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Research Paper

PREDICTIVE MODEL OF COMPRESSIVE STRENGTH FOR CONCRETE IN-SITU

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It is imperative to know the rate at which the concrete *in-situ* with given concrete mix design would gain strength. Above information is useful to develop a mathematical model which can immediately predict the value of compressive strength of concrete *in-situ*. It is required for following reasons: (i) conventionally the concrete achieves 90% of its targeted compressive strength in 28 days of curing at site. If strength is checked only after 28 days and found weak then structure might fail due to poor mix design. It would cause major financial losses as well hurt the workers responsible to dismantle the form works. (ii) It would be more useful if the results of test cubes can be known within few hours after they have been cast. The cubes are cured with wet gunny bags for 23 hours and then placed in a tub of boiling water at 100^{0}C temperature for 3½hours±5mins[8], before they are tested in compressive testing machine. The other cubes are immersed in water bath at room temperature for 28 days. After 3 days three cubes are taken out and placed in boiling water tub at 100^{0}C for 3½hours±5mins before testing for compressive strength. The remaining cubes were immersed in water at room temperature 27^{0}C , and are tested after 7 and 28 days for their compressive strength. In this paper a study is made to compare compressive strength of cubes by normal as well as accelerated curing and mathematical model is developed from compressive strength observed for 28 days.

Keywords: Compressive strength of Concrete, Similitude model analysis, Compressive strength tests, accelerated curing, normal curing

INTRODUCTION

Evaluation of compressive strength of concrete is of great interest, whether to detect altered areas or to control the concrete quality and estimate it (Breysse D, 2009). The standard methods used to assess the quality of concrete in structures from specimens can have disadvantages: (i) the results are not immediately known, (ii) the number of specimens or samples may be insufficient for an economic reason, and (iii) may not reflect the reality of the structure (International Atomic Energy Agency, 2001). The nondestructive testing method of concrete has advantage that: (i) it avoids damage on the performance of building structural components, (ii) the

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method is simple, quick and test results are available on site.

Concrete strength testing in structures, demand that the cores should not be drilled where the use of less expensive equipment is required (Hobbs B and Tchoketch K, 2007). Several nondestructive evaluation methods have been developed; based on the fact that some physical properties of concrete can be related to the compressive strength of concrete. The Schmidt rebound hammer (SRH) and the ultrasonic pulse velocity (UPV) tests, are combined to develop correlation between hammer/ultrasonic pulse velocity readings and the compressive strength of the concrete. These non-destructive measurements have proved to be an effective tool for inspection of concrete quality. The nondestructive testing of concrete has a great technical and useful importance. These techniques have been grown during recent years especially in the case of construction assessment. All available methods for evaluating *in-situ* concrete are limited, their reliability is often questioned, and the combination of two or more techniques is emerging as an answer to all these problems (Bungey J H and Millard S G, 1996). The combination of several techniques of nondestructive testing is often implemented empirically, combining two techniques most often used to enhance the reliability of the estimated compressive strength of concrete; the principle is based on correlations between observed measurements and the desired property (Breysse D, 2008). The objective of the combined tests is to evaluate the compressive strength of concrete *in situ*; the best approach is generally to develop a relationship or correlation between the UPV/ the index of rebound hammer and the compressive strength of standardized laboratory specimen, in some cases specimen are not available, then a number of cores must be taken to establish this relationship (Malhotra V M and Carino N J, 1991). The standardized combined method the most widely used is Son Reb method developed by RILEM (1983), established in Romania. The improvement in the reliability of the measures is explained by taking into account the contradictory effect of variable factors of some properties for each of the two techniques (ultrasonic pulse velocity/ rebound hammer). Above methods to evaluate the compressive strength of concrete *in-situ* needs knowledge and skills to use expensive equipment which may not be possible on every construction site. Therefore study is carried out to develop a mathematical predictive model.

