

## Effect of Corrosion on Mechanical and Durability Properties of Reinforced Self Compacting Concrete

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**Abstract:** Self-compacting concrete (SCC) is a flowing concrete mixture that is able to consolidate under its own weight. The greatly liquid character of SCC makes it appropriate for placing in difficult conditions and in sections with congested reinforcement. Use of SCC can also help minimize hearing-related damages on the worksite that are induced by vibration of concrete. One more advantage of SCC is that the time required to place the concrete in large sections is considerably reduced. Corrosion is the most significant durability problem causing deterioration of concrete structures. Hence, the objective of this work is to study the strength and corrosion resisting properties of SCC along with sodium nitrite as corrosion inhibiting admixture at the dosage of 1%, 2%, 3%, 4% and 5% by weight of cementitious material. Strength tests and durability tests were carried out and the results were compared with conventional self compacting concrete. The durability of self compacting concrete is based on the tests conducted such as Sorptivity. The corrosion resistance performance was determined by accelerated corrosion test, impressed voltage method, rapid chloride permeability test and gravimetric weight loss method. Results herein addition of inhibitor it offers lowers permeability and greater density which enable it to provide better resistance to corrosion and durability in adverse environment.

**Key words:** Self-compacting concrete • Corrosion inhibitor • Corrosion resistance • Durability • Sorptivity

### INTRODUCTION

Concrete, one of the most important materials for structures and widely used all over the world is a heterogeneous material consisting of cement, water, fine and coarse aggregate [1]. Very extensive literature on concrete includes a number of reviews [1]. While the heterogeneous structure of concrete can produce some undesirable effect, concrete remains an indispensable many materials into it [2]. A variety of types of concrete exist.

Self compacting concrete (SCC) was first developed in Japan in 1986. The SCC can flow through and fill the gaps of reinforcement and corners of moulds without any need for vibration and compaction during the placing process. The use of SCC is increasing, so called super plasticisers are typically used in SCC to reduce the water/binder ratio [3-4]. Moreover, supplementary cementitious or inert materials, such as limestone power, natural pozzolans and fly ash can to increase the velocity and fresh concrete workability and reduce the cost of SCC

[5]. The use of Pozzolanic admixtures extends the hydration reaction and produces good micropore structures, resulting in improved durability.

The use of fine aggregate reduces the demands for cement, fine fillers and fine aggregate that are required in SCC [6]. The fly ash, a by-product of thermal power plants, has been reported to improve the mechanical properties, such as freeze-thaw resistance, sulphate resistance, alkali-silica reaction, durability and abrasion resistance, when it is used as a cement replacement material in mortar and concrete [7-8]. In addition, shrinkage and permeability of hardened concrete are decreased due to the filling of micropores by fly ash. Utilisation of fly ash in concrete technology is becoming more common, causing a reduction in chloride penetration, steel corrosion and were loss of the concrete [9]. On the other hand, unsalvaged fly ash causes environmental pollution, while its storage costs are quite high. The advantage of usage of industrial waste materials in concrete, both to lower environmental pollution and to provide less expensive materials, is beyond dispute.

Corrosion of steel in concrete is a complex phenomenon. There are different factors affecting the process of corrosion in concrete [10-11]. The increase in volume of reinforcement after corrosion is one of the adverse effects on the structure apart from reduction in cross section area of reinforcement. Corrosion has been found one of the important reason causing weaknesses to concrete structures [12]. Corrosion inhibitors are chemicals that may be added to the concrete mix to practical applicability that the inhibitor should have certain requirements. It should be compatible with other admixtures that are used in self compacting concrete [13]. The physical properties and durability of concrete should not be adversely affected [14]. The use of corrosion inhibitors is still in its infancy state [15]. But the use of corrosion inhibiting admixtures has been considered as one of the most cost effective solution to the widespread corrosion problem, due to their convenient and economical application to both new and existing structures [16-17].

