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Effects of Internal Curing Agents On Durability Properties of Concrete

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This study explores the use of internal curing agents (polyvinyl alcohol, polyethylene glycol 400, polyethylene glycol 6000, super absorbent polymer A, and super absorbent polymer C) in M30 grade concrete to enhance its durability and hydration characteristics. Various dosages of each agent are combined with cement, and the effects are evaluated through compressive strength, rapid chloride permeability, acid attack, salt resistance, and degree of hydration tests. Results demonstrate that optimized internal curing significantly improves concrete performance—showing better compressive strength, greater resistance to chloride penetration, acid, and salt attack, and improved hydration compared to conventional concrete. The findings indicate that selecting proper dosages of internal curing agents can make concrete more durable, especially in water-scarce or aggressive environments.

1. Introduction

Concrete is recognised as a versatile construction material globally. Concrete is necessary to gain strength in structures. To attain its strength proper curing should be done. Curing of concrete plays, a major role in developing the strength and hardness of concrete, which leads to the improvement in durability and performance. Curing of concrete is maintaining satisfactory moisture content in concrete during its early ages in order to develop the desired properties. Because, after mixing the cement with water the process of hydration takes place which requires water for cooling purpose. If the water is not provided then shrinkage of concrete occurs which results in cracking. In the past few decades, internal curing of concrete has gained popularity and its steadily progressing from laboratory to field of practice. Internal curing refers to the process by which the Hydration of cement occurs because of availability of additional internal water that is not part of the mixing water; “Internal-Curing” is often also referred as self-curing. Internally cured concrete can be achieved by adding Internal-Curing Admixtures. The concept of internally cured agents is to reduce the water evaporation from the concrete and hence increasing the water retention capacity of the concrete.

1.1 INTERNAL CURING

Self-Curing is also known as Internal-Curing (IC), is a technique by which the hydration of cement occurs due to the availability of additional internal water that is not a part of the mixing water. Which reduces the water evaporation from the concrete and hence increasing the water retention capacity of the concrete.

1.2 NEED FOR INTERNAL CURING CONCRETE

Internal curing helps the concrete to achieve its full potential in an economic and sustainable manner and extremely useful in areas where there is scarcity of water. Internal curing improves hydration, reduces early cracking, and reduces autogenous shrinkage and other shrinkages.

1.3 MECHANISM OF INTERNAL CURING

Continuous evaporation of moisture takes place from an exposed surface due to the difference in chemical potentials (free energy) between the vapor and liquid phases. Thepolymers added in the mix mainly form hydrogen bonds with water molecules and reduces the chemical potential of the molecules which in turn reduces the vapor pressure and retention in physical moisture occurs, this reduces the rate of evaporation from the surface. Difference between conventional curing and internal curing is, while in external curing, water is applied to the surface and depth of water penetration is influenced by several factors like age, quality of concrete etc. where as in internal curing of concrete, the water is distributed throughout the mix. So, that curing of concrete takes place Continuously as shown in Figure 1.1.

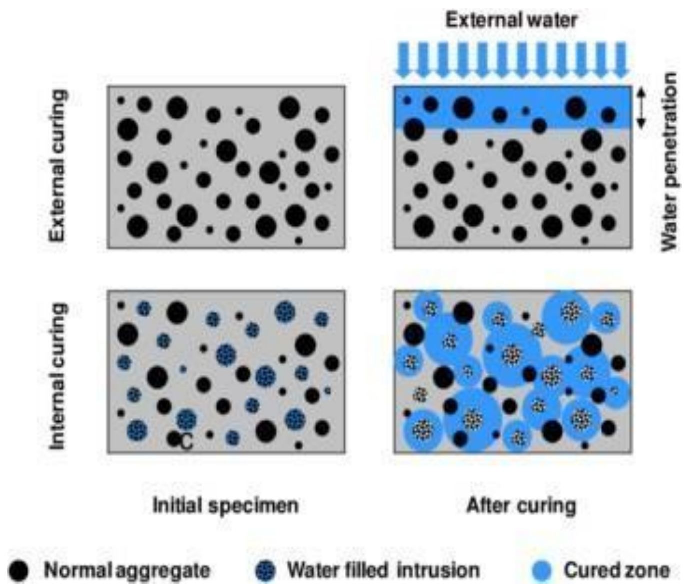


Fig 1.1 External Curing Versus Internal Curing of Concrete.

1.4 ADVANTAGES OF INTERNALLY CURED CONCRETE

Eliminates autogenous contraction. Internal curing agents delivers water to maintain a high relative humidity and prevent self-desiccation. Which offers greater durability and decreases permeability.

1.5 INTERNAL CURING AGENTS:

Polyvinyl alcohol, polyethylene glycol 400, polyethylene glycol 6000 and super-absorbent polymer A and super-absorbent polymer C are used as an internal curing agent.

1.5.1 Mechanism of internal curing agents:

1.5.1.1 Polyvinyl alcohol

Polyvinyl alcohol (PVA) which gives the ability to the concrete to dissipate less quantity of water from it, subsequently expanding the water maintenance capacity of concrete. Polyvinyl alcohol is locally available material Poly vinyl alcohol is a derivative of Poly vinyl acetate it is prepared by hydrolysis of poly vinyl acetate, its physical appearance is colourless to white solid in various forms, it has a specific gravity 1.3, Its PH range is 5.0 - 6.5, it is water soluble, its Molecular formula Is [CH2CH(OH)]. Poly vinyl alcohol is a gel like substance when it is dissolved in water due to this nature the water inside the concrete is enclosed inside this gel so that moisture loss can be reduced. the more amount of self-curing agents is added the workability also increases proportionally.

Table 1.1 Properties of polyvinyl alcohol

SI.No	Properties	Specifications
1.	Appearance	White colored cement powder
2.	Formula	$[CH_2CH(OH)]_n$
3.	pH	5.0 – 6.5

1.5.1.2 Polyethylene glycol 400

Polyethylene Glycol 400 is a clear liquid with an average molecular weight of 400. It is soluble in water and other polar organic solvents. PEG 400 is useful in a wide variety of applications including lubricants, plastics, paper, pharmaceuticals, personal care, and food industries. PEG 400 is useful as a viscosity modifier, plasticizer, and heat transfer agent in many industrial applications. Because it its humectant properties, it can be used in many personal care formulations for ointments and creams. It is also used in gelatine capsules as liquid carriers. Because of PEG 400’s hydroxyl groups, it can also be used as a chemical intermediate.

Table 1.2 Properties of polyethylene glycol 400

SI.No	Properties	Specifications
1.	Appearance	White flake powder
2.	pH	4.5 – 7.5
3.	H(OCH2CH2)nOH	Mean mol. mass 5000 - 7000
4.	Melting point	56 - 61°C

1.5.1.3 Polyethylene glycol 6000

The Polyethylene Glycol (PEG6000) has the chemical formula H(OCH2CH2) nOH, where n is the average number of repeating oxyethylene. The average molecular weight is indicated by a number suffix. El-Nasr Pharmaceuticals Chemicals Company produces obtained PEG6000, a hydrophilic internal chemical SC agent. Fresh concrete is shielded from rapid water evaporation by its chloride-free internal barrier. The PEG6000 specs from the manufacturer are listed in Table 1.3. As an interior chemical cure agent, PEG6000 was used. An electronic micro scope was used in a CEM test to look into the microstructure of PEG6000. The thorough component analysis of PEG6000 was evaluated using the EDS test as well.

