

Experimental Investigation of Water-Based Curing Techniques on Self-Compacting Concrete Strength

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Abstract: Self-Compacting Concrete (SCC) is highly workable concrete with high strength and high performance that can flow under its own weight through restricted sections without segregation and bleeding. SCC is achieved by reducing the volume ratio of aggregate to cementitious materials, increasing the paste volume and using various viscosity enhancing admixtures and superplasticizers. It is observed that the behaviour of the design concrete mix is significantly affected by variation in humidity and temperature both in fresh and hardened state. In this paper effect of few water-based curing techniques on compressive strength of M30 grade self-compacting concrete (SCC) is discussed.

It is observed that immersion method for curing gives maximum compressive strength while the lowest compressive strength is for ice curing. Hot water & Sea water give second highest strength at 28 days.

It is concluded that although pond **immersion method is best** for curing, in extreme weather conditions SCC can prove effective for hot weather and sea water conditions. Wet covering method is quite effective giving about 92% strength than that of strength received from immersion method. In cold weather compressive strength gain is quite less about 82%.

Keywords: Self compacting concrete, Immersion curing, Hot water curing, ice curing, sea water curing, wet covering, curing period, compressive strength.

I. INTRODUCTION

Self-Compacting Concrete (SCC) is highly workable concrete with high strength and high performance that can flow under its own weight through restricted sections without segregation and bleeding (EFNARC- European Federation of Producers and Applicators of Specialist Products for Structures, 2002). SCC has substantial commercial benefits because of ease of placement in complex forms with congested reinforcement (Khayat, K.H., Hu, C. and Monty, H. 1999).

As per Vijai K., et.al. (2010), SCC is achieved by reducing the volume ratio of aggregate to cementitious materials, increasing the paste volume and using various viscosity enhancing admixtures and superplasticizers. It is the use of superplasticizer which has made it possible to use w/c ratio as low as 0.25 or even lower and yet to make flowing concrete to obtain strength of the order 120 MPa or more. Building elements made of high strength concrete are usually densely reinforced.

Kumbhar P.D., et. al. (2011), observed that the behaviour of the design concrete mix is significantly affected by variation in humidity and temperature both in fresh and hardened state. The strength of concrete is affected by a number of factors, one of which is the length of time for which it is kept moist, i.e. cured, another being the method of curing. Inadequate or insufficient curing is one of main factors contributing to weak, powdery surfaces with low abrasion resistance and durability.

Exposed surfaces of concrete shall be kept continuously in a damp or wet condition by ponding or by covering with a layer of sacking, canvas, hessian or similar materials and kept constantly wet for at least seven days from the date of placing concrete in case of ordinary Portland Cement-and at least 10 days where mineral admixtures or blended cements are used. (IS 456 -2000)

Cement Concrete & Aggregates Australia (CCAA) (2006), in a data sheet mention that curing is the process of controlling the rate and extent of moisture loss from concrete during cement hydration. This can be achieved by:

- Either supplying the water from outside (Ponding & Spraying)
- Continuously wetting the exposed surface thereby preventing the loss of moisture from it.
- Leaving formwork in place
- Covering the concrete with an impermeable member
- Application of a suitable chemical (wax etc.)
- Mixing a suitable chemical in fresh concrete for internal curing
- Combination of such methods.

Qureshi L. A. et. al. (2010), experimented on high strength self compacting concrete by curing with 3 different techniques. First in a temperature controlled curing tank in the laboratory, second under prevailing site conditions and 3rd by application of a curing compound. They noted that 28-days compressive strength of cylinders cured under site conditions was 89 % of the compressive strength of cylinders cured in water tank in the laboratory (i.e., 11 % less). Similarly compressive strength of cylinders cured by applying curing compound was 93 % of the compressive strength of cylinders cured in the laboratory (i.e., 7% less).