## MATERIALS AND METHODS

**Materials Used:** The cement used was Ordinary Portland Cement (43 Grade) conforming to IS 8112-1989. Locally available well-graded clean river sand with maximum size of 4.75 mm confirmed to grading zone -II as per IS 383-1970 having specific gravity 2.60, fineness modulus 2.25 and bulk density 1721 kg/m<sup>3</sup>. Natural granite aggregate having bulk density of 1674 kg/m<sup>3</sup>, specific gravity 2.80 and fineness modulus 6.23, the aggregates is crushed by machineries and the maximum size of aggregate is 12.50 mm. Fly ash (Class F) conforming IS:3812:2003 was procured from Mettur Thermal Power Station, Salem, Tamil Nadu. For the mixing and curing of concrete the potable bore well water was availed. To increase the workability of SCC commercially available super plasticizer Conplast SP430 has been used. High yield strength deforming to IS: 1786 was used for corrosion tests. The inhibitor used were sodium nitrite NaNO<sub>2</sub> at the dosage of 1%, 2%, 3%, 4% and 5% by weight of cementitious materials. To attain strength of 25 N/mm<sup>2</sup> a mix proportion was designed based on IS 10262-2009 [18]. The conventional concrete mix proportions were modified as per EFNARC specifications. The mixture was 1:1.65:1.29 with water cement ratio 0.40.

**Strength Tests:** Concrete cubes of size 100 × 100 × 100 mm, cylinders of size 100 mm diameter and 200 mm high, prism of size 500 × 100 × 100 mm were cast with 0%, 1%,

2%, 3%, 4% and 5% of sodium nitrite for compressive, split tensile and flexural strength tests. Sodium nitrite specimens were cast for each percentage of inhibitor for 3, 7, 14, 28, 56 and 90 days strength. After 3, 7, 14, 28, 56 and 90 days curing, the specimens were tested as per IS: 516-1964.

Cylinders of size 60 mm diameter and 150 mm high with rods of 150 mm length kept at the centre were used for determination of half-cell potential measurement, accelerated corrosion test, gravimetric weight loss method.

## Durability Tests

**Sorptivity Test:** Sorptivity test measure the rate of penetration of water into the pores of concrete by capillary suction. The cylindrical specimen of size 50 mm height and 100 mm dia were cured in the respective curing type. After curing the reference concrete and addition of 3% sodium nitrite concrete specimens were kept in an oven for 110°C. Then the side surface of the specimen was sealed with coating to allow the penetration of water into the concrete only from the bottom surface. The specimens are immersed in the container containing water and the specimens were supported on rods that was submerged about 10mm. The quantity of water absorbed in the period of 30 minutes was weighted using weighing balance. Surface water of the specimen was wiped with the disuse and each weighing operation was completed within 30 seconds. The cumulative volume of water that has penetrated per unit surface area of exposure plotted against the square root of the time elapsed. The experimental setup is shown in Figure-1.

The sorptivity was computed by,

$$S=I/vt$$

where,

$$S = \text{Sorptivity (mm/min}^{0.5}\text{)}$$

$$I = \Delta W/Ad$$

$$\Delta W = \text{Change in weight} = W_2 - W_1$$

$$W_1 = \text{Oven dry weight (grams)}$$

$$W_2 = \text{Weight of specimen after 30 minutes penetration of water (grams)}$$

$$A = \text{Surface area through which water penetrated (mm}^2\text{)}$$

$$D = \text{Density of water}$$

$$T = \text{Time elapsed (min)}$$

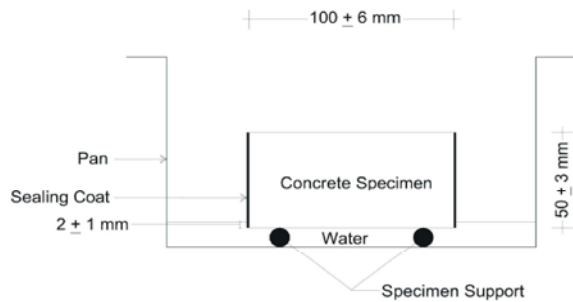


Fig. 1: Schematic of sorptivity (ASTM C1585)

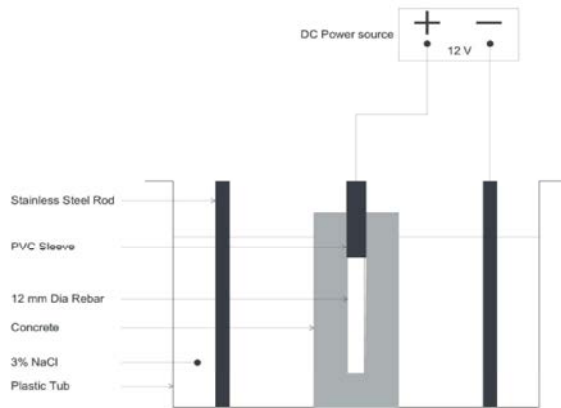


Fig. 2: Test set up for impressed voltage technique.

