

COMPARATIVE ANALYSIS OF THE COMPRESSIVE STRENGTH OF CONCRETE UNDER DIFFERENT CURING METHODS

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Abstract: Concrete is the most prevalent material in building, exhibiting many features and potential production techniques. Concrete is distinguished by its strong compressive strength and durability, traits that may have been directly affected by the preservation technique in ancient times. The aim of this study is to illustrate the significance During the concrete curing process, together with an examination of the impact of the selected curing technique about the compression resistance. Forty-eight concrete test specimens were produced in accordance with the specification. criteria. Subsequently, the samples were partitioned into eight groups, each undergoing distinct Types of curing: immersion curing, bi-daily; outdoor curing; complete immersion curing. various waters, use of a commercial curing agent; with polyethylene film coating and in the absence of treatment. Conducting compression tests at 7 and 28 days. Among the findings acquired, The batch subjected to the curing procedure with polyethylene covering exhibited superior effective resistance to compression, succeeded by immersion methods inside water.

Keywords: strong compressive, polyethylene, Types of curing, immersion curing

1.0 INTRODUCTION

Concrete is the most extensively used aggregate globally. It is recognized as a fundamental material and construction instrument in civil engineering, primarily because to its superior performance and affordability. Moreover, concrete has sufficient ductility to accommodate any building project, irrespective of its scale [1]. The binder comprises the precise combination of cement and water to maintain the concrete in a

saturated condition. Thus, the areas formerly occupied by water are now filled with moisturizing agents. In the absence of water, hydration ceases, resulting in excessive porosity that diminishes the mechanical qualities and durability of concrete [2-3], along with a variable amount of mineral additions, including aggregates (sand and gravel) [4]. The hydration facilitates the compound's application and enhances its resilience to harsh circumstances [5]. The global ready-mixed concrete business is anticipated to surpass \$600 billion in sales by 2025.

Conversely, it is crucial to recognize that fly ash (FA) is a byproduct of coal-fired power stations, and its use is significant for mitigating the environmental effect of the cement sector. Consequently, FA has been extensively used in the construction industry as a mineral addition in concrete production, as a mineral filler in asphalt concrete, and as a sub-base for pavement layers, among other applications. In the building sector, this substance is recognized as an effective additional cementing agent. Given the significance of a material's load-bearing capacity, it is essential to consider the conditions of strength. The ownership accountable for the quality monitoring of the material and the concerns of designers [8]. Concrete has exceptional compressive load capability. Nonetheless, similar to several other materials, concrete has porosity characteristics [9]. Porosity influences the structural integrity of concrete throughout its operational performance. This infiltration not only permits fluid penetration into the material but may also lead to subsequent breaking of the compound. Cracks in concrete are therefore seen as inevitable, difficult to identify,

and almost impossible to rectify. Cracking poses a latent threat to concrete buildings, since it may lead to hazardous defects over time [10].

Curing is a technique wherein hydraulic cement concrete attains hardening characteristics by the hydration of cement in the presence of water and heat. Inadequate curing may lead to substantial faults affecting the long-term stability of the concrete. These faults often present as obvious fissures, micro-cracks, and a compromised surface. An optimal curing condition enhances the strength and durability of concrete, while also significantly improving its microstructure and resistance to environmental degradation. The curing process of concrete is directly linked to its mechanical performance and resistance to environmental factors [8].

The curing process may be executed using many methods or procedures, selected based on particular environmental conditions, economic considerations, simplicity of application, and other project-related criteria [12]. Numerous research has been undertaken to validate the efficacy of various curative agents under diverse situations. Research undertaken by engineers at Landmark University in Nigeria indicates that cure is contingent upon the sort of agent used in the sample. The samples are cylindrical and possess typical features that have been previously measured, including curing time and ambient conditions. Additional studies have shown the diversity and interchangeability of advantages across various features of the molecule [5]. This indicates that several strategies provide distinct advantages individually, while simultaneously exhibit deficiencies in other aspects. The literature review identified two steam curing methods [13-16], the burning ash method [17], and microwave curing [18]. These techniques are frequently employed in concrete curing through heating and atmospheric vapour pressure, demonstrating significant advantages in achieving higher early-age compressive strength, albeit resulting in lower compressive strength at later ages.

