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EFFECTS OF CURING TIME ON COMPRESSIVE STRENGTH OF CONCRETE

Kencho Yonten[1], Nima Wangzom[2], Pema Delkar[3], Tashi Norbu[4], Lobzang Dorji[5]

Department of Civil Engineering & Surveying, Jigme Namgyel Engineering College, Dewathang.

jnec05190092@jnec.edu.bt[1], jnec05190111@jnec.edu.bt[2], jnec05190117@jnec.edu.bt[3], jnec05190157@jnec.edu.bt[4], lobzangddorji@gmail.com[5]

Abstract— The effects of curing time on the strength of M20 concrete grade is investigated in this study. The compressive strength development for non-cured cubes, curing period of 7, 14, 21, and 28 days under room temperature using Portland Pozzolana Cement (PPC) has been investigated. From the experimental observation, it is found that in general, the compressive strength increases with age of concrete irrespective of the curing and its duration. The test results shows that 7 days continuous curing cubes achieved 19.04 N/mm^2 (96 %) of the target strength at end of 15 days. It is obvious that it will achieve its target strength at the end of 28 days. The compressive strength of 14 days continuous curing cubes achieved 20.89 N/mm^2 at end of 22 days. The variation in compressive strength of concrete after 21 days of continuous curing doesn't affects much in achieving its target strength. The minimum of 7 days of continuous curing duration is necessary to gain its target strength of Portland Pozzolana Cement (PPC) concrete works. At the early ages as well as at later ages, it is essential have adequate curing for the development of strength for PCC concrete. It is also observed that under the draying ambient conditions, potential development of strength is reduced for PPC concrete.

Keywords—Curing, Non-curing, Compressive Strength, Concrete

1. INTRODUCTION

Curing of concrete plays a major role in developing the micro-structure and pore structure of concrete. Curing of concrete means maintaining moisture inside the body of concrete during the early ages and beyond in order to develop the desired properties in terms of strength and durability. Ponding method of curing was recommended to be the best of all the curing methods as it produced the highest level in compressive strength and cube densities [1]. The effect of Curing delay on concrete in hot weather where they found that properly cured concrete can have significantly superior properties compared to concrete left to set after finishing. Improperly cured concrete can be subjected to plastic shrinkage cracking, loss of moisture from fresh concrete and drying shrinkage which loss of moisture from concrete that has set among other undesired side effects [2].

Impact of curing on strength of concrete demonstrates that the method and duration of curing to a great extent affects the strength of concrete [3]. Different water sources have different levels of impurities and these generally have significant impact on the strength of concrete [4]. The highest compressive strength was achieved in samples that were cured for three days under water, then left to air-dry for 25 days, compared to samples cured using chemical compounds or samples continuously cured under water for 28 days [5].

Concrete gains strength with time after casting as concrete gains its strength rapidly in the initial days after casting. The minimum of 28 days of curing has to be done for the plain concrete under a fine atmosphere in order to gain desire strength [6],[7]. Excessive curing time may lead to the escalation of the construction cost of the project and unnecessary delays [8]. Due to inadequate curing, concrete develops shrinkage cracks, thermal cracks, along with a considerable loss in the strength of the surface layer. The curing of concrete helps in strength development on the surface of the structural member rather than the inner part. The main aim of this paper is to examine the effects of curing time on compressive strength of cement concrete and the variation of strength with respect to time after curing.

2. METHODOLOGY

2.1. Materials and Methods

This study represents a general scenario of the effect curing on compressive strength of M20 concrete were made with PCC and other locally available materials such as coarse aggregates and fine aggregates. All other parameters were kept constant and curing time was varying from 7 days, 14 days, 21 days and 28 days. The testing of the specimens was done after one day, 4 days, and 8 days after the continuous curing for 7 days, 14 days, 21 days and 28 days respectively.

2.2. Preparation of test specimen

The specimen was prepared for M20 grade of concrete with the standard mix ratio (1: 1.5: 3). The required water cement ratio is 0.55 and then the water is added until the concrete becomes homogenous and of desired consistency. The steel molds of 150x150x150mm sizes were filled with concrete in layers. Each layer is compacted by tamping not less than 35 strokes with the tamping rod. The tamping rod should enter the previous layer while tamping the subsequent layer. The total of 54 specimens were casted out of which 9 specimens were left uncured. After that, leaving the molded concrete specimens in place of hardening for a period of 24 hrs., and then de-molded.

