

A STUDY ON THE INFLUENCE OF CURING ON THE STRENGTH OF A STANDARD GRADE CONCRETE MIX

UDC 666.942.3/.7:691.32:620.175/.176(045)=111

M.V. Krishna Rao¹, P. Rathish Kumar^{2*}, Azhar M. Khan¹

¹Dept. of Civil Engg., CBIT, Hyderabad-500075, A.P, India

²Dept. of Civil Engg., NIT Warangal-506004, A.P, India

*E-mail: drrateesh@gmail.com

Abstract. *Curing is essential if concrete is to perform the intended function over the design life of the structure while excessive curing time may lead to the escalation of the construction cost of the project and unnecessary delays. Where there is a scarcity of water and on sloping surfaces where curing with water is difficult and in cases where large areas like pavements have to be cured, the use of curing compound may be resorted to. The parameters of the study include the curing period [1, 3, 7, 14 and 28 day], curing method [conventional wet curing, membrane forming compound curing and accelerated curing] and the type of cement [Ordinary Portland Cement(OPC) 43 grade, Portland Pozzolana Cement(PPC) 43 grade and Ordinary Portland Cement(OPC) 43 grade +10% Silica Fume(SF) replacement for cement]. In all a total of 99 cube specimens were cast and cured under different conditions before testing. Test results indicate a drop in strength at all ages for concretes with PPC and the one in which 10% OPC is replaced by silica Fume(SF) in comparison with the concrete with OPC. Curing by membrane forming curing compound yielded nearly the same results as that of conventional wet curing for concrete with OPC and there was a marginal decrement in concrete with PPC. Predicted 28-day strength of concrete from the accelerated curing test was found to be on a conservative side compared to control concrete.*

Key words: *Compressive Strength, Curing, Silica Fume, Non-Destructive Testing, Ordinary Portland Cement (OPC)*

1. INTRODUCTION

Curing is the process of controlling the rate and extent of moisture loss from concrete during cement hydration. In order to obtain good quality concrete, an appropriate mix must be followed by curing in a suitable environment during the early stages of hardening [1, 2]. Curing must be undertaken for a reasonable period of time if concrete is to achieve its potential strength and durability. Curing is essential if concrete is to perform its in-

tended function over the design life of the structure whereas; excessive curing time may lead to the escalation of construction cost of the project and unnecessary delays [3].

Curing encompasses the control of temperature as it affects the hydration rate in cement. If, within the curing period, natural temperatures of concrete are in the acceptable range of values, only the moisture content needs to be controlled. If the natural temperature is outside the acceptable range of values, some means will be required for controlling the temperature of concrete [3, 4]. The curing of concrete is performed both at normal and elevated temperatures also. Curing can be done in a number of ways while the most appropriate means of curing may be dictated by the site conditions or the construction method.

2 METHODS OF CURING

Broadly concrete curing processes can be classified into three categories first is the method in which the moisture loss can be prevented by continuously wetting the exposed surface of concrete, this in turn maintains the requisite quantity of water in the concrete during the early hardening period. This is also called as conventional curing. The second method minimizes moisture loss from the concrete, thus preventing the loss of mixing of water from concrete, for example, by covering it with a relatively impermeable membrane. This is known as membrane curing using curing compounds. Finally, that which keeps the surface moist and at the same time, raise the temperature of the concrete, thereby, increasing the rate of strength gain. This method is typically used for pre-cast concrete products, called accelerated curing.

The best method of curing concrete depend upon the conditions at site, or in a plant, or on the availability of curing materials, on the type of job, final appearance of the structure and the economics, and can be any one method or a combination of methods.

Some of the previous investigators [5, 6, 7] have studied the effect of curing methods with and without the use of supplementary cementitious materials on the compressive strength and performance. Whiting and Snyder [8], Nasser et al [9] and Oztekin[10] conducted a study to examine the effectiveness of different types of curing compounds in retaining water for hydration, promoting concrete strength, and reducing permeability. These studies were conducted with and without supplementary materials. All compounds performed better than samples with no curing treatment. Tantawi and Gharaibey [11], worked on the early estimation of hardened concrete strength based on accelerated strength. Shobha and Raju [12] investigated the effect of curing compound on different grades of concrete.