This research seeks to assess the compressive strength of treated concrete utilizing eight distinct curing methodologies: standard

projection, which entails surface hydration of the sample set [19-20]; outdoor curing, characterized by the absence of external interventions [5, 21]; application of two types of liquid compounds that create curing membranes; immersion in seawater and freshwater [22-23], differing solely by the water source; utilization of plastic or vinyl coverings [14, 24-25]; and immersion in freshwater with lime [1, 26]. The implementation of these procedures will be elaborated upon in the subsequent subparagraphs necessitating the advancement of these strategies. The optimal procedure will be ascertained by the compressive strength tests conducted on each cylindrical specimen, as delineated in the methodology.

2.0 HYPOTHESIS'S WORKS

The compressive strength of hydraulic concrete cylinders, assessed at 7 and 28 days under various curing methods, was evaluated in accordance with the ASTM standard requirements and procedural guidelines [27]. The laboratory results were further analyzed to determine the influence of the selected curing method on the compression resistance values of the concrete. Each curing method utilized three cylinders, resulting in the production of forty-eight samples (24 for testing at 7 days and 24 at 28 days).

2.1 Materials

The laboratory portion of this research involved the preparation of concrete samples in cylindrical form, measuring 20 cm in height and 10 cm in diameter. These samples were dosed with two types of cementitious materials: Portland cement and fly ash (FA) cement. The samples consist of the following materials: structural cement type grey, fly ash sourced from Mount Líbano, coarse sand, fine sand, gravel TM 3-8", water, a plasticising additive, and a retardant additive.

The materials underwent physical and chemical characterization tests prior to design, conducted under ambient conditions of 24.2 °C and 62.1% humidity. The physical characterization procedures were conducted in accordance with

ASTM C33 [28] and ASTM C131-03 [29], while the chemical characterization procedures were performed following ASTM 1218 [30]. The properties of the aggregates utilized in this concrete mixture are presented in Table 1.

Table 1. Physico-chemical characterization of the concrete component aggregates.

Chemical Properties	Fine Aggregate	Coarse Aggregate
Sulphate-SO4 [%]	0,088	0,712
Chlorides-Cl [%]	0,0002	0,00117
Physical Properties		
Equivalent percentage of baked sand [%]	68	-
Wear Resistance [%]	-	22,9
Light Particles [%]	0	0
Density [kg/m3]	2.616	2.539

The fly ash was utilized as a supplementary cementing material in the mixture to reduce environmental impact, with the goal of achieving LED certification and enhancing the durability of the concrete. The analysis of the ashes utilized in this study is detailed in Table 2.

Table 2. Physico-chemical properties of fly ash used.

Chemical Properties	(%)	Chemical Properties	(%)
Silicon Oxide – SiO2	44,5	Sulfur Oxide – SO3	3,2
Aluminum Oxide – Al2O3	19,3	Sodium Oxide – Na2O	1,1
Ferric Oxide – Fe2O3	14,5	Potassium Oxide – K2O	1,3
%SiO2 + %Al2O3 + %Fe2O3	78,2	Equivalent Bases – Na2Oeq	2
Calcium Oxide – Cao	6,7	Fire Losses	4,6
Magnesium Oxide – MgO	3,1	Humidity	1
Physical Properties			
Sieve fineness N°325 (45 um)	24		
Density (g/ml)	2,5		

The dosing of the raw materials for the designed concrete mixture was performed for a net capacity of 100L according to the ACI method [31] and is presented in Table 3.

Table 3. Designed mixing dosage.

