Strength And Durability Properties of Concrete Using Super Absorbent Polymer as Internal Curing Agent

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Abstract— Study about concrete and its strength parameters has become a wide area of research in the present construction industry. Super Absorbent Polymer (SAP) is a polymer that can be used as an internal curing agent which reduces cracks in concrete, thus avoiding the need for external curing. This paper studies the effect of SAP on the strength properties of concrete. Specimens are cast with varying percentages of 0.1%, 0.2%, 0.3%, 0.4% and 0.5% SAP are tested for various strength parameters. Durability tests like water permeability and rapid chloride penetration test are also conducted. SAP is a polymer that can be used as an internal curing agent which reduces cracks in concrete, thus avoiding the need for external curing. This paper studies the effect of SAP on the strength properties of concrete along with various parameters considered for the evaluation of durability performance.

Index Terms— Super Absorbent Polymer, internal curing, cracks, compressive strength, durability, permeability, external curing

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1 Introduction

Curing is a term used to explain the series promotion of internal chemical reactions in hydrated cement and concrete; this process develops the properties of hardened cement paste with sufficient water and heat over time. Curing promotes hydration, prevents water loss in concrete, and keep the material saturated or nearly saturated if possible or for sufficient time [1]. In 1991, proposed the use of lightweight aggregate to provide additional moisture for the curing of high-strength concrete and developed the concept of internal curing concrete. In 2001, American Concrete Institute (ACI) defined internal curing as 'cement hydration process caused by extra water in concrete other than mixing water' [2].

Presently, there are two common types of internal curing materials for concrete: inorganic porous materials and chemical polymers. Porous ceramic and SAP are the typical representatives of inorganic porous and synthetic polymer internal curing. Presently, there are two common types of internal curing materials for concrete: inorganic porous materials and chemical polymers. Porous ceramic and SAP are the typical representatives of inorganic porous and synthetic polymer internal curing materials, respectively [2]. Super absorbent polymers (SAP s) are a new class of additives to concrete. They are cross-linked polymers which can absorb water equivalent to several times its own mass. Due to cross linking, they are stable in water, take up the water mainly by osmosis in the fresh state of cement paste, mortar, and concrete, and release the water during hydration of cement. This behavior can support internal curing of concrete [3]. SAP ingests water and changes into gel, at that point discharges it gradually with time. From a quality perspective,

the expansion of SAP to concrete needs to inverse while the produce voids in the solid and accordingly diminishes quality, the interior water relieving given by SAP improves the level of hydration and builds the quality [4]. The present paper studies the mechanical and durability properties of concrete using sodium polyacrylate (SAP) as an internal curing agent. A series of experiments have been conducted and the results were evaluated. The strength of the concrete is increased as the bond between the light weight aggregate and the hydrated cement becomes continuous due to decrease in permeability.

2 Experimental Procedure

2.1 Materials

Cement used in the experimental work is ordinary Portland cement (OPC) conforming to IS: 4031 – 1998. The O.P. C was classified into three grades, namely 33grade, 43grade and 53grades depending upon strength of the cement. The cement used for preparing the concrete mix for this study is 53 grade Ordinary Portland Cement with specific gravity 3.15 and the details are shown in Table1. Locally available natural sand with 4.75 mm maximum size was used as fine aggregate. Coarse aggregate is usually greater than 4.75 mm, while fine aggregate is less than 4.75 mm. The properties of coarse and fine aggregates are shown in table 2 and Table 3 respectively. The super absorbing polymer is a chemical substance which can absorb extremely large amount of water relative to its own mass. Water absorbing polymers, which are classified as hydro gels when mixed, absorbs aqueous solution through hydrogen bonding with water molecules. Superabsorbent polymers are commonly made from the polymerization of acrylic acid blended with sodium hydroxide in the presence

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of an indicator to form a poly-acrylic acid sodium salt (sometimes referred to as sodium polyacrylate). This is the most common type of polymer which is used as SAP. In this experiment we use sodium polyacrylate as super absorbing polymer which is most commonly available. The sodium polyacrylate is also known as water lock and its physical properties are shown in Table 4.

Table 1: Properties of Cement

Sl. No.	Properties	Values
1	Fineness	3%
2	Specific gravity	3.15
3	Initial setting time	50 minutes

Table 2: Properties of coarse aggregate

Sl No.	Tests	Result
1	Specific Gravity	2.68
2	Water Absorption	1.3%

Table 3: Properties of fine aggregate

Sl No	Tests	Results
1	Specific gravity	2.65
2	Water absorption	1.1%

Table 4: Properties of Sodium Polyacrylate

Specific gravity	1.3
Compound type	Polymer of organic compound
State	Salt
Solubility	Insoluble in water, swells in water

2.2 Mixture Proportioning

For the experiment, mix proportioning is calculated using BIS (IS :10262-2009). Here M20 mix and the ratio of 1: 2.8: 3.9 is fixed as the mix proportion by quantifying various materials. Also, to find the optimum range of SAP for the concrete various percentage of SAP is added and tested. The different percentages of SAP are N- normal concrete mix, SAP 1- concrete with 0.1%SAP, SAP 2- concrete with 0.2%SAP, SAP 3- concrete with 0.3%SAP, SAP 4- concrete with 0.4%SAP and SAP 5 -concrete with 0.5%SAP.