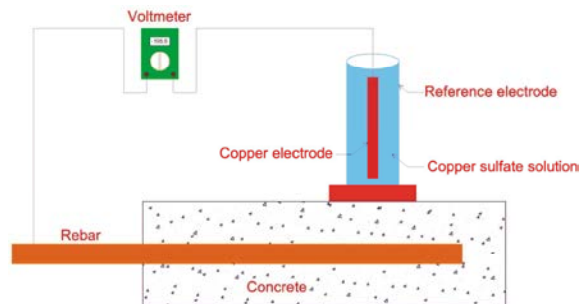


Fig. 3: Half cell Test Setup

**Impressed Voltage test (ASTM-C876):** Impressed voltage test is based on electrochemical polarization principle. The experimental setup is shown in Figure-2. To access the corrosion protection efficiency under accelerated test conditions, concrete cylinders of size 60 mm diameter and 150 mm length were cast with HYSD steel bar of 12 mm diameter embedded centrally into it. The steel rods were cleaned with pickling acid and degreased and then embedded in such a way that a constant cover is maintained all round. After 28 days curing, all the sodium nitrite specimens were taken out and dried for 24 hours then subjected to acceleration corrosion process in order to accelerate reinforcement corrosion. Each test specimen was immersed in the saline media (3% sodium chloride

solution). The rebar projecting at the connected to the positive terminals of the power pack (anode) and the stainless steel rod is connected to the negative terminal (cathode). The test specimens were subjected to a constant voltage of 12 V was applied to the system using a DC power supply regulator. The variation in development of corrosion current was monitored at regular intervals using a high impedance multimeter.

**Half-Cell Potential Measurement:** To study the effectiveness of sodium nitrite admixture in concrete, many specimens were cast in the laboratory and placed in the water tub; contain 3.5% NaCl mixed water. The specimens are connected with DC pack to induce corrosion, here positive terminal is connected with the steel rod and the negative terminal is connected with stainless steel plate to accelerate the corrosion. Then the level of corrosion was taken periodically by using half-cell potentiometer.

The half-cell is a hollow tube containing a copper electrode and immersed in copper sulfate solution. The bottom of the tube is porous and is covered in a sponge material. The copper sulfate permeates this sponge that can then be placed on a concrete surface allowing an electrical potential to be measured. The objective of the method is to measure the voltage difference between the rebar and the concrete over the rebar. Large negative voltages ( $-350$  mV) indicate that corrosion may be taking place. Voltages smaller than about 200 mV generally mean corrosion is not taking place.

**Rapid Chloride Permeability Test (ASTM-C1202):** Corrosion is mainly caused by the ingress of chloride ions into concrete annulling the original passivity present. The Rapid chloride penetration test (RCPT) is used to determine the electrical conductance of corrosion to provide a rapid indication of its resistance to the penetration of chloride ions. The RCPT is performed by monitoring the amount of electrical current that passes through concrete discs of 50 mm thickness and 100 mm diameter for a period of six hours using the apparatus and the cell arrangement is shown in Figure-4. A voltage of 60 V DC is maintained across the ends of the specimen throughout the test. One lead is immersed in a sodium chloride (NaCl) solution (0.5N) and the other in a sodium hydroxide (NaOH) solution (0.3N). The total charge passed through the cell in coulomb has been found in order to determine the resistance of the specimen to chloride ion penetration.

