# The Effect of Curing Methods and Periods on the Strength and Durability of Concrete

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***Abstract**- The type of curing and curing period at early age is very important for enhancement of Concrete Strength and Durability at later age. There is a misperception that water curing period of about 28 to 90 days might be required for mineral admixed concrete to attain properties similar or better to that of OPC concrete at later stage. There is a little research on long-term strength and durability of blended cements concrete at different curing conditions and periods. This paper presents the effect of different early curing conditions on long-term Strength and Durability properties of OPC, PPC and PSC concretes. Also studied the effect of different curing methods on the concrete strength and durability. Results showed that concrete durability increases with increase initial water curing for all type concretes. At later period, in all curing conditions, concrete with PPC and PSC attained higher strengths and durability than OPC concrete. Also ascertained that concrete attained higher strength and durability with Wet Sand Curing method than other curing methods (Immersing in water, Water spraying, Apply curing compound and No curing) and Immersing in water curing concrete properties closer to wet sand curing concrete properties.*

***Key Words: OPC, PPC, PSC, Strength, Porosity, RCPT***

## 1. INTRODUCTION:

Even though, concrete that has properly specified, batched, mixed, placed and finished can still be a failure if improperly or inadequately cured. The curing process is most critical during the initial days and it has significant impact on the quality of the concrete. The main function of curing for concrete is to preserve water for hydration process and maintain favorable temperature or prevent high temperature gradients to minimize Plastic, Drying and Thermal Shrinkage cracks. Initial curing is very important to high cement content concretes, low water cement ratio concretes, rapid high strength cement concretes and blended cement concretes. *Initial exposure of concrete at high temperature may cause strength reduction in later stage and may develop microcracks, which leads to reduce the Durability of concrete. Without curing, if concrete exposed at a temperature of 38°C during first 24 hours results in a loss of strength of concrete at 28 days about 9 to 12 percent. If water evaporation rate from the concrete (flat structure) exceeds bleed water rate or above 1.0 kg/m²/hour, there will be a chance of develops Plastic shrinkage cracks*. Since rate of evaporation depends upon Ambient Temperature, Relative Humidity, Wind Velocity and Concrete Temperature, it is advisable to start water sprinkling or Aliphatic alcohol spraying on the surface of the concrete immediately after initial screeding completed.

(IS 456-2000)[4] Exposed surfaces of concrete shall be kept continuously in a damp or moist condition by ponding or by covering with a layer of sacking, canvas, hessian or similar materials and kept constantly moist for at least seven days from the date of placing concrete in case of OPC and at least 10 days where blended cements are used. For concrete exposed to dry and hot weather conditions, curing period shall not be less than 10 days in case of OPC and 14 days in case of Blended Cements. In India, the usage of Blended Cements considerably increasing year by year. Because of slower rates of hydration in blended cements and in long-term it may yield comparable or higher strengths and durability than the OPC, researchers generally recommend 56 to 90 days results in the case of blended cements with mineral admixtures.

IS 1199 (Part 5) 2018[23] stated that for laboratory samples, up to 24 hrs. should keep the sample along with mould at 27 ± 3 °C and after demould submerge the specimens in water at a temperature 27 ± 2 °C up to testing.

ACI committee 308-2008 recommended the curing periods for concretes with different types of cements. For Type-I cement-7 days, Type-II cement-10 days, Type-III cement-3days, and Type IV & V cements-14 days.

As per ASTM C 31-19, for Field samples for Standard Cured condition, in the initial curing period, store the specimens for a period up to 48 hrs. after molding and maintain temperature 16-27°C for < 40 MPa concretes and 20-26°C for ≥ 40 MPa strength concretes. After 48 hrs initial curing completion, for final curing store the samples in water tanks and maintain temperature 23±2°C up to testing. For Field Samples for Field Cured condition, store specimens representing structure concretes as near the point in the structure they represent as possible, and afford them the same temperature protection and moisture environment as the structure.

As per ASTM C 192-14, for laboratory curing, samples shall be moist cured at 23 ± 2°C and ≥ 95% RH from the time of molding until the test.

