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Research paper

Effect of polyethylene glycol on the properties of self-curing concrete

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Abstract

Hydration of Portland cement directly effects the development of engineering properties of concrete. It is reported that for sufficient hydration to take place, the relative humidity in the pores needs to be maintained above 80%. It is very important to minimize the loss of moisture from concrete. Curing is the method of regulating the water content of concrete during cement hydration. The objective of this paper is to observe the effect of polyethylene glycol as internal curing agent, on the properties of self-cured concrete of M20, M40 and M60 grades. Compressive, split-tensile and flexural strength properties of self-curing concrete mixes are evaluated and assessment of the quality, structural integrity and compressive strength are made on internally and externally self-cured concrete. The optimum dosage of polyethylene glycol (PEG) (expressed in percentage by weight of cement) adopted for M20, M40 and M60 grades self-cured concrete are 1%, 0.5% and 0.5% respectively. There is a significant increase in the compressive, split-tensile and flexural strength properties self-curing concrete mixes at all ages of curing when compared to normal externally cured concrete mixes of about 5-20% for all the grades considered for study. This improvement could be due to continuous hydration process thus incessant availability of water resulting in less number of pores and voids and stronger bond between the aggregate and cement paste. Non-destruction evaluation studies reveal that all grades of self-curing agent induced concrete are classified as 'excellent' concretes in terms of strength and durability point of view due to improved concrete's pore structure through enhanced hydration and strengthening of interface transition zone.

Keywords: *Self-Curing Concrete; Internal Curing; Polyethylene Glycol; Self-Desiccation; Non-Destructive Tests*

1. Introduction

For effective hydration of concrete,water should be provided for at least 28 days . Any negligence in curing will severely affect the strength and durability of the concrete. Self-curing concrete is a special concrete which offers a solution to mitigate the problem of insufficient curing caused due to human negligence,lack of water in parched areas, lack of accessibility of structures in hilly areas and salts present in the water which can affect the properties of concrete. We should minimize loss of moisture from concrete during early stage.If not the extent of hydration of cement decreases and effects the properties of concrete. [1]. Curing operations should be such that the required amount of water is continuously available for hydration. Curing plays an important role in strength and durability of concrete.Negligence in curing hampers hydration process. Curing and hydration will happen simultaneously. Continuous presence of moisture is required to maintain a R.H. of 80%. If R.H is less than 80% within the capillaries, the hydration stops. In normal curing, R.H is maintained at 80% by external application of water. Self-curing provides more moisture to concrete for perfect hydration of cement and minimizes self-dessication. Upon exposure to environment, evaporation of water leads to moisture loss. This will result in the decrease of water-cement ratio as per design mix which leads to incomplete cement hydration which affects quality of concrete. When the relative humidity is less than 80 %, the hydration rate slows down and it becomes negligible if the internal relative humidity is less than 30 %.

2. Principle of internal curing in concrete

Self Curing is a special concrete gaining importance due to inherit advantages. This type of concrete doesn't need curing some chemicals are added during mixing of concrete and these are responsible for continuous hydration of cement even if there is no external application of water. When PEG 400 is introduced in the mix,it forms hydrogen bonds with water molecules and hence chemical potential of water molecules is lowered. The fall in chemical potential results in reduction of vapour pressure and results in lowering of evaporation rate from surface.The principle of internal curing is to hold the preserved water content of concrete structures within it. So, concrete structures do not require any extra water for curing purposeWater soluble alcohols are generally used as self-curing agents. Internal curing is often referred to as 'Self–curing'. Internal curing provides water to keep the relative humidity (RH) high, preventing self-desiccation from occurring [8]. The materials used as internal curing agents are:Expanded Shale, Propylene glycols like PEG 400 ,SRA (Shrinkage Reducing Admixture)
Self Curing Concrete has better hydration due to water retention compared to traditional concrete [10].