Table 1.3 Properties of polyethylene glycol 6000

SI.No	Properties	Specifications
1.	Appearance	White flake powder
2.	pH	4.5-7.5
3.	H(OCH2CH2)nOH	Mean mol. mass 5000 - 7000
4.	Melting point	56 - 61°C

1.5.1.4 Super absorbent polymers

Water-absorbing polymers, which are classified as hydrogels when mixed, absorb aqueous solutions through hydrogen bonding with water molecules. An SAP's ability to absorb water depends on the ionic concentration of the aqueous solution. In deionized and distilled water, SAP may absorb 300 times its weight (from 30 to 60 times its own volume) and can become up to 99.9% liquid, and when put into a 0.9% saline solution the absorbency drops to approximately 50 times its weight. SAP A and SAP C is used in this study listed in table 1.4 and 1.5.

Table 1.4 Properties of super absorbent polymer A

SI.No	Properties	Specifications
1.	Appearance	White fine granular
2.	Particle size	85-50 mesh
3.	pH	6.0 – 7.0
4.	% of moisture	≤ 5

Table 1.5 Properties of super absorbent polymer C

SI.No	Properties	Specifications
1.	Appearance	White fine powder
2.	Particle size	230-100 mesh
3.	pH	5.6 – 6.5
4.	% of moisture	≤ 7

1.6 OBJECTIVES OF THIS STUDY

- ✓ To study the durability behavior of internally cured concrete under different durability test method (Rapid chloride penetration, acid attack and salt resistance).
- ✓ To study the degree of hydration of cement matrix.
- ✓ The main objective of the study is to check and compare by varying the percentage of Polyvinyl alcohol (PVA), polyethylene glycol (PEG) and Super absorbent polymer (SAP) by weight of cement for M30 grade of concrete.

1.7 CONCLUSION

In this chapter the introduction on internal-curing, need for internal curing, advantages of internal curing, mechanism of internal curing and the objectives of the present study were discussed.

2. LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter a detailed literature survey on the topics of internally cured concrete with various curing agents and to study the durability behaviour of Internal curing concrete with various parameters are presented.

2.2 LITERATURE REVIEW

M. Lokeshwari, et.al [1], 2021, experimentally studied the mechanism of self-curing and their impact on utilization of SAP as self-curing agent in order to produce eco-friendly self-curing concrete. The addition of super absorbent polymers accelerates the hydration of cement when extra water is added to compensate the water absorbed by SAP in fresh mixes. The increase of SAP content in the concrete mix caused a reduction in the liquidity of concrete mix. By using Lightweight Expanded Clay Aggregate and PEG 400 as self-curing agents were studied. Mixes with 15% silica fume, 2% PEG and 15% Lightweight Expanded Clay Aggregate was found to increase the compressive strength by 26.5%, 20.6% and 8.8% respectively after 28 days. It is found out that self-cured concrete with self-curing agent PEG with a dosage of 0.02% had less weight loss with time and contained higher non-evaporable water compared with conventional concrete.

Aegula Shravan Kumar, R. Gopi, K. Murali [2], 2021, investigation on Polyethylene glycol-600 admixture in concrete would results in the strength increases compared to conventional curing. The admixture of Polyethylene Glycol-600 on weight, of cement 0.3%, 0.6%, 1%, 2% was studied. At 1% of Poly ethylene Glycol-600 by weight, it achieved maximum compressive strength, split tensile test and flexural strength test. The test result showing that the use of polymer in water soluble has upgrade presentation of concrete and increase of strength criteria.

Gopala Krishna sastry K [3], 2018, studied the usage of PEG, SAP, and Poly Vinyl Alcohol (PVA) in concrete as self-curing agents with dosage percentage of 0%, 0.5%, 1%, 1.5% and 2% by the weight of cement. The concrete strength properties such as compressive strength, flexural strength and split tensile strength were studied. It was found that usage of SAP decreased the strength properties whereas the usage of 1% of PEG achieved the desired concrete strength properties for M 25 grade concrete.

Jagannathan Kumar [4], 2012, experimentally studied the use of shrinkage reducing admixture Polyethylene Glycol – 400 on the physical and mechanical properties of concrete by varying the percentage of PEG 400 by weight of cement from 0% to 2% for M20 and M40 mixes. The use of PEG 400 helped in self-curing by giving strength like conventional curing. It was found that 1% of PEG 400 by weight of cement was optimum for M20, while 0.5 % was optimum for M40 grade concretes for achieving maximum strength without compromising workability.

Noha Yehia Elwakkad, et.al [5], 2022, investigated the impact of self-curing using polyethylene glycol - 400 on RC flat slabs. The findings of this research confirmed the effectiveness of using self-curing concrete in casting the flat slabs to improve their behaviour. Using self-curing concrete by adding PEG 0.5 % minimizes shrinkage, and early concrete desiccation. This was observed 28 days after self-curing the cast samples, in which no hair cracks were observed.

Daniel Cusson et.al [6], 2008, investigated using with different curing agents of large size prismatic high performance concrete specimens under free and restrained shrinkage. In this study pre-soaked light weight aggregate is used as a partial replacement to sand. It was demonstrated that the amount of free shrinkage strain that occurs after the peak expansion strain, which may arise at very young ages, can be used to conservatively assess the likelihood of concrete cracking. In concrete constructions, autogenous expansion, which is seen on the first day for high levels of internal curing, can greatly lower the likelihood of cracking. Compression is where both the elastic and creep strains first appear, allowing the tensile strength to rise even higher before the onset of tensile stresses.

Semion Zhutovsky et.al [7], 2012, Internal curing of high-performance concrete (HPC) with pre-saturated lightweight particles is a well-known way of preventing self-desiccation and autogenous shrinkage. However, the introduction of internal water reservoirs can harm the strength and durability features. Tests using widely established durability assessment methodologies, including as resistance to chloride penetration, air permeability, and water permeability. HPC mixtures with water to cement ratios ranging from 0.21-0.33 were tested for absorption, autogenous and drying shrinkage, and mass loss. The influence of internal curing on the durability-related parameters of high-performance concretes as a function of the water-to-cement ratio is discussed.

Maziar Kazemian et.al [8], 2022, Investigation on internal curing agents on replacing silica fume with natural zeolite for improving the ultra-high performance concrete hydration process. SEM analysis is been conducted and images shows that the natural zeolite is more effective in reducing the amount of un-hydrated cement than silica fume.

R. Davila-Pompermayer, et.al [9], 2020, Internal curing agents R-L, FA-L and MSL, a lechuguilla natural fiber is used to mitigate shrinkage and to improve durability. Properties like compressive strength, static modulus of elasticity, autogenous shrinkage, drying shrinkage, surface electrical resistivity, and the non-steady chloride migration coefficient were measured and analysed as part of their evaluation of the effectiveness of internal curing. For test ages between 14 and 91 days, the addition of internal curing causes an increase in drying shrinkage in the range of 42 to 14%. a result that is ascribed to the fact that free water in the pore network evaporates less and less over time.

M.O. Younis et.al [10], 2022, In this investigation natural resources and building waste like crushed bricks and crushed ceramics are been used in this study. PEG 6000 is used as an internal curing agent. Sorptivity, water absorption, drying shrinkage, and chloride penetration tests are used to determine durability.