Iyoda[1] stated that durability of Blast Furnace Slag concrete is more sensitive to curing condition than OPC and recommended that Slag concrete has necessary for extended curing period of 2 days by OPC concrete for keeping enough durability. Proper curing concrete increases strength, durability, abrasion resistance and volume stability etc & decreases surface dusting, scaling, permeability and cracking etc. Samir[2] studied the effect of delay curing period on the concrete properties in hot weather climate. He has reported that a minimum of 3 days curing required for rich mixes, while a longer period was required for leaner mixes (min. 7 days).

The most common method using for keeping concrete moist for particular the Horizontal members Slabs, Roads, Floors, Porticos etc. is Ponding/Flooding the surface, Occasionally sprinkling water, and Covering the surface with wet jute, paper bags, sand or sawdust. It is advisable to carry out concrete works in cool climate conditions either early morning or night instead of peak hot climates in the daytime. The ingredients used for the concrete should be stored in locations under shadow and sprinkled with water before use for concrete. By using wet and cooled aggregates in concrete, can be minimize Bug or Blow Holes, Thermal shrinkage cracks, Plastic Shrinkage cracks, Blistering, low retention time, higher dosage of admixture, compaction difficulties etc.

## 2. TYPES OF CURING METHODS:

(1) ***Water curing***: Lab or Field specimens are curing by submerging in the water tank at room temperature.
(2) ***Saturated wet covering***: Moisture retaining sheets such as sacking, canvas, hessian, burlap cotton mats, gunny bag and rugs used as wet covering to keep the concrete in a wet condition during the curing period.
(3) ***Air Curing:*** Air curing is a curing method wherein the concrete keeps in the room temperature after wet curing at specified periods.
(4) ***Curing compound:*** Curing Compounds applies on the exposed surface of the concrete by the help of roller, brush or spray. Various types of curing compound are available in the market, mainly includes water based, resin-solvent based, chlorinated rubber, wax based, Acrylic based etc. Wax and Water based curing compound is most used curing compound worldwide. Curing compounds may effect the "bond" of some floor coverings.
(5) ***Self Curing:*** Using of self-curing materials in the concrete is more advisable to the blended mineral admixture concretes, high water scarcity areas, inaccessible structures. There are two types of Self Curing materials, first one is Porous Light Weight Aggregates (LWA) and second one is Poly-Ethylene Glycol (PEG 2000 / PEG 4000) or Poly-Ethylene Alcohol (PEA) polymers. As per literature PEG self-curing is more effective than PEA self-curing. Dadaji[3] stated that the polymers added in the concrete mainly form hydrogen bonds with water molecules and reduce the chemical potential of the molecules which in turn reduces the vapor pressure, thus reducing the rate of evaporation from the concrete surface.
(6) ***Plastic Sheeting:*** Plastic sheets covers entire concrete surface and prevent moisture loss.
(7) ***Water Ponding:*** Flooding of the horizontal concrete surface to provide both moisture and a uniform curing temperature. Curing water should not be more than 12°C cooler than the concrete temperature to avoid the possibility of thermal cracking. Inappropriate ponding may leads some problems such as leaching, Dampness, surface become more porous, water may reach to steel reinforcement through capillary action or minute cracks etc.
(8) ***Wet Sand:*** Wet sand spreads on the concrete surface to cure horizontal concrete members. The wet sand thickness about 25mm sufficient to prevent moisture loss from the concrete surface and also it helps for maintain concrete surface cool condition to minimize thermal shrinkage. The wet sand concrete surface having high abrasion resistance and less permeability.
(9) ***Water Sprinkling:*** Spraying water over the concrete surface to minimize water evaporation from concrete and also maintain concrete surface cool condition to minimize plastic shrinkage cracks. In this curing method, it is very difficult to maintain wet condition continuously especially in hot climate and also more water wastage.
(10) ***Humidity /Fog Curing:*** After demould the samples used to keep in Humidity Room or Fog room until testing (RH =95 to 100% and Temperatures 25-27 °C).