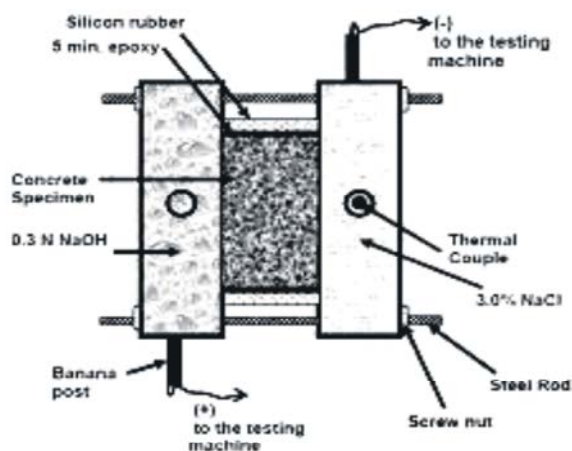


Fig. 4: Schematic diagram of RCPT (ASTM C1202-94)

**Gravimetric Weight-loss Method:** The steel rod size 12 mm diameter and 150 mm long is immersed in the pickling solution (Hydrochloric acid + water in equal parts) for 15 minutes to remove the initial rust. The initial weight (W1) of the rod was measured at the end of polarization test the cylinder specimen was broken open and weight-loss rods were retrieved. After cleaning with water, the rod was air dried and its final weight (W2) was measured. From the initial and final weight, the corrosion rate was calculated.

The corrosion rate is calculated using the following formula:

$$\text{Corrosion rate in mmpy} = 87.6 (W1-W2)/DAT$$

where,

- W1 = Initial weight in milligrams
- W2 = Final weight in milligrams
- D = Density of steel gm/cm<sup>3</sup>
- A = Area of the specimen in cm<sup>2</sup>
- T = Test period in hours.

## RESULTS AND DISCUSSION

**Compressive, Split Tensile and Flexural Strength:** The compressive strength results up to 90 days curing are shown in Figure 5. Considering the addition of sodium nitrite, the maximum strength value is obtained by adding 3% of the inhibitor to the SCC which yields about 8.8% improvement.

The split tensile strength test results at the age of 28 days are shown in Figure 6. According to figure 6, it is understood that addition of 3% sodium nitrite to the SCC yields about 3.44% improvement.

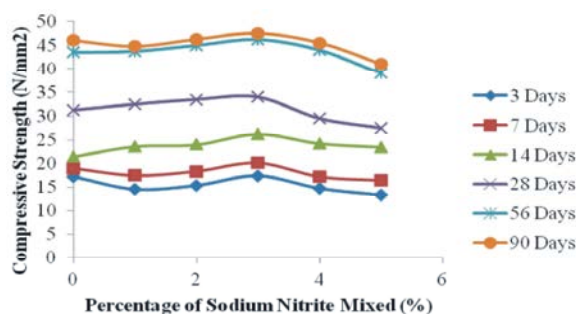


Fig. 5: Compressive Strength with Inhibitor (Mpa)

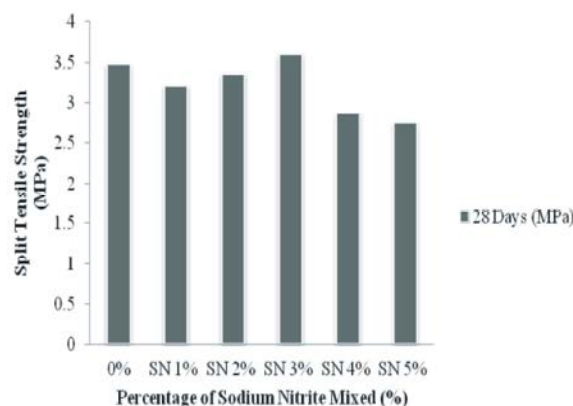


Fig. 6: Split tensile strength with Inhibitor (Mpa)

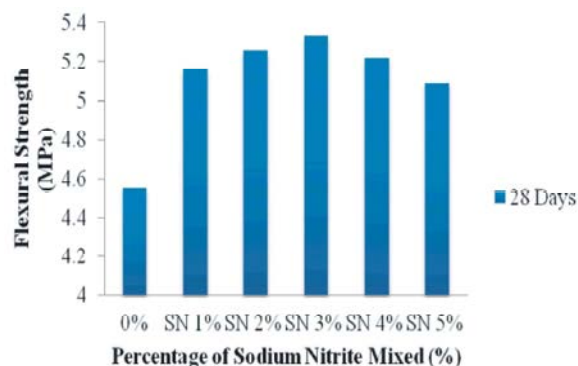


Fig. 7: Flexural strength with Inhibitor (Mpa)

Figure -7 shows the flexural strength test results after 28 days curing. Considering Figure -7, it is observed that the maximum increase in the strength is given by 3% addition of sodium nitrite to the SCC yields maximum improvement in strength about 17.14% when compared with reference specimen.