2.3. Curing of specimens

A curing tank was constructed for curing the concrete specimens properly. The temperature of the curing water varies from 20 to 25° C. The concrete specimens were cured for 7 days, 14 days, 21 days and 28 days respectively. After that, the specimens were kept in air until testing. One set of concrete were left uncured (Air curing).

2.4. Testing of specimens

The effects of curing on compressive strength of concrete with age of concrete is determined in accordance with IS-516 (1959). The compressive strength is one of the most important and useful properties of concrete. It usually gives an overall picture of the quality of concrete because it is directly related to the structure of the hardened cement paste. The compressive strength test of moist cured concrete specimens was conducted after removal of moist storage. The compressive strength of concrete cubes was tested under compressive testing machine (CTM) after one day, four days and 8 days after the 7 days, 14 days, 21 days and 28 days of curing respectively.

Figure 1: Compressive testing machine (CTM)

3. RESULTS AND DISCUSSION

Compressive of strength of a cured as well as non-cured cubes increases with respect to time but compressive strength of cured cubes is comparatively higher than non-cured cubes. Moreover, strength of cured cubes is achieved as per the desired standard compressive strength of M20 concrete grade. Concrete gain its strength at higher rate in early phase and slow in later phase. Normally concrete can be cure at least for 7 days since it gains its desired strength after concrete if done air curing.

Table 1: Results for full time air curing (Non-Curing)

Full time air curing (non-curing)				
Mode of curing	**Curing time (Days)**	**Load (kN)**	**Compressive strength (N/mm^2)**	**Average compressive strength (N/mm^2)**
Full time air curing	7	110	4.89	6.37
		190	8.44	
		130	5.78	
	14	290	12.89	11.11
		220	9.78	
		240	10.67	
	28	370	16.44	15.70
		340	15.11	
		350	15.56	

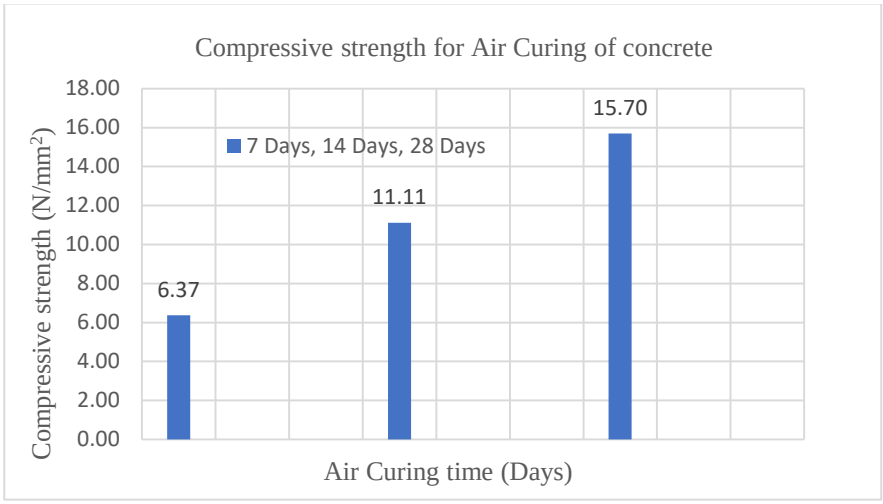

Figure 2: Compressive strength for air curing (non-curing)

The figure 1 shows the compressive strength of the concrete of M20 grade where the curing is not done. The cubes were kept in the room temperature and compressive strength test was done after 7 days, 14 days, and 28 days. The result shows for 7 days about 30% percent of the targeted compressive strength was gained and 14 days period the strength gain by the concrete was about 55.55 % percent of the targeted strength and for 28 days the strength gain was about 78.5 %.

The result obtained is the compressive strength gain by the concrete after full time water curing for 7 days, 14 days, 21 days and 28 days as shown in table 2. The strength gain at 7 days full time water curing is 10.81 N/mm^2 and 15.41 N/mm^2 after 14 days. The strength gain was rapid in the early two weeks and the rate lowers as in later weeks as 98.15% and 98.5% was achieved which is 19.63 N/mm^2 and 19.7 N/mm^2 for 21 days and 28 days full time water curing.

