Investigate The Mechanical Properties of Binder Concrete Under Various Curing Methods

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Abstract

Curing is one of the most important steps in concrete manufacturing, as it stimulates cement reactions to achieve superior mechanical properties. Since water is the most common method for curing concrete, and in light of global warming and water scarcity, this research focuses on finding alternative methods that achieve rates close to those of water curing. Various curing techniques are typically used to reach concrete compressive strength. The laboratory results of this study investigate the effect of curing techniques (namely, water, air-dry, burlap, membrane, and chemical spray) on compressive strength (F_{cu}) and indirect tensile stress (F_t) using 200 specimens. In order to reach the optimum method for concrete curing, two different cement contents (namely, 350 kg/m^3 and 450 kg/m^3) with and without chemical admixture (superplasticizer). Tests for compressive and indirect tensile strength were conducted on four different concrete mixes. Based on the experimental results, adding superplasticizer and increasing the cement content improved the mechanical qualities represented by compressive strength. The longer the curing period of the concrete, the higher the F_{cu} obtained. Additionally, adding 1% of SP has a stronger effect on F_{cu} than adding 100 kg of cement.

Keywords: Curing; Cement; Compressive strength; Core test; Tensile strength; Binder; Concrete

1. INTRODUCTION

Curing refers to the deliberate regulation of temperature and moisture exchange in concrete to promote cement hydration. It can be defined as the process of controlling the rate and amount of moisture evaporation from concrete to achieve a stable hydration of Portland cement once the concrete is placed and completed. Proper curing is essential because it improves concrete's durability, strength, abrasion resistance, watertightness, resistance to freezing, and scaling stability. Curing also significantly impacts the durability and strength of concrete structures exposed to hard conditions or at risk of reinforcing bars corrosion [1].

Curing can performed either during the manufacture of concrete products or after casting, allowing the cement to undergo hydration. To achieve optimum strength and durability, long term curing is necessary, as the cement hydration process may take several weeks rather than just a few hours [2]. Curing may also involve temperature regulation, as this directly affects the rate at which the cement undergoes hydration. The duration of the curing process depends on the desired properties of the concrete, its intended use, and the prevailing environmental conditions, including the temperature and relative humidity of the surrounding environment. To produce high-quality concrete, it is essential to properly prepare a suitable mixture and then cure it in a suitable environment during the early stages of hardening. Concrete can be cured using several processes, including hydrocuring, membrane curing, electrical curing, and high-pressure steam curing [3, 4].

Although different curing methods may be employed, having a certain degree of water curing is preferable. The use of membranes or plastic sheets to cure concrete is now the most practical and effective method in construction, especially in cases where water for curing concrete is unavailable or when an inappropriate curing method is used. A minimum thickness of 0.01 mm is required for sheets according to ASTM C 171-2007 specifications to ensure the required strength [5].

Several research studies in the literature have investigated how water curing affects the mechanical properties of concrete [6-18]. Given the global movement towards environmentally-friendly buildings and the widespread issue of water scarcity, water use in the curing process has become challenging. It is essential to explore alternative methods that can achieve the desired curing effects without affecting the concrete properties. This is particularly important considering the emergence of green concrete types that are incompatible with water curing.

The current study aims to determine the effects of different concrete treatment methods on the mechanical properties of both standard samples and structural elements by conducting laboratory samples and structural elements, studying the effects of different curing methods, and comparing them with water curing.

2. EXPERIMENTAL PROCEDURE

An experimental program was created to investigate the mechanical properties of concrete based on variations in binder material content, curing methods, and the use of a superplasticizer admixture. This study employs locally available materials to manufacture concrete.

The research parametric study examines various curing procedures, varying cement content (namely, 350 and 450 kg/m^3), and the impact of adding a chemical admixture (namely, superplasticizer) at 1% weight ratio of cement.

