecuadorian bamboo fiber-low-density polyethylene (ldpe) biocomposites," *Evergr. Jt. J. Nov. Carbon Resour. Sci. Green Asia Strateg.*, 10 (*01*) 43–54 (2023). https://doi.org/10.5109/6781037

42) Bureau of Indian Standards, "Method of tests for strength of concrete is 516:1959 (reaffirmed 2004)," *Bur. Indian Stand. New Delhi*, New Delhi,India (2004).

43) A.S. Al-Gahtani, "Effect of curing methods on the properties of plain and blended cement concretes," *Constr. Build. Mater.*, 24 (*3*) 308–314 (2010). doi:10.1016/j.conbuildmat.2009.08.036.

44) S.B. Piplewar, N.M. Kanhe, and D. Pandey, "Intermittent curing of m20 concrete," *Int. J. Struct. Civ. Engg. Res*, 2 (*3*) 165–171 (2013). www.ijscer.com.

45) S. Singh, L. Nagdeve, H. Kumar, and K. Dhakar, "Rice straw based natural fiber reinforced polymer for sustainable bio- composites : a systematic review," *Evergr. Jt. J. Nov. Carbon Resour. Sci. Green Asia Strateg.*, 10 (*02*) 1041–1052 (2023). https://doi.org/10.5109/6793661

46) F. Sajedi, and H.A. Razak, "Effects of curing regimes and cement fineness on the compressive strength of ordinary portland cement mortars," *Constr. Build. Mater.*, 25 (*4*) 2036–2045 (2011). doi:10.1016/j.conbuildmat.2010.11.043.

47) A. Goel, J. Narwal, V. Verma, D. Sharma, and B. Singh, "A comparative study on the effect of curing on the strength of concrete," *Int. J. Eng.*

Adv. Technol., 2 (*6*) 401–406 (2013). http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.676.24.

48) R.G. Burg, "The influence of casting and curing temperature on the properties of fresh and hardened concrete," *(No. R&D Bull. RD113T) Portl. Cem. Assoc.*, 18 (1996).

49) M. Safiuddin, S.N. Raman, and M.F.M. Zain, "Effect on different curing methods on the properties of microsilica concrete," *Aust. J. Basic Appl. Sci.*, 1 (*2*) 87–95 (2007).