EXPERIMENTAL SETUP AND OBSERVATION SCHEDULE

The test cubes of different mix design, for determining the compressive strength of concrete in lab have been casted as per schedule:

- First batch of 18 cubes for each of the grades: M20, M25, M30, have been casted in May 2013. The cement used was OPC-43 grade and coarse aggregate was lime stone ranging from 4.75mm to 20mm in size. All 18 cubes have been subject to normal curing method. It comprises: cover the concrete cubes with wet gunny bags for a day, and after that they are immersed in water tub upto 3 days before testing their compressive strength.
- 3 cubes of each mix were tested for compressive strength after 1 and 3 days in turn and average result of 3 cubes test is accepted as true compressive strength.

- Similar cube making and testing process is adopted for PPC and PSC cement.
- Second batch of 36 cubes for each of the grades: M20, M25, M30, have been casted in 3rd week of May 2013. The cement used was OPC-43 grade and coarse aggregate as lime stone. 18 cubes have been subject to accelerated curing method and remaining 18 cubes were cured in water tub at normal room temperature. The accelerated curing comprises: all 18 cubes are cured with wet gunny bags for 23 hours and then placed in a container having boiling water of 100^{0}C temperature for 3½ hours before they were tested. The other cubes were immersed in water bath at room temperature. After 3 days, three cubes are taken out and placed in boiling water tub at 100^{0}C for 3½ hours before testing. The remaining cubes immersed in water at room temperature are tested after 7 and 28 days for their compressive strength. This mode of curing helps in achieving higher compressive strength even on 1st day after the casting.

Figure 1: Concrete Test Cubes Casting and Compressive Testing Process

Figure 1a: Normal Curing (NC)

Figure 1b: Accelerated Curing (Boiling Water Curing) BWC

ANALYSIS OF RESULTS

Compressive Strength Test Results of 1st Batch of Cubes

Compressive strengths curve for mix M20 are shown in Table 3. Compressive strength gain in case of accelerated curing is initially very high in all types of cement and abruptly falls before achieving the uniform gain. Normal curing marked in red line is uniformly increasing. The advantage of accelerated curing is that the test can be conducted after few hours which will help in assessing the quality of work done.

Normal Curing VS Accelerated Curing for M20 mix, Lime Stone – Coarse Aggregate

Normal Curing Vs. Accelerated Curing for M25 mix, Limestone – Coarse Aggregate

The trend of results is similar to (4.3)

Normal Curing Vs. Accelerated Curing for M30 mix, Limestone – Coarse Aggregate

The trend of results is similar to (4.3).

Table 1: Observed Values of Compressive Strength

No.	Mix Grade	Mix Proportion	W/C Ratio
		Cement:Sand:C.A	
1	M20	1:1.756:3.061	0.5
2	M25	1:1.540:2.690	0.45
3	M30	1:1.460:2.550	0.43

COMPARISON WITH IS M-40 CONCRETE MIX (NORMAL CURING)

1st Batch May 2013 – Normal Curing for 1,3,7,28 Days Immersed in Water at Room temperature–Cement OPC-43 Grade Av. Compressive Strength Test After No. of Days Curing

No.	Mix Grade	1 day NC (N/mm^2)	3 day NC (N/mm^2)	7 day NC (N/mm^2)	28 day NC (N/mm^2)	Standard Value (N/mm^2)	Targeted Strength (N/mm^2)
1	M20	4.00	9.39	19.55	23.48	20	28.25
2	M25	5.17	11.78	20.07	28.74	25	33.25
3	M30	5.53	12.93	24.74	30.74	30	38.25

1st Batch May 2013 - Normal Curing for 1,3,7,28 Days Immersed in Water at Room Temperature - Cement PPC Av. Compressive Strength Test After No. of Days Curing

No.	Mix Grade	1 day NC (N/mm^2)	3 day NC (N/mm^2)	7 day NC (N/mm^2)	28 day NC (N/mm^2)	Standard Value (N/mm^2)	Targeted Strength (N/mm^2)
1	M20	3.80	9.18	16.74	22.88	20	28.25
2	M25	3.81	9.73	17.33	23.70	25	33.25
3	M30	5.10	13.30	22.96	31.70	30	38.25

1st Batch May 2013 - Normal Curing for 1,3,7,28 Days Immersed in Water at Room Temperature - Cement PSC Av. Strength Test After No. of Days Curing