3 RESEARCH SIGNIFICANCE

There is a limited work on the effect of curing period and curing techniques on the strength and performance aspects of concrete. Also the studies on the effect of accelerated curing are scant in the literature. The present work is aimed at studying the influence of type of cement, age and type of curing on M40 grade concrete. This work encompasses all the aspects of curing and sets a guideline for effective concrete making in this range of concrete which has applications in rigid pavement and concreting applications. Non destructive tests such as Rebound hammer and Ultra-sonic pulse velocity (UPV) were also conducted to facilitate a comparative study with that of the destructive test.

4 EXPERIMENTAL PROGRAM

The experimental program involved testing of a total of 99 test specimens of standard cubes of size 150 x 150 x 150mm cast and tested to cover the three parameters viz., age of curing (1, 3,7,14 and 28 days), type of cement (OPC 43, PPC 43 and OPC 43+10% silica fume) and the type of curing (conventional curing, membrane curing and accelerated curing). The details of the specimens cast is shown in Table 1.

Table 1 Details of specimens cast

S.No	Type of Concrete Mix	Type of Curing	No of Cubes
1	OPC	Conventional Curing	15
2	PPC	Conventional Curing	15
3	OPC+10% SF	Conventional Curing	15
4	OPC	Membrane Curing	15
5	PPC	Membrane Curing	15
6	OPC+10% SF	Membrane Curing	15
7	OPC	Accelerated curing	3
8	PPC	Accelerated curing	3
9	OPC+10% SF	Accelerated curing	3
Total Specimens cast			99

4.1 Materials used

a) *Cement*: Ordinary Portland Cement 43 grade confirming to IS 8112-1989 [13] and Portland Pozzolana Cement 43 grade confirming to IS 383-1970 [14] was used in the study. The details of the physical properties of various cements tested in accordance with IS: 4031-1988 [15] is shown in Table- 2.

Table 2 Physical properties of different types of cements

S.No.	Property	Test result		
		OPC	OPC+10% Silica Fume	PPC
1.	Normal consistency (%)	30	34	32
2.	Specific gravity	3.14	3.09	3.05
3.	Initial and final setting time (min)	55,175	46,150	50,160
4.	Fineness (%)	8	5	6

b) *Fine Aggregate*: River sand procured from a near by source was used as fine aggregate in this study. The physical properties of fine aggregate such as specific gravity, fineness modulus, porosity, void ratio etc., were determined in accordance with IS: 2386-1963 [16]. The details are shown in Table 3.

Table 3 Properties of aggregates

S.No.	Property	Fine aggregate	Coarse aggregate
1.	Specific Gravity	2.54	2.69
2.	Fineness Modulus	2.95	6.84
3.	Porosity(%)	42.8	40.00
4.	Void Ratio	0.75	0.44

c) *Coarse Aggregate*: The properties of coarse aggregate like size, shape, grading, surface texture etc play an important role on the workability and strength of concrete. These properties are determined as per IS 2386-1963 [16] and shown in Table- 3 above.

d) *Micro Silica*: Micro silica or Silica Fume (SF) (Grade 920-D) used in this investigation was obtained from Elkem India Private Limited, Mumbai, India. The silica fume used has a specific gravity of 2.1 and a lime reactivity of 90%.

e) *Curing Compound*: Concure WB water based concrete curing compound complying with the internationally recognized ASTM C309-90[17] standard was used in this investigation. It was obtained from Fosroc Chemicals (India) Limited, Hyderabad.

f) *Water*: Potable water was used in the investigations for both mixing and curing.

g) *Mix Proportioning*: The mix proportioning for M40 grade concrete used in the present work was designed as per ACI 211.1-1991 method [18]. The mix proportioning adopted was cement: sand: Coarse aggregate/water-cement ratio respectively 1:1.59:1.95/0.43.