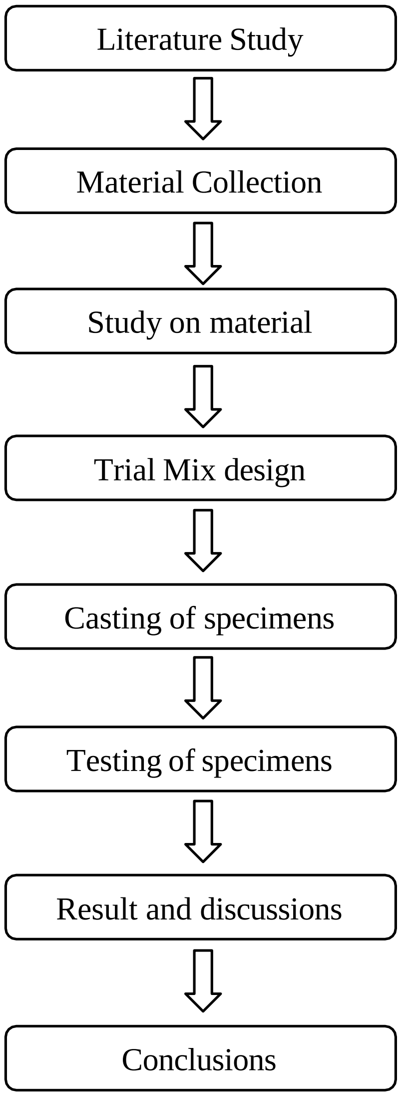
2.3 CONCLUSION

In this chapter, a detailed literature survey was carried out to study the behaviour of internally cured concrete using internal curing agents.

3. METHODOLOGY

3.1 INTRODUCTION

In this chapter, methodology of the project is discussed.



3.2 CONCLUSIONS

The methodology of the whole project is discussed for Phase-2 identifying the problem statement, literature review, material properties are determined and arrived a trial mix design for M30 grade of concrete.

4. MATERIAL PROPERTIES

4.1 INTRODUCTION

By conducting certain material studies, it may be possible to improve the quality of the constituent materials used to produce self-curing concrete. These studies include checking the specific gravity, bulk density, initial and final cement setting periods, and other basic material qualities of internal-curing agents.

4.2 CEMENT

Ordinary Portland Cement (OPC) is the most widely used cement in the world due to its availability and inexpensive cost of production. Ordinary Portland cement with a strength of 52.5 MPa was added to create high strength self-curing concrete. Table 4.1 lists the concrete's physical characteristics. OPC 53 grade chettinad cement was employed in this investigation.

Table 4.1 Physical properties of cement

Properties	Results Obtained	Requirements of IS: 12269
Specific gravity	3.15	3.1 - 3.15
Initial setting time in minutes	90	≥ 30
Final setting time in minutes	240	≤ 600
Standard consistency in %	32%	30 – 35
Compressive strength, MPa	54	> 53

4.3 COARSE AGGREGATE

Natural coarser particle aggregates can be produced by natural rock disintegration, hard stone/gravel grinding, or a combination of the two. As rough aggregate, shattered blue granite stones that adhere to table 2 of IS 383 and graded aggregate of nominal scale 12mm from a nearby quarry are employed.

Table 4.2 Physical properties of coarse aggregate

Properties	Results Obtained	Requirements of IS: 383
Specific gravity	2.78	≥ 2.60
Fineness modulus	2.3	---
Bulk density, kg/m3	1580 kg/m^3	---
Water absorption, %	0.50%	≤ 3.00

4.4 FINE AGGREGATE

Fine aggregate is the essential ingredient in concrete that consists of natural sand or crushed stone. The properties of fine aggregates also have a significant impact on the shrinkage of the concrete.

Table 4.3 Physical properties of fine aggregate

Properties	Results obtained	Requirement of IS: 383
Specific gravity	2.65	≥ 2.60
Sieve analysis	Zone II	2.10 – 3.37
Water absorption, %	0.5%	≤ 3.00
Bulk density	1458 kg/m^3	---

4.5 SUPERPLASTICIZER

An admixture of a new generation based on modified polycarboxylic ether is called Master Glenium SKY 8233. The product was primarily created for high performance concrete applications where the highest level of durability and performance is required.

Master Glenium SKY 8233 has a low alkali content and no chloride. It works with all kind of cements. Table 4.4 shows the properties of superplasticizers.

Table 4.4 Properties of superplasticizers

Properties	Results obtained
Appearance	reddish brown liquid
Relative density	1.08 ± 0.02 at 25°C
pH	≥ 6
Chloride ion content	< 0.2%

4.6 CONCLUSION

This chapter gives detailed information of physical properties and specifications of cement, fine aggregate, coarse aggregate, and superplasticizers were discussed.

5. MIX DESIGN

5.1 GENERAL

To produce concrete of required strength and properties, selection of ingredients and their quantity is to be found which is called concrete mix design. Proper mix design will solve every problem arises in concrete while placing or curing etc. In this chapter a detailed mix design for M30 grade of concrete is arrived according to IS 10262:2019.

5.2 MIX DESIGN CALCULATION

Code books followed- IS 10262:2019; IS 456:2000

Grade	: M30
Type of cement	: OPC Grade 53
Maximum Nominal size of aggregate	: 20mm
Minimum cement content	: Severe (RC), 320kg/m3
Maximum w/c ratio	: 0.45
Workability	: Low (25-75 slump)
Type of Aggregate	: Crushed angular aggregate
Chemical admixture	: Superplasticizer (Master Glenium Sky 8233)
Specific gravity of cement	: 3.15
Specific gravity of coarse aggregate	: 2.8 Specific
gravity of fine aggregate	: 2.68
Specific gravity of chemical admixture	: 1.08 Fine
aggregate grading	: Zone II

STEP 1: TARGET STRENGTH FOR MIX PROPORTIONING

f'ck = fck + 1.65S and f'ck = fck + X

Therefore, the maximum value is taken as target strength.

Where,
S – Standard deviation (From IS 10262 Table 2)
X – Factor based on grade of concrete (From IS 10262 Table 1) f'ck =
fck + 1.65S
= 30+1.65x5
= 38.26 Nmm^{-2}

f'ck = fck + X
= 30 + 6.5
= 36.5 Nmm^{-2}

Therefore, the target strength obtained will be 38.26 Nmm^{-2}.

STEP 2: APPROXIMATE AIR CONTENT

For 20mm entrapped air percentage is 1%. (From Table 3: IS 10262)

STEP 3: SELECTION OF W/C RATIO

From Graph IS 10262: 2019 w/c
obtained = 0.48
From IS 456: 2000, Table 3&5 Exposure (Severe)
Maximum; w/c = 0.45
Therefore; adopted w/c = 0.45

STEP 4: SELECTION OF WATER CONTENT

From Table 4 IS 10262: 2019
Water content = 186 kg (for 50mm slump) 20mm aggregate
Estimated Water Content for 75 mm slump
= 186 + 3% of water content
= 186 + (3x186)/100
= 191.58kg

Hence, Water Content = 191.58 x 0.8
= 153.264
≈ 153kg

STEP 5: CALCULATION OF CEMENT CONTENT

w/c ratio = 0.45
Cement content = 153/0.45
= 342.22kg/m^3
≈ 343kg/m^3

From Table 5 (IS 456: 2000)

Minimum cement content for severe exposure = 320kg/m^3.
Therefore, 343 kg/m^3 > 320 kg /m^3
Hence Ok.

