An Experimental Investigation on Internal Sealing of Self Curing & Self Compacting Concrete Using Higher Molecular Weight of Poly-ethylene Glycol (PEG)

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Abstract— Curing of concrete means maintaining optimum moisture content in concrete during its early stages in order to attain the desired characteristic properties. Proper curing is not possible in many cases due to human negligence, inaccessibility of structures and in areas where fluoride presence is more in water. This investigation is aimed to utilize the benefits of both self-curing as well as self-compacting. The present investigation involves the use of self-curing agent viz., polyethylene glycol (PEG) of molecular weight 4000 (PEG 4000) for dosages ranging between 0.1 to 1% by weight of cement added to mixing water. Two mixes with different w/c ratio were considered in the investigation.

Workability tests i.e. slump flow, T50, V-funnel, J-ring, L-box were conducted on the fresh concrete whereas water retention and compressive strength were evaluated to determine the properties of hardened concrete.

Comparative studies were carried out for water retention and compressive strength for conventional SCC and self-cured SCC. The compressive strength of self-cured SCC are comparable with traditional cured specimens at lower w/c ratio whereas does not provide satisfactory results at higher w/c ratio.

Keywords- self-curing, Hydration, polyethylene glycol (PEG), water retention, compressive strength, Sprinkler curing

Introduction:

Curing is used for promoting the hydration of the cement and controls the temperature, moisture movement from and into the concrete. Curing allows continuous hydration of cement and promotes continuous gain in the strength, once curing stops, strength gain of the concrete also stops. Proper curing of concrete structures is important to meet performance and durability requirements. In conventional curing process, this is achieved by external curing applied after mixing, placing and finishing.

A) Need for self–curing

When the mineral admixtures react completely in a blended Cement system, their demand for curing water (external or internal) can be much greater than that in a conventional ordinary Portland cement concrete. When this water is not readily available, due to depercolation of the capillary porosity, for example, significant autogenous deformation and (early-age) cracking may result. Due to the chemical shrinkage occurring during cement hydration, empty pores are created within the cement paste, leading to a reduction in its internal relative humidity and also to shrinkage which may cause early-age cracking. This situation is intensified in HPC due to its generally higher cement content, reduced water/cement (w/ c) ratio and the pozzolanic mineral admixtures (fly ash, silica fume). The strength achieved by IC could be more than that possible under saturated curing conditions. Often specially in HPC, it is not easily possible to provide curing water from the top surface at the rate required to satisfy the ongoing chemical shrinkage, due to the extremely low permeabilities often achieved.

B)Mechanism of internal curing

The difference in the chemical potentials (free energy) between the vapour and liquid phases cause continuous evaporation of moisture from an exposed surface. Continuous evaporation of moisture takes place from an exposed surface due to the difference in chemical potentials (free energy) between the vapour and liquid phases. The polymers added in the mix mainly form hydrogen bonds with water molecules and reduce the chemical potential of the molecules which in turn reduces the vapour pressure, thus reducing the rate of evaporation from the surface.

C) Advantages of Self-Curing

1) Self-curing (SC) is a method to provide the water to hydrate all the cement, accomplishing what the mixing water alone cannot do.
2) It provides water to keep the relative humidity (RH) high,
3) It keeps self-desiccation from occurring.
4) Eliminates largely autogenous shrinkage.
5) Self-curing reduces labour cost on site.
6) Suitable for the areas where water is scarce.

7) Cracking of concrete provides passageways resulting in deterioration of reinforcing steel,
8) Low early-age strength is a problem,
9) Permeability or durability must be improved,
10) Need for: reduced construction time, quicker turnaround time in precast plants, lower maintenance cost, greater performance and predictability.

1.5 Self-compacting concrete

Self-compacting concrete is basically a concrete which is capable of flowing in to the formwork, without segregation, to fill uniformly and completely every corner of it by its own weight without any application of vibration or other energy during placing. There is no standard self-compacting concrete. Therefore each self-compacting concrete has to be designed for the particular structure to be constructed. However working on the parameters which affect the basic properties of self compacting concrete such as plastic viscosity, deformability, flowing ability and resistance to segregation, self-compacting concrete may be proportioned for almost any type of concrete structure. To establish an appropriate mixture proportion for a self-compacting concrete the performance requirements must be defined taking into account the structural conditions such as shape, dimensions, reinforcement density and construction conditions. The construction conditions include methods of transporting, placing, finishing and curing. The specific requirement of self-compacting concrete is its capacity for self compaction, without vibration, in the fresh state. Other performances such as strength and durability should be established as for normal concrete. The highly fluid nature of SCC makes it suitable for placing in difficult conditions and in sections with congested reinforcement. Use of SCC can also help minimize hearing-related damages on the worksite that are induced by vibration of concrete. Another advantage of SCC is that the time required to place large sections is considerably reduced.

