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# EXPERIMENTAL ASYMPTOTIC ANALYSIS OF FIBROUS SELF-CURING CONCRETE EXPOSED TO ACID AND SALT ATTACK

**S. JEMIN JOEL*, D. MARUTHACHALAM** AND S. ANTONY JEYENDRAN*****

* Sri Krishna College of Technology, Coimbatore 641 042, India
** Sri Krishna College of Engineering and Technology, Coimbatore 641 008, India
*** Sri Krishna College of Technology, Coimbatore 641 042, India

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**Key words:** Curing, Self-curing Agent, Self-curing Concrete, Fibrous Self-curing Concrete.

## ABSTRACT

**Self-curing concrete is one of the special concretes in mitigating insufficient curing disorder due to human negligence and paucity of water in arid areas, inaccessibility of structures in difficult terrains and in areas where the presence of fluorides in water will badly affect the characteristics of concrete. The use of super absorbent polymer (SAP) in concrete helps in self-curing and thus better hydration of cement is achieved. Present study involves the effect of SAP and fibre on durability aspects. The grade of concrete selected was M40. It was found that SAP could help in self curing by giving strength on par with conventional curing. The dosage of SAP is 0.3% by weight of cement and polypropylene fibre (PPF) varying from (0.1%-0.5%) by the volume fraction of concrete. Experimental investigation is about Acid attack, Sulphate attack and Corrosion resistance of Self-Curing Concrete (SCC) and Fibrous Self-Curing Concrete (FSCC).**

## INTRODUCTION

Curing is the process of maintaining a satisfactory moisture content and temperature in concrete in order to achieve the desired strength and hardness. Drying removes the water needed for hydration. Without adequate water and insufficient hydration, concrete tends to be weak. In outdoor concreting, temperature, humidity and wind velocity Contribute to the loss of water by evaporation. Properly cured concrete has better durability and better surface hardness and is less permeable. The Prevention of loss of moisture from concrete is important not only from strength development point of view but also from prevention of plastic shrinkage, decrease in permeability and improvement of resistance to abrasion. The loss of 28 days strength seems to be directly related to loss of moisture during the first three days. It is evident that 5% loss in moisture leads to nearly 75% loss in strength. Hence continuous curing is to be done for the first three days. Intermittent curing seems to be even worse than no curing at all.

***Corresponding author's email:** jeminjoel@gmail.com; dmaruthachalam@gmail.com
(* PG Student; ** Professor; *** Assistant Professor)

## MATERIALS USED

### Self-Curing Agent

When water is not readily available, significant autogenous deformation and (early-age) cracking may result (Craeye *et al.*, 2011). Internal curing is used as a substitute to overcome the problem like plastic shrinkage, permeability and resistance to abrasion. One of the methods to overcome such problem faced by internal curing is the use of light weight aggregate. The other methods are the use of water absorbent polymer (polyethylene glycol and paraffin wax) and wood derived materials. The disadvantage of using such materials is that being light weight aggregate, it can negatively impact strength and can lead to variability in performance. Polyethylene glycols are more controllable but are relatively expensive compared to light weight aggregate. Wood derived material may be an alternative to other internal curing materials. It provides consistency at a lower cost but only 50% strength is reached and micro cracks are introduced by wood derived materials. The above cited deficiencies can be reduced by using super absorbent polymer as internal curing agent without compromising on the strength and durability properties. However, the low water-cement (w/c) ratio, which is necessary for the enhancement of strength and durability, leads to a so-called self-desiccation of concrete, as a result of the cement hydration process. This causes considerable volume changes known as autogenous shrinkage, which in turn lead to concrete cracking. The internal curing of concrete using well distributed water reservoirs seems to be better solution to this problem.

### Polypropylene Fibre

In the past, problems were encountered in mixing, workability and durability of fibre reinforced concrete but these have almost been overcome by the emergence of new types of synthetic fibres. Polypropylene fibre is one among them. The primary advantage of polypropylene fibre over others is its easily tailoring properties and its resistance against corrosive attack of the environment. Fibre reinforcement in concrete reduces cracking and shrinkage and thus ensures volume stability of the cementitious composite to a great extent (Isabel Padron and Ronald, 1990). Polypropylene fibres are actually man-made synthetic fibres resulted from research and development in the petrochemical and textile industries. Addition of fibres in concrete reduces the amount of bleed water form concrete and so the rate of bleeding decreases. The use of polypropylene fibres may increase the time to initial and final set of the concrete as this led to a slower rate of drying in the concrete (Singh, 2010).