From the results of strength tests, it is observed that when compared to reference specimens, all the inhibitor added specimens display slightly a higher strength than the reference specimens. In the case of nitrite based inorganic inhibitors, addition of 3% sodium nitrite shows maximum strength and further increase in dosage resulting

Table I: Sorptivity Value

Specimen Name	Dry Wt in grams (W1)	Wet Wt in grams (W1)	Sorptivity Value In $10^{-5}$ Mm/min <sup>0.5</sup>
CC	855.25	857.65	0.849
SN	832.28	833.75	0.095

Table II: Impressed Voltage Test Value

Time	SCC	SN3
0 hrs	0.1	0
50 hrs	0.25	0.1
100 hrs	0.39	0.16
150 hrs	0.46	0.22
200 hrs	0.59	0.34
250 hrs	0.66	0.42
300 hrs	0.78	0.56
350 hrs	0.84	0.66
400 hrs	0.98	0.74
450 hrs	1.06	0.82
500 hrs	1.15	0.9

in decrease in strength due to decrease in the degree of hydration and therefore, a high capillary porosity or a change in the cement micro structure.

**Durability Tests**

**Sorptivity Test Results:** The sorptivity can be determined by the measurement of the capillary rise absorption rate on reasonably homogeneous material. The quantity of water absorbed in time period of 30 minutes was measured by weighting the specimen on a top pan balance weighting upto 0.1 mg. Table I and Figure 1, shows the Schematic of sorptivity.

**Impressed Voltage Test Results:** Impressed Voltage readings were taken on specimen every 50 hours upto 500 hrs. Table II and Figure 2, shows the variations of impressed voltage readings with accelerated time.

The Figure 8 shows the time vs current density behaviour of corrosion inhibiting specimens in the impressed voltage test. It can be seen that there is a reduction in current density for corrosion inhibiting specimens compared to reference specimen. The observation is due to a higher resistance of sodium nitrite inhibiting materials against chloride ingress. Incase of corrosion inhibitors mixed specimens current density values are high when compared with reference specimen.

**Half Cell Potentiometer Results:** Half cell potentiometer readings were taken on specimen every 50 hours. The experimental set up is as shown in Figure 3. Table II and Figure 9 shows the variations of half cell potentiometer readings with accelerated time.

Table III: Half Cell Potentiometer Value

Time in Hrs	SCC	SN3
0	0	0
50	-92	-45
100	-293	-173
150	-402	-245
200	-489	-319
250	-551	-389
300	-623	-460
400	-678	-533
450	-736	-602
500	-798	-668