4.2 Casting

The performance of concrete is influenced by mixing and a proper and good practice of mixing can lead to better performance and quality of the concrete. In the present study, M40 grade standard concrete cubes of size 150 x 150 x 150mm were cast for determining the compressive strength. The cast specimens were demoulded at the end of 24±2 hours and cured for the required number of days with different curing methods.

4.3 Curing Methods

The effect of three different methods of curing are investigated.

a) *Conventional Curing*: The conventional curing involves dipping the specimens in water at 25°C at the end of 24 hours of casting after allowing for air drying.

b) *Membrane-forming curing compounds*: Concure WB water based concrete curing compound complying with the internationally recognized ASTM C309-90 [17] standard was employed. The surface of the concrete was thoroughly moistened before the application of the compound to prevent its absorption into the concrete. Then the compound was uniformly applied to surfaces of the cube, ensuring complete coverage, with a brush after its removal from the mould. The specimens were tested after 1, 3, 7, 14 & 28 days of such membrane curing.

c) *Accelerated Curing by Boiling Water Method*: After casting the specimens they were subjected to accelerated curing by boiling water method as per IS 9013-2004 [19]. The specimens were stored in a place free from vibration, in moist air for at least 90 percent relative humidity and at a temperature of 27± 2°C for 23 hours ±15 minutes from the time of addition of water to the ingredients. The specimens were then gently lowered into the curing tank and totally immersed for a period of 3.5 hours ± 5 minutes. The temperature of the water in the curing tank was maintained at boiling (100°C) at sea level. After curing for 3.5 hours ± 5 minutes in the curing tank, the specimens were removed from the boiling water, taken off the moulds and cooled by immersing in cooling water tank at 27± 2°C for 2 hours.

4.4 Tests on Concrete

a) *Fresh Concrete*: Slump test and Compaction factor tests were employed to evaluate the workability of concrete [20]. The details are shown in Table 4.

Table 4 Details of workability measurement

S.No	Type of concrete mix	Slump (mm)	Compaction Factor
1	OPC	85	0.90
2	PPC	92	0.92
3	OPC+10% SF	97	0.94

b) *Hardened Concrete*: Cube specimens of size 150x 150x150 mm were used to determine the compressive strength at the end of 1, 3, 7, 14 and 28 days. The test was conducted in the laboratory, as per IS 516-1969 [21] on a digital compression testing machine of 3000 KN capacity and the load at the time of failure of specimen was recorded to compute the compressive strength. In case of accelerated curing, the 28 days strength is predicted based on the equation: 28-days compressive strength = 1.64x (accelerated concrete strength) + 8.09 MPa.

5 RESULTS AND DISCUSSION

The results obtained from the experimental investigations involving various parameters are carefully analyzed. Table- 5 shows the details of the compressive strength for all the three series of mixes cured by all the three methods. The variation of corresponding compressive strengths, for three series of mixes and different curing procedures are also plotted. In case of accelerated curing method, only the 28 day strength is determined based on the one day strength as explained by the earlier equation. The non-destructive tests viz., Rebound Hammer Test and the Ultra-sonic pulse velocity are performed and are give in Table- 6. The test specimens covering the three series of mixes that are cured for different ages using different curing techniques are considered in this study.

Table 5 Compressive strength of specimens

S.No	Type of concrete mix	Type of curing	Compressive Strength (MPa)				
			1 days	3 days	7 days	14 days	28 days
1	OPC	Conventional	21.58	25.51	38.65	49.05	52.03
2	PPC	Conventional	18.77	24.43	34.49	42.23	46.56
3	OPC+10% SF	Conventional	21.49	28.29	39.67	50.00	53.00
4	OPC	Membrane	20.50	24.60	35.73	43.40	48.03
5	PPC	Membrane	14.49	17.60	28.77	37.04	43.76
6	OPC+10% SF	Membrane	20.45	26.70	32.07	38.85	46.49
7	OPC	Accelerated	-	-	-	-	40.97
8	PPC	Accelerated	-	-	-	-	29.34
9	OPC+10% SF	Accelerated	-	-	-	-	40.96