2.1 Materials

The concrete mixture in this investigation used the following materials:

- Cement (C), CEM-I-42.5-N, complies with the specifications outlined in EN 197 and ESS 4756-1/2013 [19].
- Fine aggregate, consisting of medium well-graded sand with a fineness modulus of 2.5 and passing through a sieve with a size of 4.75 mm, complies with the specifications outlined in ESS 1109-2002 [20] and ASTM C33-2013 [21].
- Coarse aggregates (CA) are produced from crushed limestone with a maximum nominal size of 10 mm. They have a specific gravity of 2.55, a relative density of 2.86, and an aggregate absorption percentage of 0.86%, meeting the standards of ESS 1109-2002 [20].
- Water (W), All concrete mixtures and curing processes for all specimens were carried out using tap water following ECP 203-2020 [22-23] requirements.
- Superplasticizer (SP), precisely Type F (ASTM C 494), known as high-range water reducing, was added at a concentration of 1% by weight of cement.

2.2 Preparation and testing methods for specimens

Four different concrete mixtures were created to accomplish the research objectives. The mixtures were made using a water-cement ratio of either 0.45 or 0.6, depending on whether the admixture (SP) was employed or not, in order to get the desired workability. Table (1) illustrates the components of the concrete mixtures. The solid materials volume was kept constant, while the admixture (SP) weight equaled 1% of the cement weight.

Table 1: Components of the concrete mixtures (kg/m^3)

Mixtures	Cement	Aggregate		Water	Admixture
		Sand	Crushed Dolomites		
Mix 1	350	720	1080	210	0
Mix 2	350	619	1238	175	3.5
Mix 3	450	720	1080	210	0
Mix4	450	866	1733	225	4.5

To achieve the research variables and to understand the effect of various cement content and the presence of superplasizer admixture, One hundred twenty cubes of 150x150x150 mm were tested to determine compressive strength at 7 days ($\mathbf{F_{cu\text{-}7}}$) and 28 days ($\mathbf{F_{cu\text{-}28}}$). Additionally, 60 cylindrical specimens with dimensions of 150x300 mm were used to test the indirect tensile strength (f_t) after 28 days. For core tests, 20 slabs measuring 50x50x12 mm were used. Each slab needed three core specimens to be extracted after 28 days of curing to assess compressive strength. The mechanical qualities were evaluated in accordance with the specifications given in ECP203/2019 [23] and ACI 308-1/2011 [24-25]. A hydraulic testing machine, capable of exerting a maximum force of 2000 kilonewtons, was employed to conduct tests on cube specimens following the guidelines outlined in BS EN 12390 /2019 [26].

a) Specimens' preparation

b) Curing the specimens with the five methods

Figure 1: Test Specimen Preparation

a) Water curing

b) Membrane

c) Burlap

d) Chemical spray

Figure 2: Difference curing methods

3. Results and Discussion

3.1 Fresh concrete properties

The workability of various mixtures was tested by slump test. The slump test findings conform to the specifications of ESS 1858/ 2008 [27], ASTM C1611, and ESS 360/2007. The slump test results for mixes are presented in Table 2.

Table 2: The Slump Test Results for all Mixes

Mix ID	Mix 1	Mix 2	Mix3	Mix 4
Slump (mm)	70	65	55	50

Table 2 and Figure 3 demonstrate that adding 100 kilograms of cement to Mix 3 results in a 21% decrease in slump when compared to Mix 1. When superplasticizer is added to mix 2, the slump falls by 7%. Similarly, for mixes 3 and 4, the slump is reduced by 10%.