Akeem Ayinde Raheem et al (2013)[10] found that Wet sand curing concrete attained highest strengths than water immersed, Air, Water spray, Polythene and Burlap curing concrete strengths. Abhismit Ashok Bhamare[15] ascertained that OPC concrete majorly affected by intermittent curing than PPC and PSC concretes. Verbeck[20] ascertained that One-day strength increases with increasing curing temperature, but 28-day strength decreases with increasing curing temperature.

## 3. EXPERIMENTAL:

M20 and M25 Grade Concretes designed as per IS 10262-2009. M25 concrete samples were casted by using OPC 53G, PPC and PSC cements at same cement content and W/C. M20 Grade Concrete samples casted with PPC to study the effect of strength and durability at different curing methods. The physical properties and chemical composition of cements are presented in Table 2.

After casting concrete cubes kept in room temperature condition up to 24 hours. After demoulding all cubes stored in the water-curing tank. To determine the effect of Water Curing and the combination of Water Curing & Ambient Temperatures at Inside and Outside Room on concrete Strength and Durability by using OPC, PPC and PSC, samples were cured at different ages of Water curing and Ambient Temperature conditions. I-set samples water cured 7 days, II-set samples water cured 10 days, III-set samples water cured 14 days and IV-set samples water cured 28 days and after that, all samples kept inside room under Ambient Temperature Condition. V-Set samples only water cured up to 360 days. VI-set samples water cured 14 days and after that kept in Ambient Temperature outside room (under direct sunlight/rains/Fog). The details of Tests schedule are given Table 1.

*Table 1. Details of Concrete Tests Schedules*

| Description | Concrete Samples | Curing Conditions |
|---|---|---|
| Up to 365 days curing Conditions for OPC, PPC and PSC concrete Cubes | I-Set | **7d WC + IR** (upto 7 days WC + after Air Curing Inside Room) |
| | II-Set | **10d WC + IR** (upto 10 days WC + after Air Curing Inside Rom) |
| | III-Set | **14d WC + IR** (upto 14 days WC + after Air Curing Inside Room) |
| | IV-Set | **28d WC + IR** (upto 28 days WC + after Air Curing Inside Room) |
| | V-Set | **360d WC** (up to 365 Water Curing) |
| | VI-Set | **14d WC + OR** (upto 14 days WC + after Air Curing Outside Room) |

Concrete samples Compressive and Flexural strength tests conducted as per IS 516 :2004, Rapid Chloride ion Penetration Tests conducted as per ASTM C 1202-19 and Porosity determined as per ASTM C 642-97. Ultra Sonic Pulse Velocity (UPV as per IS: 516 (part 5/Sec 1) - 2018)

M25 Grade Concrete test data are given in Table 3. The results of compressive strength tests are shown in Fig. 1, Fig.2, and Fig. 3. Long-term strength, Permeability and Porosity are shown in Fig.4, Fig.5 and Fig. 6.

M20 Grade Concrete Compressive Strength, Flexural Strength, RCPT and Ultra Sonic Pulse Velocity test results are given in Table 4.