The preparation of concrete is done in the laboratory. The components such as coarse aggregate, M-sand, ordinary Portland cement of 53 grade (as per mix design), super absorbing polymer (sodium polyacrylate) and magnetized water is required. The mix proportion is calculated and is obtained as 1:2.8:3.9. The super absorbing polymer is added to the mix by replacing a certain amount of cement from the mix. Different percentage of SAP is added in each mix in order to determine the optimum percentage. 0.1%, 0.2%, 0.3%, 0.4% and 0.5% of SAP is used in each mix, also a normal concrete is prepared for the comparison of strength in different concrete blocks through which we determine the optimum range of SAP which is to be used is shown Table 5.

Table 5: Quantities of materials of different concrete mix

M	N	SAP 1	SAP 2	SAP 3	SAP 4	SAP 5
CA	35.2kg	74.56 Kg	59.80kg	59.803 kg	59.803 kg	59.803 kg
FA	27.29kg	53.728 Kg	43.09kg	43.094 kg	43.094 kg	43.094 kg
SAP	0g	19 g	30.5g	45.77g	61.03g	76.29 g
Water	4.5 l	7.62 l	7.62 l	11.44 l	15.25 l	19.07 l
OPC	11.13kg	19.025 Kg	15.25kg	15.259 kg	15.259 kg	15.259 kg

M- materials, CA- Coarse Aggregate, FA- Fine Aggregate

2.3 Test Methods

2.3.1 Compressive strength

15cm x 15cm x 15cm concrete cubes were tested as per IS: 516-1959. The test was conducted in 120T Compression testing machine. The load was applied at the rate of about 140kg/cm^2/min until the specimen fails. At the phase of testing, each specimen must be kept in compressive testing machine. The maximum load at the breakage of concrete specimen will be noted. From the values, the compressive strength is calculated as shown below.

$$\text{Compressive strength} = \text{Load}/\text{Area}$$

2.3.2 Flexural strength

The concrete beams of size 10cm x 10cm x 50cm were tested as per IS: 516-1959. The load was applied through two similar rollers mounted at one third points of the supporting span. The load was applied without shock until the failure occurs. Measure the distance between line of fracture and nearest support.

$$\text{Flexural strength} = PL/Bd^2$$

Where, P = load applied

B = Breadth of the beam

d = depth of the beam

L = length of the beam

2.3.3 Split tensile strength

Concrete cylinders of 15cm diameter and 30 cm height were tested for Split tensile strength as per IS: 5816-1999.The specimen was positioned horizontally between the loading surfaces of the compression testing machine and the load was applied without any shock until the failure of the specimen. The formula used for calculation is shown below.

Split Tensile strength $= 2P/\pi DL$

Where, P = Maximum load in N

L = Length of the specimen

D = diameter of the specimen

2.3.4 Water sorptivity test

This test is used to find the sorptivity index of concrete sample. Specimens of 70mm diameter and 30mm thickness or 100mm diameter and 50mm thickness are prepared by coring and slicing. The specimen is dried at 50˚C for 7 days after curing and before testing. The oven dried sample is allowed to cool in laboratory condition. After weighing, the specimen is placed in supports inside a tray with test solution (water or saturated calcium hydroxide solution) such that the bottom 2mm of the specimen is submerged. The mass of the specimen is measured at regular time intervals after wiping excess water from the bottom surface using a damp cloth. The concrete is then vacuum saturated after which the mass is again measured.

Table 6: Classification criteria

Water Sorptivity Test (Mm/√H)	Concrete Quality
<6	Very good
6-10	Good
10-15	Poor
>15	Very poor

2.3.5 Water permeability test

This test is used to determine the depth of water penetration in concrete sample due to permeation. The test is performed on 150mm size cubes. A test surface was selected perpendicular to the cast face and was roughened using a steel wire brush. The specimens were mounted on to the permeability cells and were tightened well in order to avoid water leakages. The air compressor was switched on, followed by the water inlet valve. A bar (0.5N/mm^2) water pressure is applied on the top of the cube by adjusting the air pressure through a valve system. This pressure is kept constant for a period of three days. After three days, the pressure is released and the specimens were removed from the permeability cell. Immediately after removing the specimens are split into two. Before evaporation, the depth of water penetration is marked with the help of a marker pen. The maximum and the average depth of the water penetration are recorded.

