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Performance Evaluation of Sodium Nitrite Corrosion Inhibitor in Self Compacting Concrete

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Abstract

A kind of special concrete known for its flowing property and the mixture affixes under its self-weight. Henceforth under congested circumstance it obviates the difficulty of placing concrete moreover reducing the time in setting up large sections meanwhile affording increased strength and commanding durability characteristics than standard concrete. The major consequence facing all around is that durability concern with respect to corrosion of steel. The premature failures in concrete are caused due to this corrosion of steel. To improve a service life of concrete, corrosion inhibitors have been used as effective measures to inhibit corrosion. But there are numerous inhibitors were exists in the market. Only Sodium Nitrite (SN) has proven corrosion inhibiting capabilities simultaneously refine the mechanical properties of concrete. Therefore the presence of sodium nitrate in the self compacting concrete as the corrosion inhibiting admixture, the strength and corrosion resisting properties were studied by the dosage added 0%, 1%, 2%, 3%, 4% and 5%, by the weight of cement. Mix design for M25 grade of concrete according to BIS method (IS 10262:2009). Cement is replaced with consistent percentage of fly ash (40%). Then the standard concrete mix proportions were modified into SCC properties as per EFNARC specifications and different trail mixes were done. The investigation on the properties of self compacting concrete in spite of the effect of corrosion inhibiting admixture is done on the trial basis. The effect of Corrosion inhibiting admixture (a sodium nitrate based inhibitor) along with the properties of fresh concrete and the hardened concrete are determined. From the results it is proven that the self compacting concrete increases the strength of the concrete with accretion of inhibitor (sodium nitrite). Ultimately it was concluded that the compressive strength of cubes at 3% of sodium nitrite was increased strength by 8.8% in comparison with standard self compacting concrete (SN0) mix.

Keywords: Admixtures, Corrosion Inhibitor, Fresh Characteristics, Hardened Properties, Self Compacting Concrete, Super Plasticizer

1. Introduction

Self-Compacting Concrete (SCC), brought forth in the late 80's in Japan shows remarkable progress for about two decades in concrete technology. It was engendered to assure amply compaction via self consolidation thereby make ease of placement of concrete in structures with congested reinforcement and also in restricted areas. Due to its high flow ability, SCC does not require vibrators to carry out consolidation by which compete filling of formworks are done even though the access is denied by narrow gaps betwixt reinforcement bars. In the production of SCC, the ingredients involved are similar to that of customary vibrated normal concrete with some exceptions that SCC domesticates lesser sum of aggregates and larger sum of powder i.e., cement and filler particles smaller than 0.125 mm and also special plasticizer which enhance flow ability. Filler matters such as fly ash, glass filler, limestone powder, silica fume are used. High flow ability and high segregation resistance of SCC are obtained by using:

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(i) larger quantity of fine particles, i.e. a limited aggregate content (coarse aggregate: 50% of the concrete volume and sand: 40% of the mortar volume); (ii) low water/powder ratio; and (iii) higher dosage of super plasticizer. In order to avoid segregation of SCC, stabilizer is required which maintains proper cohesiveness. Typical ranges of proportions and quantities of the constituent materials for producing SCC are mentioned in the literature. Su et al, Patel et al, and Sonebi mentioned the related information concerning design of SCC mixtures. EFNARC annotated the discrete tests for assessment of compatibility and flow ability.

