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Full Length Research Article

Development of Self-curing Concrete using Polyethylene as Internal Agent

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ABSTRACT

Self-curing or internal curing is a process in which moisture present in the concrete is preserved for more effective hydration of cement and reduced self-desiccation. In this paper, Self-curing concrete of M20, M40 and grades are developed using optimized dosage of polyethylene glycol as internal curing agent. Compressive, split- tensile and flexural strength properties of self-curing concrete mixes are evaluated and exhaustive cost analysis is made on internally and externally cured concrete for economic feasibility.The optimum dosage of polyethylene glycol (PEG) (expressed in percentage by weight of cement) for M20, M40 and grades self-curing concrete are 0.5% and 1% respectively. There is a significant increase of about 5-20% in the compressive, split-tensile and flexural strength properties of self-curing concrete mixes when compared to normal externally cured concrete mixes for all the grades considered for study. This improvement may be attributed to the continuation of the hydration process as a result of continuous availability of water. This result in gin, lower voids and pores , and greater bond force between the cement paste and aggregate. It was found that there is significant cost saving ranging from Rs.2500 -3000 per cubic meter of concrete if internally cured.

Introduction

Self-curing referred as Internal-Curing is a process of controlling the moisture loss from the concrete. Concrete curing methods are basically divided into two groups i.e. Water adding method and Water retaining method. The internal-curing technique is a part of water retaining method. There are two major methods available for internal curing of concrete. The first method uses saturated porous light weight aggregate (LWA) to supply an internal source of water, which can replace the water consumed by chemical shrinkage during cement hydration. The second method uses hydrophilic materials in concrete which reduces the evaporation of water from the surface of concrete and also helps in water retention. In the present study, the second method is adopted. (A Francis, J John, 2013). The use of hydrophilic materials in concrete controls the loss of water and also attracts moisture from the atmosphere which provides continuous curing to concrete. Some special type of materials used in the internal curing process are Lightweight Aggregate (LWA) (natural and synthetic, expanded shale), Super-absorbent Polymers (SAP) and SRA (Shrinkage Reducing Admixture) i.e., propylene glycol, polyvinyl alcohol, Paraffin Wax, Acrylic acid. Mixing water itself cannot help in complete hydration of cement paste whereas internal curing can provide the required amount of water for complete hydration and to maintain the high relative humidity (RH) which prevents self-desiccation. This mechanism produces hard, dense concrete and minimizes shrinkage cracking, thermal cracking.

Proper curing of concrete structures is vital to meet performance and durability requirements. Curing allows incessant hydration of cement and subsequently continuous gain in the strength. Lack of proper moisture conditions virtually slows down the hydration of the cement. Hydration practically stops when the relative humidity within the pores falls below 80%.The conventional curing is achieved by external applied water after hardening of concrete. Self- curing or internal curing is a process of preserving moisture in concrete for more effective hydration of cement and reduction of self-desiccation. When concrete is exposed to the arid environment, evaporation of water takes place therefore loss of moisture will reduce the initial water-cement ratio which will result in the incomplete hydration of the cement affecting the quality of the concrete. Evaporation in the initial stage leads to plastic shrinkage cracking and at the final stage of setting it leads to drying shrinkage cracking. So curing period and temperature are very important factors that affect the strength development rate. At high temperatures, ordinary concrete loses its strength due to the formation of the cracks between two thermally incompatible ingredients, i.e., cement paste and aggregates.