1.6 Principles of SCC mixture design

Small sized and limited coarse aggregate reduce internal stresses causing blockage. HRWRs increase the paste flow,
VMAs increase paste viscosity to reduce segregation and mineral admixtures lower the heat of hydration and enhance the stability.

1.7 Need of Study

A very limited work is reported from this area having the benefits of both self-curing as well as self-compaction. The future for this type of concrete is very bright due to scarcity of skilled man power, non-mechanization of construction industry, abundant availability of construction materials available at very low cost. The properties of this type of concrete, if found satisfactory would be a great step in concrete technology compiling the advantages of both internal curing as well as self consolidation.

2. LITERATURE REVIEW

2.1 Self-Curing Concrete:

Collepardi et al. [4] shows the advantages of the combined use of SRA and CaO-based expansive agent to produce shrinkage-compensating concrete even in the absence of an adequate wet curing. Neither expansive agent nor SRA, when used separately, can definitively and safely avoid the risk of cracking caused by drying shrinkage in real concrete Structures under the practical conditions of curing on many job-sites. The expansive agent used in the study was Cao and the SRA was propylene glycol. The dosage of propylene glycol and Cao was 1.15% and 10% by weight of cement respectively. w/c ratio adopted was 0.45.
Mixes adopted:
a. Mix A (with Cao only)
b. Mix B (with Cao only)
c. Mix C (with Cao and SRA)
d. Mix D (with SRA only)
In the presence of SRA there was a significant reduction in the drying shrinkage due to reduced surface tension of water. Surprisingly SRA does not reduce the water evaporation from concrete when exposed to unsaturated air.
There is a synergistic effect in the combined use of SRA and a CaO-based expansive agent in terms of more effective expansion in the absence of wet curing and lower shrinkage after removing the polyethylene sheet used to simulate the protection from drying before the demolding on the job site. These interesting results should be confirmed by using different type of SRA and/or CaO expansive agent. Preliminary results indicate that this synergistic effect does not exist when a sulfo-aluminate expansive agent is used to form ettringite
Raghavendra et al. [11] carried an experimental investigation with various curing methods adopted in the construction industry especially for vertical structures and compared it with traditional water curing method.
Types of curing done:
1. Air curing
2. Standard Water curing
3. Self-curing
4. Nonstandard water curing
5. Membrane curing
M-50 grade of concrete with constant w/c ratio of 0.3 was adopted.
Tests conducted on specimens:
a. Slump test (on fresh concrete)
b. Compressive strength test (on hardened concrete)

From the results of the investigation, it can be concluded that the concrete cured with selfcuring compound and membrane curing compound have an efficiency of 92.5 % and 90 % respectively when compared to conventionally cured standard water curing method whereas nonstandard water curing and air curing method have an efficiency of 75 % and 70 % respectively when compared to Standard water curing method. Therefore nonstandard water curing and air curing methods has to be avoided at the construction sites otherwise which may leads to loss in strength of concrete. Hence curing of concrete with self-curing compound and membrane curing can be adopted efficiently where performance specifications are important than prescriptive specifications for concrete. No remarkable difference was observed in slump values of both the specimens i.e. with and without self-curing agent.

2.2 Self-Compacting Concrete

Okamura et al. [14] proposed a new type of concrete, which can be compacted into every corner of a formwork purely by means of its own weight. In 1986, he started a research project on the flowing ability and workability of this special type of concrete, later called self-compacting concrete. The Self-Compacting ability of this concrete can be largely affected by the characteristics of materials and the mix proportions. In his study, Okamura (1997) has fixed the coarse aggregate content to 50% of the solid volume and the fine aggregate content to 40% of the mortar volume, so that Self-Compact ability could be achieved easily by adjusting the water to cement ratio and super plasticizer dosage only. After Okamura began his research in 1986, Ozawa [1998] has done some research independently from Okamura, and succeeded in developing self-compacting concrete for the first time.