Raw Materials	Dry weights	
	Quantity (kg)	Tolerance (%)
Portland Cement	246	±4
Fly Ashes	43	±4
Coarse Sand	468	±3
Fine Sand	468	±3

Gravel TM 3-8''	950	±3
Water	165	±1
Additive 1 (Plasticizer)	1,44	±3
Additive 2 (Super Plasticizer)	2,17	±3

The water-soluble solutions of plasticising and super plasticising additives were incorporated to effectively regulate, balance, and sustain the design of the mixture. It is important to observe that the calculation did not modify the water-cement conditions. Consequently, the initial additive (plasticizer) facilitated the mixture to attain enhanced malleability, minimized segregation, and preserved its viscosity; while the subsequent additive (superplasticizer) functioned as a reducer and retarder of setting water. The mixture was evaluated in light of the characteristic temperature conditions of the coastal zone (Barranquilla-Atlántico).

2.2 Methodology

2.2.1 Mixing: The previously dosed materials were placed in a concrete mixer for a period of 15 minutes, ensuring a uniform mixing process

2.2.1 Trials in a fresh state.

The tests were carried out to verify the quality and efficiency of the mixture, to guarantee the correct mixing process of the concrete. The settlement test according to ASTM C143-90 [32] and the density and air content tests according to ASTM C231-09 [33] were performed. The procedure of these trials is



illustrated in Figures 1 and 2. The results showed a settlement of 6 ± 1 in, a density of 2.116 kg/m^3 and air content of 2%.

Figure 1. Settlement test illustration.



Figure 2. Air content test illustration

2.1.3. *Manufacture of concrete cylinders.*

We proceeded to manufacture and form concrete cylinders in plastic molds that had dimensions of 10 cm in diameter and 20 cm in length (Figure 3). After 24 hours, the cylinders were uncoupled and prepared for the application of the different



curing techniques already mentioned as an objective of this



investigation (Figure 4).

Figure 3. Concrete sample formwork


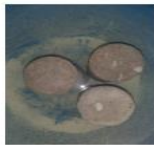






Figure 4. Uncoated concrete cylinders

2.1.4. *Application of curing methods.*

The curing methods that were applied in this study correspond to conventional on-site and unconventional methods. Eight curing methods were chosen: immersion in drinking water, immersion in seawater, immersion in drinking water + lime + temperature control application of brand name curing agent #1. Application of brand name curing agent #2, coating with polyethylene plastic foil, standard manual spraying of fresh water and non-application of curing (6 specimens for each of the curing techniques). Each of these procedures was performed on each trio of samples during the 7 and 28 days after they were unwrapped.

Table 4 specifies the nomenclature and description of the eight curing techniques chosen for the investigation.

Table 4. Nomenclature for selected and applied curing techniques.

			
T1 - Immersion in tap water	T2 - Immersion in sea water	T3 - Immersion in tap water + lime + temperature control	T4 - Curing agent 1
			
T5 - Curing agent 2	T6 - Polyethylene plastic sheets	T7 - Manual water sprinkling	T8 - Without curing

2.2.5 *Hardened State Tests.*

The compressive strength tests were implemented on each of the samples. Two machines were used to carry out these tests. The first one is a cylinder compression frame, with a capacity of 1500 kN, of the reference CT-1500 of the Dirimpex brand. The second machine is a super- automatic console Automax reference 50-C10F04 also of the brand Dirimpex. These machines worked together to carry out the compression tests, which were carried out according to the ASTM C39 standard. Three specimens (of the six specimens of concrete cured under each curing method) failed within 7 days of stripping, and the other three specimens corresponding to each method failed within 21 days (28 days after stripping).

3. ANALYSIS OF RESULTS

3.1 *Compressive strength (f'c) at 7 days.*

Based on the results obtained from the compressive strength tests of the concrete samples subjected to the curing process during the first 7 days, showed that the batch of samples submitted under the curing technique corresponding to polyethylene plastic sheets (T6) presented a higher resistance value, reaching an average value of 26.7 MPa, followed by the curing agent of brand #1 (T4), which had to undergo an average compression of 26.1 MPa to fail. Moreover, the method of flooding with drinking water with lime + temperature control (T3), presented the weakest yield, with a value of f_c of 22,8 MPa. These resistance values are slightly lower than those achieved by the samples without receiving any curing method (25,5 MPa).