Table 7: Classification criteria

Concrete type	Depth of water penetration
Dense concrete with slag and superplasticizer	5
Concrete to be used in aggressive environment	< 30
Concrete to be used in water retaining structures	<50

2.3.6 Rapid chloride permeability test

Table 8: Classification criteria

Concrete type	Depth of water penetration
Dense concrete with slag and superplasticizer	5
Concrete to be used in aggressive environment	< 30
Concrete to be used in water	<50

retaining structures	

This test is to determine the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions. The test involves the application of a potential of 60volts on a vacuum saturated cylindrical concrete specimen. One side of the specimen is exposed to 3% NaCl solution and to opposite side to 0.3M NaOH solution. The resulting current is measured at an interval of 30 minutes for a total period of 6 hours. From the current measurements, the total charge passed (in coulombs) is calculated using trapezoidal rule. This charge passed is used to categorize the concrete into different classes.

3 Test Results and Discussions

3.1 Mechanical Properties

3.1.1 Compressive strength

From the table 9 it is understood that, when 0.3% of SAP (SAP 3) is added the compressive strength is seen to be increased on 7th day as well as the 28th day. Therefore, SAP 3 can be opted as the optimum value of SAP when compressive strength is given preference. Figure 1 is a graph plotted to show the variation of compressive strength on 7th day and 28th day when different percentages of SAP added.

Table 9: Compressive strength test results

Sl. No	Concrete mixes	7th day Compressive strength (N/mm^2)	28th day Compressive strength (N/mm^2)
1	N	20	28.6
2	SAP 1	20.5	29.31
3	SAP 2	22.2	31.74
4	SAP 3	25.1	35.89
5	SAP 4	21.8	31.17
6	SAP 5	20.4	29.17

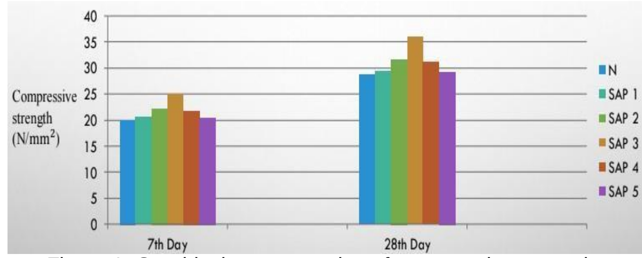

Figure 1: Graphical representation of compressive strength test

3.1.2 Flexural strength

From the table 10 it is understood that, when 0.3% of SAP is added the flexural strength is seen to be increased on 7th day as well as the 28th day. Therefore, SAP 3 can be opted as the optimum value of SAP when flexural strength is compared with normal and other concrete mixes. Figure 2 is a graph plotted to show the variation of flexural strength on 7th day and 28th day when different percentages of SAP added.

Table 10: Flexural strength test results

Sl. No	Concrete mixes	7th day Flexural strength (N/mm^2)	28th day Flexural strength (N/mm^2)
1	N	3.4	4.86
2	SAP 1	3.75	5.36
3	SAP 2	4.01	5.73
4	SAP 3	4.76	6.80
5	SAP 4	4.39	6.27
6	SAP 5	4.12	5.86

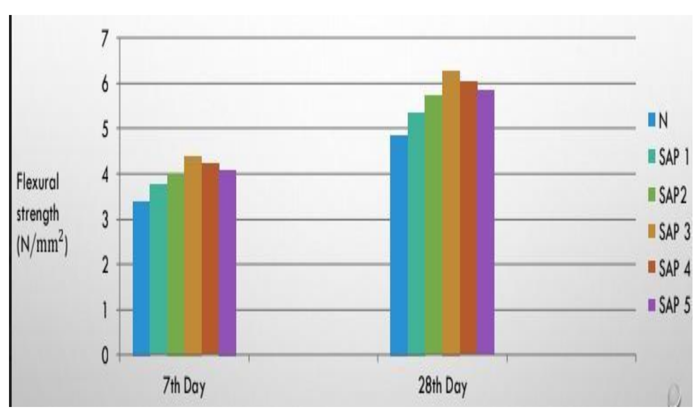

Figure 2: Graphical representation of flexural strength

3.1.3 Split tensile strength

From the table 11 it is understood that, when 0.3% of SAP is added the split tensile strength is seen to be increased on 7th day as well as the 28th day. Therefore, SAP 3 can be opted as the optimum value of SAP when split tensile strength is compared to normal and other concrete mixes. Figure 3 is a graph plotted to show the variation of flexural strength on 7th day and 28th day when different percentages of SAP added.