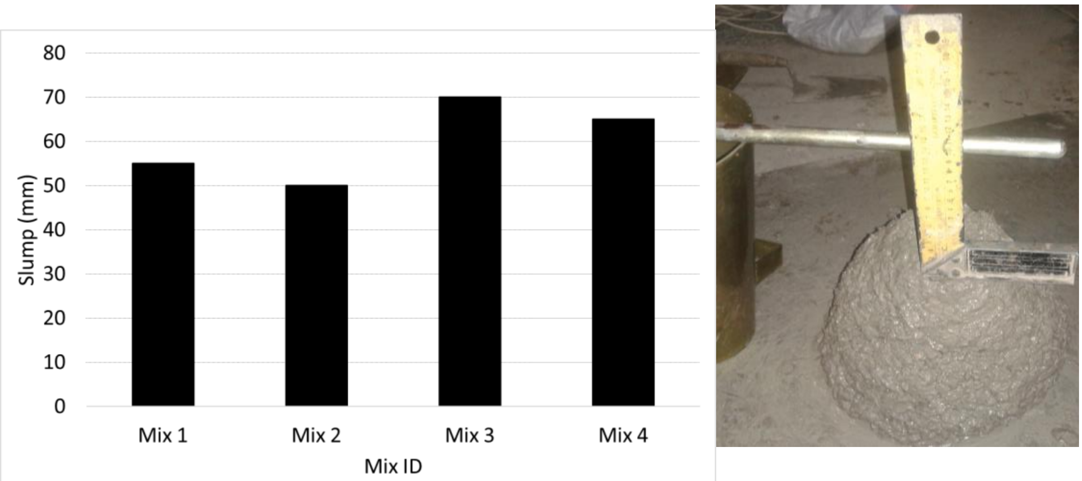


Figure 3: Slump Results

3.2 Hardened properties

Experimental measurements are used to determine the concrete's hardened characteristics, specifically its $\mathbf{F_{cu-7}}$, $\mathbf{F_{cu-28}}$, and $\mathbf{F_t}$, as shown in Figure 4. The results are shown in Table 3 and Figures 5,6.

a) Test setup for compressive strength

b) Test setup for Indirect tensile strength

Figure 4: Test specimen setup

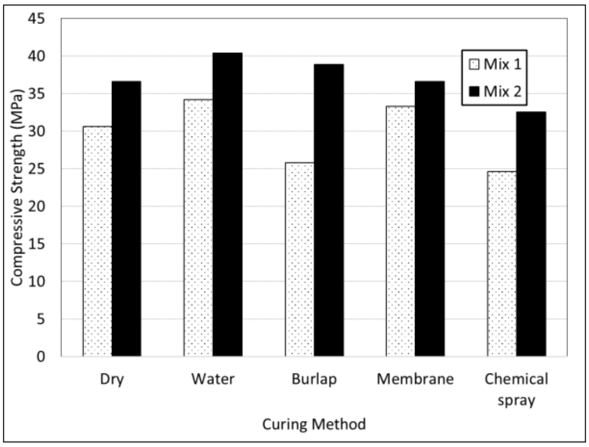
3.2.1 Compressive Strength

The concrete cube test's compressive strength offers insight into the entirety of concrete's properties. Through this singular examination, one may assess whether the concreting process has been executed correctly or not. A compressive strength test was conducted using typical concrete cubes measuring 150*150*150 mm at 7 and 28 days. The test results for F_{cu-7} and F_{cu-28} of different concrete are shown in Table 3. The values in the table represent the average of three cubes.

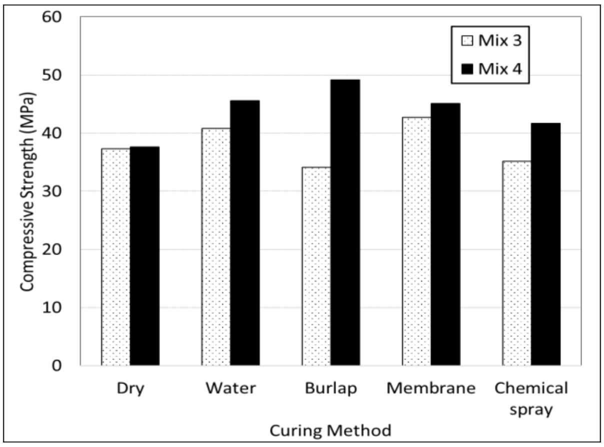
Table 3: Compressive Strength of Mixes Cured by Various Methods at Different Ages (MPa)