STEP 6: VOLUME OF COARSE AGGREGATE AND FINE AGGREGATE CONTENT

From table 5 IS 10262: 2019 Volume of
CA (Zone II) w/c = 0.62 Therefore w/c =

0.5
For w/c = 0.45; 0.62+0.01 = 0.63

Volume of CA = 0.63
Volume of FA = 1 - Volume of CA
= 1 - 0.36
= 0.37

STEP 7: MIX CALCULATIONS

Calculation per unit volume of concrete

a) Total volume = 1 m^3
b) Volume of entrapped air in wet
c) Volume of cement = (mass of cement/S. G of cement) x (1/1000)
= (340/3.15) x (1/1000)
= 0.107 m^3

d) Volume of water = (153/1) x (1/1000)
= 0.153 m^3

e) Volume of chemical admixture = (2.72/1.08) x (1/1000)
= 0.0025 m^3

f) Volume of all in aggregate = [(1-0.01) - (0.107+0.154+0.0025)]
= 0.727 m^3

g) Mass of coarse aggregate = Volume of all in aggregate x Volume of CA x SG x1000
= 0.727x2.8x0.63x1000
= 1283 kg

h) Mass of Fine aggregate = Volume of all in aggregate x Volume of FA x SG x1000
= 0.727x2.68x0.37x1000
= 721 kg

Table 5.1 Mix proportion for M30 Grade of concrete

W/C RATIO	CEMENT	FINE AGGREGATE	COARSE AGGREGATE
153 kg/ m^3	340 kg/ m3	721 kg/ m3	1283 kg/ m3
0.45	1	2.120	3.773

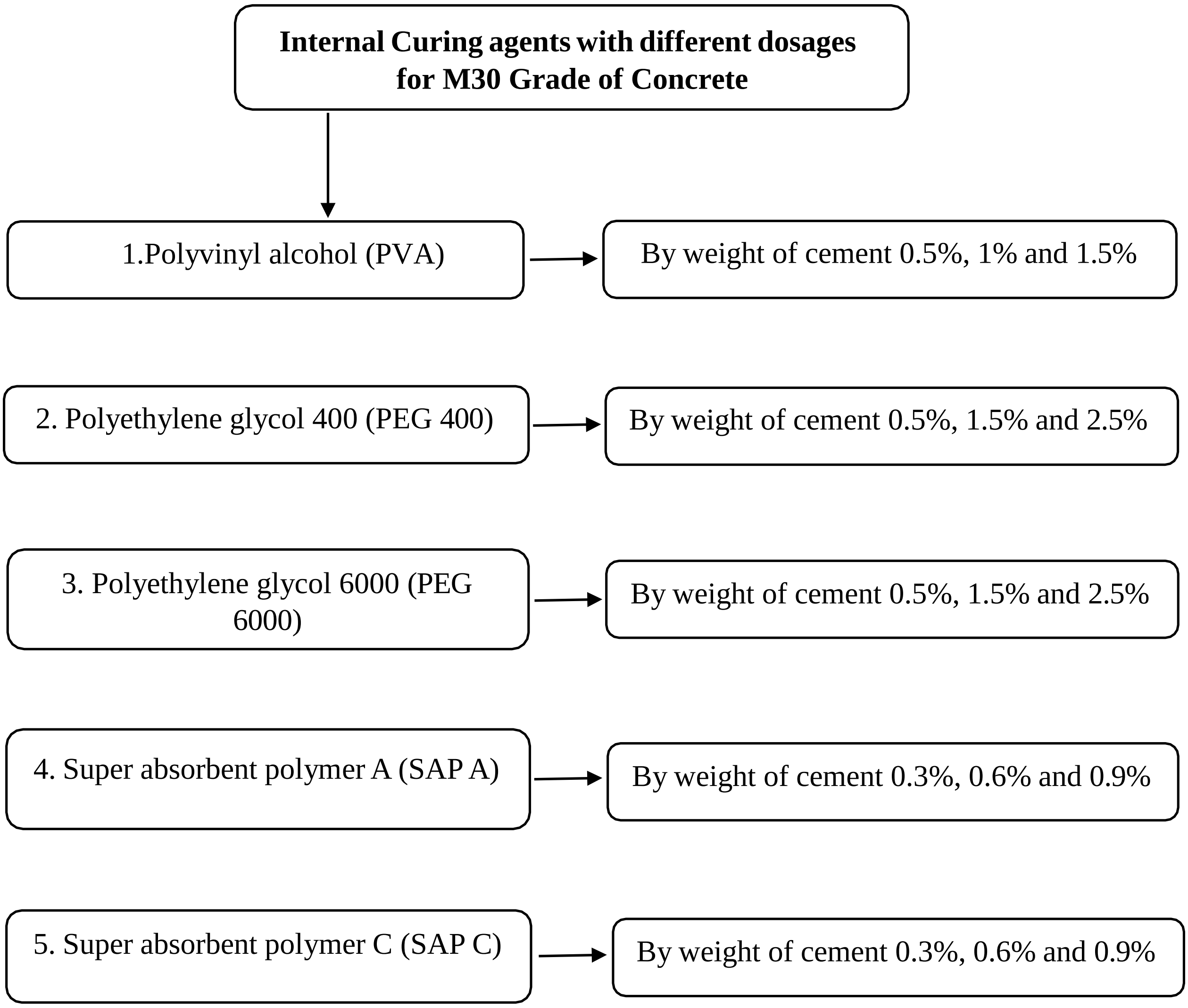
5.3 CONCLUSION

This chapter follows IS 10262:2019 for mix design of concrete mix of grade M30. The mix ratio is determined by the mix design weight batching computation.

6. COMBINATIONS OF INTERNAL CURING AGENTS

6.1 INTRODUCTION

In this chapter, different combinations of internal curing agents are listed below.



6.2 CONCLUSION

These internal curing agents with different dosages are incorporated in this study and comparison of each mix is carried out.

7. CASTING AND CURING OF CONCRETE SPECIMENS

7.1 INTRODUCTION

Concrete plays a vital role to carry out the test using internal curing agents. Hence in this chapter casting procedure and specimen details are discussed.

7.2 CASTING OF SPECIMENS

The concrete mixing process includes both dry and wet mixing. The ingredients M-sand, cement, and coarse aggregate were thoroughly mixed in dry condition. Half of the mixing water is added with curing agents like (polyvinyl alcohol, polyethylene glycol 400, polyethylene glycol 6000, super absorbent polymer A and super absorbent polymer C) are added to the dry mix accordingly, finally Master Glenium SKY 8233 was mixed in the remaining water and added to the concrete mixture and mixed thoroughly. Casting of specimens illustrated in Figure 7.1.

Figure 7.1 Casting of specimens

7.3 CURING PROCEDURE FOR CONCRETE

Concrete curing is the process of retaining sufficient moisture in concrete at the appropriate temperature to allow cement to hydrate at an early stage. Hydration is the chemical process that occurs when cement and water come into contact, resulting in the formation of a range of compounds that help the cement set and harden. The hydration process is influenced by the starting concrete temperature, ambient air temperature, concrete size, and mix design. As a result, self-curing specimens are cured at room temperature, as illustrated in Figure 6.2. Water curing is done for conventional concrete sample.

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Figure 7.2 specimens are ambient cured

7.4 TEST SPECIMEN DETAILS

For each mix, the standard coding for each test must be followed. Table 6.1 shows the test specimen size as well as the code to be used.

Table 7.1 Test specimen details

Test	Specimen size	Code to be followed
Cube compressive strength	100 x 100 x 100 mm (cube)	IS 516 (1959)
Rapid chloride permeability test	100 mm dia x 50 mm height	ASTM C 1202
Acid attack test	100 x 100 x 100 mm (cube)	ASTM C1898-20
Salt resistance	100 x 100 x 100 mm (cube)	ASTM C1012

7.5 CONCLUSION

In this chapter, casting of specimens, curing procedure and specimen details are discussed.

8. TEST ON CONCRETE SPECIMENS

8.1 INTRODUCTION

This section introduces the findings of experimental studies conducted on test samples to assess the properties of internal curing concrete. Efforts were made to evaluate the strength and durability properties of internal curing concrete at different dosages of polyvinyl alcohol (PVA), polyethylene glycol 400 (PEG 400), polyethylene glycol 6000 (PEG 6000), super absorbent polymer A (SAP A) and super absorbent polymer C (SAP C) and results were examined. The strength related properties assessed by compressive strength test. Durability properties namely Rapid chloride permeability test (RCPT), acid attack, salt resistance is conducted. The heat of hydration for each mix is examined and degree of hydration is calculated.