No.	Mix Grade	1 day NC (N/mm^2)	3 day NC (N/mm^2)	7 day NC (N/mm^2)	28 day NC (N/mm^2)	Standard Value (N/mm^2)	Targeted Strength (N/mm^2)
1	M20	3.92	10.15	19.92	24.44	20	28.25
2	M25	3.93	10.62	19.25	25.33	25	33.25
3	M30	4.41	11.88	20.44	28.29	30	38.25

Table 2: Observed Values of Compressive Strength - Coarse Aggregate - Limestone 3rd Week May 2013 - Accelerated Curing for 3½ hrs. in Boiling Water - Cement OPC 43 Grade Av. Strength Test after No. of days Curing

No.	Mix Grade	23 hrs NC & 3½ h BWC (N/mm^2)	3 Days NC & 3½ h BWC (N/mm^2)	7 day NC (N/mm^2)	28 day NC (N/mm^2)	Standard Value (N/mm^2)	Targeted Strength (N/mm^2)
1	M20	4.00	9.39	19.55	23.48	20	28.25
2	M25	5.17	11.78	20.07	28.74	25	33.25
3	M30	5.53	12.93	24.74	30.74	30	38.25

3rd Week May 2013 - Accelerated Curing for 3½ hrs. in Boiling Water - Cement PPC Av. Strength Test after No. of Days Curing

No.	Mix Grade	23 hrs NC & 3½ h BWC (N/mm^2)	3 Days NC & 3½ h BWC (N/mm^2)	7 day NC (N/mm^2)	28 day NC (N/mm^2)	Standard Value (N/mm^2)	Targeted Strength (N/mm^2)
1	M20	12.74	10.22	16.74	22.88	20	28.25
2	M25	13,48	11.18	17.33	23.70	25	33.25
3	M30	17.18	14.44	22.96	31.70	30	38.25

3rd Week May 2013 - Accelerated Curing for 3½ hrs. in Boiling Water - Cement PSC Av. Strength Test After No. of Days Curing

No.	Mix Grade	23 hrs NC & 3½ h BWC (N/mm^2)	3 Days NC & 3½ h BWC (N/mm^2)	7 day NC (N/mm^2)	28 day NC (N/mm^2)	Standard Value (N/mm^2)	Targeted Strength (N/mm^2)
1	M20	11.70	11.48	19.92	24.44	20	28.25
2	M25	12.66	12.10	19.25	25.33	25	33.25
3	M30	14.29	13.03	20.44	28.29	30	38.25

Table 3: Compressive Strength Comparison of Mix M20

Mix Grade	1 Day	3 Days	7 Days	28 Days
Mn20-OPC	4.00	9.39	19.55	23.48
Ma20-OPC	19.25	18.17	19.55	23.48
Ma20-PPC	12.74	10.22	16.74	22.88
Ma20-PSC	11.7	11.48	19.92	24.44

Note: n - normal curing; a- accelerated curing.