### Fibre [PPF] : Polypropylene

**Table 2.** Polypropylene Properties

| Specification | Values |
|---|---|
| Specific gravity | 0.9 |
| Length | 38mm |
| Diameter | 0.1mm |
| Aspect Ratio | 380 |

### Super-adsorbent Polymer [SAP]: GFP- 1605

**Table 3.** SAP Properties

| Specification | Values |
|---|---|
| Form-dry | White powder |
| Form-wet | Transparent gel |
| Particle size | 0-1 mm |
| Absorption in distilled water | 800 g for 1 g |
| Absorption in sea water | 40 g for 1 g |
| pH of absorbed water | Neutral |
| Density | 1.08 |
| Bulk density | 0.85 |
| Hydration/Dehydration | Reversible |
| Stability of dry Product | 5 years |
| Stability of wet product | 4 years |
| Decomposition in sunlight | 6 months |
| Available water | 95% approx |

**Water:** Water used was fresh, colourless, odourless and tasteless portable water that was free from organic matter of any type.

**Table 1.** Material Properties

| Material | Code provision | Size | Specific gravity |
|---|---|---|---|
| OPC 53 grade | IS 12269 – 1987 (14) | 12 µm | 3.15 |
| Fine aggregate (FA) | IS 383 –1970 (7) | Finer than 4.75 mm | 2.67 |
| Coarse aggregate (CA) | IS 383 – 1970 (7) | 12.5 mm | 2.60 |
| Super plasticizer (SP) | IS 9103-1999 (11) | Semi solid | 1.23 |

## MIX PROPORTION AND MIX DETAILS

The mix proportions were carried out based on IS 10262-(2009) for M40 grade. Mix design can be defined as the process of selecting ingredients of concrete and determining their relative proportions with the objective of producing concrete of certain minimum strength and durability as economically possible. The mix proportions of different mixes are shown in Table 4. The concrete mixture becomes rather clingy resulting in increasing of the adhesion and cohesiveness of fresh concrete. During mixing the movement of aggregates shears the fibres apart, so that they open into a network of linked fibre filaments and individual fibres. These fibres anchor mechanically to the cement paste because of their large specific surface area. The concrete mixture with polypropylene fibres results in the fewer rate of bleeding and segregation as compared to plain concrete. This is because the fibres hold the concrete together and thus slow down the settlement of aggregates (Singh, 2010).

## RESEARCH PROGRAM AND PROCEDURES

The experimental program was designed to investigate the strength of Self-Curing concrete by adding super absorbent polymer (GFP-ABSORB-1605) and Polypropylene fibre at 0.1%, 0.2%, 0.3%, and 0.5% by the volume fraction of concrete. It was aimed to study the mechanical properties, acid attack, sulphate attack and corrosion resistance. The scheme of experimental program is given in Table 5.

### Slump Test

The slump test is the most well-known and widely used test method to characterize the workability of fresh concrete. Adequate workability is required for proper placement, consolidation and finishing of concrete. The workability has been investigated at varied volume of fibre and SAP as constant.

### Compressive Strength

The compressive strength of concrete cube was determined based on IS: 516–1959. The compressive strength test is conducted in the Compression testing machine of 2000 kN capacity. The specimens are tested at the age of 7 and 28 days. The maximum load applied on specimen was recorded. $fc = P/A$, where P is the load and A is the area.