Curing Method	**Mix 1**		**Mix 2**		**Mix 3**		**Mix4**	
	7	**28**	**7**	**28**	**7**	**28**	**7**	**28**
Dry	17.7	30.6	27	36.6	24.8	37.3	26.5	37.6
Water	23.7	34.2	31.5	40.4	30.5	40.8	38.2	45.6
Burlap	22.9	25.8	31.7	38.9	26	34.1	31.7	49.2
Membrane	21.6	33.3	26.8	36.6	21.6	42.7	38.1	45.1
Chemical spray	21.5	24.6	30.5	32.5	26.5	35.2	31.8	41.7

For concrete mixes containing 350 Kg/m^3 of cement, with or without the addition of superplasticizer (Mix 2 and Mix 1), as depicted in Fig. 5-a, it is obvious that the F_{cu-28} of the concrete mix cured at room temperature (air-dry) decreased by 10%, compared to the control concrete mix cured in water. The mixture cured using burlap exhibits a reduction of 25% and 4% for concrete without and with SP, respectively, compared to a mixture cured in water. When chemical spray is used for curing, there is an average reduction of 25% compared to the mix cured in water. The mixture cured with plastic membrane sheets shows an average reduction of 6% compared to the mixture cured in water.



a) 350Kg/m^3



b) 450Kg/m^3

Figure 5: Compressive Strength for Concrete Mixes Cured in Various Methods at 28 days

For concrete mixes containing 450 Kg/m^3 of cement, with or without the addition of superplasticizer (Mix 4 and Mix 3), as depicted in Fig. 4, $\mathbf{F_{cu\text{-}28}}$ when the specimens were cured at room temperature (air-dry), fell by 8% for mix 3 (without SP) and increased by 18% for mix 4 (with SP) compared to the control mix, which was cured in water. The concrete mixture cured using burlap exhibits a 17% decrease compared to the mix cured in water when no superplasticizer (SP) is used. When using a chemical spray for curing, there is an average reduction of 10% compared to curing with water. The concrete mixture cured using plastic membrane sheets exhibits a 5% reduction in strength compared to the mixture cured using water without SP.

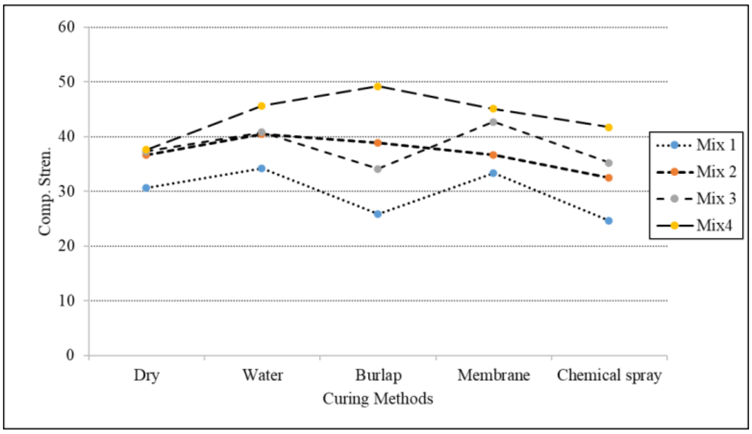


Figure 6: Compressive Strength for Concrete Mixes Cured in Various Methods at 28 days

