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Compressive Strength of Medium Strength M30 Grade Self Compacting Concrete Using Water Retaining Curing Techniques

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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 retaining curing techniques on compressive strength of M30 grade self-compacting concrete (SCC) is discussed.*
It is observed that polyethylene film curing gives very good compressive strength at 28 days about 95% of strength achieved through immersion method for curing; however early age compressive strength of specimens cured polyethylene film is more than immersion method. Curing compound method delivers about 92% compressive strength than immersion method, while the lowest compressive strength is for dry curing.
KEYWORDS: *Curing compound, Compressive strength, Dry curing, Immersion curing, Polyethylene film wrap, Self compacting concrete.*

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 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.) and combination of such methods.

Dry curing is a curing method wherein the concrete cubes are left in open air to be cured at room temperature. Researchers have been working on the natural air drying of concrete since long. **Md. Safuddin et al. (2007)** carried out experiments to study the effect of this type of curing on the properties of Microsilica Concrete with a water binder ratio of 0.35. Dry-air curing produced 15.2%, 6.59% and 3.36% reduction in compressive strength, dynamic modulus of elasticity and ultrasonic pulse velocity respectively. This was owing to the early drying of concrete which virtually ceased hydration of the cement because the relative humidity within capillaries dropped below 80% **(Neville A.M., 1996)** and thus the formation of major reaction product, Calcium silicate hydrate the major strength providing and porosity reducer, stops before the pores are adequately blocked by it. Experimental results indicate that Dry-curing is not an efficient method to achieve good hardened properties of concrete.

Md. Safuddin at el. (2007) noted that wrapping curing is more efficient than dry-air curing as it results in greater compressive strength, ultrasonic pulse velocity and dynamic modulus of elasticity and lower surface absorption. This is because wrapped curing moisture movement from the concrete surface was hindered due to the impervious layer of the film and as a result good amount of moisture was available to be used throughout the hydration process.

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).

Curing compounds namely, acrylic and water based are effective in decreasing plastic and drying shrinkage strain for both ordinary and blended cements and the curing efficiency of such compounds with respect to compressive strength are in the range of 84 to 96 percent **(Al-Gahtani, 2010).**

The strength of concrete is affected by a number of factors, one of which is the length of time for which it is kept cured, another being the method by which it is being cured. Inadequate or insufficient curing is one of main factors contributing to weak, powdery surfaces with low abrasion resistance.

In the present paper we have chosen three different methods of curing in which water is not used as supplementary curing medium rather water is retained in the concrete and compared the results of conventional immersion curing method. The different techniques used for curing are:

1. Conventional immersion or pond method – acronym M3I
2. Polyethylene film wrap– M3P,
3. Curing compound – M3C
4. Dry curing – M3N

The effect of these curing techniques on the compressive strength of M30 grade self-compacting concrete (SCC) is studied.

II. MATERIALS & METHODOLOGY

2.1 Materials:

The materials used in developing the reference M30 SCC have following properties:

Cement: Ordinary Portland cement of 53grade (Sanghi brand) with Specific Gravity 3.15, available in local market. The properties of cement used are given in Table 1.

Table 1: Properties of cement

PROPERTY	VALUE	IS CODE: 8112–1989 Specifications
Specific Gravity	3.15	3.10-3.15
Consistency	28%	30-35
Initial setting time	35min	30min
Final setting time	178min	600min
Compressive strength at 7 days N/mm^2	38.49	43
Compressive strength at 28 days N/mm^2	52.31	53

Table 2: Properties of Fly-ash

Constituents	Weight by %
Loss on ignition	4.17
Silica (SiO_2)	69.40
Iron Oxide (Fe_2O_3)	3.44
Alumina (Al_2O_3)	28.20
Calcium Oxide (CaO)	2.23
Magnesium Oxide (MgO)	1.45
Total Sulphur (SO_3)	0.165
Insoluble residue	-
Sodium Oxide (Na_2O)	0.58
Potassium Oxide (K_2O)	1.26

Water: Water is an important ingredient of concrete as it actually participates in the chemical reaction with cement. Potable water was used for mixing.
Fly Ash: Class C Fly ash was used with Specific Gravity 2.13, Vanakbori Thermal Station, Dist. Kheda, Gujarat, India. The properties of Fly ash used are given in Table 2.
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. Dosage of superplasticizer is 1.1% of cementitious material. The properties of superplasticizer are: pH≥6, Chloride ion content<0.2% and light brown liquid in color.
Polyethylene film: Polyethylene film is a lightweight, effective moisture retarder and is easily applied to complex as well as simple shapes. As recommended by ASTM C 171 the specimens were wrapped with 0.01 mm thick transparent plastic film.
External curing compounds: This liquid when applied over the surface of concrete members forms an impermeable membrane that minimizes the loss of moisture from the concrete. Two coats of wax based liquids with brand name FAIRCURE was sprayed over the freshly finished specimen.