8.2 STRENGTH CHARACTERISTICS

8.2.1 CUBE COMPRESSIVE STRENGTH

The compressive strength of the concrete mix will be tested on 100x100x100 mm cubes in accordance with IS 516 -1959. All the cubes were cured under humidity for the required amount of time. To test compressive strength at the age of 28 days of curing, an average of three specimens is collected with each experiment combination.

The studies were carried out under constant stress once the sample was placed in the centre of the CTM. The load was constantly applied until its direction was reversed. The change in load direction indicates that the sample has failed. The load at that time was recorded as the ultimate load, which is comparable to the compressive strength of concrete when divided by the cross-sectional area of the plane perpendicular to the axis of loading. Figure 8.1 depicts the test setup.

Compressive Strength = $\frac{P}{A}$

Where,

P= Ultimate compressive load of concrete (N)

A = Surface area in contact with the platens (mm^2)

Figure 8.1 compressive strength setup test

8.2.2 RAPID CHLORIDE PERMEABILITY TEST

ASTM C1202 is used for RCPT. This test is used to determine the concrete's ability to resist chloride ion penetration. This test provides an electrical indication of concrete's ability to resist chloride ion penetration. This test predicts the useful life of concrete constructions. It can also be utilised for quality control depending on durability. In this test, a concrete specimen with a diameter of 100 mm and a height of 50 mm is cast and cured for 28 days. The specimen is then placed in a vacuum desiccator for 1 hour before being fixed in the voltage cell depicted in Figure 8.2. To prevent leaking, the specimen is encapsulated with silica gel.

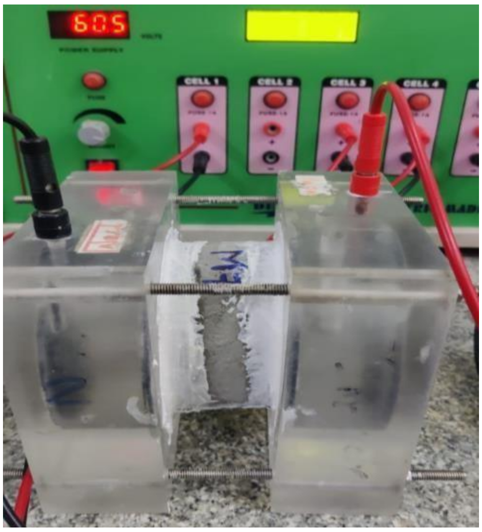

Figure 8.2 Specimen fixed in voltage cell

In the cell, the NaOH and NaCl solution is added at the desired concentrations (3% NaCl per litre of distilled water and 3% NaOH per litre of distilled water). The wires are linked in the voltage cell for 6 hours, a constant voltage (V) is given to a concrete specimen and the current (I) going through the concrete is measured to determine the chloride ion passes in coulombs. Figure 8.3 depicts the test setup. The charge passed (Q) is determined using the formula below.

$$Q = 900\ (I_0 + 2I_{30} + 2I_{60} + ... + 2I_{300} + 2I_{330} + 2I_{360})$$

Where

Q = Charge passed in coulombs.

I_0 = Current (amperes) immediately after voltage is applied and I_t = Current (amperes) at t min after voltage is applied.

Table 8.1 shows how the concrete is classified based on the charges passed in coulombs.

Table 8.1 RCPT test values range as per ASTM C1202

Charge passed in coulombs	Chloride ion penetrability
> 4000	High
2000 - 4000	Moderate
1000 – 2000	Low
100 – 1000	Very low
< 100	Negligible

Figure 8.3 Test setup of Rapid Chloride Permeability Test

8.2.3 ACID ATTACK TEST

To carry out this test, concentrated sulphuric acid was combined with ordinary potable water at a concentration of 10 m/liter (i.e., 1% concentration). The specimens were cured in normal room temperature for 28 days before being submerged in acid for 56 days from the day of casting. Following 28 days of immersion in acid solution, the level of weight loss is discovered. The percentage decrease in compressive strength caused by acid attack is also determined. Figure 8.4 depicts an acid-immersed specimen.

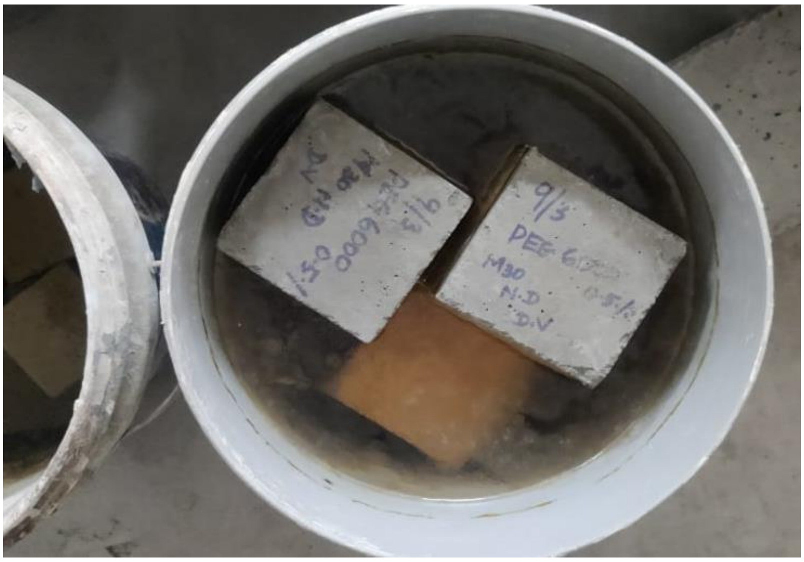

Figure 8.4 Specimens immersed in acid solution

8.2.4 SALT RESISTANCE

To carry out this test, NaCl was combined with ordinary potable water at a concentration of 10 m/liter (i.e., 5% concentration). The specimens were cured in normal room temperature for 28 days before being submerged in salt solution for 56 days from the day of casting. Following 28 days of immersion in salt solution, the level of weight loss is discovered. The percentage decrease in compressive strength caused by salt resistance is also determined. Figure 8.5 depicts a salt-immersed specimen.

Figure 8.5 Specimens immersed in salt solution

8.2.5 DEGREE OF HYDRATION

The heat of hydration of cement is the heat released by the reaction between cement and water. Because of the exothermic nature of this reaction, cement hydration generates a substantial quantity of heat. Cement hydration is a slow process. The hydration process is faster at first and then slows down. The amount of water retained in concrete mix indicates the degree of hydration of the cement matrix. The given formula is to calculate the degree of hydration.
Where,

$$\textit{Degree of hydration} = \frac{W1 - W2}{W2} \times 100$$

W1 – Initial weight of sample after oven dried
W2 – Final weight of sample after kept in muffle furnace

60 grams of cement matrix is crushed into a fine powder figure 8.6 and the samples are oven dried for 24 hours. After oven dried the initial weight is measured in figure 8.7 and the samples are placed in muffle furnace under 1050℃ after 4 hours the samples are weighed and kept in desiccator for cooling purpose shows in figure 8.8.

Figure 8.6 samples are placed in crucible

The initial and final weight of sample is noted and with the given formula degree of hydration is calculated. Figure 8.7 shows the samples placed in muffle furnace.

(a) (b)

Figure 8.7 (a) & (b) Samples are placed in muffle furnace at 1050℃

Figure 8.8 shows the sample after keeping in muffle furnace at 1050℃ and the final weight is measured.