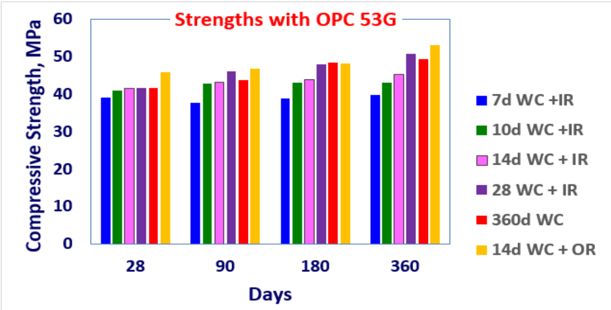


*Fig. 1 Concrete Strengths with* ***OPC 53G***

*Table 2 Physical and Chemical Properties of OPC, PPC and PSC Cements*

| Description | OPC 53G | PPC | PSC |
|---|---|---|---|
| **Physical Properties** | | | |
| Fineness - Specific surface ($m^2$/kg) | 309 | 355 | 347 |
| IST (minutes) | 250 | 190 | 365 |
| FST (Minutes) | 315 | 350 | 430 |
| **Compressive Strength (MPa)** | | | |
| 1 Day | 24.0 | 13.1 | 8.0 |
| 3 Days | 37.1 | 24.6 | 21.6 |
| 7 Days | 45.2 | 35.9 | 33.0 |
| 28 Days | 56.5 | 44.8 | 50.6 |
| **Chemical Composition (%)** | | | |
| Loss on Ignition | 3.30 | 3.98 | 0.39 |
| $SiO_2$ | 20.61 | 28.26 | 29.53 |
| $Al_2O_3$ | 4.58 | 7.89 | 12.78 |
| $Fe_2O_3$ | 4.76 | 6.41 | 1.89 |
| CaO | 62.63 | 47.78 | 45.33 |
| MgO | 0.61 | 1.39 | 7.12 |
| $Na_2O$ | 0.17 | 0.21 | 0.22 |
| $K_2O$ | 0.34 | 0.37 | 0.34 |
| $SO_3$ | 2.37 | 2.87 | 1.65 |
| $Mn_2O_3$ | 0.07 | 0.08 | 0.09 |
| $TiO_2$ | 0.27 | 0.43 | 0.46 |
| $P_2O_5$ | 0.17 | 0.17 | 0.11 |
| $Cr_2O_3$ | 0.00 | 0.01 | 0.00 |
| Cl | 0.00 | 0.05 | 0.01 |
| Insoluble Residue | 2.23 | 22.67 | 1.04 |

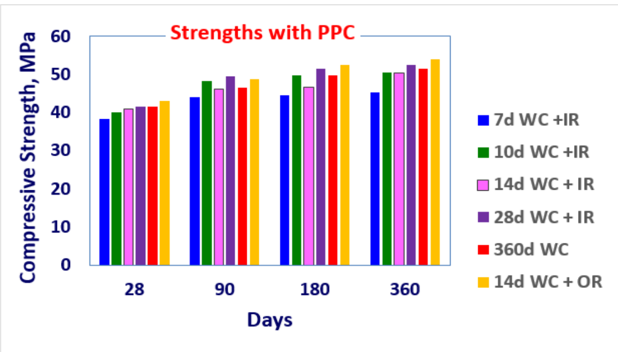


*Fig. 2 Concrete Strengths with* ***PPC***

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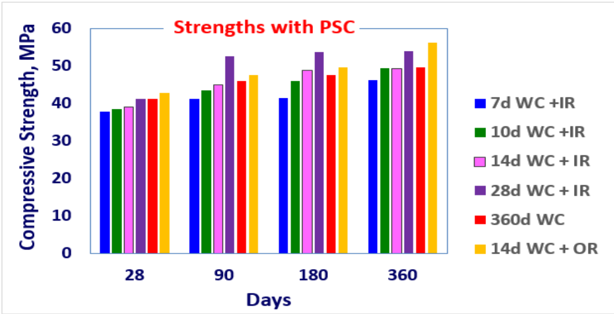


*Fig. 3 Concrete Strengths with* ***PSC***

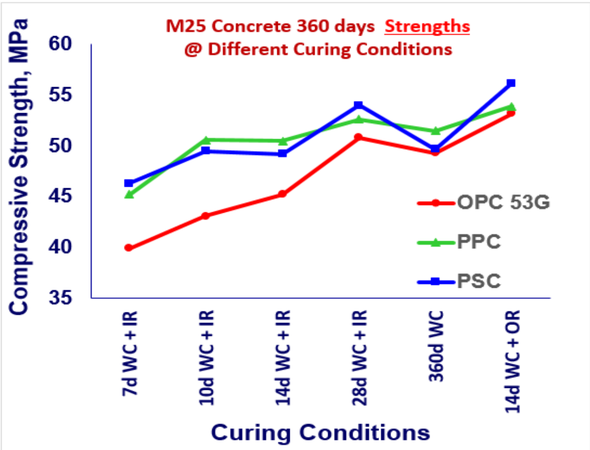


*Fig. 4 M25 Grade Concrete* ***Strengths*** *@* ***360 days*** *with Different Cements at Different Curing Conditions*