Continuous evaporation of moisture takes place from an exposed surface due to the difference in chemical potentials between the vapour and liquid phases. The chemical polymers added in to the mix as self-curing agents primarily form hydrogen bonds with water molecules and reduce the chemical potential of the water molecules which in turn reduces the vapor pressure subsequently reducing the rate of evaporation from the surface. The mechanism of internal curing is to hold the preserved water content of concrete structures so that they do not require any additional water for curing purpose. It is found that one cubic meter of finished concrete requires about three cubic meter of curing water. Providing water for external curing has so melimitations such as availability of good quality water, lack of accessibility of the structure, limited water cement ratio used in high performance concrete. To counter the above concerns, internal curing is the most appropriate solution. When polyethylene glycol (PEG) is added to water it forms hydrogen bonds which reduces water evaporation from concrete subsequently increasing the cement hydration**.** Rate of hydration increases the amount of solid phase of the paste as water is consumed by chemical reactions of hydration. In addition, water adsorbed onto the surfaces of the solids in the hydration products keeps them saturated maintaining the relative humidity in the paste to evade the phenomenon of self-desiccation. When the relative humidity drops below 80 %, the hydration rate slows down and it becomes negligible when the internal relative humidity drops, to 30%. In the present paper, Self-curing concrete of M20 and M40 grades are developed using optimized dosage of polyethylene glycol as internal curing agent. Workability, water retention capacity, compressive, split-tensile and flexural strength properties of self-curing concrete mixes are evaluated and exhaustive cost analysis is made on internally and externally cured concrete. The effect of internal curing initiates immediately with the initial hydration of the cement, so that its benefits are witnessed at ages as early as 2 or 3 days. Internal curing is advantageous in low water–cement ratio (w/c) concretes because of the chemical shrinkage during hydration and its low permeability. Since the water incorporated into and adsorbed by the cement hydration products has a specific volume less than that of bulk water, a hydrating cement paste will imbibe water (about 0.07gmof water/1gmof cement) from available sources. While in higher w/c concretes, this water is often supplied by external (or surface) curing. In low w/c concretes, the permeability of the concrete is too low to allow the effective transfer of water from the external surface to the interior of concrete. This is the major reason to justify the need for internal curing. If water can be dispersed uniformly throughout the concrete, it will be readily available to migrate to the surrounding cement paste and contribute for the hydration process as required. From the review of literature it is found that the influence of molecular weight and dosage of self-curing agents was not given due significance to study the efficiency of self-curing. This paper focuses on determination of the optimum dosage and the molecular weight of PEG to accomplish efficient self-curing of concrete by studying the water retention by loss /or gain of weight of the specimens. Manufacturing cost of externally cured and internally cured concrete mixes of various grades are also estimated to understand the economic viability.

Materials and mix proportions

Polyethylene glycol

In, this project, after several trials, Polyethylene glycol (PEG) of molecular weight 400 is chosen as self-curing agent. Polyethylene-glycol is a condensation polymer of ethylene oxide and water with the general formula $H(OCH_2CH_2)_nOH$, where n is the average number of repeating ox ethylene groups typically from 4 to about 180.Polyethylene glycol 400 is strongly hydrophilic. After trials, it was found that polyethylene glycol (PEG) of lower molecular weight i.e., PEG 400 is more efficient as a self-curing agent when compared to the PEG of higher molecular weight. Increasing the molecular weight of polyethylene glycol also results in decreasing solubility in water and also past literature reported that hygroscopic capacity decreases as molecular weight increases. Table 1 shows the properties of PEG 400. Table 2 presents the quantities per cu.m. for various grades of concrete.

Table 1. Properties of PEG 400

Property Name	Property Value
Specific gravity	1.12 at 27^{o}C
pH	>6
Molecular weight (gm/mol)	400
Appearance	Clear liquid
Colour	White
Hydroxyl value (mg KOH/gm)	300
Nature	Water soluble
Molecular formula	$H(OCH_2CH_2)_nOH$
Density g/cm^3	1.125

Table 2. Quantities per cu.m. for various grades of concrete

S no	Cement kg	Fine aggregate kg	Coarse aggregate Kg	Water L	Polyethylene Glycol (PEG) L
M20	320.4	727.3	1105.4	173.0	3.20
M40	390.7	776.0	1019.7	164.1	1.95

Reference: *K.Gangadhar et. al., 2017*

Results

This section presents test results of various experimental investigations carried out on various grades of normal cured and self-curing concrete mixes.

Workability

Table 3 presents workability of various grades of concrete mixes incorporated with various dosages of Polyethylene Glycol (PEG 400).

Table 3. Workability of various grades of concrete mixes incorporated with various dosages of Polyethylene Glycol (PEG 400)

Polyethylene Glycol (PEG) Dosage (Percentage by weight of cement)	Slump in mm M20	Slump in mm M40
0 %	90	66
0.5 %	98	69
1%	108	77

Table 4. Compressive strengths of self-curing concrete mixes made with various dosages of Polyethylene Glycol (PEG 400)

Polyethylene Glycol (PEG) Dosage (Percentage by weight of cement)	Compressive Strength at 28 days age of curing M20	Compressive Strength at 28 days age of curing M40
0 % (external curing)	26.90	48.25
0.5 %	27.40	58.15
1%	31.18	48.40
1.5%	26.40	47.60
2%	26.40	47.40

Table 5. Compressive, Split-tensile and Flexural strength properties of normal and self-curing concrete mixes at various ages of curing.