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Figure 8.8 Samples after heat of hydration

Figure 8.9 Samples placed in desiccator for cooling

8.3 CONCLUSION

This chapter describes test techniques in accordance with IS codes and ASTM standards.

9. RESULTS AND DISCUSSION

9.1 INTRODUCTION

This chapter describes the experimental study that was conducted to assess the effects of internally cured concrete utilising various curing agents such as polyvinyl alcohol, polyethylene glycol 400, polyethylene glycol 6000, super absorbent polymer A, and super absorbent polymer C. Strength characteristics like cube compressive strength and durability characteristics like Rapid chloride permeability test, acid attack, salt resistance and degree of hydration test are conducted. The results obtained from the experimental study were discussed in the following section.

9.2 CUBE COMPRESSIVE STRENGTH

Figure 9.1 depicts the compressive strength of cube specimens after CTM failure. For conventional concrete, PVA (0.5%, 1%, 1.5%), PEG400 (0.5%, 1.5%, 2.5%), PEG6000 (0.5%, 1.5%, 2.5%), SAP A (0.3%, 0.6%, 0.9%) and SAP B (0.3%, 0.6%, 0.9%) the compressive strength variation after 28 days of curing is shown.

Figure 9.1 Compressive strength test

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The compressive strength for each mix is determined. Figure 9.2 shows the strength characteristics of control mix, PVA - 0.5%,1% and 1.5%. Comparatively PVA 0.5% gives better results compared to the control mix(CC).

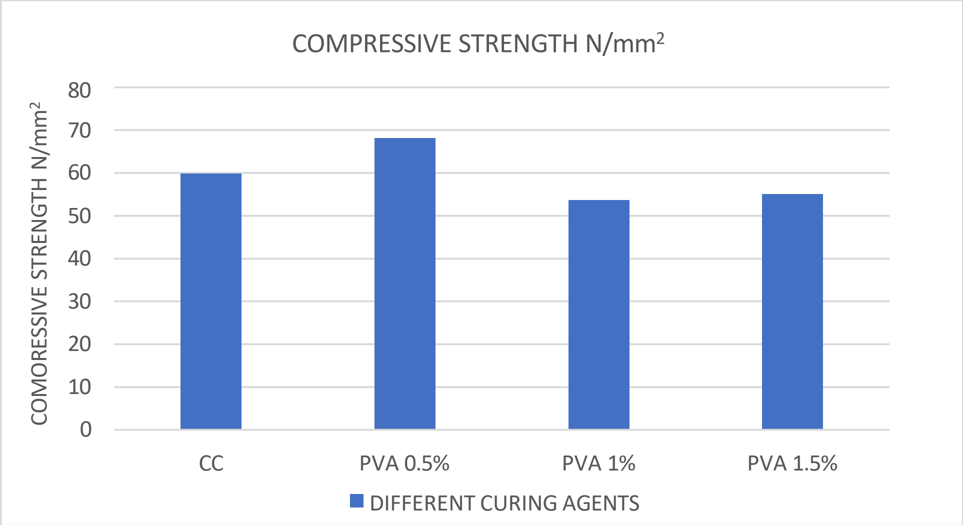

Figure 9.2 Compressive strength for control mix and PVA

The optimum dosage for PEG400 is 1.5%, which gives better strength compared to the other varying dosages. Shows in figure 9.3.

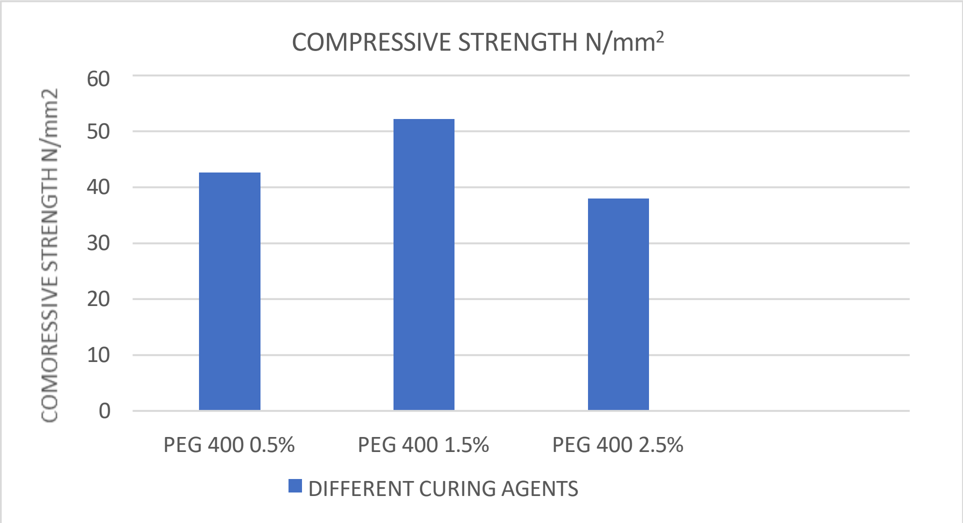

Figure 9.3 Compressive strength of PEG400

Figure 9.4 represents the increased compressive strength of PEG6000, 0.5% compared to the other two varying dosages and control mix (CC).

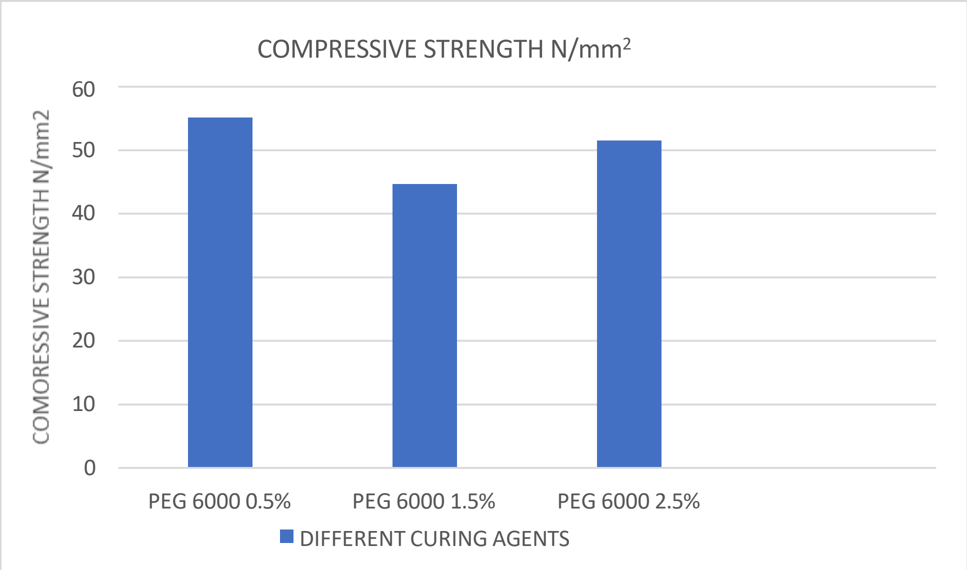

Figure 9.4 Compressive strength of PEG6000

For SAP A 0.6% gives maximum strength compared to SAP A 0.3% and SAP A 0.9% and also found to have increased strength compared to the control mix (CC).