Table 6 Non-destructive test results

S.No	Type of concrete mix	Type of curing	Average Rebound number/ UPV(Km/sec)				
			1 day	3 days	7 days	14 days	28 days
1	OPC	Conventional	22, 4.00	23,4.09	24,4.16	27,4.26	28,4.29
2	PPC	Conventional	23, 3.21	22,4.04	23,4.16	26,4.17	28,4.23
3	OPC+10% SF	Conventional	23, 3.80	23,4.04	23,4.10	27,4.18	27,4.26
4	OPC	Membrane	23, 3.79	24,4.06	23,4.12	25,4.20	26,4.27
5	PPC	Membrane	22, 3.54	22,3.89	22,4.02	24,4.14	26,4.15
6	OPC+10% SF	Membrane	22, 3.85	22,4.05	23,4.01	26,4.16	26,4.21
7	OPC	Accelerated	-	-	-	-	24, 4.16
8	PPC	Accelerated	-	-	-	-	22, 4.04
9	OPC+10% SF	Accelerated	-	-	-	-	24, 4.10

5.1 Effect of age on compressive strength

Fig.1 depicts the variation of compressive strength with age, for all the three series of mixes considered, cured by conventional wet curing, membrane forming curing compound and accelerated curing. The compressive strengths obtained for concrete mixes with OPC, PPC and OPC with 10% SF met the desired characteristic strength of 40 N/mm². An increase in compressive strength is noticed with increase in age.

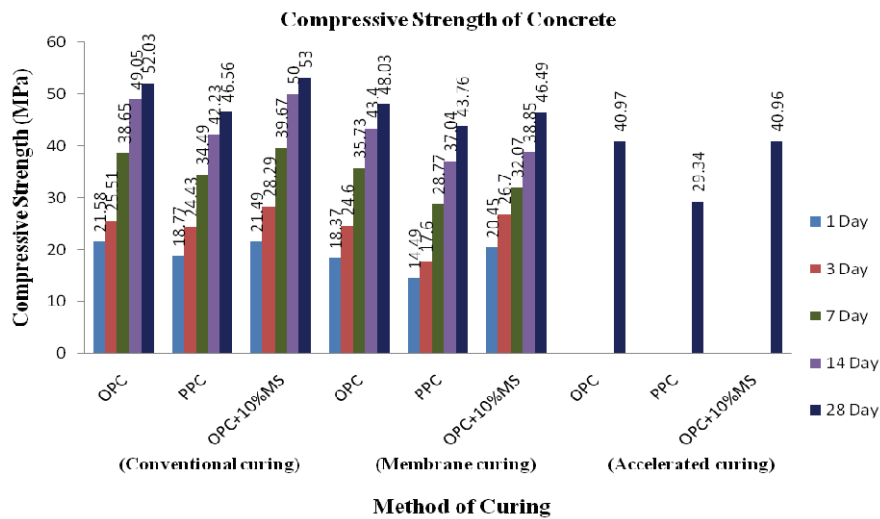


Fig. 1 Comparison of compressive strengths for different methods of curing

(a) Conventional Wet Curing

The 1 day and 7 day compressive strengths of concrete with OPC and OPC with 10% SF have been almost same. The 28 day compressive strength for concretes of PPC and OPC with 10% Silica Fume (SF) replacement dropped by 11.75% and 11.41% respec-

tively in comparison to the concrete with OPC. The compressive strength of concrete with PPC is found lesser than those of OPC and OPC with 10% Silica Fume (SF) replacement at all the ages, which could be attributed for slow development of strength in concrete with PPC. The percentage increase in compressive strength from 1 to 3 days, 3 to 7 days, 7 to 14 days and 14 to 28 days has been 18.21%, 51.51%, 26.91% and 6.08% respectively for specimens of OPC. The increase in strength for similar comparison is observed as 30.15%, 41.18%, 22.44% and 10.25% respectively for specimens containing PPC. In case of specimens with 10% OPC replaced by Silica Fume (SF), the percentage increase has been 31.64%, 40.23%, 14.39% and 2.91% respectively.