3.1 Compressive strength (f_c) at 28 days

According to the values given by the compressive strength tests carried out on the sample groups at 28 days, the samples cured with polyethylene foil (T6) repeat as the most resistant. This time with a value of 32.7 MPa. Followed by the T6, are the drinking water and seawater flooding techniques (T1-T2), with values of 32.2 and 32 MPa, respectively. These two techniques did not present the same efficiency in the seven-day tests. It is pertinent to note that all the samples increased their performance considerably concerning the previous test, so it is easy to deduce that these methods must incorporate into the concrete through a longer rest time.

This was the case for the samples to which the drinking waterflood technique with a solution and temperature control (T3) was applied, which showed the most unfavorable results in the first test, while in the latter they delivered a more resistant product than the samples to which the method related to the spraying with drinking water (T7) and the technique with curing agent #1 (T4) were applied, which provided a final compressive strength of only 27.4 MPa, being further outweighed by the uncured samples. In other words, it could be said that the method with the curing agent of the trademark #1 has counterproductive effects on the concrete in the long term, since in the previous trial (at 7 days) presented an immediate efficiency, which, with the passage of days, was diminished.

Figure 5 shows an illustration of the characteristic failures of the cylinders tested at both 7 and 28 days, their appearance being very similar for each of the groups of samples subjected to the different curing techniques studied.



Figure 5. Typical cylinder failures tested at 7 and 28 days.

Figure 6 summarises the average compressive strength values of groups of samples by curing technique used at 7 and 28 days, respectively:

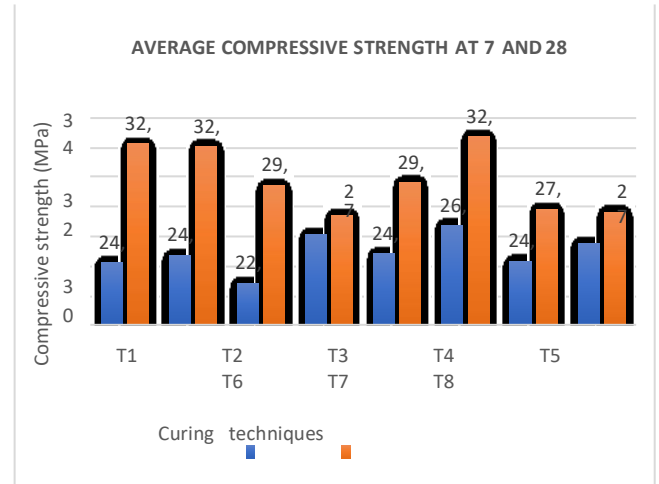


Figure 6. Average compressive strength values of the batches of the samples tested.

Figure 7 illustrates the efficiency of each of the curing techniques selected for the analysis, contrasted with the samples that were not subjected to any curing process (T8). It is worth highlighting the similarity of the technique corresponding to the manual spraying of water (T7), which is a method commonly used in works, with the samples uncured. That fact could be supported as it is a manual process with a lot of care to consider, it is difficult to guarantee its correct and constant procedure.