### Splitting Tensile Strength

This test method covers the determination of splitting tensile strength of concrete cylinders as per IS: 5816–1399 (1999). This test method consists of applying a diametric compressive force along the length of a cylindrical concrete specimen at a rate that is within a prescribed range until failure occurs. This loading

**Table 4.** Mix Proportion of Concrete Developed

| Mix | Cement ($kg/m^3$) | FA ($kg/m^3$) | CA ($kg/m^3$) | SAP (%) | Fibre ($kg/m^3$) | Water (L/m3) | S.P (L/m3) |
|---|---|---|---|---|---|---|---|
| C M | 395 | 715.28 | 1150 | ----- | ----- | 158 | 4.7 |
| SCC | 395 | 715.28 | 1150 | 0.3 | ----- | 211.32 | 4.7 |
| FSCC1 | 395 | 715.28 | 1150 | 0.3 | 0.9 | 211.32 | 4.7 |
| FSCC2 | 395 | 715.28 | 1150 | 0.3 | 1.8 | 211.32 | 4.7 |
| FSCC3 | 395 | 715.28 | 1150 | 0.3 | 2.7 | 211.32 | 4.7 |
| FSCC5 | 395 | 715.28 | 1150 | 0.3 | 4.5 | 211.32 | 4.7 |

**Table 5.** Specimen Details

| Type of specimens | Property | No. of specimens | Test age (days) | Size of specimens (mm) |
|---|---|---|---|---|
| Cube | Compressive Strength | 36 | 7 and 28 | 150 x 150 x 150 |
| Cylinder | | | | |
| | Splitting Tensile Strength | 36 | 7 and 28 | 150 Diameter x 300 Height |
| Prism | Modulus of Rupture | 36 | 7 and 28 | 100 x 100 x 500 |
| Cube | Acid Attack | 54 | 28, 56 and 90 | 150 x 150 x 150 |
| Cube | | | | |
| | Sulphate Attack | 36 | 28, 56 and 90 | 100 x 100 x 100 |
| Cylinder | Corrosion Resistance | 36 | 28, 56 and 90 | 100 Diameter x 200 Height |

Table 6. Strength Properties

| Mix | Slump value (mm) | Compressive strength (MPa) | | Splitting tensile strength (MPa) | | Modulus of rupture (MPa) | |
|---|---|---|---|---|---|---|---|
| | | 7 days | 28 days | 7 days | 28 days | 7 days | 28 days |
| CM | 82 | 26.12 | 42.84 | 3.77 | 4.30 | 5.21 | 5.68 |
| SCC | 115 | 32.84 | 43.20 | 3.23 | 4.84 | 5.28 | 6.12 |
| FSCC1 | 124 | 33.27 | 43.34 | 3.28 | 4.88 | 5.44 | 6.22 |
| FSCC2 | 132 | 34.44 | 44.23 | 3.35 | 4.92 | 5.60 | 6.41 |
| FSCC3 | 146 | 35.18 | 45.88 | 3.48 | 5.32 | 5.72 | 6.68 |
| FSCC5 | 118 | 28.95 | 41.12 | 3.11 | 4.72 | 5.81 | 6.76 |

induces tensile stresses on the plane containing the applied load and relatively high compressive stresses in the area immediately around the applied load. The maximum load applied on specimen was recorded. fs =2 P/pDL, where P is the load, D is the diameter and L is the length. The universal testing machine, of 1000kN capacity was used for the application of the load.

### Modulus of Rupture

This test method covers the determination of the modulus of rupture of concrete by the use of prism as per IS: 9399–1979 (1976). Load was applied through similar rollers mounted at the third points of the supporting span, spaced at a distance of 133mm centre to centre. The load and displacement data were obtained for each specimen. The modulus of rupture test on concrete was carried out on universal testing machine of capacity 1000kN.

### Acid Attack

Cubes of size 150mm x 150mm x 150mm were cast and cured. After 28 days of curing, cubes are immersed in water tank containing 5% concentrated sulphuric acid ($H_2SO_4$) for 28, 56 and 90 days respectively. Then the specimens are taken out from the acid water and the surfaces of the cubes are cleaned. The percentage weight loss and percentage compressive strength losses have been taken for a set of cubes at 28, 56 and 90 days.

### Sulphate Attack

When concrete exposed to environment containing aggressive chemicals, it leads to deterioration of concrete which can be assessed in terms of loss of weight of concrete. Cubes of size 100mm x 100mm x 100mm were cast and cured. After 28 days of curing, cubes were immersed in water tank containing 5% sodium sulphate ($Na_2SO_4$) for 28, 56 and 90 days respectively. This type of testing represents an accelerated testing procedure, which indicates the performance of particular concrete mixes to sulphate attack on concrete. The degree of sulphate attack is evaluated by measuring weight losses of the specimens conducted at 28, 56, and 90 days respectively.