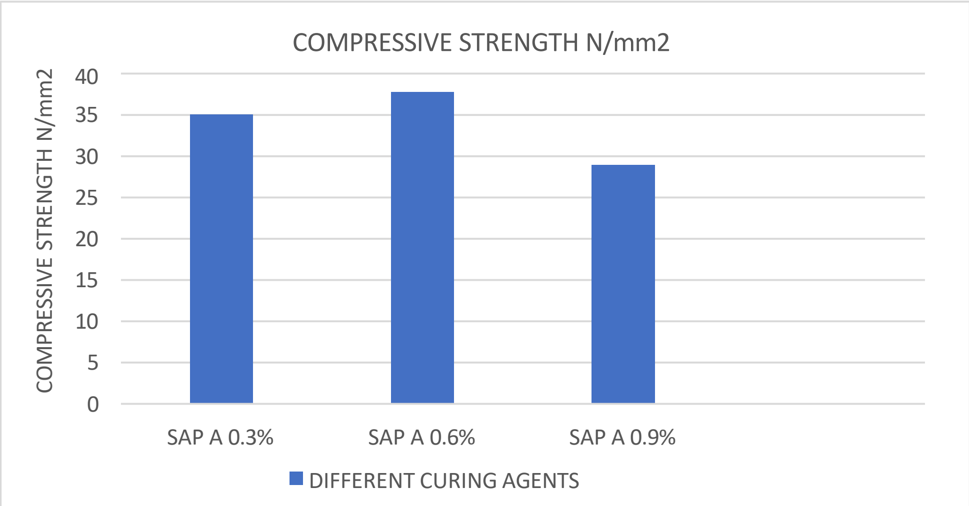

Figure 9.5 Compressive strength of SAP A

Figure 9.6 shows the increased strength of SAP C 0.6% and SAP C 0.9%. These two varying dosages is adoptable.

Compared to all the mixes (PVA, PEG400, PEG6000, SAP) 0.5% among them is found to have better strength on addition to internal curing agents and also comparatively 0.5% gives high strength than the conventionally water cured specimens.

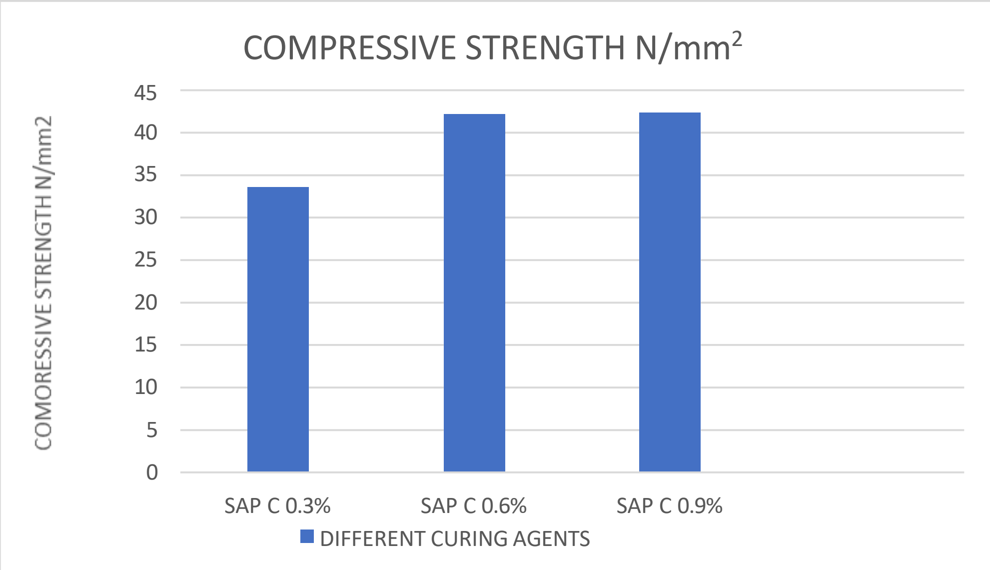

Figure 9.6 Compressive strength of SAP C

9.3 RAPID CHLORIDE PERMEABILITY TEST

After 28 days of curing, a Rapid chloride permeability test (RCPT) is performed on the entire mix. The number of charges passed in coulombs along with ion permeability for each mix is shown in table 9.1. From the above table it is observed that Control mix, PVA 0.5%, PVA 1%, PVA 1.5%, PEG400 1.5%, PEG400 2.5%, PEG6000 0.5%, PEG6000 1.5%, PEG6000 2.5%, SAP A 0.6%, SAP C 0.6% has low ion penetration due to the optimum dosage of curing agents. SAP A 0.3%, SAP A 0.9%, SAP C 0.3%, SAP C 0.9% has moderate chloride ion penetration. PEG400 0.5% has high chloride ion penetration due to pores and improper compaction. PEG400 2.5% has better compared to other mixes.

Table 9.1 Rapid chloride ion permeability after 28 days of Curing

MIX	CHARGES PASSED IN COULOMBS	CHLORIDE ION PERMEABILITY
MIX 1- CC	1252.35	Low
MIX 2- PVA 0.5%	1263.15	Low
MIX 3 – PVA 1%	1364.4	Low
MIX 4 – PVA 1.5%	1428.3	Low
MIX 5 – PEG400 0.5%	4325.4	High
MIX 6 – PEG400 1.5%	1709.55	Low
MIX 7 – PEG400 2.5%	1052.55	Low

MIX 8 – PEG6000 0.5%	1428.75	Low
MIX 9 – PEG6000 1.5%	1658.7	Low
MIX 10 – PEG6000 2.5%	1511.55	Low
MIX 11 – SAP A 0.3%	2588.85	Moderate
MIX 12 – SAP A 0.6%	1994.4	Low
MIX 13 – SAP A 0.9%	2744.1	Moderate
MIX 14 – SAP C 0.3%	2087.55	Moderate
MIX 15 – SAP C 0.6%	1915.2	Low
MIX 16 – SAP C 0.9%	2637.45	Moderate

9.4 ACID ATTACK

After 28 days of curing acid attack test is performed for each mix is shown in figure 9.7. The percentage loss in weight and strength is observed and shown in table 9.2.

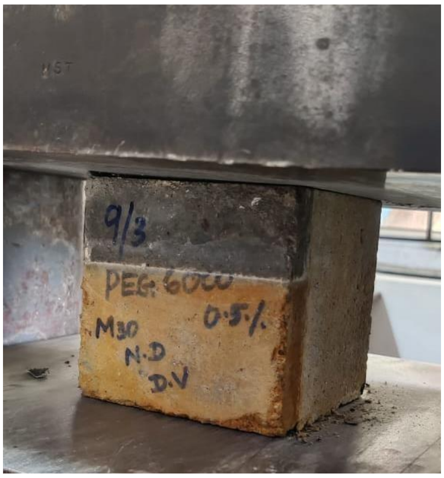

Figure 9.7 Acid immersed specimen after 28 days

Comparatively the strength is varied after immersing in acid solution for 28 days, decrease in Compressive strength for control mix and other varying dosages of internally cured concrete.

There is not much difference in 1.5% PVA, for PEG400 0.5% and 2.5% has increased in strength. PEG6000 0.5% & 1.5% decreased by 3% and SAP A & SAP C has slightly decreased in strength. The optimal dosage which can be adopted in case of acid attack are PVA 1.5%, PEG400 0.5%, PEG6000 0.5%, SAP A 0.6% and SAP C 0.3%.

Table 9.2 Compressive strength after acid attack

MIX	COMPRESSIVE STRENGTH AFTER ACID ATTACK (N/mm^2)
MIX 1- CC	54.202
MIX 2- PVA 0.5%	41.447
MIX 3 – PVA 1%	44.881
MIX 4 – PVA 1.5%	53.465
MIX 5 – PEG400 0.5%	47.333
MIX 6 – PEG400 1.5%	47.088
MIX 7 – PEG400 2.5%	39.241
MIX 8 – PEG6000 0.5%	53.709
MIX 9 – PEG6000 1.5%	42.918
MIX 10 – PEG6000 2.5%	45.371
MIX 11 – SAP A 0.3%	32.896
MIX 12 – SAP A 0.6%	25.257
MIX 13 – SAP A 0.9%	27.267
MIX 14 – SAP C 0.3%	32.382
MIX 15 – SAP C 0.6%	40.912
MIX 16 – SAP C 0.9%	39.567

9.5 SALT RESISTANCE

Salt resistance test of all the mix is carried out after 28 days of curing and specimens after salt resistance is shown in figure 9.8. The percentage loss of weight and strength is noted and shown in table 9.3.