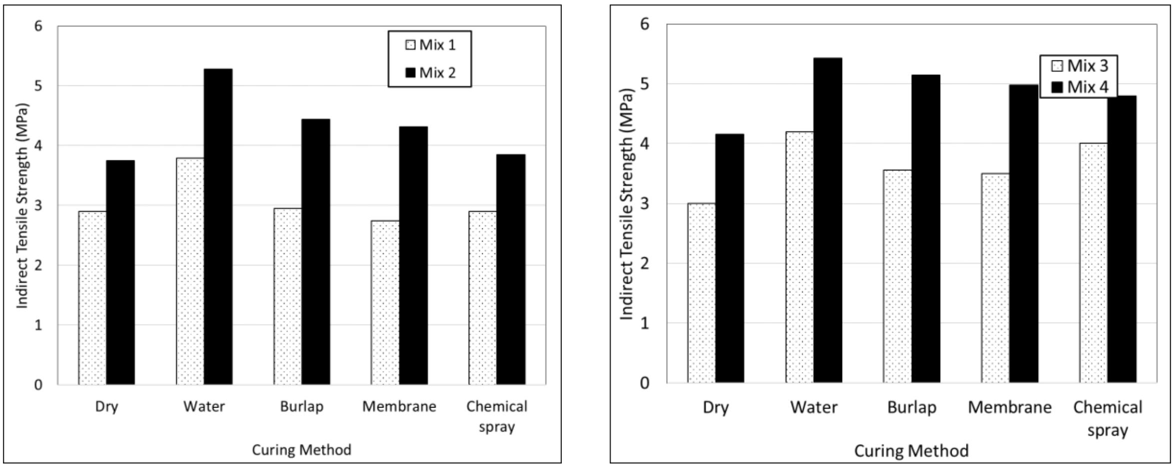
The $\mathbf{F_{cu\text{-}28}}$ for specimens cured by water rises by 19.3% when the cement content is increased by 100 kg/m^3 in mix 1 and mix 3. The addition of SP enhances the compressive strength by 17.5% and 12% for mix 2 and mix 4, respectively. The $\mathbf{F_{cu\text{-}28}}$, when cured in air-dry conditions, increases by 22% when the cement content is increased by 100 kg/m^3. Using plastic membrane sheets, burlap, and chemical spray during techniques resulted in a respective increase in $\mathbf{F_{cu\text{-}28}}$ of 28.2%, 32.2%, and 43.1%.

3.2.2 Indirect Tensile Strength

On a cylinder of standard concrete measuring 150 mm by 300 mm, the indirect tensile strength test was conducted after 28 days. Table 4 shows the average value of F_t for different concrete mixtures due to three cylinders.

Table 4: Indirect Tensile Strength of the Concrete Mixes Cured by Various Methods at 28 Days (MPa)

Curing Method	350 Kg/m³		450 Kg/m³	
	Mix 1	**Mix 2**	**Mix 3**	**Mix 4**
Dry	2.9	3.75	3.0	4.16
Water	3.79	5.28	4.2	5.43
Burlap	2.95	4.44	3.56	5.15
Membrane	2.74	4.31	3.5	4.98
Chemical spray	2.9	3.85	4.01	4.8



a) 350 Kg/m³ **b) 450 Kg/m³**

Figure 7: Indirect Tensile Strength for Concrete Mixes Cured in Various Methods at 28 Days

The $\mathbf{F_t}$ for specimens cured in water increases by 11% with the increase of cement content from 350 kg/m^3 (mix 1) to 450 kg/m^3 (mix 3). The addition of SP results in a 39.3% increase in $\mathbf{F_t}$ for mix 2 with a cement content of 350 kg/m^3 and a 29.3% increase for mix 4 with a cement content of 450 kg/m^3. In contrast, the specimens cured in air-dry conditions showed a minor rise in indirect tensile strength by 5% with the increase of cement content from 350 kg/m^3 (mix 1) to 450 kg/m^3 (mix 3). Using plastic membrane sheets, burlap, and chemical spray for curing resulted in a respective increase in indirect tensile strength of 27.7%, 20.7%, and 38.3%.

For concrete mixes containing 350 Kg/m^3 of cement, with or without the use of a superplasticizer (Mix 2 and Mix 1), As illustrated in Fig. 6-a, $\mathbf{F_t}$ of the concrete mix, cured at room temperature (air-dry), is reduced by an average of 26% compared to the control concrete mix, which was cured in water. The use of burlap, plastic membrane sheets, and chemical spray curing techniques for the mix increased indirect tensile strength by 50.5%, 57.3%, and 32.75%, respectively, compared to a mix that did not contain SP.