Table 2: Compressive strength of cured concrete and standard

No. of days of Full time Curing	**Compressive Strength (N/mm^2)**	**Standard Strength, (%)**	**Standard Compressive Strength (N/mm^2)**
7	10.81	65%	13
14	15.41	90%	18
21	19.63	99%	19.8
28	19.7	99.90%	19.98

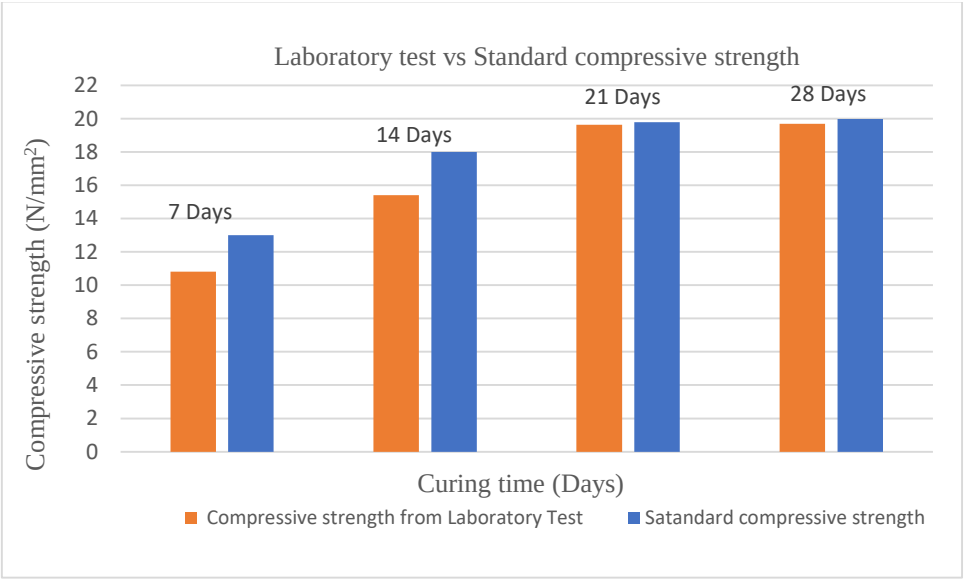

Figure 3: Comparison of compressive strength of cured cubes and standard

The figure 3 shows the comparison of compressive strength of concrete obtained after fulltime curing and the standard compressive strength of M20 grade of concrete. In the initial phase, it is observed that there exists comparable difference with almost 10.95% for 7 days full time curing and 12.95% for 14 days curing time. However, in the later phase, after 21 days, the differences observed is minimal as shown in figure 3.

Table 3: Compressive strength of cured concrete vs Air curing (Non-Curing)

No. of days of Full Air Curing (Non-Curing)	**Compressive Strength (N/mm^2)**	**No. of days of Full time Curing**	**Compressive Strength (N/mm^2)**	**% Difference**
7	6.37	7	10.81	41.07
14	11.11	14	15.41	27.90
21	14.5	21	19.63	26.13
28	15.7	28	19.7	20.30