Type	Property	Grade of the concrete	Age of curing (28 days)
Normal concrete (water cured)	Compressive strength Mpa	M20 M40	26.84 49.53
	Split tensile strength Mpa	M20 M40	3.10 4.30
	Flexural strength Mpa	M20 M40	4.46 5.41
Self curing concrete(Air cured)	Compressive strength Mpa	M20 M40	31.18 58.15
	Split tensile strength Mpa	M20 M40	3.55 4.89
	Flexural strength Mpa	M20 M40	5.82 6.90

Table 6. Manufacture cost of normal concrete mixes (Rs. per cu.m)

Grade of Concrete	Cement (a)	Microsilica (b)	Fine aggregate (c) (kg)	Coarse aggregate (d) (kg)	Water (e)	Super plasticizer (f)	Cost / cu.m. (a)+(b)+(c)+(d)+(e)+(f)
M20	320.4 kg x Rs.6 = Rs.1922.40	-	727.3 x Rs.1.8 = Rs.1309.14	1105.4 kg x Rs.0.70 = Rs.773.78	173 L x Rs. 0.50 = Rs.86.50	-	**Rs.4091.82**
M40	390.7 kg x Rs.6 = Rs.2344.20	-	776 kg x Rs.1.8 = Rs.1396.80	1019.7 kg x Rs.0.70 = Rs.713.79	164.1 L x Rs. 0.50 = Rs.82.00	-	**Rs.4536.79**

Table 7. Total Cost of Normal (Externally Cured) Concrete per cu.m.

Grade of Concrete	Cost of Concrete per cu.m (a)	Cost of Water required for external curing of one cu/m. of concrete (b)	Cost of Extra labor required to apply the water externally (c)	Total cost incurred for externally cured Concrete per cu.m. (a)+(b)+(c)
M20	Rs.4091.82	3000L x Rs.0.50 = Rs.1500	400x7 =2800	**Rs.8391.82**
M40	Rs.4536.79	3000L x Rs.0.50= Rs.1500	400x7 =2800	**Rs.8836.79**

Table 8. Total Cost of Self-curing (Internally cured) concrete mixes (Rs. per cu.m)

	Cement (a)	Microsilica (b)	Fine aggregate (c)	Coarse aggregate kg (d)	Water L (e)	PEG (f)	Super plasticizer L (g)	Cost / cu.m. (a)+(b)+(c)+(d)+(e)+(f)+(g)
M20	320.4 kg x Rs.6 = Rs.1922.40	-	727.3 kg x Rs.1.8 = Rs.1309.14	1105.4 kg x Rs.0.70 = Rs.773.78	173 L x Rs. 0.50 = Rs.86.50	3.20 L x Rs.544 = Rs.1740.80	-	Rs.5832.62
M40	390.7 kg x Rs.6 = Rs.2344.20	-	776 kg x Rs.1.8 = Rs.1396.80	1019.7 kg x Rs.0.70 = Rs.713.79	164.1 L x Rs. 0.50 = Rs.82.00	1.95 L x Rs.544 = Rs.1060.80	-	Rs.5597.59

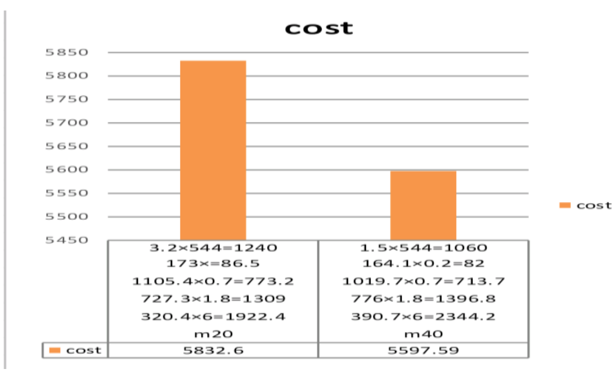

Fig 1. Cost comparison of externally and internally cured concrete per cu.m.

Table 9 Cost comparison of externally and internally cured concrete per cu.m.