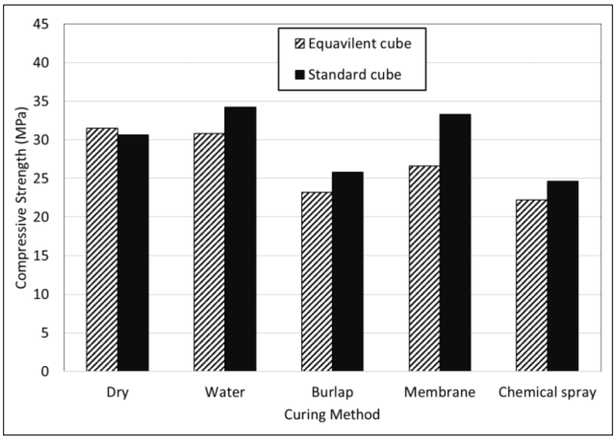
Figure.7-b demonstrates the indirect tensile strength of concrete mixes with a cement content of 450 Kg/m^3, both with and without the addition of superplasticizer (Mix 4 and Mix 3). It is observed that after curing at room temperature (air-dry), the concrete mix experienced a 25% decrease in $\mathbf{F_t}$ compared to the mix cured in water. The mixture, which was treated with burlap, plastic membrane sheets, and chemical spray, exhibited an increase of 44.6%, 42.3%, and 19.75%, respectively, in comparison to a mixture without the addition of SP.

3.2.3 Core test in slabs

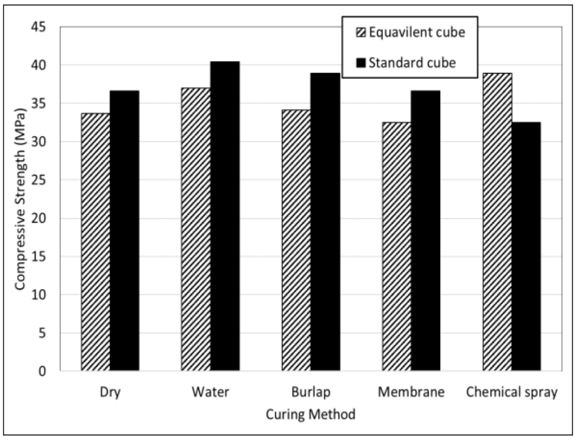
Concrete core testing was conducted on slabs to determine equivalent compressive strength and compare it with standard cube samples. Table 5 and Table 6 illustrate the results of the core test and equivalent cube compressive strength.

Table 5: Compressive Strength of Core and Equivalent Cube (350 Kg/m^3) Mixes Cured by Various Methods (MPa)

Mix ID	Mix 1			Mix 2		
Curing Method	Core Result	Equivalent cube	Standard cube	Core Result	Equivalent cube	Standard cube
Dry	25.08	31.5	30.6	33.1	33.7	36.6
Water	30.3	30.8	34.2	30.5	36.98	40.4
Burlap	22.8	23.2	25.8	29.6	34.1	38.9
Membrane	26.27	26.6	33.3	28.7	32.5	36.6
Chemical spray	21.8	22.2	24.6	33.9	38.9	32.5