3. Project significance

In the present paper, Self-curing concrete of grades in three ranges M20, M40 and high strength M60 are developed using optimized dosage of polyethylene glycol as internal curing agent. Workability, Weight retention, Compressive, split-tensile and flexural strength characteristics of self-curing concrete mixes are evaluated and investigations are carried out to estimate the quality and properties like structural integrity and compressive strength using Rebound hammer and Ultrasonic pulse velocity tests.

4. Materials and mix proportions

4.1. Polyethylene glycol

In this project, Polyethylene glycol (PEG), a strongly hydrophilic substance having molecular weight of 400 is chosen as self-curing agent. Polyethylene-glycol is a polymer formed by the condensation between ethylene oxide and water,having the general formula H(OCH2CH2)n OH, where n being the average number of oxy-ethylene groups typically ranging from 4 to about 180. Table 1 shows the properties of PEG 400.

Table 1: Properties of PEG 400 (Source: Www.Parchem.Com)

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

Table 2: Presents the Quantities Per Cu.M. Of Different Grades of Concrete

Grade of Concrete	Cement kg	Microsilica	Fine aggregate kg	Coarse aggregate kg	Water L	Polyethylene Glycol (PEG) L	Super plasticizer L
M20	320.4	-	727.3	1105.4	173.0	3.20	-
M40	390.7	-	776.0	1019.7	164.1	1.95	-
M60	436.0	27.8 (6% b.w.c)	779.9	1118.0	120.6	2.32	4.2

5. Research findings

This section presents results of different experimental investigations held on different grades of traditional cured and self-cured concrete mixes.

Figure 1 shows the optimum dosage of PEG 400 (expressed in percentage by weight of cement) to be used in various grades of self-cured concrete.

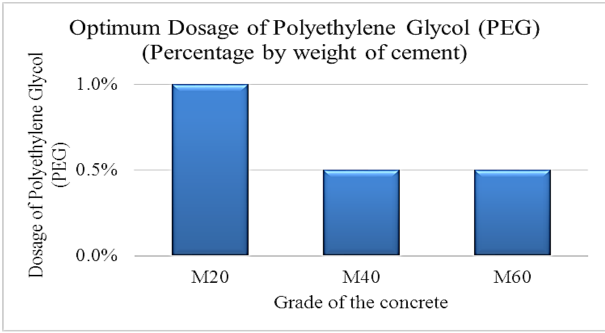

Fig. 1: Optimum Dosage of PEG 400 and Quantity in Litres per CU.M.

Table 3 exhibits the Water retention capacity of self-cured concrete mixes made with optimum dosages of Polyethylene Glycol (PEG 400) in terms of weight loss.

Table 3: Water Retention Capacity of Normal Air Cured and Self-Cured Concrete Mixes

Type	Grade of the concrete cube of size 100mm	Average Weight Loss with age in grams				
		0 days	3 days	7 days	14 days	28 days
Normal Concrete (Air cured)	M20	0	88	113	162	199
	M40	0	35	57	75	97
	M60	0	21	33	45	61
Self-cured Concrete (Air cured)	M20	0	9	17	25	38
	M40	0	6	16	21	28
	M60	0	4	10	17	23

Figure 2 presents the Compressive strength properties of normal and self-curing concrete mixes at 28 days age of curing. Table 4 presents the Compressive, Split-tensile and Flexural strength properties of normal and self-curing concrete mixes at various ages of curing.

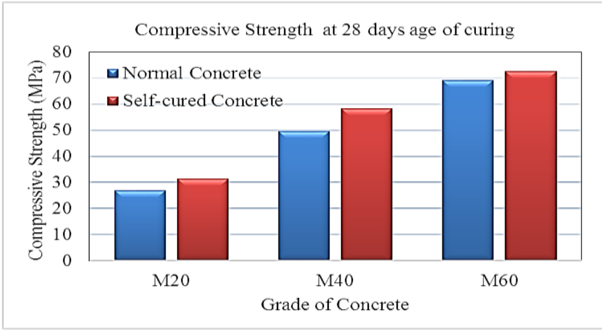

Fig. 2: Compressive Strength Properties of Normal and Self-Curing Concrete Mixes at 28 Days Age of Curing.