	Cost of normal Concrete (External Curing) per cu.m	Cost of self-curing agent (PEG400) incorporated Concrete (Internal Curing) per cu.m	Cost Saving
M20	Rs.8391.82	Rs.5832.62	Rs.2559.20
M40	Rs.8836.79	Rs.5597.59	Rs.3239.20

Cost analysis

Manufacture cost of Normal concrete mixes in Rupees per cu.m is presented in table 6. Total cost incurred for Normal (externally cured) concrete in Rupees per cu.m.is presented in Table 7.Manufacture cost of Self-curing (Internally cured) concrete mixes in Rupees per cu.m. is presented in Table 8. Table 9 compares the rate incurred for externally and internally cured concrete mixes in Rupees per cu.m. For external curing it was estimated that for one cu.m. of concrete at least 3 cu.m or 3000 Liters water is required. Time of application of water externally is about 8hr/day for 7 days continuously at Rs.400 per day as Labor charges. Costs of materials are assumed based on market prices as follows: Cement –Rs6/kg; Micro silica –Rs22/kg; Fine aggregate – Rs1.8/kg and Coarse aggregate -Rs0.70/kg; Water-Rs0.50/L; Super plasticizer-Rs40/kg; Polyethylene Glycol (PEG400)-Rs.544/L

Discussion

In the present study, M20 and M40 grades of external water cured normal concrete specimens and air cured self-curing concrete specimens using optimized dosage of polyethylene glycol as internal curing agent are developed. It is observed that as grade increases workability decreases in self-curing concrete mixes. Similarly as dosage of polyethylene glycol (PEG) increases, workability increased. The optimum dosage of polyethylene glycol (PEG)(expressed in percentage by weight of cement) for M20, M40 and M60 grades self-curing concrete are 0.5% and 1% respectively.

There is a significant increase in the compressive, split-tensile and flexural strength properties of self-curing concrete mixes at all ages of curing when compared to normal externally cured concrete mixes of about 5-20% for the grades considered in this study. This improvement may be attributed to the continuation of the hydration process as a result of continuous availability of water resulting in, lower voids and pores, and greater bond force between the cement paste and aggregate as stated in the previous literature.

It is understood that, the role of self-curing agent polyethylene glycol is to reduce water evaporation from concrete, hence there is an increase in the water retention capacity of self –cured concrete, when compared with normal concrete, which leads to enhanced compressive strength. This improvement in strength is not only due to the ability of concrete to retain water which causes continuation of the cement hydration, but also due to the conversion of calcium hydroxide into CSH. This CSH formed on the surface of aggregate particles strengthens the aggregate-matrix transition zone which becomes less porous and more compact. The research findings of past researchers demonstrated that the PEG is affecting the bond between the aggregate particles and the cement paste. The region between the cement paste and aggregate particles is usually populated by massive crystals of CH, and it is generally believed that the nature of these crystals influences the strength of the cement paste-aggregate bond, which in turn affects the strength of the concrete as a whole. It has been previously reported by other researchers that the addition of the PEG has the effect of altering the morphology of CH in cement pastes. There is evidence from past literature that the PEG is altering CSH gel morphology.

Appears to enhance the nature of the CSH gel, leading to better permeability characteristics. Low dosage of polyethylene glycol is more efficient for achieving self-curing concrete when compared to the higher dosages. Polyethylene glycol of lower molecular weight is found to be more efficient as a self-curing agent when compared to the PEG of higher molecular weight.

In practice, for actual site conditions, the conventional concrete requires water for external curing as well as an extra labor to apply the water to the concrete for a minimum duration of 7days at 8hr/day whereas with the development of internally cured concrete the amount of water applied for external curing and its labor cost can be saved as there is no such requirement of curing in case of internal cured concrete. So an attempt was also made to find out the rate sand compare the cost incurred for the normal concrete and internal cured concrete. It was found that there is significant cost saving ranging from Rs.2500 - 3000 per cubic meter of concrete if concrete is internally cured. DP Bentz, P Lura, JW Roberts, (2005)

Conclusions

From the results obtained in this study the following conclusions can be noted:

- The use of self-curing agent (polyethylene glycol) in concrete mixes improves the strength properties of concretes under air curing regime which may be attributed to a better water retention and causes continuation of the hydration process of cement past resulting in less voids and pores, and greater bond force between the cement paste and aggregate.
- It is observed that as grade increases workability decreases in self-curing concrete mixes. Similarly as dosage of polyethylene glycol (PEG) increases, workability increased.
- The optimum dosage of polyethylene glycol (PEG) (expressed in percentage by weight of cement) for M20, M40 and M60 grades self-curing concrete are 1%, 0.5% and 0.5%respectively.
- It was found that there is significant cost saving ranging from Rs.2500 -3000 per cubic meter of concrete if concrete is internally cured.

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