Alumina (Al ₂ O ₃)	28.20
Calcium Oxide (CaO)	2.23
Magnesium Oxide (MgO)	1.45
Total Sulphur (SO ₃)	0.165
Insoluble residue	-
Sodium Oxide (Na ₂ O)	0.58
Potassium Oxide (K ₂ O)	1.26

❖ **Aggregates (FA & CA)**

High strength or rich concrete can be adversely affected by use of large size aggregates as discussed in Shetty M.S. (2005), a text book of Concrete Technology. Based on this fact and after studying mix design literature of SCC, the various aggregates used are as under:

Sand, ≤ 4.75mm: Specific gravity 2.55 & Fineness Modulus 2.87, Zone II, Bodeli, Vadodara.

Grit, 4.75 to 12.5mm: Specific gravity 2.75 & Fineness Modulus 5.76, Sevaliya, Kheda District. The properties of aggregates used are given in Table 3.

Table 3: Properties of sand

Particulars	Sand	Grit
Source	Bodeli, Gujarat	Sevalia, Gujarat
Zone	Zone II	-
Specific Gravity	2.55	2.75
Fineness Modulus	2.87	5.76
Bulk Density	1776 kg/m ³	1764 kg/m ³
Colour	Yellowish White	Greyish Black

❖ **Superplasticizers (SP):** Polycarboxylates ether condensate (PCE) based superplasticizers were used Brand name Glenium B276 Suretec. Dosages of superplasticizers 1.1% of cementitious material. The properties of superplasticizer are: pH≥6, Chloride ion content<0.2% and light brown liquid in color.

❖ **Gunny Bag:** These are also called jute bags. They retain water and keep the samples wet. The bags were available from local market.

2.2 MIX PROPORTION OF SCC and PREPERATION OF SPECIMEN:

There is no standard method for SCC mix design and many academic institutions, admixture suppliers, ready-mixed, pre cast and contracting companies have developed their own mix proportioning methods. Various trials were performed with 0.01 m³ of concrete with locally available materials and checked the fresh property tests (Slump flow, J-ring flow, V-funnel, L-box and U-box) according to the standards of European Guidelines and finalized the mix proportion of M30 grade of SCC, considered as a reference SCC The selection of super plasticizer and its doses where fixed using Marsh Cone. Before finalizing the type of superplasticizer and its dosage, Marsh cone method was used to study the effect of water/cement ratio and dosage of superplasticizer type on cement pastes with different superplasticizer dosages. (Agullo L., et. al. 1999)

Once the mix design was achieved, concrete cubes were cast. Slump Flow Test was carried out on each batch in order to ascertain concrete flow for self-compacting concrete. All concrete batches were prepared in rotating drum mixture. First, the aggregate are introduced and then one-half of the mixing water was added and rotated for approximate two minutes.

Next, the cement and fly ash were introduced with superplasticizer already mixed in the remaining water. Most manufactures recommend at least 5 minutes mixing upon final introduction of admixture. The final mix design for reference mix adopted is shown in Table 4.

Table 4: Mix proportions for reference mix design, Materials/m³

Refer ence Mix	Ceme nt Kg	Fly- Ash Kg	Fine Aggt. Kg	Coarse Aggt. in Kg		Wat er Lit.	SP
				Grit	Grave l		
M30 SCC	375	175	785	0	735	214. 5	1.07 %

2.3 TESTS CONDUCTED ON FRESH SCC:

Various tests such as Slump flow & T50 test, J-Ring test, L-Box test, U-Box test & V-funnel test were performed to study the workability of SCC. Test results and their acceptance criteria as per EFNARC are listed in Table 5.

2.4 CURING METHODS USED:

Three specimens were cured for each selected techniques of curing namely normal water immersion, hot water, ice, sea water & wet covering.

Water immersion: The specimens are placed in a water shallow pond immediately after de-moulding. They remain in pond continuously till the day of testing.

Hot Water Curing: In this test the specimen are placed in airtight oven within 30 min of adding water. The oven is brought to temp 93 C in an hour time and kept this temperature for 5 hours. The specimen are removed from oven, stripped, cooled and tested within 30min.

Ice curing: The specimens were placed in a ice making drum in an ice factory for the specified period. The temperature inside the drum is maintained at zero °C. The drums were taken out in the morning of the day of testing in order to thaw the ice before testing.

Sea water curing: The sea water was brought to laboratory from bay of Cambay and kept in small drums with specimens inside. This is quite similar to immersion curing.