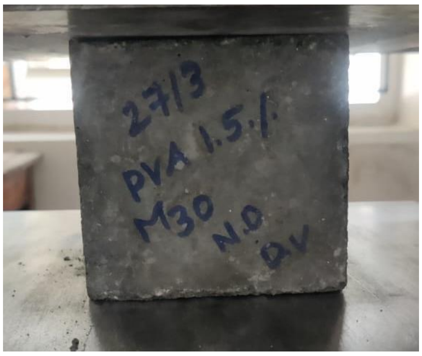

Figure 9.8 Salt immersed specimen after 28 days

Compressive strength characteristics after immersing in salt solution the strength is decreased for each mix. For conventional 10% decrease in strength in found.

The optimal dosage that can be adopted in case salt resistance are PVA 0.5%, PEG400 0.5%, PEG6000 2.5%, SAP A 0.3%, SAP C 0.3%.

Table 9.3 Compressive strength after salt resistance

MIX	COMPRESSIVE STRENGTH AFTER SALT RESISTANCE (N/mm^2)
MIX 1- CC	69.405
MIX 2- PVA 0.5%	57.879
MIX 3 – PVA 1%	37.278
MIX 4 – PVA 1.5%	35.561
MIX 5 – PEG400 0.5%	41.899
MIX 6 – PEG400 1.5%	26.487
MIX 7 – PEG400 2.5%	29.921
MIX 8 – PEG6000 0.5%	32.864
MIX 9 – PEG6000 1.5%	30.902
MIX 10 – PEG6000 2.5%	44.881
MIX 11 – SAP A 0.3%	29.964
MIX 12 – SAP A 0.6%	23.285
MIX 13 – SAP A 0.9%	25.964
MIX 14 – SAP C 0.3%	29.561
MIX 15 – SAP C 0.6%	35.960
MIX 16 – SAP C 0.9%	35.854

9.6 DEGREE OF HYDRATION

Heat of hydration of all the mix is carried out after 28 days of curing process. The 60 grams of sample is taken which is crushed and sieved in 300 microns are shown in figure 9.9.

The amount of water retained is observed for each mix and shown in figure 9.10.

Figure 9.9 cement matrix for hydration process

The amount of water retained in concrete mix indicates the degree of hydration of the cement matrix. By the usage of internal curing agents PVA 0.5%, PEG400 0.5%, PEG6000 0.5%, SAP A 0.6%, SAP C 0.6% gives better results compared to the conventional concrete.

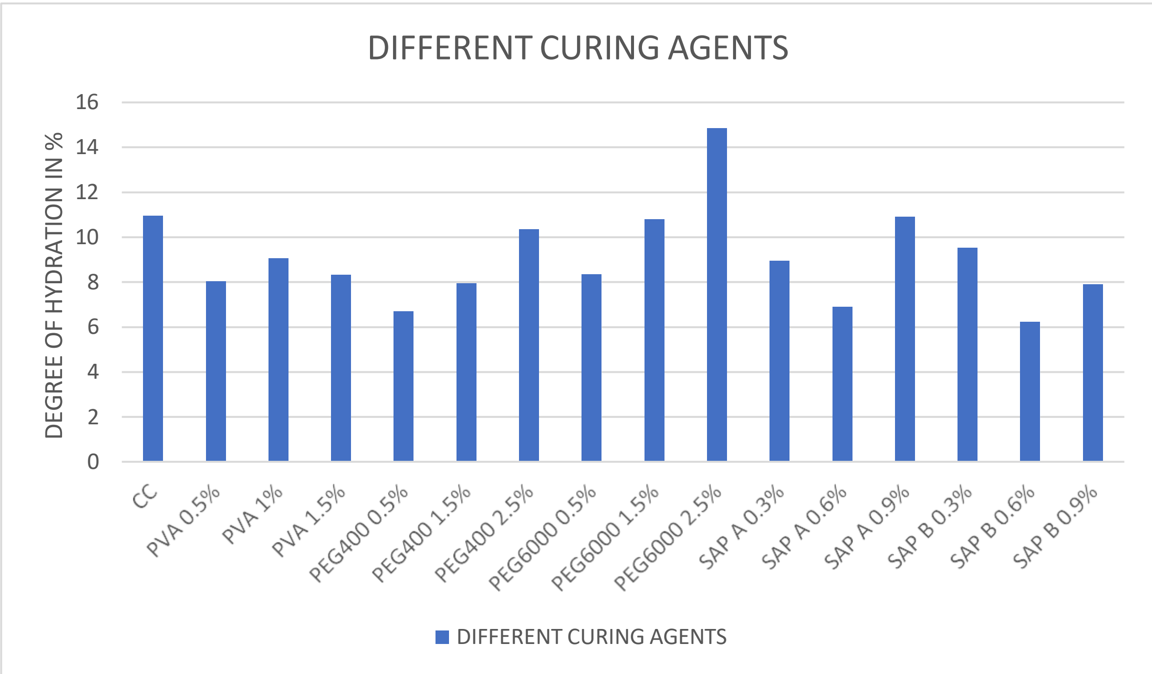

Figure 9.10 Degree of hydration of each mix

9.7 CONCLUSION

In this chapter results and discussion of all the test is conducted for each mix and compared with conventional concrete.

10. CONCLUSIONS

The specimens of cube and cylinder were casted and tested to evaluate the compressive strength characteristics and durability behaviour like rapid chloride permeability, acid attack and salt resistance. And heat of hydration is evaluated for each mix. The following conclusions based on the addition of internal curing agents.

1. The compressive strength of concrete for internally cured specimens gives better results compared to the control mix. PVA 0.5%, PEG400 1.5%, PEG6000 0.5%, SAP A 0.6% and SAP C 0.6% has increased in strength compared to the control mix.
2. The RCPT test results obtained, PEG400 0.5% has high chloride ion permeability compared to other mixes and it is negligible. PVA 0.5%, PVA 1%, PVA 1.5%, PEG400 1.5%, PEG400 2.5%, PEG6000 0.5%, PEG6000 1.5%, PEG6000 2.5%, SAP A 0.6%, SAP C 0.6% has low ion penetration due to the optimum dosage of curing agents. SAP A 0.3%, SAP A 0.9%, SAP C 0.3%, SAP C 0.9% has moderate chloride ion penetration. The low chloride ion penetration is adopted for each mix.
3. The optimal dosage which can be adopted in case of acid attack are PVA 1.5%, PEG400 0.5%, PEG6000 0.5%, SAP A 0.6% and SAP C 0.3%.
4. The optimal dosage that can be adopted in case salt resistance are PVA 0.5%, PEG400 0.5%, PEG6000 2.5%, SAP A 0.3%, SAP C 0.3%.
5. The amount of water retained in concrete mix is calculated. By the usage of internal curing agents PVA 0.5%, PEG400 0.5%, PEG6000 0.5%, SAP A 0.6%, SAP C 0.6% shows better results compared to the control mix.
6. Comparatively in case of PVA 0.5%, PEG400 1.5%, PEG6000 0.5%, SAP A 0.6% and SAP C 0.3% has better results in compressive strength, RCPT, acid attack, salt resistance and degree of hydration.