Table 4: 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	60 days	90 days	180 days	365 days
Normal Concrete (Water cured)	Compressive Strength (MPa)	M20	26.84	30.90	31.69	32.87	33.51
		M40	49.53	53.78	55.20	56.54	57.38
		M60	69.15	75.49	79.61	84.37	85.92
	Split Tensile Strength (MPa)	M20	3.10	3.18	3.32	3.50	3.52
		M40	4.30	4.41	4.66	4.83	4.87
		M60	4.41	4.49	4.68	4.87	4.89
	Flexural Strength (MPa)	M20	4.46	4.70	4.88	4.94	4.97
		M40	5.41	5.70	5.95	6.13	6.17
		M60	8.23	8.44	8.65	8.74	8.77
Self-cured Concrete (Air cured)	Compressive Strength (MPa)	M20	31.18	36.16	37.52	38.25	38.72
		M40	58.15	63.35	63.65	65.32	65.80
		M60	72.61	79.26	83.59	88.59	90.22
	Split Tensile Strength (MPa)	M20	3.55	3.70	3.85	4.01	4.03
		M40	4.89	5.15	5.38	5.49	5.50
		M60	5.36	5.54	5.65	5.70	5.73
	Flexural Strength (MPa)	M20	5.82	6.02	6.20	6.28	6.28
		M40	6.90	7.11	7.29	7.42	7.44
		M60	9.94	10.10	10.27	10.33	10.36

This section presents experimental investigations to assess the quality and properties of self curing concrete like structural integrity and compressive strength of normal and self-cured M20, M40 and high strength M60 grade concrete mixes using Rebound hammer test and Ultrasonic pulse velocity measurements.

The Rebound Hammer Test is conducted as per IS: 13311 (Part 2) – 1992 on different grades of traditional and self-curing concrete cubes of size 150mm. This test mainly evaluates the quality of surface hardness based on the rebound numbers obtained. Table 5 and 6 presents criteria to determine quality of concrete surface as per IS: 13311 (Part 2) – 1992 and integrity and homogeneity of concrete as per IS: 13311 (Part 1) – 1992 respectively

Table 5: Quality of Concrete Based on Average Rebound Hammer

Average rebound number	Quality of concrete surface
> 40	Very good hard layer
30 to 40	Good layer
20 to 30	Fair
< 20	Poor

Ultrasonic Pulse Velocity Test is conducted as per IS: 13311 (Part 1) – 1992 on different grades of conventional and self-curing concrete cubes of size 150mm. This test qualitatively assesses the integrity and homogeneity of concrete. This test also determined the density and elastic properties of the concrete.

Table 6: Concrete Quality Based on USPV as Per IS: 13311 (Part 1) – 1992

Pulse velocity	Concrete quality
>4.5 km/s	Excellent
3.5 – 4.5 km/s	Good
3.0 – 3.5 km/s	Medium
<3.0 km/s	Doubtful

To make a more realistic assessment of the quality and integrity of concrete, a prudent approach of combined use of Non–destructive tests namely rebound hammer tests and ultrasonic pulse velocity were used. Mean rebound values and mean ultrasonic pulse velocities (USPV) are measured to understand the quality, integrity and strength of self-curing agent incorporated concrete and compare with normal concrete's corresponding properties.
The Table 7 lists the mean rebound values, mean pulse velocity values of different grades of self-curing agent incorporated and normal concrete specimens at 28 age of curing, along with their estimated compressive strengths.