Wet Covering with Gunny Bags: Wet jute bag covers were placed as soon as the specimens were de-molded to maintain water on the surface of the concrete. They were kept wet continuously for the entire period of experiments.

The various acronyms used for specimens of tests are: M3I for Pond Immersion, M3H for Hot water curing, M3S for sea water, M3B for ice curing and M3W for Wet Covering.

2.5 TESTS CONDUCTED ON HARDENED M30 SCC:

Compressive strength: For compressive strength cubes of 150×150×150mm were cast from reference mix of SCC and kept for different types of curing up to 90 days. Three specimen were tested after 3, 7, 28, 56 and 90 days, using a calibrated compression testing machine of 2,000 KN capacity as per **IS: 516-1959 (2004)**.

Compressive strength $f_c = P/A$, where, P is load & A is area of cube (a)

III. RESULTS AND DISCUSSION:

3.1 Tests results of Fresh SCC:

The overall fresh SCC properties of reference mix are shown in Table 5. The various tests namely Slump flow, L-Box, U-Box, & V-funnel were conducted on fresh SCC reference mix as per EFNARC guidelines. The slump flow test has spread of 620mm. The limiting parameters specified by EFNARC and the results are noted in table 5. It can be observed that the reference mix satisfies all the criteria as per standards specified by EFNARC.

Table 5: Fresh SCC properties of reference mix

Sr. No.	Test Method	Property	Unit	Typical range of values as per EFNARC		Results of Tests
				Min.	Max.	Mix M30
1	Slump-flow	Filling ability	mm	600	800	620
2	T50-Slump flow	Filling ability	sec	2	5	3.8
3	L-box	Passing & Segregation	(h ₂ /h ₁)	0.8	1.0	0.83
4	U-box	Passing & Segregation	(h ₂ -h ₁)	0	30	10.2
5	V-funnel	Filling ability	sec	6	12	9.8

3.2 COMPRESSIVE STRENGTH FOR M30 SCC:

The average compressive strength for various specimens at different ages for M30 SCC is summarized in Table 6.

Table 6: Compressive Strength N/mm² for M30 SCC

Method/ Acronym	Results	Compressive Strength N/mm ²				
		3 Days	7 Days	28 Days	56 Days	90 Days
Immersion M3I	C1	18.3	30.5	35.3	40.1	44.5
	C2	18.7	32.7	35.8	39.2	43.2
	C3	19.6	31.4	33.6	41.9	46.2
	Average	18.9	31.5	34.9	40.4	44.6
	Std. Deviation	0.7	1.1	1.2	1.3	1.5
Hot water M3H	C1	0.0	0.0	33.1	0.0	0.0
	C2	0.0	0.0	32.7	0.0	0.0
	C3	0.0	0.0	34.0	0.0	0.0
	Average	0.0	0.0	33.3	0.0	0.0
	Std. Deviation	0.0	0.0	0.7	0.0	0.0
Ice M3B	C1	17.4	23.1	27.5	32.3	37.5
	C2	16.6	21.8	28.3	32.7	36.2
	C3	17.9	20.9	29.6	34.0	38.8
	Average	17.3	21.9	28.5	33.0	37.5
	Std. Deviation	0.7	1.1	1.1	0.9	1.3
Sea water M3S	C1	18.7	31.8	34.0	39.7	44.9
	C2	21.4	33.1	33.6	38.8	44.5
	C3	20.9	31.0	31.8	38.4	41.9
	Average	20.3	32.0	33.1	38.9	43.7
	Std. Deviation	1.4	1.1	1.2	0.7	1.7
Wet Covering M3W	C1	20.9	29.6	32.3	38.4	44.0
	C2	20.5	30.5	32.7	37.1	43.2
	C3	21.8	29.2	30.5	38.8	44.5
	Average	21.1	29.8	31.8	38.1	43.9
	Std. Deviation	0.7	0.7	1.2	0.9	0.7

It is widely accepted that strength at 28 days is considered as governing strength for concrete mix design. It is observed that for M30SCC, immersion method for curing gives maximum compressive strength 34.9 N/mm², at 28 days; however 90 days strength is 44.6 N/mm², which is 27.9% more than 28 days strength. The good compressive strength can be attributed to proper hydration of cement and reduction in voids due to presence of pozzlonic material like fly ash. The results are in confirmation of the results of the study by **Md. Safiuddin et al. (2007)**.