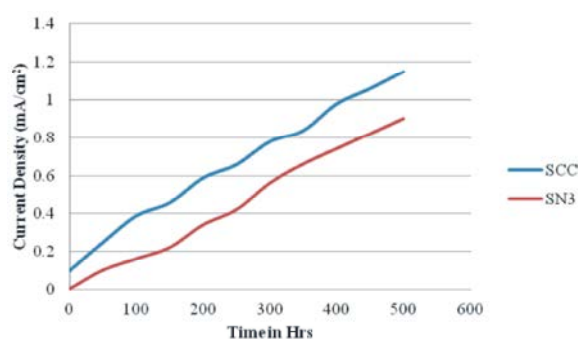


Fig. 8: Current Density Value

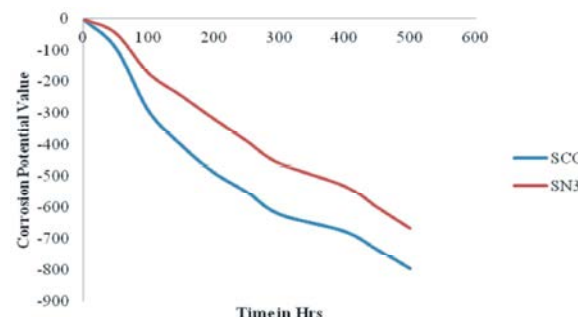


Fig. 9: Half Cell Comparison Value



Fig. 10: Cracked Specimen

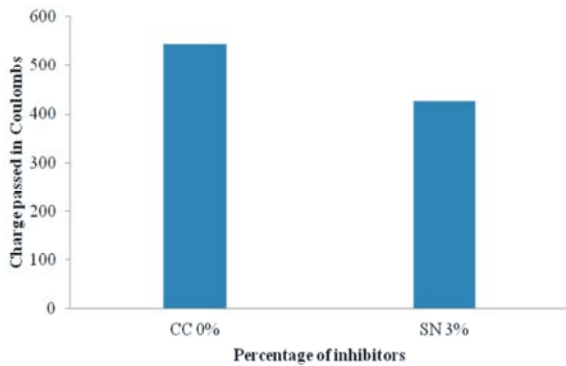


Fig. 11: Rapid chloride permeability test

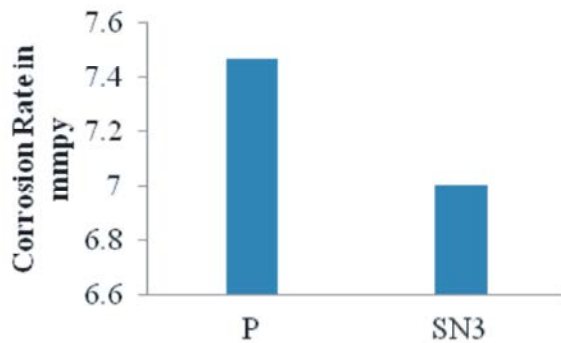


Fig. 12: Corrosion Rate with Addition of Inhibitor

Figure 10 show that, the crack propagation which occurred in corrosion inhibitor mixed SCC specimen.

The Figure 8 shoes the time vs corrosion potential behaviour of corrosion inhibiting specimens in the half cell potentiometer test. It can be seen that there is a reduction in corrosion potential for sodium nitrite corrosion inhibitor admixture specimens compared to reference specimens. The observation is due to a higher resistance of sodium nitrite inhibiting materials against chloride ingress. Incase of corrosion inhibitors mixed specimens current density values are high when compared with reference specimen.

**Rapid Chloride Permeability Test:** Figure - 11 shows the chloride diffusion results of the optimum percentage of inhibitor. The RCPT value for control concrete at 28 days is found to be 543.60 Coulomb. From the figure it is evident that optimum percentage of sodium nitrite 3% inhibitor yields a comparatively lower value than control specimen for the inorganic inhibitor. From the figure it is observed that addition of 3% sodium nitrite show lower coulomb values than the reference mixes. The inhibitors reduce the ingress of chlorides by filling concrete by the formation of complex compounds and reduce the extent of corroded area.

**Gravimetric Weight-loss Method:** Figure 12 shows the reduction of corrosion rate by the addition of inhibitor. Corrosion rate from the weight -loss measurements clearly indicates that the rate of corrosion decreases with the increases of percentage of inhibitor up to 3%.

It is also evident from the corrosion test results that the corrosion resistance of sodium nitrite inhibitor mixes is lower than the reference concrete.

## CONCLUSION

From the experimental studies concerning the strength and durability behaviour of inhibitors in self compacting concrete, the following conclusions have been obtained:

- The self compacting concrete containing fly ash can be effectively utilized in construction industry with good quality materials, appropriate dosage of super plasticizer, appropriate mixing sustainable development against environmental pollution;
- Addition of super plasticizer not only reduces the water content without affecting the workability but also enhances the strength slightly due to effective dispersibility of cement agglomerates in the SCC.
- The incorporation of inhibitors as admixture dose not shows any adverse effects on the strength up to certain percentage. Among the various percentages of inhibitors added (1%, 2%, 3%, 4% and 5% by weight of cementitious materials), the specimens with 3% of sodium nitrite show maximum improvement in the compressive, split tensile and flexural strength when compared with the reference specimen which is without addition of inhibitor;
- Over dosing of corrosion inhibitor results in the acceleration of setting time which leads to a reduction in the ultimate strength of concrete;
- The addition of inhibitors as admixture to SCC displays very lower permeability;
- The sorptivity of the concrete also shows lower water penetration for SN3 specimen than the reference concrete.
- The inorganic inhibitor sodium nitrite protect steel in concrete by keeping the chloride ions from reacting with the ferrous ions of ferric oxide defects and cause a large anodic shift of the corrosion potential, forcing the metallic surface into passivation range.;
- To conclude, considering strength as well as durability criteria, the optimum percentage addition of inorganic corrosion inhibitor by weight of cement in SCC is 3% for sodium nitrite.

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