a) Mix 1



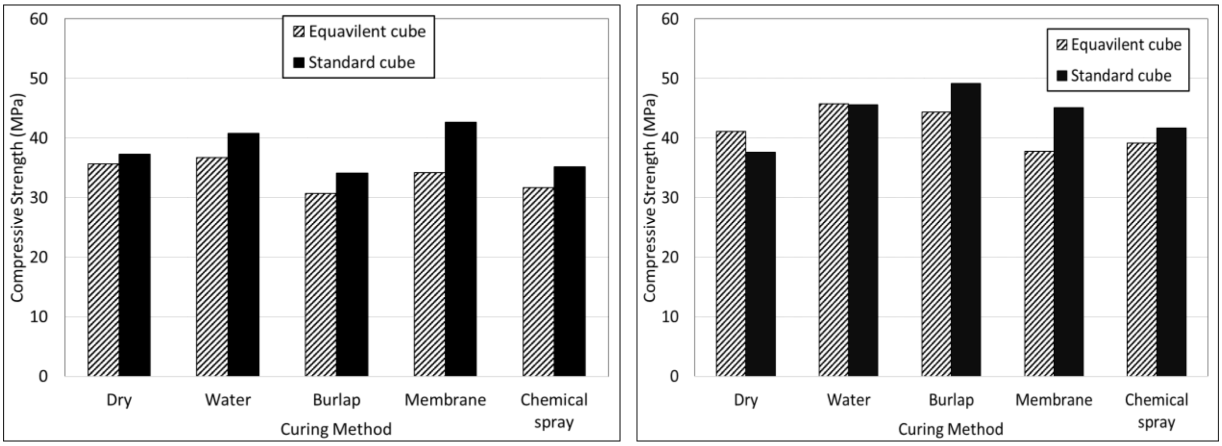
b) Mix 2

Figure 8: Comparision between Equavilat and Standard Cube Compressive Strength for 350 kg/m^3 Concrete Mixes Cured in Various Methods

For concrete mixes containing 350 Kg/m^3 of cement (Mix 1 and Mix 2), as depicted in Figure 6, it is shown that the equivalent strength of the cubes, based on the compressive strength obtained from core tests, reached 90% of the standard cube compressive strength when cured using different methods.

Table 6: Compressive Strength of Core and Equivalent Cube (450 Kg/m^3) Mixes Cured by Various Methods (MPa)

Mix ID	Mix 3			Mix 4		
Curing Method	Core Result	Equivalent cube	Standard cube	Core Result	Equivalent cube	Standard cube
Dry	36.8	35.7	37.3	40.4	41.1	37.6
Water	36.2	36.7	40.8	40.2	45.8	45.6
Burlap	30.2	30.7	34.1	39.8	44.4	49.2
Membrane	33.6	34.2	42.7	35.4	37.8	45.1
Chemical spray	31.2	31.7	35.2	35.5	39.2	41.7



a) Mix 3 **b) Mix 4**

Figure 7: Comparision between Equivalent and Standard Cube Compressive Strength for 450 kg/m^3 Concrete Mixes Cured in Various Methods

For Mix 3 and Mix 4, having a cement content of 450 Kg/m^3, as illustrated in Figure 7, it is observed that the equivalent cube strength, determined through core test compressive strength, reached 90% of the standard cube compressive strength when cured in water, burlap, and chemical spray. However, when cured with a membrane, the equivalent strength only reached 80%.

4. CONCLUSIONS

Following are the main findings derived from the experimental research conducted.

- Water curing of concrete is essential as it allows the concrete to reach the optimum compressive strength by being fully saturated with the byproducts of cement hydration.
- The $\mathbf{F_{cu\text{-}28}}$ of the concrete mix, cured at room temperature, exhibited a 10% decrease and an 18% increase when SP was added, as compared to the mix cured in water.
- The burlap and plastic membrane sheets curing method results in a 20% and 6% reduction in compressive strength for concrete without using SP respectively and a 4% reduction for concrete with SP, compared to water curing.
- Increasing cement content by 100 kg/m^3 (350 Kg/m^3 to 450 Kg/m^3) increases the $\mathbf{F_{cu\text{-}28}}$ cured in air-dry by 22%. Plastic membrane sheets, burlap, and chemical spray methods increased compressive strength by 28.2%, 32.2%, and 43.1%, respectively.
- Increasing 100 kg/m^3 of cement (350 Kg/m^3 to 450 Kg/m^3) raises $\mathbf{F_t}$ The use of plastic membrane sheets, burlap, and chemical spray methods resulted in a corresponding increase in indirect tensile strength of 27.7%, 20.7%, and 38.3%.
- Adding SP increases the F_t of concrete mix cured using burlap and plastic membrane sheets, chemical spray methods by 50%, 57.3% and 25%, respectively, compared with a mix without SP.
- The concrete elements reached 90% of the standard cube $\mathbf{F_{cu\text{-}28}}$ when cured in water, burlap, and chemical spray and only 80% when cured by a membrane.
- According of the research results, it is recommended to study other engineering properties such as creep and durability under the influence of different curing methods , as well as to study the effect of curing methods on the late ages of concrete and to study new curing methods that achieve sustainability and protect natural resources.

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