Figure 2: Normal Curing Vs. Accelerated Curing M20 Mix

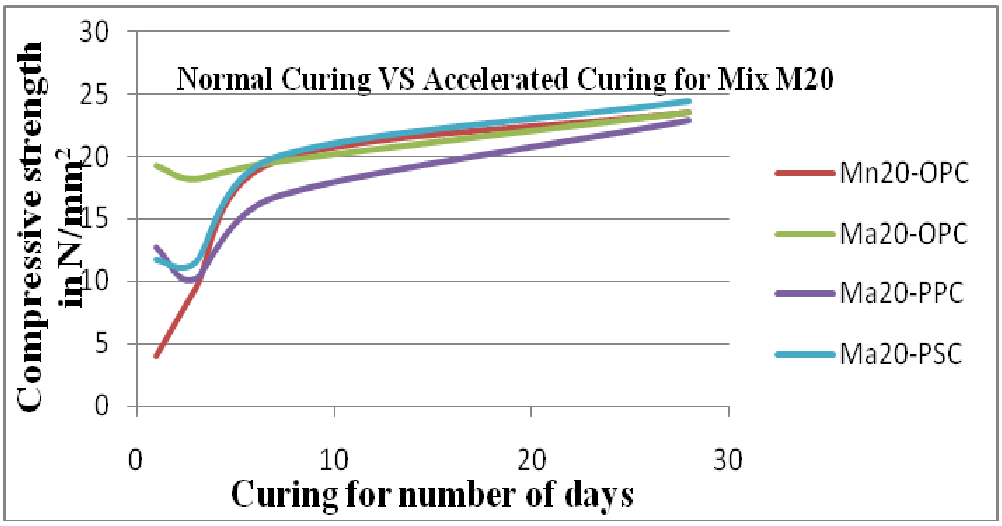
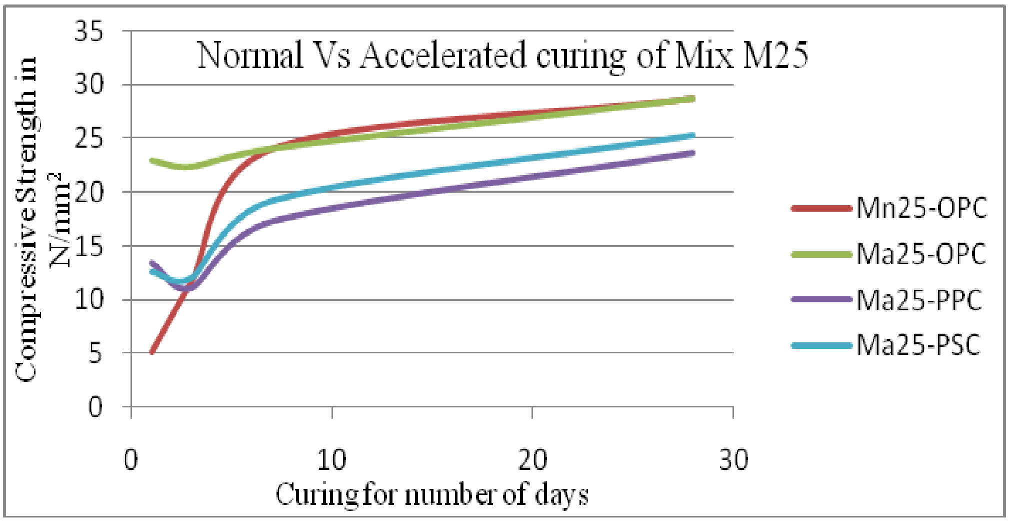


Table 4: Compressive Strength Comparison of Mix M25				
Mix Grade	**1 Day**	**3 Days**	**7 Days**	**28 Days**
Mn25-OPC	5.17	11.78	24.07	28.74
Ma25-OPC	22.96	22.37	24.07	28.74
Ma25-PPC	13.48	11.18	17.33	23.7
Ma25-PSC	12.66	12.10	19.25	25.33

Note: n - normal curing; a- accelerated curing.

Figure 3: Normal Curing Vs. Accelerated Curing M25 Mix



In order to compare results of normal curing cubes M20, M25, M30 etc. with IS M40 grade concrete standard values, the observed data is represented in Table 6. Compressive strengths obtained after 3, 7, 28 days are then plotted in Figure 5. It may be noted that the standard strength of concrete IS M40 can be achieved within 28 days of curing. The IS code M40 curve is shown in purple colour line. It is noticed from Figure 5 that gain in strength for 1st day in case of IS M40 is little higher to 1st day normal curing of other grades of cement and after wards it has gain similar to normal curing method. There is dynamic similarity about the gain of compressive strength among different grades of concrete and IS M40 mix, therefore a similitude model can be developed for making practical applications.

The compressive strength of concrete mix IS 40 with coarse aggregate as lime stone (20 mm size) is given in Table 6. Using these results, ideal curve equation can be determined to compute the compressive strength on particular day for concrete *in-situ* as explained below:

Predictive Model of Compressive Strength for Mix IS M40 Grade

The compressive strength of concrete mix IS 40 with coarse aggregate as lime stone (20 mm size) is given in Table 6. Using these results, ideal curve equation can be

Table 5: Normal Curing VS Accelerated Curing M30 Mix

Mix Grade	1 Day	3 Days	7 Days	28 Days
Mn30-OPC	5.53	12.93	24.74	30.74
Ma30-OPC	24.88	23.77	24.74	30.74
Ma30-PPC	17.18	14.44	22.96	31.70
Ma30-PSC	14.29	13.03	22.44	28.29

Note: n - normal curing; a- accelerated curing.