### Corrosion Resistance

An accelerated laboratory electrochemical method, first developed by the Nordtest method (Nordtest, 1989) for corrosion was used. This procedure is an accelerated laboratory method of testing reinforced concrete for corrosion protective properties. The method was designed to compare various concrete mixes, but can also be used to investigate concrete protective coatings and rebar claddings. Cylindrical concrete specimens of 100 mm diameter and 200 mm height are being used with steel bar of 12 mm diameter which is placed centrally with 45 mm cover on all sides. Specimens were partially immersed into 5% of sodium chloride (NaCl) solution at room temperature after 28 days of curing. Then, the exposed steel bars were connected to the positive terminal of a constant 30 volt D.C. The negative terminal of the DC power source was connected to a stainless steel mesh placed near the specimen in the solution. The stainless steel was used as the cathode. Each time the current intensity showed a sudden rise indicated the cracking of the specimen by corrosion. So, in order to determine the time at which the specimen cracked (referred to as corrosion time), the intensity of the electric current was recorded at different time intervals. The specimens were visually inspected daily for cracks while the current flow was continuously monitored using an ammeter. After cracking, the specimens were taken out, visually inspected, and carefully split open to assess the corroded steel rod. As the chloride ions reach the steel/concrete interface above the threshold concentration, the steel surface begins to corrode (Sahmaran *et al.,* 2008). The reinforcement bars were then cleaned as per ASTM G1 by dipping it in Clark's solution (HCl of specific gravity 1.19 L + antimony trioxide 20 g + stannous chloride 50 g) for 25 minutes. Each bar was then weighed again to the accuracy of 0.1 mg to find out the change in weight.

## RESULTS AND DISCUSSION

### Slump Test

For the workability of fresh concrete, traditional slump cone test was conducted. The test was performed on concrete without polypropylene fibres termed as (SCC) specimens and on polypropylene fibre reinforced concrete (FSCC) specimens. Mixtures were proportioned to give slump values which are needed to ascertain adequate workability of the fresh concrete to be placed and finished. The experimental results show that the addition of polypropylene fibres (PPF)reduced the flow characteristics. This is because during mixing of the concrete, the coarse aggregates damage the fibrillated (PPF) fibres to some degree and perhaps do not permit the fibre to fully open into a lattice structure, instead the fibre open into a network of linked fibre filaments and individual fibres.

### Compressive Strength

The compressive strength tests were performed on six concrete mixtures. Three replicate specimens were tested at each test age for each type of mixture. The effect of volume fraction of fibre and SAP has a huge role in the compressive strength. From Table 6 it is clear that the fibres tend to increase the ductility of the mix by increasing the failure strains, however these have varying effect on the compressive strength. The maximum compressive strength was observed for 0.3% of fibre addition, which had achieved target strength of 45.88 MPa at the age of 28 days. The mix (FSCC3) achieved a maximum of 7% increase in compressive strength over control mix. In (FSCC) specimens, the bulging of specimens was observed without any significant deterioration of the test specimen.

### Splitting Tensile Strength

Splitting tensile strength of various mix proportion are given in Table 6. At each of the test age, the specimens were tested and the load data was obtained from which stress data was computed. The average stress displacement behaviour of (FSCC) shows a linear trend up to the cracking. The fibre comes into action after the first crack. The fibres bridge these cracks and restrain them from further opening and hence improve the load-carrying capacity of structural member beyond cracking. 0.3% of fibre addition achieved maximum target strength of 5.32 MPa at the age of 28 days. The mix (FSCC3) shows 24% increase in splitting tensile strength over control mix. The failure or the splitting on the cylinder occurred when the fibres elongation exceed the allowable i.e. the breaking of the fibres under axial tension.

### Modulus of Rupture

The modulus of rupture tests were performed on prism specimen as mentioned in Table 6. At the test age, three replicate specimens were tested with the universal testing machine. Before the occurrence of the first crack, the load-deflection behavior of all (FSCC) specimens was found to be similar to that of control mix specimens. Just after the appearance of the first crack, control mix specimens suddenly failed. However in (FSCC) specimens, after the occurrence of the first crack, a drop is observed in the load-deflection as the load is released and transferred from the matrix to the fibres, and afterwards that the specimens continues to withstand a portion of the load with increasing deformations and widening of the cracks. The (FSCC) beams continue to resist load with increasing deformations by virtue of the elongation of the randomly distributed discrete fibres and ultimately fails at large deformations as the fibres reach their maximum elongation. The mix (FSCC5) shows a maximum strength of 6.79 MPa at the age of 28 days, which has an increase of 19% over control mix.