Hot water curing gives about 95% strength than immersion curing within short period of time. With increased temperature of water during curing, maturity attained is higher which contributes to more strength in less time.

The lowest strength is for ice curing 28.5 N/mm², about 81% of immersion curing. This is due to the reason that at around -3 to -4°C, enough of the pore water will freeze so that hydration will completely stop. (**Grace W.R. Construction products, 2006**).

Sea water curing gives second highest strength about 95% of immersion method at 28 days. It can be observed that SCC is little affected by curing with sea water at later age. This is due to the reason that aggressive salt ions penetrate into the interior portion of the concrete mass and change the hydration mechanism with the formation of some expansive products such as ettringite or frields salt and some leachable/soft compounds. As a result, micro cracks develop within the concrete mass together with leaching action of the newly formed compounds lead to the deterioration of concrete strength. However early age strength gain in sea water is more than water immersion method. This may be due to the accelerating effects of some of the sea salts like NaCl, K₂SO₄ which cause a more rapid dissolution of compounds of cement particularly tricalcium silicate in water and hence facilitates more rapid hydration of concrete. This is in confirmation with **Md. Moinul Islam, et al, (2012)**, who noted that the concrete specimens made by mixing sea

water and cured in plain/sea water shows higher strength deterioration compared to plain water made and cured concrete for relatively longer period of curing.

This indicates that for extreme weather conditions SCC can prove effective for hot weather and sea water conditions while cold weather does not cater sufficient strength.

Wet covering gives 31.8 N/mm², about 91% at 28 days. The higher strength may be attributed to availability of enough moisture for hydration process throughout the curing period.

3.2.1 Relation between Compressive strength and curing technique for M30SCC:

The compressive strength was correlated with age of curing for the different methods of curing by regression analysis using Microsoft Excel software. Fig. 1, 2, 3 & 4 shows correlation between compressive strength and age of curing for immersion and other curing techniques for M30SCC.

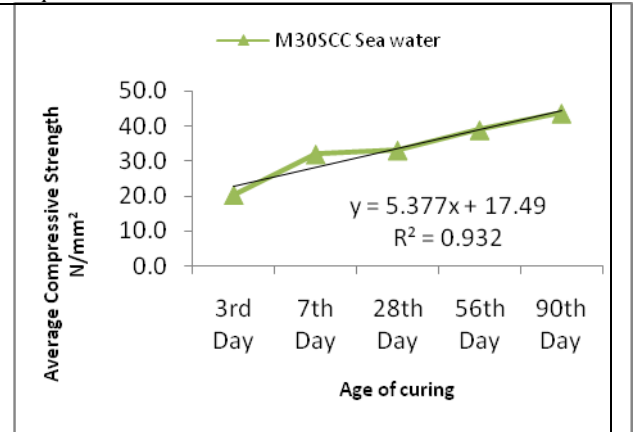
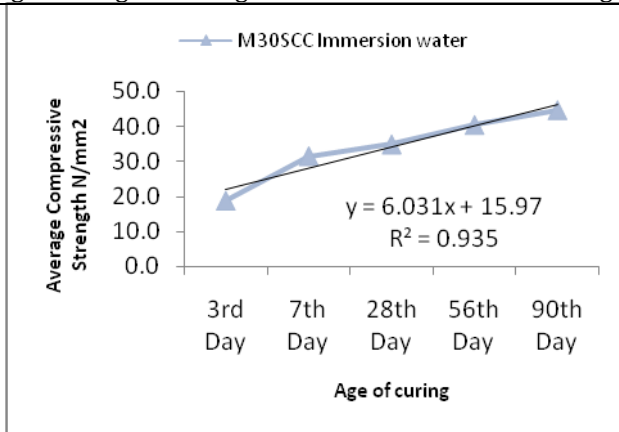