2.2 Mix proportion of SCC and preparation 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 m^3 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/m^3	
Reference Mix	M30 SCC
Cement Kg	375
Fly-Ash , Kg	175
Fine Aggt., Kg	785
Coarse Aggt., Kg	735
Water, Lit.	214.5
SP	1.07%

2.3 Tests conducted on fresh SCC:

Tests on fresh concrete were performed to study the workability of SCC. The various tests such as Slump flow, L-Box, U-Box, & V-funnel were conducted on fresh SCC reference mix as per EFNARC while the 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, Polyethylene film wrap, external curing compound and dry curing.

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.

Polyethylene film: The specimen were wrapped with a transparent 0.01 mm thick plastic material after de-molding and are placed over the exposed surfaces of concrete as soon a placed in a semi open place in ambient temperature. Care was taken that at-least three wraps of sheet are placed without marring the finish of specimens.

External curing compounds: Wax based liquids with the brand name FAIRCURE was sprayed over the freshly finished specimen once the free water on the surface has evaporated and there was no water sheen on the surface visible on the specimens. This liquid forms an impermeable membrane that minimizes the loss of moisture from the concrete.

Dry Curing or Air Curing: The specimens after removal of moulds were kept in the ambient temperature without any curing. The specimens were kept outside laboratory in semi open covering. No extra treatment or external water was supplied to specimen. The ambient temperature was between 13- 24 ^{o}C with RH 20 – 35%.

The various acronyms used for specimens of tests are: M3I for Pond Immersion, M3P for Polyethylene film wrap, M3C for curing compound and M3N for Dry curing.

2.5 Tests conducted on hardened M30 SCC:

Compressive strength tests were conducted at different ages of concrete for different methods of curing. For each property, three specimens were tested for each method of curing. Cubes of 150×150×150mm are cast from reference mix of SCC and kept for different types of curing up to 90 days. The specimens are 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	Unit	Typical range of values as per EFNARC		Results of Tests
			Min.	Max.	Mix M30
1	Slump-flow	mm	600	800	620
2	T50-Slump flow	sec	2	5	3.8
3	L-box	(h_2/h_1)	0.8	1.0	0.83
4	U-box	(h_2-h_1)	0	30	10.2
5	V-funnel	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: Average Compressive Strength N/mm^2 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
Polyester Film M3P	C1	23.1	26.2	33.1	38.4	43.2
	C2	22.7	27.0	32.7	37.1	41.4
	C3	24.0	27.5	34.0	36.6	41.9
	Average	***23.3***	***26.9***	***33.3***	***37.4***	***42.1***
	Std. Deviation	0.7	0.7	0.7	0.9	0.9
Curing compound M3C	C1	15.3	21.8	33.1	37.1	40.5
	C2	15.7	22.7	32.3	35.8	39.2
	C3	14.8	22.2	30.5	36.6	39.7
	Average	***15.3***	***22.2***	***32.0***	***36.5***	***39.8***
	Std. Deviation	0.4	0.4	1.3	0.7	0.7
Dry curing M3N	C1	18.3	21.8	25.7	29.2	33.1
	C2	19.2	23.1	25.3	27.9	30.5
	C3	17.9	22.2	24.9	28.3	31.8
	Average	***18.5***	***22.4***	***25.3***	***28.5***	***31.8***
	Std. Deviation	0.7	0.7	0.4	0.7	1.3

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/mm^2, at 28 days; however 90 days strength is 44.6 N/mm^2, 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 lowest strength is for dry curing 25.3 N/mm^2. The lower strength is due to unavailability of sufficient water for proper hydration of cement. The results are in confirmation of the results of the study by Md. Safiuddin et al. (2007).

Polyethylene film curing gives second highest strength about 95% of immersion method while curing compound gives about 92%. The better strength is due to the fact that presence of polyethylene film and impervious members of curing compound reduces the evaporation loses leaving thereby sufficient water in concrete for hydration. These results of curing compound are in tune with Qureshi L. A. et al. (2010) who concluded that compressive strength of specimens cured by the surface application of chemical compound is decidedly greater than 90 % of that of cured ideally in water tank.

This indicates that Polyethylene film wrap and curing compound can provide an alternative method of curing and sustainability of water can be achieved for curing of concrete where water scarcity is there or the quality of water is not of good standards.