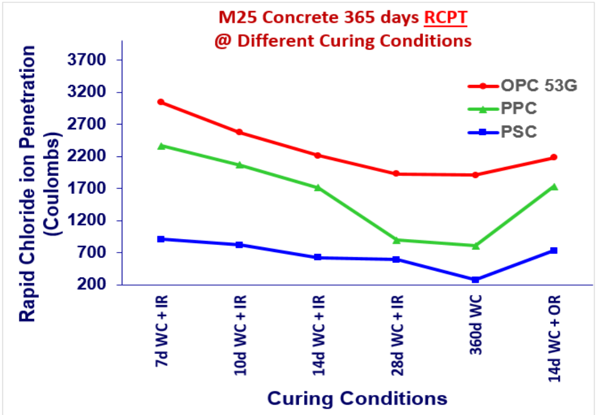


*Fig. 5 M25 Grade Concrete* ***RCPT*** *@* ***360 days*** *with Different Cements at Different Curing Conditions*

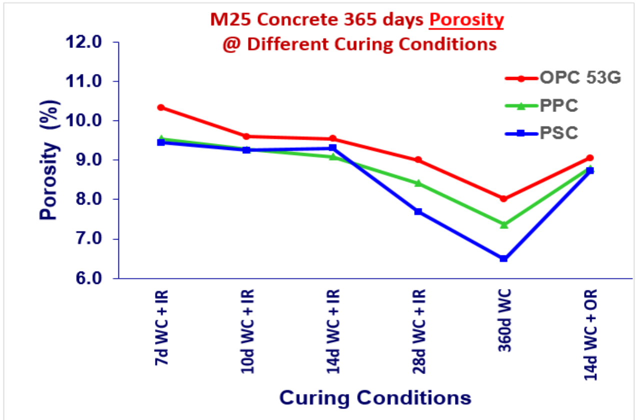


*Fig. 6 M25 Grade Concrete* ***360 days Porosity*** *with Different Cements at Different Curing Conditions*

**Table 4. M20 Concrete Test Results with PPC at Different Curing Methods**

| *Curing Method* | *Compressive Strength (MPa)* | | *Flexural Strength (MPa)* | | *Ultrasonic Pulse Velocity (m/s)* | *Rapid Chloride Ion Penetration (Coulombs)* |
|---|---|---|---|---|---|---|
| | *7-D* | *28-D* | *7-D* | *28-D* | *28-D* | *28-D* |
| ***Normal Curing (immersed in water @27±2°C )*** | ***17.8*** | ***28.1*** | ***3.6*** | ***5.4*** | ***4647*** | ***753*** |
| Occasionally Water sprinkling curing (Kept outside Room) | 17.8 | 25.5 | 3.1 | 4.6 | 4295 | 4349 |
| With Curing Compound (kept outside Room) | 18.3 | 27.5 | 3.1 | 4.5 | 4216 | 4350 |
| **Wet Sand Curing (Kept outside Room)** | **19.0** | **30.1** | **3.9** | **5.9** | **4660** | **622** |
| Without any curing (kept Inside Room) | 17.7 | 28.9 | 3.0 | 5.5 | 4303 | 6082 |
| Without any curing (kept Outside Room) | 18.2 | 24.1 | 2.3 | 3.8 | 4183 | 7220 |