Zhao et al. [19] studied the effect of initial water-curing period and curing condition on the properties of self-compacting concrete. The properties of SCC under different initial watercuring period and curing condition, i.e. the compressive strength, the flexural strength, the carbonation depth and the chloride ion diffusion coefficient of SCC were investigated. Six different curing regimes were applied to the specimens, the first of which the sample was stored under initial water-curing periods of 3, 7, 14 days, in the remaining three regimes, the samples were continuous full water (FW) curing condition, continuous full standard (FS) curing condition and continuous full room (FR) curing condition.

SCC with the initial water curing period for 7 days has a maximum compressive strength, flexural strength, SCC under FR curing condition has a higher compressive strength, flexural strength than that under FS, FW curing condition. SCC with the initial watercuring period for 7 days and SCC under FR curing condition have a higher strength gaining rate.

SCC under FR curing condition has a lower carbonation depth than that with FS, FW curing condition. The 28-days compressive strength and 28-days carbonation depth of SCC under different initial water-curing period and curing condition have a high correlation.

3.Research Significance

From the literature review carried out on different materials i.e. Light weight aggregate (LWA) and Super absorbent polymers (SAP) it can be concluded that use of these potential materials tend to decrease the mechanical properties of concrete.

Thus in the current program use of shrinkage reducing admixture i.e. PEG has been made in order to get the maximum efficiency in relation to mechanical properties.

Also from the earlier investigation carried out in the institution the dosage has been reduced to 0 to 1% to make the concrete more efficient.

4. SCOPE AND OBJECTIVE OF INVESTIGATION

1. The objective of the investigation is to use the water soluble polymeric glycol, selected from a group consisting of polyethylene glycol (PEG) of average molecular weight (M.W) from 200 to 10000 as selfcuring agent and to decide the optimum dosage for different curing conditions under arid atmospheric conditions.
2. The objective is to study the compressive strength and water retention by varying the percentage of PEG from 0% to 1% by weight of cement for self-compacting concrete and compare it with conventional SCC. Concrete weight loss with time was evaluated to determine the water retention capacity. Slump flow test, J ring test, L box test and V-Funnel test were carried out on the fresh concrete to evaluate the workability of concrete.
3.Two mixes of self-compacting concrete were considered for the study. Polyethylene glycol (PEG) of molecular weight 4000 was used as a self-curing agent in concrete. The concrete mix with and without Self curing agent were subjected to different types of curing i.e. conventional and indoor curing to study the above mention parameters.
4.Other objectives were to compare the effect Polyethylene glycol (PEG) on other grades of SCC and to find out the optimum dosage for each grade.

5 Experimental programme

The experimental program is designed to investigate the strength of self-curing self compacting concrete by adding poly ethylene glycol PEG4000 @ 0.1%, 0.5% and 1% by weight of cement to the concrete. The experimental program is aimed to study the workability, compressive strength and water retention capacity. The slump flow test, J ring test, U box test, L box and V-Funnel test were conducted for all mixes to know the fresh property of concrete. Compressive strength test was conducted at 7 and 28 days. The cubes were weighed for 3, 7,14,21,28 and 56 days from the date of demoulding to investigate the water retention capacity. In this investigation the maximum dosage of self-curing agent was restricted to 1% and minimum dosage to 0.1%. Two different mixes with 28 days cube compressive strengths of concrete were aimed i.e. 70MPa & 50MPa. A total of 90 cubes were cast for the experimental programme. The flow chart of the experimental programme is shown below in figure 4.1