(b) Membrane Curing

It can be observed that 1 day, 3 day and 28 day compressive strengths of concrete with OPC and OPC with 10% Silica Fume (SF) replacement are almost the same. The 28-day compressive strength for PPC and OPC with 10% Silica Fume(SF) replacement dropped by about 9.76% and 3.31% respectively in comparison with concrete containing OPC. The compressive strength of concrete with PPC is found to be lower than that of the concrete with OPC and OPC with 10% Silica Fume (SF) replacement at all the ages. The percentage increase in compressive strength from 1 to 3 days, 3 to 7 days, 7 to 14 days and 14 to 28 days has been 33.91%, 45.24%, 21.47% and 10.67% respectively for specimens of OPC. The increase in strength for similar comparison is found to be 21.46%, 63.47%, 28.75% and 18.14% respectively for specimens of PPC. For specimens containing 10% OPC replaced by Silica Fume (SF), the percentage increase in compressive strength from 1 to 3 days, 3 to 7 days, 7 to 14 days and 14 to 28 days has been 30.56%, 20.11%, 21.14%, and 19.67% respectively.

(c) Accelerated Curing (Boiling Water Method)

It could be seen that the 28-day compressive strengths of concretes with OPC and OPC with 10% Silica Fume (SF) replacement were found to be almost same. For concrete with PPC, the strength dropped by 39.64% and there has been a negligible decrease in the same for the mix of OPC with 10% micro silica in comparison to the one containing OPC. The compressive strength of concrete with PPC is lower than that of the concrete with OPC and OPC with 10% Silica Fume (SF) replacement which could be attributed to slow rate of strength gain in pozzolana cements.

5.2 Effect of method of curing on Compressive strength

a) Concrete Mix Containing OPC

Fig (1) depicts the variation of compressive strength with age for concrete with OPC. It has been observed that the 1 day, 3 day compressive strengths of cubes cured with water and curing compound were almost the same. The 7 days compressive strength of cubes cured with water is 8.17% more than those cured with curing compound. The 14 days compressive strength of cubes cured with water is 13.02% more than those cured with curing compound where as the 28 days compressive strength of cubes cured with water has been 11.91% and 31.19% greater than those cured with curing compound and accelerated curing. Similar trend is observed in concrete with PPC and in concrete where in 10% of OPC is replaced by Silica Fume (SF) as well.

b) Concrete Mix Containing PPC

Fig. 1 represents the variation of compressive strength with age for concrete with PPC. It is observed that the 1day,3day,7day,14day compressive strengths of cubes cured with water are 38.81%, 38.81%, 9.88%, and 14.01% respectively more than those cured with curing compound. The 28 days compressive strength of cubes cured with water has been 6.40% and 58.70% greater than those cured with curing compound and accelerated curing respectively.

c) Concrete Mix Containing 10% OPC replaced by Silica Fume (SF)

Fig. 1 shows the variation of compressive strength with age for concrete with 10% OPC replaced by micro silica. The 1 day compressive strength of cubes cured with water and curing compound is found to be almost the same. It is observed that the 3day, 7day, and 14day compressive strengths of cubes cured with water are 5.95%, 23.70%, and 16.81% respectively more than those cured with curing compound. The 28 days compressive strength of cubes cured with water has been 0.45% and 14.01% greater than those cured with curing compound and accelerated curing respectively.

6. NON-DESTRUCTIVE TESTING OF CONCRETE

a) Rebound Number

Figs 2 and 3 depict the variation of rebound number, at different ages, for specimens of three series of mixes cured by conventional wet curing and membrane curing respectively. The Rebound numbers on different cubes have been more or less the same and ranged from 22-29 for specimens of conventional wet curing and 22-26 for specimens cured with membrane forming curing compound respectively.