Shetty defines durability of concrete as the ability of concrete to counteract weathering action, chemical attack and abrasion while maintaining its desired engineering properties. In the concrete infrastructure the reinforcing steel subjected to corrosion is a major concern. Velu Saraswathy, Vidiem and Vedalaksmi have reported that many structures in adverse environments have experienced unacceptable loss in serviceability of safety earlier than anticipated due to the corrosion of reinforcing steel and thus need replacement, rehabilitation or strengthening. Adoption of chemical method using certain corrosion inhibiting chemicals and coating to reinforcement to prevent corrosion was suggested by Brown and Schutter G. Luol. Under chlorine laden environment, corrosion inhibitor deserves the accepted method of improving durability of reinforced concrete and it was reported by Ping Gu and Elliott. According to NACE (National Association of Corrosion Engineers) inhibitors are the substances which, when added to an environment, decrease the rate of attack on a metal. The conclusions of David Bone, Hope and Luol, De. Schutter reveals that the corrosion inhibitors function by reinforcing the passive layer or by forming oxide layer thus preventing the outside agents and reducing the corrosion current. For about more than 20 years it is being in practice that Calcium nitrite is used as a corrosion inhibitor against chloride attack and also as a set accelerator. The addition of 4% Sodium nitrate in concrete improves the durability properties in addition to mechanical properties of concrete were suggested by Prabhakar who evaluated the performance of Sodium nitrate inhibitor in concrete. Numbers of studies were carried out to investigate the use of corrosion inhibitors in enhancing the corrosion resistive properties of conventional concrete. This thesis deals with the evaluation of Sodium nitrate (at various percentage viz, 1%, 2%, 3%, 4% and 5%) with respect to the weight of cement in self compacting concrete in resisting corrosion.

1.1 Objectives

Flow ability, passing ability and segregation resistance are the significant characteristics of SCC in the fresh state. Compressive strength, split tensile strength, flexural strength tests are conducted to study about the performance of Sodium nitrate added to SCC and also durability study is conducted and evaluated. From the results obtained, the most favourable percentage of corrosion inhibitor (Sodium nitrate) in the SCC could be determined.

2. Experimental Programme

2.1 Materials

Ordinary Portland Cement (OPC), Fine Aggregate (FA), Coarse Aggregate (CA), fly ash (FA), Super-Plasticizer (SP), Corrosion Inhibitor (CI) (sodium nitrite) and water are the ingredients of the mixture. Notably, Ordinary Portland Cement (43 grade) has been used in the investigation throughout. Fine aggregate comprised of clean river sand with maximum size of 4.75 mm conformed to grading zone–II as per IS 383-1970, with specific gravity 2.60, fineness modulus 2.25 and bulk density 1721 kg/m^3 was used throughout the work. For this study, Coarse aggregate has been availed from the nearby stone quarries. The aggregates are crushed by machineries and the maximum size of aggregate should be 12.5 mm with specific gravity 2.80, and fineness modulus 6.23 and bulk density 1674 kg/m^3. The fly ash (class F) conforming to IS:3812:2003 was procured from Mettur Thermal Power Station, Salem, Tamil Nadu. For mixing and curing of concrete the potable bore well water was availed. In order to increase the workability of self compacting concrete, the chemical admixture such as Conplast SP430 as super plasticizer which is commercially available is used. Sodium nitrate ($NaNO_2$) is an inorganic compound slightly white to yellowish crystalline powder. It is hygroscopic and can easily dissolve in water. In industrials, sodium nitrate is used as an additive due to its characteristics of effective corrosion inhibitors. A mixture proportion based on IS: 10262 – 2009 was designed to achieve the strength of 25 N/mm^2. The conventional concrete mix proportions were modified as per EFNARC specifications. Thus ultimately arrived SCC mixture was 1: 1.65: 1.29 with water-cement ratio 0.40.

2.2 Methodology

Concrete cubes, cylinder, and beams were casted in the respective sizes of dimension 100 x 100 x 100mm, 100 mm diameters and 200m length, and 100 x 100 x 500mm accordingly. After 24 hours, the specimens were separated from mould and let for curing. These samples were tested for compressive, flexural and split tensile tests with the presence and absence of Sodium Nitrate. The specimens were tested at the intervals of 3, 7, 14, 28, 56 and 90 days. The water absorption test was conducted on the hardened concrete specimens.