It can be observed from results of dry curing that as in the case of conventional concrete in SCC also curing plays an important role for developing the required strength through the process of hydration. 28 days compressive strength without curing is 25.3 N/mm2 which is 72.5% of immersion strength. However 90 days strength is 91.3% which indicates that with prolonged curing SCC can achieve sufficient strength without curing also.

3.3 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.

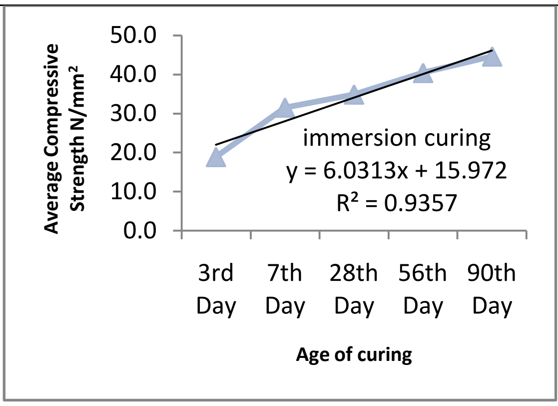

Fig. 1: Relation between compressive strength and Age of curing for water immersion curing for M30SCC

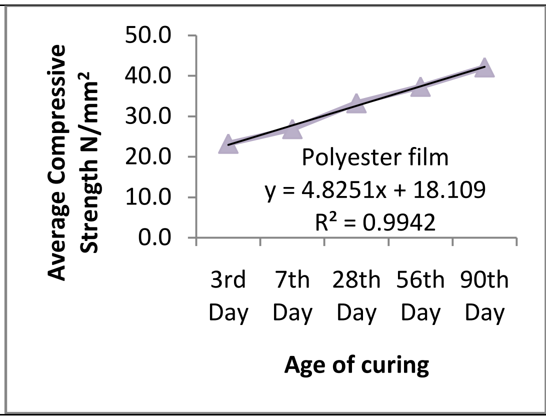

Fig. 2: Relation between compressive strength and Age of curing with Polyethylene film wrap for M30SCC

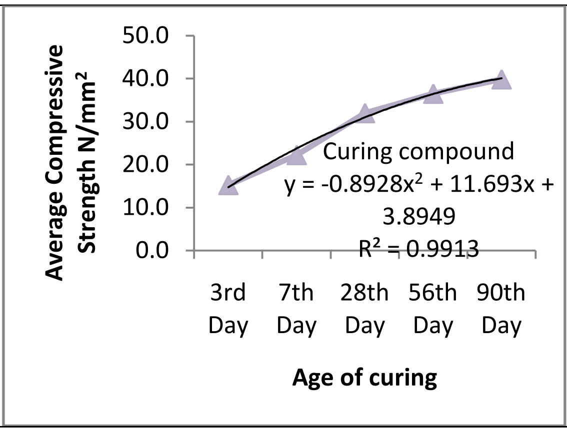

Fig. 3: Relation between compressive strength and Age of curing for curing compound for M30SCC

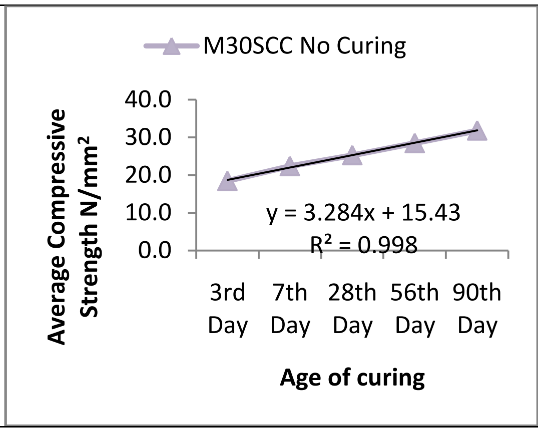

Fig. 4: Relation between compressive strength and Age of curing for dry curing for M30SCC

For immersion curing the best-fit line exhibited a linear relationship between the compressive strength ranging from 22.0 to 46.1 N/mm^2. 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 Polyethylene film wrap curing the best-fit line exhibited a linear relationship between the compressive strength ranging from 22.93 to 42.23 N/mm^2. The coefficient of determination for the best-fit line was 0.9942, and the correlation coefficient was 0.9971. Refer Fig. 2. These values of correlation coefficients show an excellent compatibility between two specified properties.

For curing compound the results exhibited a polynomial relationship between the compressive strength ranging from 14.7 to 40.04 N/mm^2. The coefficient of determination for the best-fit line was 0.9913, and the correlation coefficient was 0.9956. These values of correlation coefficients show a very good compatibility between two specified properties. Refer Fig. 3.