Fig. 1: Relation between compressive strength and Age of curing for water immersion curing for M30SCC

Fig. 2: Relation between compressive strength and Age of curing for sea water curing for M30SCC

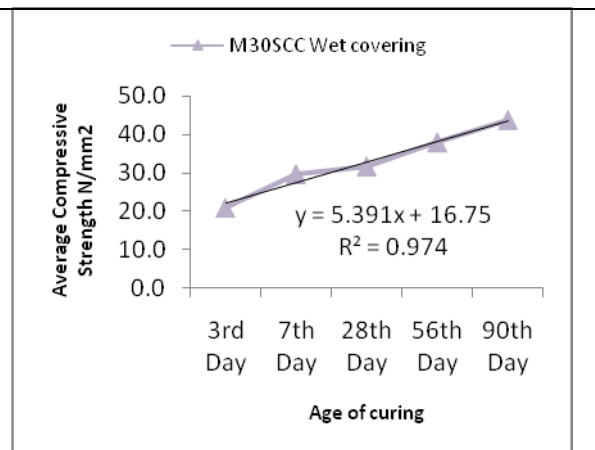
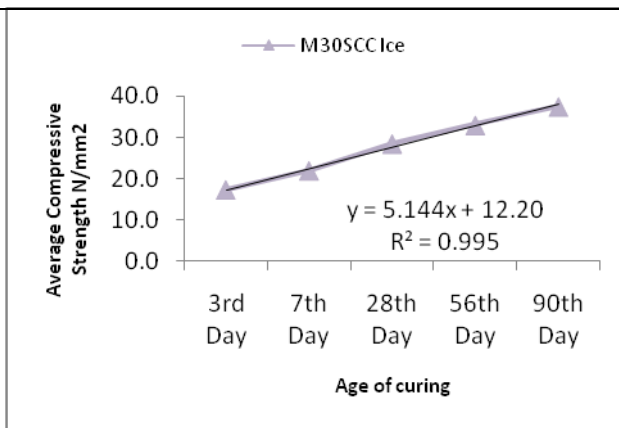


Fig. 3: Relation between compressive strength and Age of curing for ice curing for M30SCC

Fig. 4: Relation between compressive strength and Age of curing for wet covering for M30SCC

For immersion curing the best-fit line exhibited a linear relationship between the compressive strength ranging from 22.0 to 46.1 N/mm². The coefficient of determination for the best-fit line was 0.9357, and the correlation coefficient was 0.967. A similar relationship between the compressive strength and curing of concrete was noticed by other researchers (Neville 1996, Al-Feel J. R. & Al-Saffar N. S. 2008, Jagannadha kumar M.V. et al 2012).

For sea water curing the best-fit line exhibited a linear relationship between the compressive strength ranging from 22.9 to 44.4 N/mm². The coefficient of determination for the best-fit line was 0.933, and the correlation coefficient was 0.966. Refer Fig. 2.

For ice curing the results exhibited a linear relationship between the compressive strength ranging from 17.4 to 37.9 N/mm². The coefficient of determination for the best-fit line was 0.9953, and the correlation coefficient was 0.9976. These values of correlation coefficients show a very good compatibility between two specified properties. Refer Fig. 3.

For wet covering curing the results exhibited a linear relationship between the compressive strength ranging from 22.15 to 43.72 N/mm². The coefficient of determination for the best-fit line was 0.9747, and the correlation coefficient was 0.9873. These values of correlation coefficients show quite good compatibility between two specified properties. Refer Fig. 4.

It can be concluded that for M30SCC, compressive strength increases with age of curing and the rate of increase depends on techniques used for curing of concrete. At 28 days the highest strength achieved through immersion method of curing is 34.9 N/mm² and the lowest strength with ice curing is 28.5 N/mm², about 81% of highest strength. In all the techniques prolonged curing adds to compressive strength of concrete.

3.2.2. Correlation between Compressive strength with immersion method and other selected curing technique for M30SCC:

The compressive strength achieved with immersion method was correlated with compressive strength results with other selected methods of curing by regression analysis using Microsoft Excel software. Fig. 5 shows the above mentioned correlation.