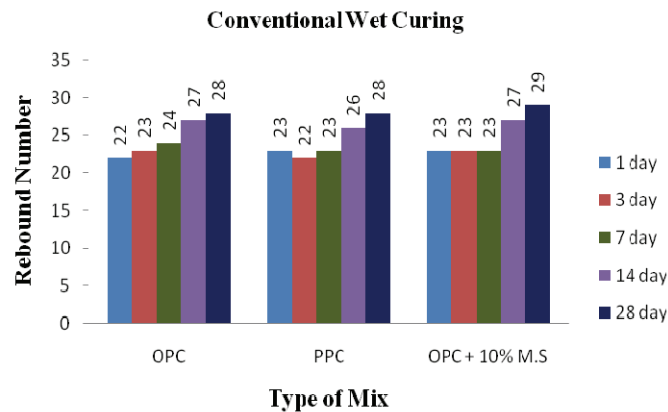


Fig. 2 Variation of rebound number with age (Conventional wet curing)

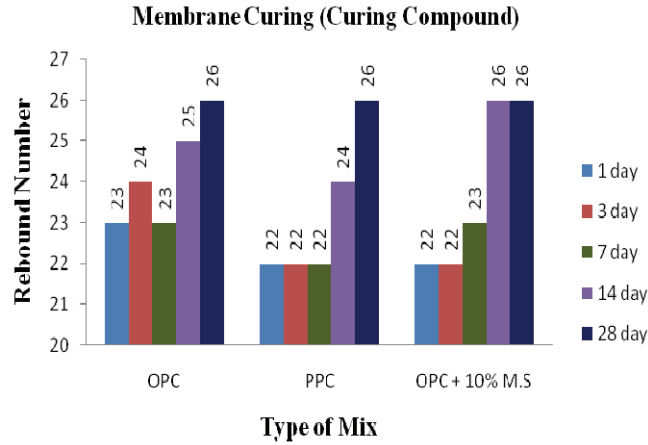


Fig. 3 Variation of Rebound number with Age (Membrane curing)

b) *Ultrasonic Pulse velocity (UPV)*

Figs 4 and 5 depict the variation of UPV in km/sec, at different ages, for specimens of three series of concrete mixes cured by conventional wet curing and membrane curing respectively. All the pulse velocity values possess good concrete quality grading as per IS: 13311-1992 (Part-1) [22]. The pulse velocity values of concrete at 28 days with OPC have been 1.42% & 0.70% and 2.90% & 1.43% more than that of concrete with PPC and OPC with 10% Silica Fume (SF) replacement for specimens cured by conventional wet curing and membrane curing respectively. At 28 days, the pulse velocity value of concrete with OPC is more than that of concrete with PPC and OPC with 10% Silica Fume (SF) replacement. In general, the UPV values of all concretes tested indicate the concrete of good quality excepting the one of PPC with medium quality concrete at 1 day age.

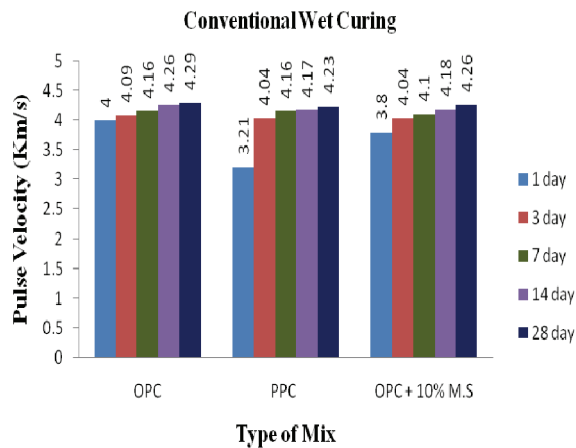


Fig 4 Variation of Pulse velocity with Age (Conventional wet curing)

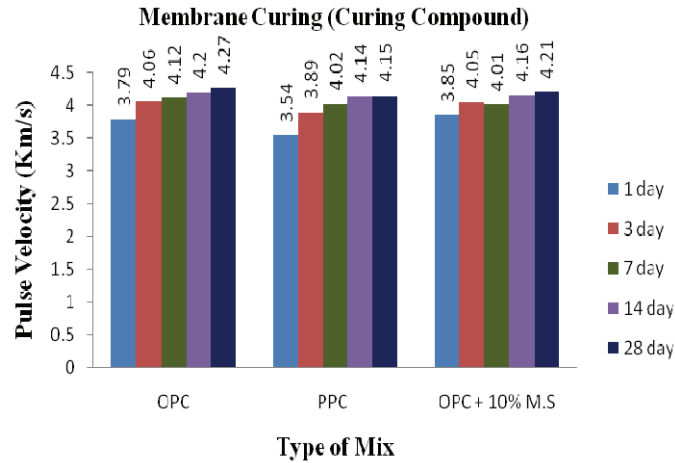


Fig 5 Variation of Pulse velocity with Age (Membrane curing)