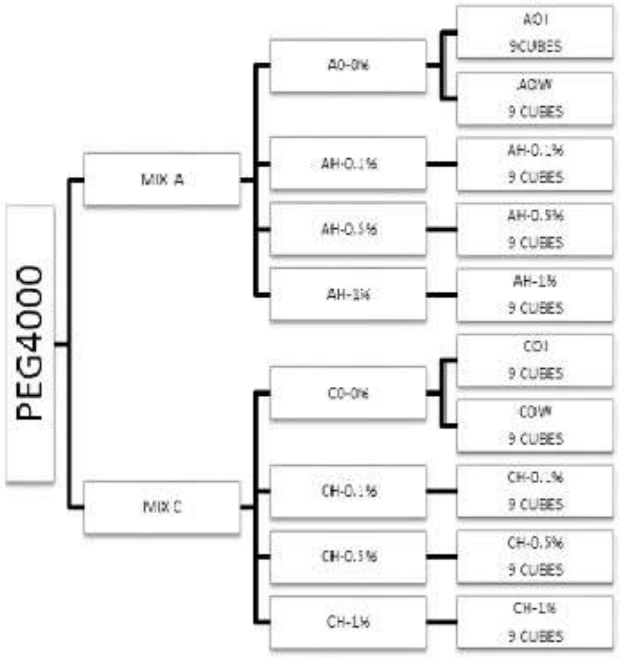

Fig. 5.1 Flow Chart of Experimental Programme

5.1 Nomenclature for specimen

MIX A - 28 days cube compressive strength of about 70 MPa
MIX C - 28 days cube compressive strength of about 50 MPa
O - Ordinary Portland cement (OPC)
PEG - Polyethylene Glycol
H - PEG 4000(Higher Molecular Weight)

I - Indoor Curing
W - Wet/Conventional Curing
SP - Superplasticizer
S.C.A - Self-Curing Agent
SCC - Self-Compacting Concrete

i. For example sample with name AOW represents SCC Mix A with PEG 4000 and dosage of 0% by weight of cement subjected to wet curing.
ii.Sample AOI represents SCC Mix A with PEG 4000 and dosage of 0% by weight of cement subjected to indoor curing.
iii. Sample AH1 represents SCC Mix A with PEG 4000 and dosage of 1% by weight of cement subjected to indoor curing.

5.2 Materials used

The different materials used in this investigation are:

1. Cement
2. Fine aggregate
3. Coarse aggregate
4. Polyethylene Glycol(PEG-4000)
5. Polycarboxylate Ether (superplasticizer)
6. Fly Ash
7. Silica Fume
8. Water

1. Cement- Cement used in the investigation was 53 grade ordinary Portland cement confirming IS: 12269-1987. It was taken from a single lot and stored properly throughout the programme. The physical properties of cement are shown in Table 5.1

Table 5.1 Physical properties of cement

Specific gravity	3.14
Initial setting time	40 min
Final setting time	560 min

2. Fine aggregate: The fine aggregate conforming to zone II according to IS: 383-1970 was used. The fine aggregate used was obtained from a nearby river course. The fine aggregate used was prepared from two types of sand i.e. Sand-I conforming to Zone-I and Sand-II conforming to Zone-III.

50% of Sand-I and 50% of Sand-II was used to obtain Sand- III conforming to Zone-II. The sieve analysis for Sand-I, Sand-II, Sand-III is shown in Tables 5.2, 5.3, 5.4 and the gradation curve obtained in figure 5.2.

Table 5.2 Sieve analysis for Sand-I

Sieve size (mm)	Wt. retained (Kg)	% wt. retained	Cumulative % wt. retained	% passing	ZONE I Grading (IS-383)
10	0	0	0	100	100
4.75	0.003	0.31	0.31	99.69	90-100
2.36	0.1	10.35	10.66	89.33	60-95
1.18	0.38	39.75	50.41	49.58	30-70
0.6	0.37	38.30	88.71	11.28	15-34
0.3	0.093	9.62	98.34	1.65	5-20
0.15	0.016	1.65	100	0	0-10
0.966	SUM	348.4472			
F.M			3.48	ZONE- I	

Table 5.3 Sieve analysis for Sand-II

Sieve size (mm)	Wt. retained (Kg)	% wt. retained	Cumulative % wt. retained	% passing	ZONE I Grading (IS-383)
10	0	0	0	100	100
4.75	0	0	0	100	90-100
2.36	0.01	1.04	1.04	98.95	60-95
1.18	0.1	10.41	11.45	88.54	30-70
0.6	0.18	18.75	88.71	69.79	15-34
0.3	0.52	54.16	84.37	15.62	5-20
0.15	0.15	15.62	100	0	0-10
0.96	SUM	227.08			
F.M			2.27	**ZONE- I**	

Table 5.4 Sieve analysis for Sand-III

Sieve size (mm)	Wt. retained (Kg)	% wt. retained	Cumulative % wt. retained	% passing	ZONE II Grading (IS-383)
10	0	0	0	100	100
4.75	0	0	0	100	90-100
2.36	0.05	5.15	5.15	94.84	60-95
1.18	0.16	16.49	21.65	78.35	30-70
0.6	0.21	21.65	43.30	56.70	15-34
0.3	0.44	45.36	88.66	11.34	5-20
0.15	0.11	11.34	100	0	0-10
0.97	SUM	258.76			
F.M			2.59	**ZONE- II**	