For dry curing the results exhibited a linear relationship between the compressive strength ranging from 18.72 to 31.86 N/mm^2. The coefficient of determination for the best-fit line for dry curing was 0.998, and the correlation coefficient was 0.999. These values of correlation coefficients show an excellent 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/mm^2 and the lowest strength with dry curing is 25.3 N/mm^2, about 73% of highest strength. In all the techniques prolonged curing adds to compressive strength of concrete.

3.4 Correlation between Compressive strength with immersion method and other 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, 6, & 7 shows the above mentioned correlation.

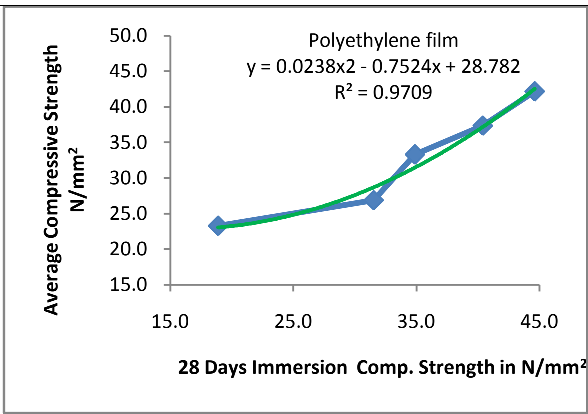

Fig. 5: Correlation between Comp. strength with immersion method and Polyethylene film curing technique for M30SCC

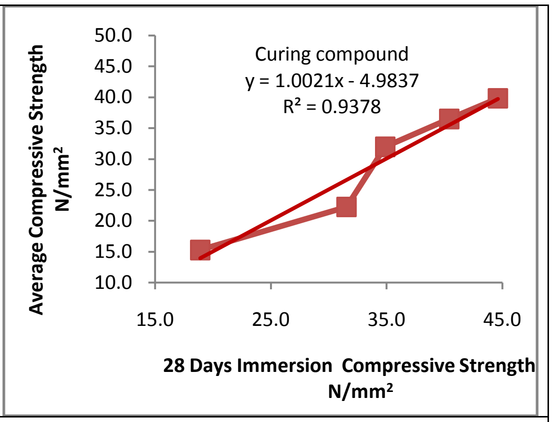

Fig. 6: Correlation between Comp. strength with immersion method and curing compound technique for M30SCC

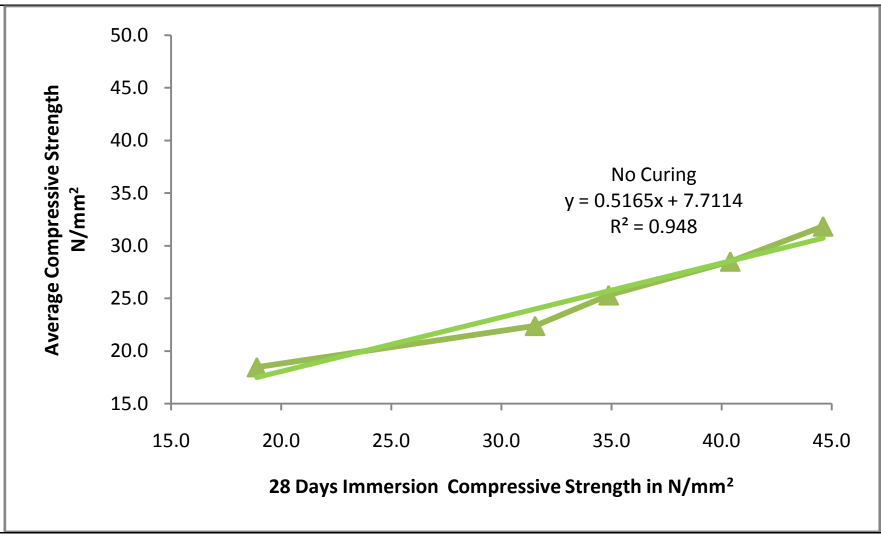

Fig. 7: Correlation between Comp. strength with immersion method and dry curing for M30SCC

Fig. 5, 6 & 7 exhibits the correlation between compressive strength of immersion curing and other selected methods of curing in which water is absent 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 dry curing or no curing is observed to be the weakest. However with prolonged age of 90 days SCC can achieve strengths at par with design strength without curing also.
- Curing with Polyethylene Film can be a good alternate to conventional immersion method especially for surface or inclined members.
- Curing compound and Polyethylene Film methods of curing can be used as an effective method of curing in the area with water scarcity without compromising the design strength of SCC.

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