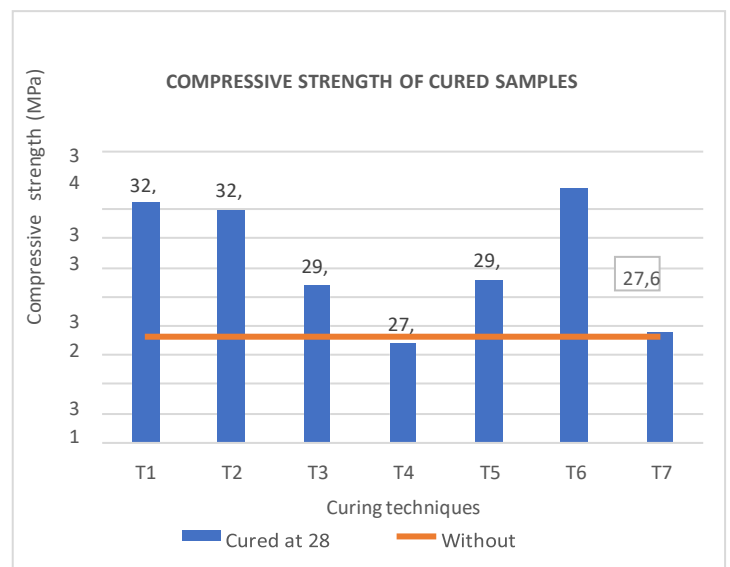


Figure 7. Comparison of the results of curing versus curing techniques.

Table 5 presents a simple statistical analysis of the results obtained, given from the value of the standard deviation, rating these results according to the criterion of ACI 214 [34], as: excellent, very good, good and, only in a poor case (T7), indicating for the latter a considerable dispersion in the values released. It should be noted that resistance was worked with at 28 days, as the results of the ACI 214 report are valid only for this age.

Based on the results of the investigation, the peak of efficacy was evident in the technique using polyethylene plastic sheets (T6), which showed favorable results from its compression trial applied at 7 days (26.7 MPa) ratifying with an average resistance of 32.7 MPa after 28 days. At the same time, when evaluating the experimental results, it was possible to observe the negative influence on the compression resistance of the commercial curing agent #1 (T4), which was evidenced at 28 days with an average resistance of 27,7 MPa, differing from samples that were not cured (T8) by only 0.5 MPa (26.7 MPa), with the latter being the least effective curing technique of all those studied here. For this reason, perhaps a better control or greater application of the product is suggested.

About the manual spraying technique for drinking water (T7), it can be concluded that although it is the most frequently used standard technique in the local construction industry and from which better results were expected, yielded an average compressive strength at 28 days also very similar to not applying any type of curing (27.8 MPa versus 26.7 MPa). With the result, the recommendation to change the curing methods in the usual constructions is generated, putting in alert the quality of the concrete in a matter of resistance to the compression.

Finally, the technique of immersion in seawater (T2) was found to increase the resistance to 28 days of the samples by a value of 32 MPa, demonstrating the benefits of compression resistance in concrete. However, it is worth noting that these analyses were carried out to a specific standard without reinforcement, so that the response of reinforced concrete to the application of the technique of curing by immersion in seawater is opened to other investigations, which is presumed to have corrosion and carbonation consequences due to the concentration of salts, lowering the pH of the concrete. It is necessary to emphasize that the application of this technique would be appropriate to the demand for environmental awareness and the inevitable use of water in construction.

4.0 CONCLUSIONS AND RECOMMENDATIONS

- From the results of the present investigation, it is concluded that the techniques where immersion in water (T1, T2 and T3) and the technique of coating with polyethylene plastic around specimens (T6) are the most effective methods to perform curing on site.

- The cylinders with curing agent 1 (T4), presented an adequate behavior to the resistance to the compression at 7 days, but its lack of efficacy is evident in more advanced days and to be able to maintain the humidity in the concrete because resistance to compression was obtained very similar to the resistance that was obtained without carrying out the curing process.
- The compression resistance of the cylinders with the seawater curing technique yielded positive results. However, the seawater is not recommended for use with concrete as the reinforcing steel is usually in conjunction with the concrete and could end up with problems of accelerated corrosion and carbonation.
- Positive results according to ACI 214 on the standard deviation of the compressive strength of concrete cylinders are evident, which supports an adequate experimental procedure. However, the T7 technique gave "poor" confidence because when simulating spraying conditions on-site, it probably was not performed uniformly, as it happens in construction sites.
- The need for the curing process in the concrete is evident independently of the technique used to achieve greater resistance to compression.

Finally, despite the results found in the research, it is recommended to continue analyzing the influence of concrete curing methods on other parameters such as durability, water absorption, carbonate penetration, among others; and it is also recommended to carry out a microstructural analysis of the samples tested to further deepen the interpretation of the results obtained, as well as taking a greater number of samples per batch.

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