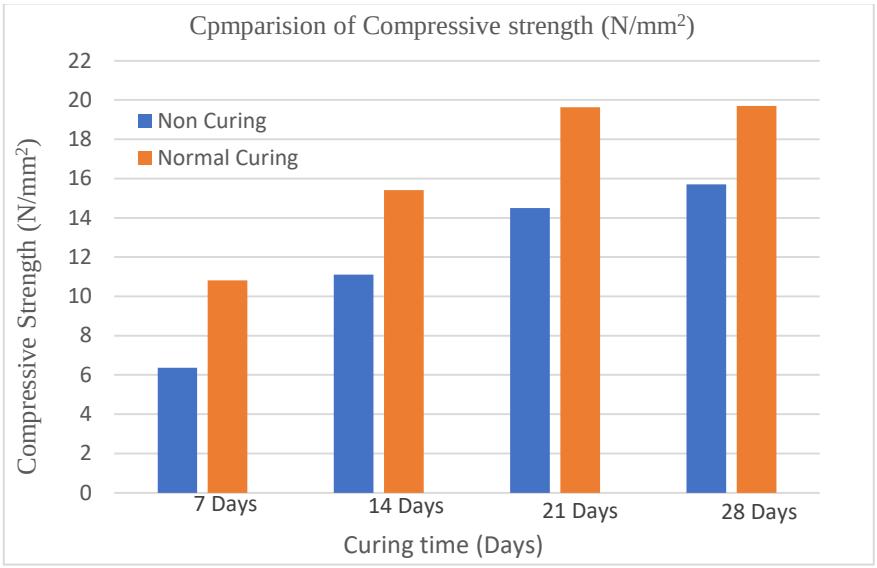

Figure 4: Comparison of compressive strength of cured and non-cured cubes

The comparison between the compressive strength of the concrete between full time cured and non-cured cubes is shown in figure 4. It is observed that the compressive strength increases for both the cases as the number of days also increases but the strength gained by the non-curing cubes are comparatively less compare to the cured ones. The result shows the variation of strength is higher at the initial stage of concrete where at 7 days, 14 days, 21 days and 28 days the variations are 41.07 %, 27.9% 26.13% and 20.3% respectively as shown in table 3. It is also observed that the concrete gains strength even if it left uncured, however it doesn't meet the target strength as the IS code standard. At the end of 28 days, the strength gain is only 15.7 N/mm2 which is 78.5 % of target strength for uncured cubes.

Table 4: Compressive strength of cured concrete vs Air curing vs Sstandard Values

No. of days of Full Air Curing (Non-Curing)	**Compressive Strength, N/mm2**	**No. of days of Full Curing**	**Compressive Strength, N/mm2**	**Standard Compressive Strength, N/mm2**
7	6.37	7	10.81	13
14	11.11	14	15.41	18
21	14.5	21	19.63	19.8
28	15.7	28	19.7	19.98

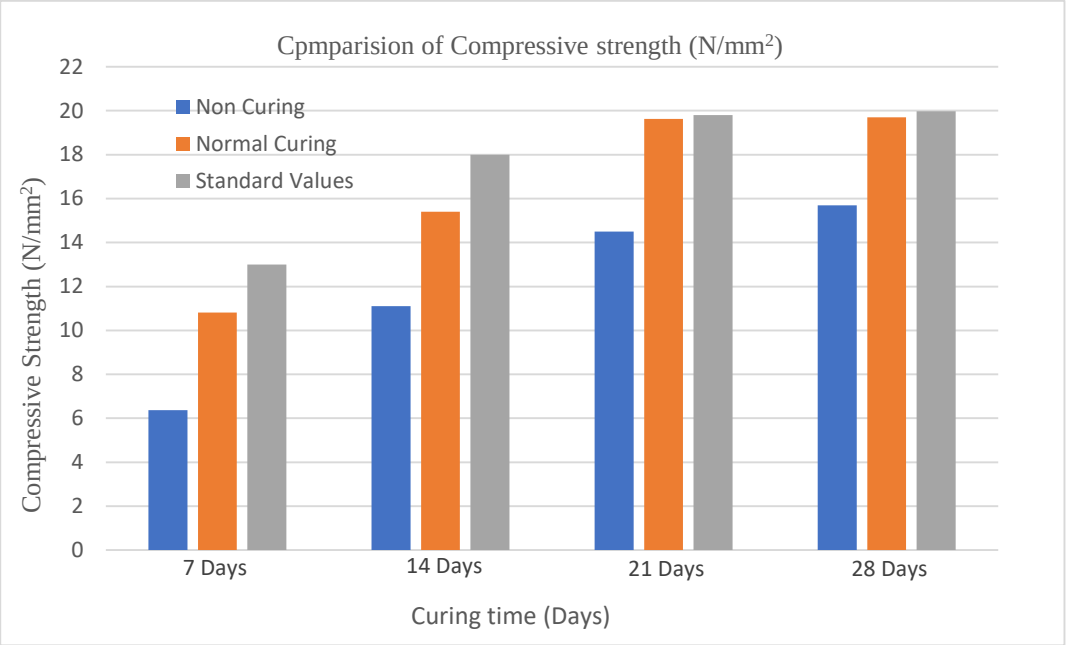

Figure 4: Comparison of compressive strength of cured vs non-cured vs Standard Values

The figure 4 shows the comparison of compressive strength of non-curing, curing and the standard strength of the concrete of M20 grade of concrete. Comparing the strengths though non-curing cubes also gains its compressive strength but comparatively low as compared to the standard strength. The concrete cubes with full time water cured for 7 days and 14 days also gives lower results at the initial strength, however, at later stages, it is observed that the strength achieves its target strength as that of the standard one as shown in table 4. It clearly reveals that the curing effects the strength of concrete with age of concrete.