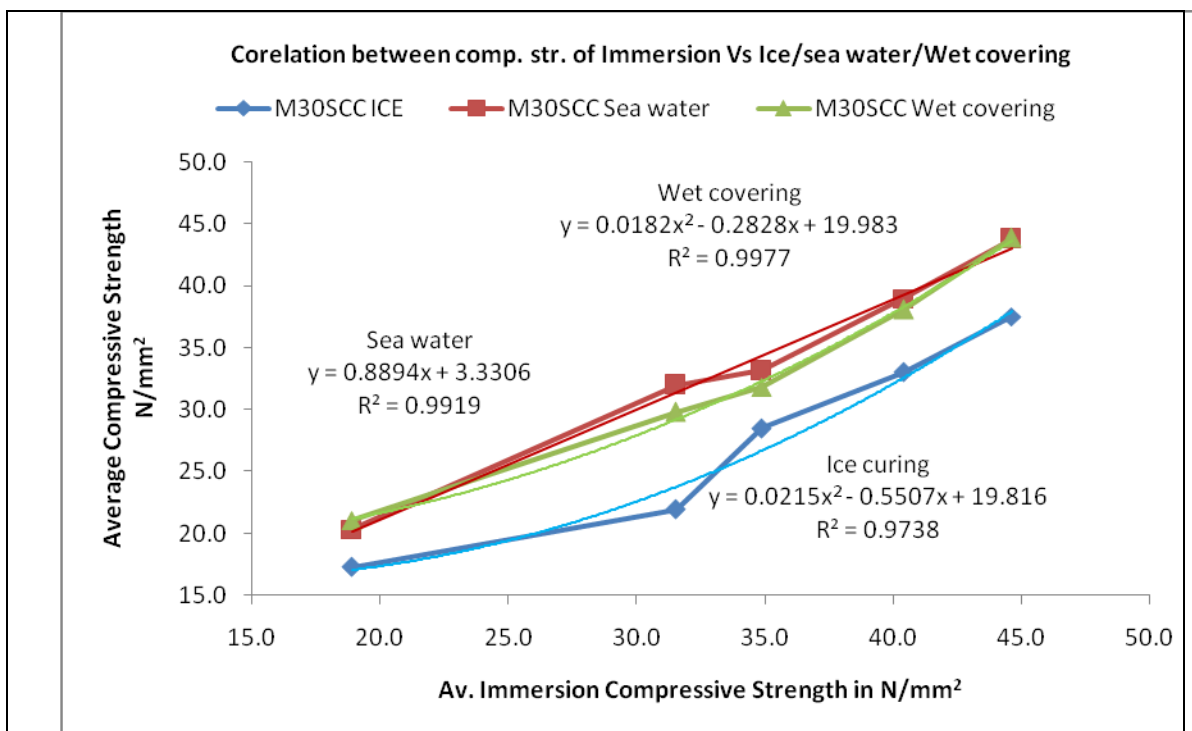


Fig. 5: Correlation between Compressive strength with immersion method and other selected curing technique for M30SCC

Fig. 5, exhibits the correlation between compressive strength of immersion curing and other selected methods of curing in which water is used as supplementary curing medium, for M30SCC. The correlation equation for best fit line, the coefficient of determination and the correlation coefficient is displayed on the graph. These values of correlation coefficients show a good compatibility between two specified properties.

IV. CONCLUSION

- ❑ It has been verified, by using the slump flow, U-tube tests and other tests on fresh SCC that self-compacting concrete (SCC) achieved consistency and self-compactability under its own weight, without any external vibration or compaction.
- ❑ It is concluded from above study that method of curing has considerable effect on the compressive strength of SCC.
- ❑ Immersion curing gives best result for curing in SCC while ice curing is observed to be the weakest.
- ❑ Hot water curing can give good compressive strength within short period of time. This method can prove beneficial in precast industry.
- ❑ Sea water when used for curing of SCC may give higher compressive strength at early age but prolonged curing gives strength lesser than conventional water immersion method.

- ❑ Wet covering method of curing gives almost parallel compressive strength to immersion method strength with saving in water.

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