*Table 3. M25 Grade Test Results with Different Cements*

*@ Different Curing Conditions*

| Cements | Days | Curing Conditions | | | | | |
|---|---|---|---|---|---|---|---|
| | | I-Set (7d WC+IR) | II-Set (10d WC+IR) | III-Set (14d WC+IR) | IV-Set (28d WC+IR) | V-Set (365d WC) | VI-Set (14d WC+OR) |
| **Compressive Strength, MPa** | | | | | | | |
| OPC 53G | 28 Days | 39.1 | 40.9 | 41.5 | 41.8 | 41.8 | 45.9 |
| | 90 Days | 37.8 | 42.8 | 43.3 | 46.2 | 43.9 | 46.8 |
| | 180 Days | 38.8 | 43.1 | 43.9 | 47.9 | 48.5 | 48.2 |
| | 360 Days | 39.9 | 43.1 | 45.2 | 50.8 | 49.3 | 53.2 |
| PPC | 28 Days | 38.5 | 40.2 | 40.9 | 41.6 | 41.6 | 43.2 |
| | 90 Days | 44.1 | 48.4 | 46.2 | 49.6 | 46.5 | 48.8 |
| | 180 Days | 44.6 | 49.7 | 46.6 | 51.5 | 49.7 | 52.4 |
| | 360 Days | 45.2 | 50.6 | 50.5 | 52.6 | 51.5 | 53.9 |
| PSC | 28 Days | 37.9 | 38.4 | 39.0 | 41.2 | 41.2 | 42.8 |
| | 90 Days | 41.3 | 43.5 | 45 | 52.5 | 45.9 | 47.6 |
| | 180 Days | 41.4 | 46.0 | 48.8 | 53.7 | 47.6 | 49.6 |
| | 360 Days | 46.3 | 49.5 | 49.2 | 54.0 | 49.7 | 56.2 |
| **Rapid Chloride ion Penetration, (Coulombs)** | | | | | | | |
| OPC 53G | 360 Days | 3042 | 2575 | 2210 | 1927 | 1904 | 2178 |
| PPC | 360 Days | 2361 | 2067 | 1712 | 891 | 805 | 1730 |
| PSC | 360 Days | 905 | 817 | 622 | 592 | 276 | 732 |
| **Porosity (%)** | | | | | | | |
| OPC 53G | 360 Days | 10.34 | 9.59 | 9.54 | 9.00 | 8.02 | 9.05 |
| PPC | 360 Days | 9.54 | 9.27 | 9.09 | 8.42 | 7.36 | 8.80 |
| PSC | 360 Days | 9.45 | 9.25 | 9.30 | 7.69 | 6.48 | 8.71 |

## 4. RESULTS:

***(a) Compressive Strengths of OPC, PPC and PSC concretes at different curing conditions:***

From Fig. 1 to Fig. 4, it has observed the effect of water curing and the combination of Water curing and Ambient Temperature curing at different ages on the compressive strength of OPC, PPC and PSC concretes. From the results, it has determined that initial optimum water curing and curing period significantly effects the concrete strength and durability and almost same behavior observed in OPC, PPC and PSC concretes. Later strengths increases with increase initial water-curing periods and longer water curing period (360d WC) slightly reduced the strengths. Later strengths of OPC, PPC and PSC concretes at 28d WC+IR and 14d WC + OR curing conditions show higher than the 360 days water curing concretes. For OPC, PPC and PSC concretes highest strengths observed at 14d WC + OC curing condition than all other curing conditions. This may be due to when concrete exposed to direct outside weather it has subjected to Rains, Fog, and higher Temperatures.

***(b) Porosity and RCPT of OPC, PPC and PSC concretes at different curing conditions:***

From the Fig. 5, it has determined that after initial water curing if concrete exposed to normal room temperature, later age concrete Porosity and RCPT values decreases with increase initial water curing period. Also found that after initial water curing, if concrete subjected direct outside weather (heavy rains in rainy, very hot in summer and Fog in winter), concrete Porosity and RCPT values shows slightly higher value than the under shade concretes. In all the curing conditions OPC concrete shows higher Porosity and RCPT values than PPC and PSC concretes.

Summary of Test Results: At later period, concrete with PPC and PSC attained higher strengths and durability than OPC Concrete and same trend observed with all curing conditions.

***(c) Strength and Durability of Concrete at different curing Methods:***

From the Table 4, it has proven that concrete attained higher Strength and Durability with Wet Sand Curing than other curing methods (Immersing in water, Water spraying, Curing Compound, and without curing). From the without curing kept outside concrete samples test results, it has observed that concrete attained initial (7-days) higher strengths and later (28-days) lower strengths than the curing concretes, lower strength may be due to micro cracks developed in the concrete at later period. Wet Sand curing and Immersed Water Curing concrete strength and durability show almost equal. Wet sand curing concrete additional advantages are 1. Less Leaching, 2. Less Water consumption, 3. Less Monitoring, 4. High surface hardness 5. High Abrasion Resistance etc.

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