Table 5: Full water curing for 7 days

Full time Water Curing for 7 days

Mode of curing	No. of days after curing for 7 days	Load (kN)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
Full time water curing for 7 days	8 (1 day)	230	10.22	10.81
		210	9.33	
		290	12.89	
	11 (4 days)	320	14.22	11.70
		240	10.67	
		230	10.22	
	15 (8 Days)	430	19.11	19.04
		460	20.44	
		395	17.56	

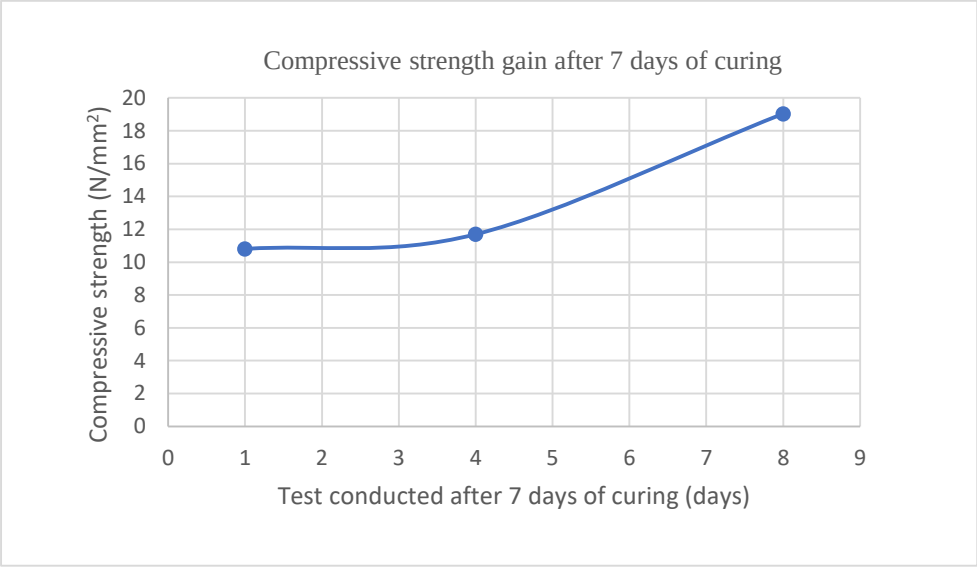

Figure 5: Compressive strength of concrete after 7 days of curing

The specimens were cured for 7 days fulltime curing and the test was carried out on 8th day, 11th day and 15th day after the casting of cubes as shown in table 5. This means keeping the specimen one day, four days and 8 days of air curing after 7 days of complete water curing. On the 8th day of concrete age, the strength is 10.81 N/mm^2. The compressive strength of concrete is 11.7 N/mm^2 and 19.04 N/mm^2 respectively on 11th and 15th days of concrete age. From figure 5, it shows that the strength of the concrete increases at higher rate with age of concrete and achieves 95.2 % of its desired strength for M20 at the end of 15th days after casting.

Table 6: Full water curing for 14 days

Full time Water Curing for 14 days

Mode of curing	No. of days after curing for 14 days	Load (kN)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
Full time water curing for 14 days	15 (1 day)	375	16.67	15.41
		270	12.00	
		395	17.56	
	18 (4 days)	390	17.33	16.30
		350	15.56	
		360	16.00	
	22 (8 Days)	450	20.00	20.89
		490	21.78	
		470	20.89	