7. CONCLUSIONS

The following conclusions have been drawn from the experimental study

1) The results have been encouraging for concrete mixes with OPC and the one in which 10% of OPC has been replaced by silica fume. The 3 day compressive strength of concrete with 10% replacement of OPC by silica fume and cured with curing compound is 8.54% more than the concrete with OPC.

2) The 28 day compressive strength of concrete with PPC & 10% OPC replaced by silica fume dropped by 11.75% & 11.41% and 9.76 & 3.31% respectively in comparison with the concrete containing OPC when cured by conventional wet curing and by curing compound.

3) At all ages, the compressive strength of concrete with PPC is found to be lower than that of the concrete with OPC & the one with 10% of OPC replacement by silica fume for all curing methods.

4) The strength of concrete with PPC is lower than those concretes with OPC and the one with 10% of OPC replacement by silica fume at all ages but the design strength of 40 N/mm² has been achieved in all the cases.

5) The rate of increase of strength from 3 days to 7 days and 3 days to 28 days, for OPC, PPC and OPC with 10% silica fume concretes, when cured by conventional wet curing and by curing compound, are in the ranges of 20.11% to 63.47% and 65.08% to 148.64% respectively.

6) The 28-day compressive strength of concretes with OPC, PPC & 10% OPC replaced by silica fume and cured by conventional wet curing have been more than the corresponding ones cured by compound curing.

7) Curing compound produces nearly same results as that of conventional wet curing for concrete with OPC while a marginal decrement is observed in concrete made of PPC and the one in which 10% of OPC is replaced by silica fume.

8) The Rebound numbers on different cubes have been more or less the same. They are in the range 22-29 for specimens of conventional wet curing and 22-26 for specimens cured with membrane forming curing compound respectively.

9) The ultrasonic pulse velocity values of various concretes, cured by different techniques, correspond to good concrete quality grading but the one with PPC at one day age is of medium quality concrete.

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STUDIJA UTICAJA NEGE NA ČVRSTOĆU STANDARDNOG KVALITETA BETONA

M.V. Krishna Rao, P. Rathish Kumar, Azhar M. Khan

Nega je neophodna kako bi beton obavljao svoju funkciju za projekovani vek konstrukcije, dok prekomerna nega može dovesti do povećanih troškova projekta i nepotrebnog zadržavanja. Tamo gde je nestašica vode kao i na nagnutim površinama gde se nega betona vodom obavlja teško i u slučajevima gde se nalaze velike površine, poput pločnika koje treba negovati, može se pribеći korišćenju jedinjenja za negu betona formiranjem membrane. Parametari studije obuhvataju periode nege od 1, 3, 7, 14 i 28 dana, metode nege (konvencijalna nega kva[en]jem vodom, nega jedinjenjem koje formira membranu i ubrzani tretman) i vrste cementa (Običan Portland cement (OPC) 43 klase, Portland cement Pucolan (PPC) 43 i običan Portland cement (OPC) 43 klase+10% silikatne prašine (SF) kao zamene za cement. Ukupno 99 uzoraka kocke su izliveni i negovani pod različitim uslovima. Rezultati testa ukazuju na pad čvrstoće u svakom starosnom dobu betona sa PPC i u onoj kojoj je 10% OPC zamenjeno silikatnom prašinom (SF) u odnosu na beton sa OPC. Nega sa membrano folijom dala je skoro iste rezultate kao kod konvencionalne mokre nege za beton sa OPC i došlo je do marginalnih smanjenja u betonu sa PPC. Predviđene 28-dnevne čvrstoće betona testa ubrzane nege su bile konzervativne u poređenju sa kontrolnim betonom.

Ključne reči: Čvrstoća na pritisak, nega, silikatna prašina, ispitivanje bez razlaganja, običan Portland cement (OPC)