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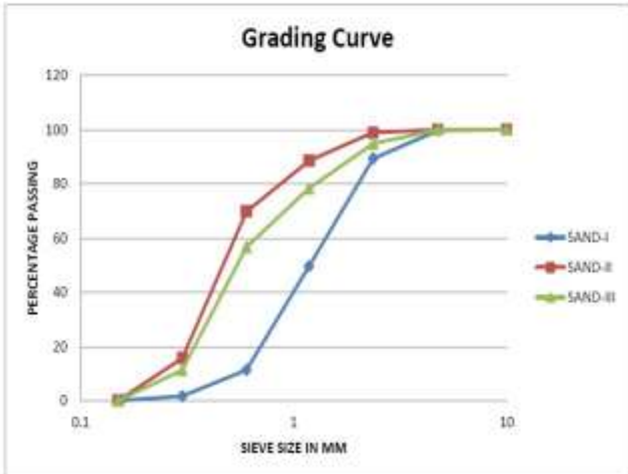
Table 5.4 Sieve analysis for Sand-III



The physical properties of fine aggregate are shown in Table 5.5.

Table 5.5 Physical properties of fine aggregate

Fineness modulus	2.59
Bulk density	1.45 gm/cc
Specific gravity	2.65

3. Coarse aggregate: The coarse aggregate used is procured from a local crushing unit having 20mm nominal size. 20mm well-graded aggregate according to IS-383 is used in this investigation. The coarse aggregate procured from quarry was sieved through all the sieves (i.e. 16mm, 12.5mm. 10mm and 4.75mm). The material retained on each sieve was filled in bags and stacked separately. The sieve analysis for coarse aggregate is shown in Table 5.6 and the physical properties are shown in Table 5.7.

Table 5.6 Sieve analysis for Coarse Aggregate

Sieve size	% Wt. Reta i ned	Cumulat i ve % Wt. Retained	% passin g	% passing for graded aggregate of nominal size 20mm (IS 383)
80	0	0	100	-
40	0	0	100	100
20	0	0	100	95-100
10	70	70	30	25-55
4.75	30	100	0	0-10

Table 5.7 Physical properties of coarse aggregate

Fineness modulus	7.3
Bulk density	1.5 gm/cc
Specific gravity	2.80

4. Polyethylene Glycol-4000: Polyethylene glycol is a condensation polymer of ethylene oxide and water with the general formula H(OCH2CH2)nOH, where n is the average number of repeating oxyethylene groups typically from 4 to about 180. The abbreviation (PEG) is termed in combination with a numeric suffix which indicates the average molecular weight. One common feature of PEG appears to be the water-soluble nature. The chemicals were mixed with water thoroughly prior to mixing of water in concrete. The material was procured from M/S Central Drug House (P) Ltd., New Delhi. The specifications for PEG-4000 are listed in Table 5.8

Table 5.8 Specifications of PEG 4000

Sr. No.	SPECIFICATION	PEG 4000
1	MOLECULAR WEIGHT	3600-4400
2	PHYSICAL FORM	white flakes
3	MOISTURE	0.1% max
4	HYDROXYL VALUE	25 - 35 (mg KOH/g)
5	pH	5 – 7
6	SPECIFIC GRAVITY	1.08 - 1.09
7	SOLUBILITY IN WATER	50-65%
8	MELTING POINT	About 60°C

5. Fly Ash: The fly ash used in the experiment was from Ramagundam thermal power station (NTPC) and was sieved by 150 micron sieved for the experiment. The specific gravity was 2.17. The fly ash had a silica content of 63.99%, silica+ alumina +iron oxide content of 92.7%, Calcium oxide of 1.71% , Magnesium oxide of 1.0%, Sulphuric anhydride of 0.73% , water and soluble salts of 0.04%, pH value of 10 and a loss on ignition of 2.12.

6. Silica Fume: It is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. The main field of application is as pozzolanic material for high performance concrete. The bulk density of silica fume depends on the degree of densification in the silo and varies from 130 to 600 kg/m3. The specific gravity of silica fume is generally in the range of 2.2 to 2.3. It typically ranges from 15,000 to 30,000 m2/ kg.