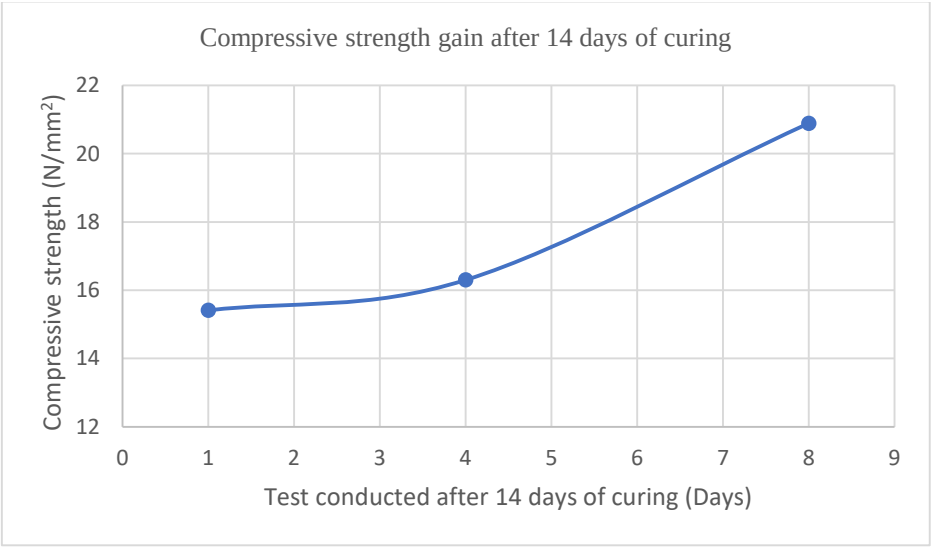

Figure 6: Compressive strength of concrete after 14 days of curing

The specimens were cured for 14 days fulltime curing and the test was carried out on 15th day, 18th day and 22nd day after the casting of cubes as shown in table 6. This means keeping the specimen one day, four days and 8 days of air curing after 14 days of complete water curing. On the 15th day of concrete age, the strength is 15.41 N/mm^2. The compressive strength of concrete is 16.3 N/mm^2 and 20.89 N/mm^2 respectively on 15th and 22nd days of concrete age. From figure 6, it shows that the strength of the concrete increases at higher rate at initial days with age of concrete and achieves more than 100 % of its desired strength for M20 at the end of 22nd days after casting.

Table 7: Full water curing for 21days

Full time Water Curing for 21 days

Mode of curing	No. of days after curing for 21 days	Load (kN)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
Full time water curing for 21 days	22 (1 day)	450	20.00	19.63
		400	17.78	
		475	21.11	
	25 (4 days)	475	21.11	20.81
		460	20.44	
		470	20.89	
	29 (8 Days)	515	22.89	21.85
		410	18.22	
		550	24.44	

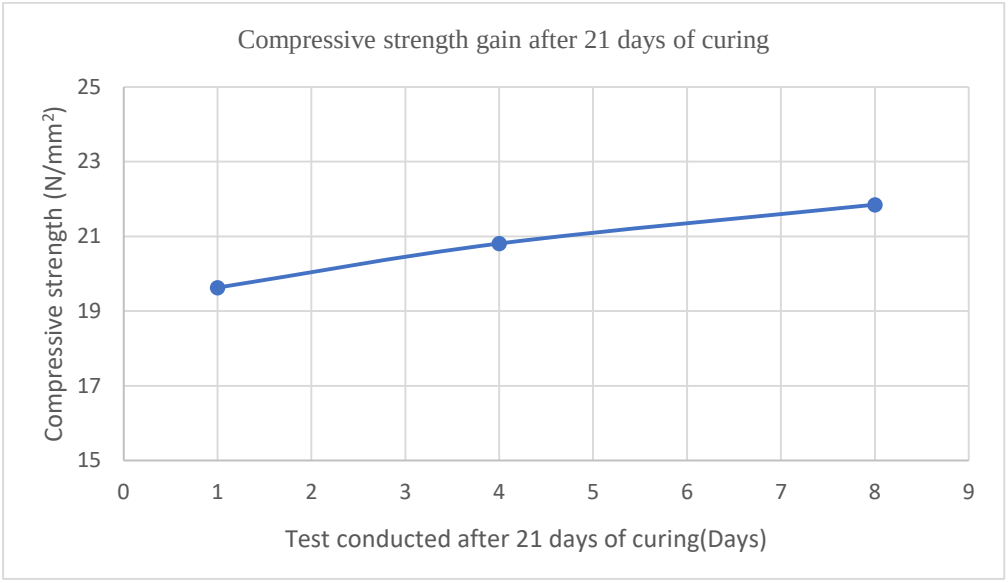

Figure 7: Compressive strength of concrete after 21 days of curing

The specimens were cured for 21 days fulltime curing and the test was carried out on 22nd day, 25th day and 29th day after the casting of cubes as shown in table 7. This means keeping the specimen one day, four days and 8 days of air curing after 21 days of complete water curing. On the 22nd day of concrete age, the strength is 19.63 N/mm^2. The compressive strength of concrete is 20.81 N/mm^2 and 21.85 N/mm^2 respectively on 25th and 29th days of concrete age. From figure 7, it shows that the strength of the concrete increases with age of concrete at constant rate and achieves more than 100 % of its desired strength for M20 grade starting from 25th days after casting.