Table 7: Combined Rebound Hammer and Ultrasonic Pulse Velocity Values of Various Grades of Normal and Self-Cured Concrete Mixes

Property	Grade of the concrete	Type of Concrete	
		Normal cured	Self-cured
Mean Rebound Number	M20	25	33
	M40	36	41
	M60	41	48
Mean Ultra sonic Pulse Velocity, km/s	M20	4.26	4.77
	M40	4.49	4.93
	M60	4.89	5.22
Estimated Compressive strength, MPa	M20	28.18	32.74
	M40	51.19	60.17
	M60	72.61	74.21
Quality	M20	Good	Excellent
	M40	Good	Excellent
	M60	Excellent	Excellent

6. Discussions

In the current study, influence of polyethylene glycol as internal curing agent on characterstics of M20, M40 and high strength M60 grades of concrete mixes is evaluated The optimum dosage of polyethylene glycol (PEG) (expressed in percentage by weight of cement) for M20, M40 and M60 grades self-cured concrete are found to be 1%, 0.5% and 0.5% respectively based on the maximum compressive strength attainment. There is a considerable increase in the compressive, split-tensile and flexural strength properties of self-curing concrete mixes of about 5-20% when compared to normal externally cured concrete mixes of all the grades considered for study. This improvement is due to the continuous hydration process due to which continuous availability of water resulting in lower pores and voids and strengthens the bond force between the aggregate and cement paste.
The incorporation of polyethylene-glycol to concrete reduces water evaporation,which leads to an increase in water retention capacity of the concrete eventually leading to improved compressive strength. This improvement in strength is due to incessant cement hydration is becauseof retained water presence and also due to the conversion of calcium hydroxide into calcium silicate hydrate (CSH) strengthening the interface aggregate-matrix transition zone which becomes less porous and more compact. The most likely explanation given by the past researchers is that the PEG 400 is affecting the bond between the cement paste and the aggregate paste which is usually surrounded by massive crystals of CH, having the nature of these crystals effects the strength of the cement paste-aggregate bond, which in turn influences the greater strength of the concrete. Past researchers reported that the addition of the PEG can make changes in the morphology of CH in cement pastes. This appears to enhance the nature of CSH gel, leading to better permeability characteristics.
The rebound index gives an idea about the hardness of concrete upto a certain depth and the internal cracks.It does not indicate heterogeneity along the cross section will not be indicated by rebound numbers. Measuring Ultra Sonic pulse velocity helps in assessing concrete density and modulus of elasticity. Combination of Ultra Sonic Pulse Velocity and Rebound hammer helped in assessing strength and quality It is seen the rebound number values and ¬ultrasonic pulse velocity increased due to refined pore structure and microstructure of hardened self-curing agent incorporated concrete making the concrete highly dense. Similar observation is noted in all the grades of self-curing agent treated concrete specimens. This considerable growth of compressive strength is due to the addition of hydration products which modifies the concrete pore structure by plugging the voids /or the pores within cement–sand matrix, as part of PEG's chemical activity.

7. Conclusions

The following conclusions can be noted through the results of study and experiments:
The use of self-curing agent (polyethylene glycol) in concrete mixes improves the strength also the properties of concretes under regime of which are due to a good water retention. This results in continuous cement hydration and minimum pores and voids.This helps in establishing stronger bond force between aggregate and cement paste. The optimum dosage of polyethylene glycol PEG 400 (expressed in percentage by weight of cement) for M20, M40 and high grade M60 grades self-cured concrete are 1%, 0.5% and 0.5% respectively.
There is a considerable increase in the compressive, split-tensile and flexural strength properties self-curing concrete mixes at all ages of curing when compared to normal externally cured concrete mixes.
It is hereby concluded that for all grades of self-curing agent incorporated concrete, rebound numbers obtained indicate the superior surface hardness than normal concrete and also the USPV measurements were greater than 4.5km/sec which denotes that all grades of self-curing agent induced concrete are classified as 'excellent' concretes in terms of strength and durability point of view due to improved pore structure which also effects durability and mechanical response through enhanced hydration and strengthening of inter facial transition zone whereas controlled concretes are classified from 'good' to 'excellent'.

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