Figure 4: Normal Curing Vs Accelerated Curing M30 Mix

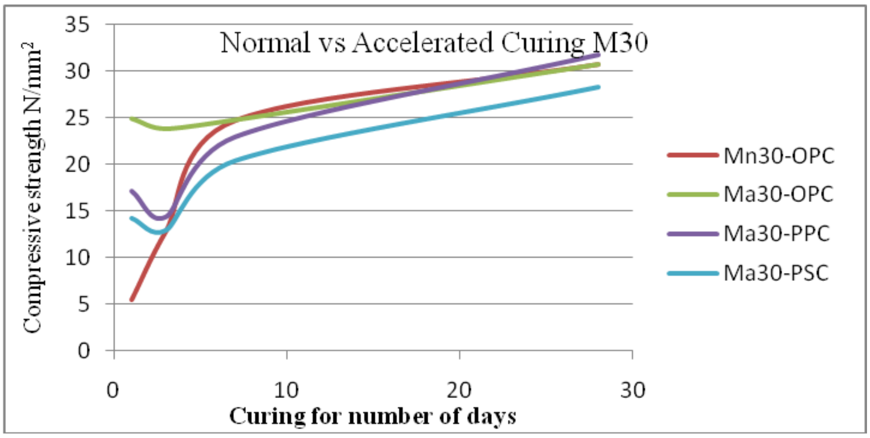
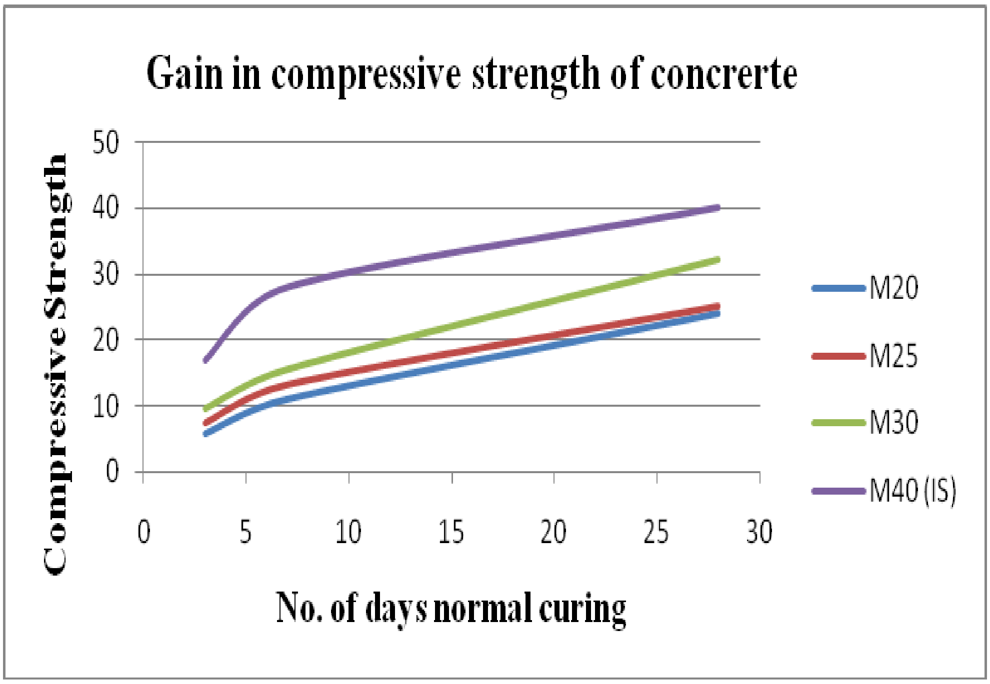