Table 8: Full water curing for 28days

Full time Water Curing for 28 days

Mode of curing	No. of days after curing for 21 days	Load (kN)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
Full time water curing for 28 days	29 (1 day)	450	20.00	19.70
		480	21.33	
		400	17.78	
	32 (4 days)	500	22.22	21.70
		475	21.11	
		490	21.78	
	36 (8 Days)	540	24.00	23.11
		550	24.44	
		470	20.89	

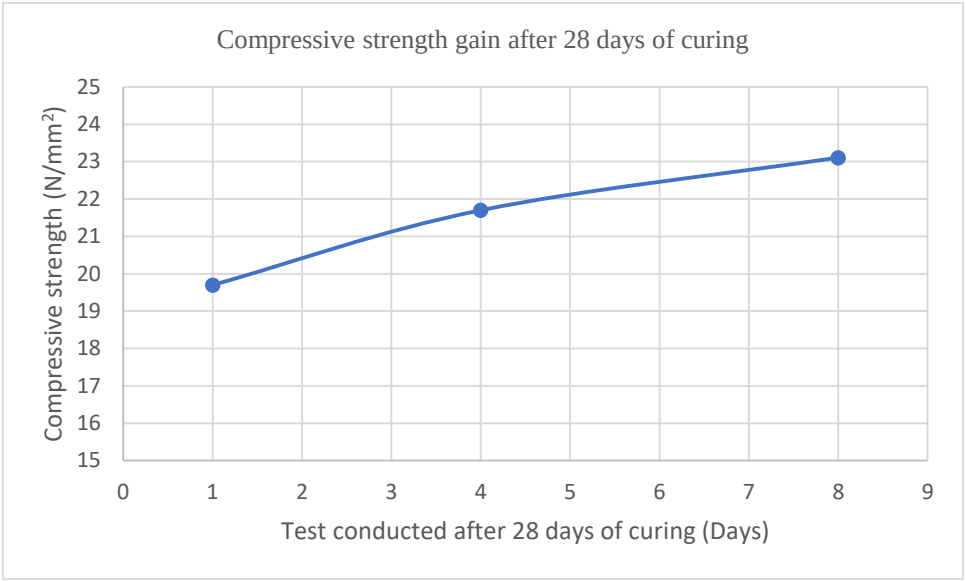

Figure 8: Compressive strength of concrete after 28 days of curing

The specimens were cured for 28 days fulltime curing and the test was carried out on 29th day, 32nd day and 36th day after the casting of cubes as shown in table 8. This means keeping the specimen one day, four days and 8 days of air curing after 28 days of complete water curing. On the 29th day of concrete age, the strength is 19.7 N/mm^2. The compressive strength of concrete is 21.7 N/mm^2 and 23.11 N/mm^2 respectively on 32nd and 36th days of concrete age. From figure 8, it shows that the strength of the concrete increases with age of concrete at constant rate and achieves 98.5 % of its desired strength for M20 grade. It is also observed that the strength of concrete keeps increasing even after 30 days of age.

Table 9: Variation of compressive strength after curing

Test conducted after curing (days)	7 Days Curing			14 Days curing			21 Days curing			28 days of curing		
	Compressive strength (N/mm^2)	Increment	Increase in %	Compressive strength (N/mm2)	Increment	Increase in %	Compressive strength (N/mm2)	Increment	Increase in %	Compressive strength (N/mm2)	Increment	Increase in %
1	10.81			15.41			19.63			19.7		
4	11.7	0.89	8.23	16.3	0.89	5.78	20.81	1.18	6.01	21.7	2	10.15
8	19.04	7.34	62.74	20.89	4.59	28.16	21.85	1.04	5.00	23.11	1.41	6.50