Table 11: Split tensile strength test results

Sl. No	Concrete mixes	7th day Split tensile strength (N/mm^2)	28th day Split tensile strength (N/mm^2)
1	N	3.56	5.09
2	SAP 1	3.86	5.51
3	SAP 2	4.1	5.86
4	SAP 3	4.3	6.15
5	SAP 4	4.17	5.96
6	SAP 5	3.8	5.43

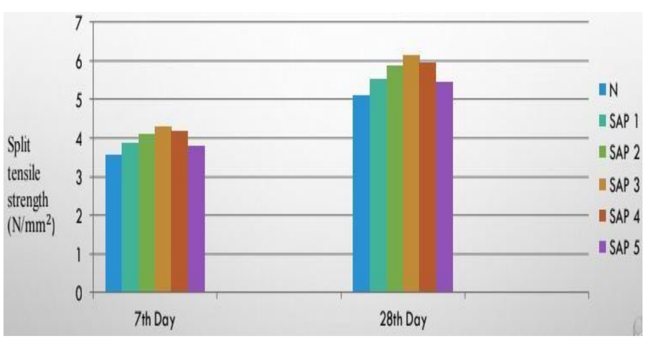

Figure 3: Graphical representation of Split tensile strength

3.2 Durability Properties

The durability of cement concrete is its ability to resist weathering action, chemical attack, or any other kind of deterioration. Durable concrete maintains its original quality and serviceability when exposed to environment. The transport of aggressive gases or liquids into concrete depends on its permeability of concrete. Penetration of contaminant into concrete is one of the most critical parameters of durability of concrete in aggressive environments. In this experiment the durability properties of optimum replacement of SAP (SAP 3) and conventional concrete (N) mixes are taken in consideration.

3.2.1 Water sorptivity test

According to table 12, the test result shows that there is no significant change in the quality of the concrete as the value of both conventional and optimum percentage of concrete specimens are within the range of 6-10 mm/√h. Therefore, both the concrete specimens are of good quality.

Table 12: Water sorptivity test results

Sl.No	Mix	Water sorptivity (mm/√h)	Concrete quality
1	N	10	Good
2	SAP 3	8	Good

3.2.2 Water permeability test

According to table 13, the depth of water penetration for normal (N) and SAP 3 concrete specimen are 25mm and 28mm respectively. As the depth of water penetration is less than 30 mm for both the concrete mixes, therefore the concrete specimens are likely to be used in aggressive environment.

Table 13: Water permeability test results

Sl.No	Mix	Depth of water penetration (mm)
1	N	25
2	SAP 3	28

3.2.3 Rapid chloride permeability test

According to table 14, the resistance of SAP 3 to chloride penetration is similar compared to the normal concrete. Normal (N) and 0.3% of SAP replaced concrete (SAP 3) show low chloride penetrability.

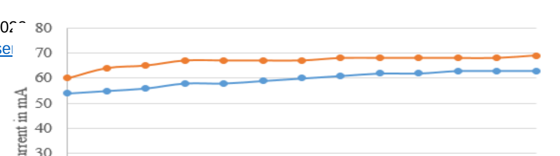

Figure 4: Graphical representation of current Vs time

Table 14: Rapid chloride penetration test results

Time (s)	N(mA)	SAP 3 (mA)
0	54	60
30	55	64
60	56	65
90	58	67
120	58	67
150	59	67
180	60	67
210	61	68
240	62	68
270	62	68
300	63	68
330	63	68
360	63	69
Charge passed	1287.9	1442.7
Chloride ion penetrability	Low	Low

4 Conclusions

Sodium polyacrylate is a very good and commonly used super absorbing polymer which is also known as water lock. It is primarily used as a thickening agent because of its unique ability to absorb and hold onto water molecules. By using SAP, the concrete is cured internally without wasting too much by curing process and the properties of concrete are improved by the usage of magnetized water and SAP.

- The optimum range of super absorbing polymer (SAP) is found to be 0.3%.
- The compressive strength of modified concrete at optimum value is found to be increased by 25.5% when compared to conventional concrete. When the strength of the conventional concrete is compared with the modified concrete, the modified concrete with 0.3% of SAP shows the best outcome.
- The flexural strength of modified concrete at optimum value is found to be increased by 40% when compared to normal concrete.
- The split tensile strength of modified concrete at optimum value is found to be increased by 21% when compared to conventional concrete.
- There is no significant change in the quality of the concrete as the value of both conventional and optimum percentage of concrete specimens are of good quality.
- In the case of water permeability test, the depth of water penetration is less than 30 mm for both the concrete mixes, therefore the concrete specimens are likely to be used in aggressive environment.
- The resistance of SAP 3 to chloride penetration is similar compared to the normal concrete. N and SAP 3 replaced concrete show low chloride penetrability.

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