Table 6: Strength Test After No. of Days Normal Curing at Room Temperature

No.	Mix Grade	3 Days	7 Days	28 Days	Standard Value	Targeted Strength
1	M20	5.75	11	24	20	28.25
2	M25	7.50	13.25	25	25	33.25
3	M30	9.50	15.50	32.25	30	38.25
4	M40 (IS -code)	17.50	28.25	40	40	48.50

Figure 5: Dynamic gain in Compressive strength of different concrete mix



determined to compute the compressive strength on particular day for concrete *in-situ* as explained below:

Let the compressive strength gain be given by the equation:

$$y = a(b)^x \quad ...(13)$$

where y - Compressive Strength after particular number of days of curing

a - factor comprising parameters of different mix design of concrete say M40,

b - Coefficient of number of days the system is subject to curing, type of curing and different water cement ratio used in the mix.

x - Number of days the cubes are subject to curing

The parameters 'a' and 'b' can be determined by substituting the standard values in the equation (1).

Compressive Strength Curve					
Let the strength variation equation be: $y=ab^x$ Concrete					
Grade	Days	3		7	28
M40	Comp.N/mm2	17		28	40
Solution for a and b constants of the required equation					
No.	x	y	Y	x^2	xY
			$\log_{10}y$		
	3	17	1.23045	9	3.69135
	7	28	1.44716	49	10.1301
	28	40	1.60206	784	44.8577
	38	85	4.27967	842	58.68
Eqn.	3A+38B = 4.2797 ...(1)				
	38A+842B = 58.679 ...(2)				
On solving (1) & (2) A = 1.26957 Therefore a = 18.602					
B = 0.01239 and b = 1.0289					
and final equation is $y= 18.602(1.029)^x$					
Targeted strength 48.50 = 18.602(1.029)x					
Check for 1. strength after 14 days =27.757 Check for 2. strength after 28 days =41.418 Check for 3. targeted 48.50 N/mm^2 will be achieved after 33.50 days					

Predictive Model of Compressive Strength for Accelerated Curing

The compressive strength of concrete mix M30 with coarse aggregate as lime stone (20 mm size) is given in Table 2. Using these results, ideal curve equation can be determined to compute the compressive strength on particular day for concrete *in-situ* as explained below:

Let the compressive strength gain be given by the equation:

$$y = a(b)^x \qquad ...(1)$$

where y – Compressive Strength after particular number of days of curing

a - factor comprising parameters of different mix design of concrete

Compressive Strength Curve M30 Grade of concrete , Cement – OPC 43 Grade					
Let the strength variation equation be: $y=ab^x$ Concrete					
Grade	Days	1	3	7	28
M30	Comp.	24.88	23.77	24.74	30.74
Solution for a and b constants of the required equation					
No.	x	y	Y	x^2	xY
			$\log_{10}y$		
	1	24.88	1.39585	1	1.39585
	3	23.77	1.37603	9	4.12809
	7	24.74	1.3934	49	9.7538
	28	30.74	1.4877	784	41.6557
	39	104.13	5.65298	843	56.93
Eqn.	4A+39	B = 5.653			
	39A+843	B = 56.933			
On solving	A = 1.37497	Therefore	a = 23.712		
	B = 0.00393	and	b = 1.0091		
	and final equation is $y= 23.71(1.009)^x$				
Check for 1. strength after 1 day 23.927 Check for 2. strength after 28 days 30.542 Equation $y= 23.71(1.009)^x$ for accelerated curing system shows that:					

b - Coefficient of number of days the system is subject to curing, type of curing and different water cement ratio used in the mix

x - Number of days the cubes are subject curing in lab

The parameters ‘a’ and ‘b’ can be determined by substituting the standard values in the equation (1).

i. Accelerated curing gives initial higher values of compressive strength over normal curing method. The strength even on 1st day is about 75-80% of value obtainable after 28 days. Therefore it is useful in taking decision about the quality of concrete work well in advance.