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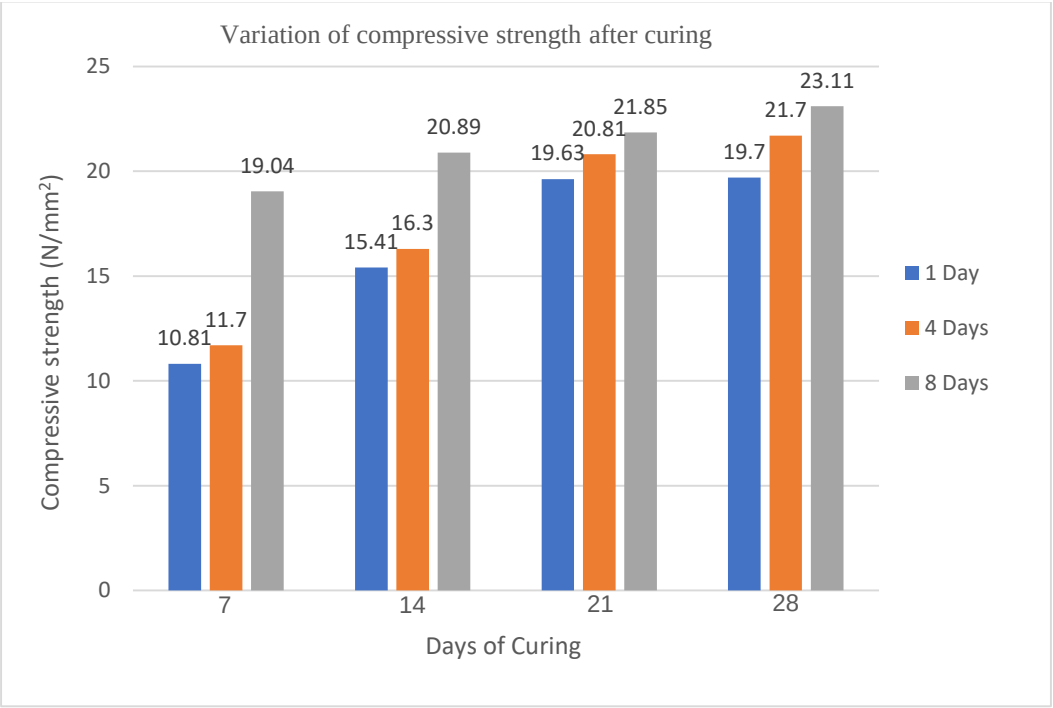

Figure 9: Variation of compressive strength after curing

The variation of compressive strength of concrete after different period of curing duration is shown in the table 9. The specimens are tested after one day, four days and 8 days for every 7 days, 14 days, 21 days and 28 days of curing duration respectively. The age of concrete is kept constant while testing the specimens irrespective of curing duration. From the figure 9, it is observed that when the specimens are cured for 7 days, the test result for first day is 10.81 N/mm^2. The test results for 4th and 8th days of age of concrete strength is 11.7 N/mm^2 and 19.04 N/mm^2. For the specimens which was cured for 14 days, the test result for first day in 15.14 N/mm^2. The test results are 16.3 N/mm^2 and 20.89 N/mm^2 for four and eight days respectively. It is observed that the strength variation of first one day and four days for both curing time for 7 and 14 days are minimal as shown in figure 9. The test results for the 8th days shows the variation in strength is high as 62.74% for 7 days curing and 28.16 % for 14 days curing. It is observed that when the specimens are cured for 21 days and 28 days, the variation of strength after curing is very minimal. It ranges from 19.63 N/mm^2 to 23.11 N/mm^2 for the first 8 days. However, it is observed that the strength increases steadily with time irrespective of curing curation.

4. CONCLUSION

This study was investigated the effect of curing on compressive strength of concrete cubes in terms of different curing duration and with uncured cubes. In general, it is observed that, the compressive strength increases with age of concrete irrespective of the curing and its duration. From this research study, following conclusions are drawn:

- The compressive strength for non-cured cubes achieved only 15.7 N/mm^2 (78.5 %) of the target strength at end of 28 days. This reveals the curing is necessary for the concrete to achieve the target strength.
- The compressive strength of 7 days continuous curing cubes achieved only 19.04 N/mm^2 (96 %) of the target strength at end of 15 days. It is obvious that it will achieve its target strength at the end of 28 days.
- The compressive strength of 14 days continuous curing cubes achieved 20.89 N/mm^2 at end of 22 days, which reveals that the standard target is achieves only after 8 days of air curing.
- The compressive strength of 21 days continuous curing cubes achieved 21.81 N/mm^2 at end of 25 days. The air curing of 4 days is required to achieve it standard target.
- The compressive strength of 28 days continuous curing cubes achieved 21.7 N/mm^2 at end of 32 days. The air curing of 4 days is required to achieve it standard target.
- The variation in compressive strength of concrete after 21 days of continuous curing doesn't affects much in achieving its target strength according to this research finding.
- The minimum of 7 days of continuous curing duration is necessary to gain its target strength Portland Pozzolana Cement (PPC) concrete works.
- Adequate curing at early ages as well as at later ages is essential in the strength development of PCC concrete. It can be concluded that drying ambient conditions reduce the development of strength of PCC concrete.

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