7. Polycarboxylate Ether: High range water reducing admixture commonly called as super plasticizers was used for improving the flow or workability for decreased water-cement ratio without sacrifice in the compressive strength. These admixtures when they disperse in cement agglomerates significantly, decreases viscosity of the paste forming a thin film around the cement particles. In the present investigation, water-reducing admixture CHRYSO FLUID OPTIMA P-77 (poly carboxylic ether based) obtained from M/S Chryso Chemicals, India was used. The specifications are tabulated below in Table 5.9.

Table 5.9 Specifications of Polycarboxylated Ether

Sr. No.	SPECIFICATION	PEG 4000

1	FORM	Liquid
2	COLOUR	Transparent to Slight Turbid
3	RELATIVE DENSITY	1.1
4	SOLID CONTENT (% BY WEIGHT)	33
5	pH VALUE	7
6	ASH CONTENT	0.018
7	FREE CHLORIDE CONTENT (% BY WEIGHT)	Nil
8	WATER REDUCTION	40%
9	COMPATIBILTY	Compatible with all types of Cement, Fly Ash, GGBS etc.

8. Water: Potable water was used in the experimental work for both mixing and curing purposes.

6. Conclusions

After analyzing the results obtained from the experimental programme, the following conclusions could be made regarding the use of PEG-4000 in case of self-compacting concrete with low as well as high w/c ratios.

6.1 For Water Retention

Increasing the percentage dosage of PEG-4000 increases the weight loss for lower w/c ratio. Thus lower dosage showing better water retention for lower w/c ratio. Increasing the percentage dosage of PEG-4000 decreases the weight loss for higher w/c ratio. Thus for higher w/c ratio higher dosage shows better water retention. Weight loss is more in initial ages compared to later ages for both the grades of concrete. However the loss is more in initial ages for lower grade compared to higher grade. This may be attributed to better sealing of lower w/c ratio in higher grade of concrete. With increase in age of curing, there is general increase in the weight loss. However the loss is more at lower grade as compared to high grade. ÿ Water retention of SCC with low w/c ratio improves with the addition of PEG-4000 and the optimum dosage is found to be 0.1% Water retention of SCC with high w/c ratio improves only at high dosage of PEG-4000. Thus the optimum dosage for high w/c ratio is found to be 1%

6.2 For Compressive Strength

Compressive strength of SCC with lower w/c ratio improves with the addition of PEG-4000 and is almost equivalent to
wet curing. Thus PEG-4000 inclusion proves to be beneficial. The optimum PEG dosage at lower w/c ratio was found to be 0.1%. Compressive strength of SCC with high w/c ratio does not show favorable results and were observed to be less than indoor curing for all the dosages. Thus addition of PEG-4000 for high w/c ratio is insignificant.

7. COMPARATIVE STUDY OF TEST RESULTS

In this chapter with reference to the similar work carried on PEG-4000 for 28 days cube compressive strength of about 60MPa i.e. Mix B, the comparison has been made for water retention and compressive strength so that addition of PEG-4000 can be analyzed.

7.1 Water retention

The conclusions that can be drawn in terms of water

retention are:

Increasing the percentage dosage of PEG-4000 increases the weight loss for lower w/c ratio i.e. Mix A. whereas increasing the percentage dosage of PEG- 4000 decreases the weight loss for higher w/c ratio i.e. Mix B and Mix C. For lower w/c ratio lower dosage of PEG-4000 gives better water retention whereas for higher w/c ratios higher dosage shows better water retention. Weight loss is more in initial ages compared to later ages for all the grades of concrete. However the loss is more in initial ages for lower grades compared to higher grade. This may be attributed to better sealing of lower w/c ratio in higher grade of concrete.

7.2 Compressive Strength

The compressive strength values at the age of 7 and 28 days for all the mixes i.e. Mix A, Mix C.

The conclusions arrived are:

Compressive strength of SCC with lower w/c ratio (Mix A) improves with the addition of PEG-4000 and A) improves with the addition of PEG-4000 and is almost equivalent to wet curing. Thus PEG-4000 inclusion proves to be beneficial. The optimum PEG dosage at lower w/c ratio was found to be 0.1% for Mix A. Compressive strength of SCC with high w/c ratio (Mix B) improves with the addition of PEG-4000 and is higher than indoor curing at all dosages of PEG-4000. The optimum dosage was found to be 1%. Compressive strength of SCC with high w/c ratio (Mix C) does not show favorable results and were observed to be less than indoor curing for all the dosages. Thus addition of PEG-4000 for high w/c ratio is insignificant.

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