OPC 43 Grade Cement					
M20 1 Day Acclerated curing BWC	19.25 N/mm^2	M25 1 Day Acclerated curing BWC	22.96 N/mm^2	M20 1 Day Acclerated curing BWC	24.88 N/mm^2
M20 28 Days Normal curing NC	23.48 N/mm^2	M25 28 Days Normal curing NC	28.74 N/mm^2	M30 28 Days Normal curing NC	30.74 N/mm^2
Note: Concrete of OPC Cement with different mix proportions and different water cement ratios, gains approx 80% of its 28 days strength by normal curing on 1st day by accelerated curing.					

PSC Cement					
M20 1 Day Acclerated curing BWC	11.70 N/mm^2	M25 1 Day Acclerated curing BWC	12.66 N/mm^2	M20 1 Day Acclerated curing BWC	14.29 N/mm^2
M20 28 Days Normal curing NC	24.44 N/mm^2	M25 28 Days Normal curing NC	25.33 N/mm^2	M30 28 Days Normal curing NC	28.29 N/mm^2
Note: Concrete of PSC Cement with different mix proportions and different water cement ratios, gains approx 55% of its 28 days strength by normal curing on 1st day by accelerated curing.					

PPC Cement					
M20 1 Day Acclerated curing BWC	12.74 N/mm^2	M25 1 Day Acclerated curing BWC	13.48 N/mm^2	M20 1 Day Acclerated curing BWC	17.18 N/mm^2
M20 28 Days Normal curing NC	22.88 N/mm^2	M25 28 Days Normal curing NC	23.70 N/mm^2	M30 28 Days Normal curing NC	31.70 N/mm^2
Note: Concrete of PPC Cement with different mix proportions and different water cement ratios, gains approx 50% of its 28 days strength by normal curing on 1st day by accelerated curing.					

CONCLUSION

1. From the experiment it has been observed that OPC concrete gains approx 80% of its 28 day strength on 1st day on accelerated curing ,similarly PSC concrete gains approx 55% of its 28 day strength on 1st day on accelerated curing, similarly PPC concrete gains approx 50% of its 28 day strength on 1st day on accelerated curing, with any type of concrete mix with different water cement ratios. This will help in predicting concrete compressive strength at early age i.e., on 1st day, that whether concrete mix is formed according to mix proportion according to design load as instructed by design engineer, or the contractor is to be instructed to change the quantity of ingredients that is being added, so that required compressive strength can be obtained after 28 days for a particular concrete mix .

2. Predicting compressive strength by accelerated curing is very simple process , so any lay man at the site can perform this process and can predict strength of concrete . As it does not requires much time and also all the instruments are very cheap , that can be available at any site . Also no skilled labour is required , only watch is to be kept on time while doing accelerated curing for 3½ hours boiling water curing. Also water temperature is to be maintained at 100^0C while boiling.

3. It is apparent from the tests that accelerated curing shows rapid strength gain in concrete in initial stages. Therefore accelerated curing technique is useful in the prefabrication industry, wherein high early age strength enables the removal of the formwork within 24 hours, thereby reducing the cycle time, resulting in cost-saving benefits. Early gain in strength can be explained due to heightened temperatures in boiling stage, the hydration process moves more rapidly and the formation of the Calcium Silicate Hydrate crystals is more rapid. The formation of the gel and colloid is more rapid and the rate of diffusion of the gel is also higher. However, the reaction being more rapid leaves lesser time for the hydration products to arrange suitably, hence the later age strength is lower and finally after 7 days strength attend by both methods is same.

4. Also from experiment it is noticed that P.P.C. increases the later age strength of concrete as it reacts with calcium hydroxide and turns it into calcium-silicate-hydrates (C-S-H). However P.P.C (portland pozzolona cement) have higher activation energy and therefore, their rate of hydration is lower as compared to ordinary portland cement (OPC). This results in lower early age strength as compared to OPC. Accelerated curing techniques radically help to increase the rate of strength gain.

(5) The similitude model of IS M40 is a useful asset in construction industry to accept the quality of concrete *in-situ*. A ready reckoner is prepared from this model to facilitate the site supervisor to take spot decision about the acceptance of concrete mix used in casting.

There is need to carry out few more experiments to widen the scope of predictive model with respect to "Role of different coarse aggregate locally available other than lime stone."

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