### Acid Attack

**Fig. 1** Specimens Immersed in ($H_2SO_4$) Solution

### Sulphate Attack

**Fig. 2** Specimens Immersed in (Na2SO4) Solution

## CONCLUSION

Based on the experiment work carried out, the following conclusions were drawn.

- Compressive strength of fibrous self-curing concrete was higher than conventionally cured concrete and self-curing concrete.
- Splitting tensile strength of fibrous self-curing concrete was higher than conventionally cured concrete and self-curing concrete.
- Modulus of rupture of fibrous self-curing concrete was higher than conventionally cured concrete and self-curing concrete.
- When the specimens are immersed in ($H_2SO_4$) so-

**Table 7.** Acid Attack on Concrete

| Mix | Average reduction in weight (%) | | | Compressive strength loss (%) | | |
|---|---|---|---|---|---|---|
| | 28 Days | 56 Days | 90 Days | 28 Days | 56 Days | 90 Days |
| CM | 3.97 | 4.50 | 5.36 | 10.8 | 12.46 | 13.91 |
| SCC | 2.49 | 3.04 | 4.61 | 6.94 | 7.56 | 8.63 |
| FSCC1 | 2.22 | 2.99 | 3.86 | 5.39 | 6.27 | 7.46 |
| FSCC2 | 2.08 | 2.12 | 3.24 | 5.26 | 5.69 | 6.74 |
| FSCC3 | 1.55 | 1.81 | 2.72 | 4.96 | 5.46 | 6.25 |
| FSCC5 | 2.52 | 3.08 | 4.28 | 7.1 | 7.98 | 9.47 |

**Table 8.** Sulphate Attack on Concrete

| Mix | Average reduction in weight (%) | | |
|---|---|---|---|
| | 28 Days | 56 Days | 90 Days |
| CM | 2.32 | 3.29 | 3.96 |
| SCC | 2.16 | 2.76 | 3.24 |
| FSCC1 | 2.02 | 2.44 | 2.81 |
| FSCC2 | 1.92 | 2.14 | 2.32 |
| FSCC3 | 1.76 | 1.97 | 2.12 |
| FSCC5 | 2.23 | 3.04 | 3.27 |

### Corrosion Resistance

**Table 9.** Corrosion Resistance in Concrete

| Mix | Weight loss of steel bar (%) | | | Visual observation of corroded specimen | | |
|---|---|---|---|---|---|---|
| | 28 Days | 56 Days | 90 Days | 28 Days | 56 Days | 90 Days |
| CM | 7.85 | 5.96 | 4.6 | severe | severe | mild |
| SCC | 6.45 | 5.40 | 4.14 | severe | severe | mild |
| FSCC1 | 5.17 | 4.69 | 3.68 | severe | mild | mild |
| FSCC2 | 3.80 | 3.21 | 2.73 | mild | mild | mild |
| FSCC3 | 2.41 | 1.81 | 1.44 | mild | mild | mild |
| FSCC5 | 3.54 | 3.18 | 2.48 | mild | mild | mild |

lution for 28, 56, and 90 days, the percentage loss in weight and compressive strength reduces gradually up to 0.3% of fiber content after that it increases.

- When the specimens are immersed in ($Na_2SO_4$) solution for 28, 56, and 90 days, the percentage of weight loss gradually decreases with increases in fibre content up to 0.3% after that it increases.
- The loss of weight in rebar due to corrosion was less for concrete mixes containing fibre.
- The intensity of current measured decreases with increase in fibre dosage and as the curing period increases the number of days for the concrete to develop initial crack also increases.
- Performance of the super absorbent polymer is exaggerated by the mix ratio, primarily the cement content and the w/c ratio.
- The optimum dosage of super-absorbent polymer is of 0.3% of cement content.
- The optimum dosage of polypropylene fibre is of 0.3% by the volume fraction of concrete.

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