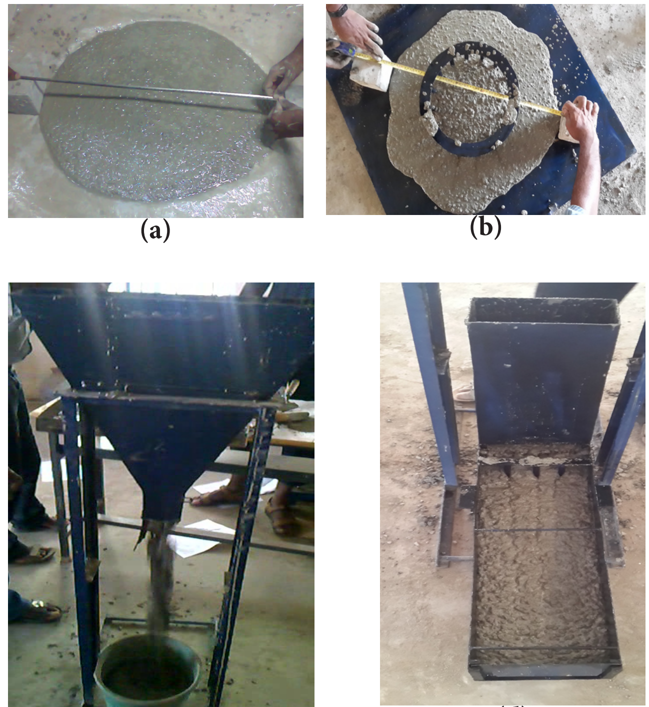
2.3 Mix Proportion

As per IS 10262 the concrete mix design was prepared. Concrete mix was prepared with M25 grade of concrete and the Water-Cement ratio of 0.40. According to EFNARC specifications, the standard concrete mix proportions were modified into different trial mixture proportions. The experimentation results were shown in Table 1. In order to study the workability, various tests on the fresh concrete should be performed. The conducted tests were shown in Figure 1(a, b, c & d). As per the EFNARC the tests results and their acceptance criteria were listed in Table 2.

In course of examining the fresh and hardened properties of Self-Compacting Concrete (SCC), a number of 6 mixes were employed. The quantity of sand, coarse aggregates, water/binder ratio and sp dosage were kept constant throughout the mixes with varying corrosion Inhibitor (CI). The Mix Id SN0 is a reference mix which excludes CI. In mixes SN1, SN2, SN3, SN4 and SN5 Corrosion inhibitors were added on 1% interval up to 5% (by weight) respectively. The water/binder ratio for all the mixes was maintained constant as 0.40.

Table 1. Mixture Proportion

Sodium Nitrite %	W/C ratio	Water (kg/m^3)	Cement (kg/m^3)	Sodium Nitrite (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)
0	0.4	220.5	330.7	0.00	907.7	713.2
1	0.4	220.5	330.7	5.50	907.7	713.2
2	0.4	220.5	330.7	11.00	907.7	713.2
3	0.4	220.5	330.7	16.51	907.7	713.2
4	0.4	220.5	330.7	22.01	907.7	713.2
5	0.4	220.5	330.7	27.51	907.7	713.2



(c) (d)

Figure 1. Test conducted on fresh SCC **(a)**. Slump flow & T50 Test **(b)**. J- Ring Test **(c)**. V -Funnel Test **(d)**. L- Box Test.

Table 2. Fresh SCC properties of reference mix

SI.No	Test Method	Unit	Results of Tests	Typical range of values as per EFNARC	
			Mix M25	Min.	Max.
1	Slump flow	mm	700	650	800
2	L - Box	(H2/H1)	0.89	0	1.0
3	V - funnel	Sec	7	6	12
4	J-Ring	mm	8	0	30

3. Test on Concrete

3.1 Fresh Properties of Concrete Mix

The tests such as slump flow, V-funnel, L-box and J-ring tests are conducted through which the fresh properties of concrete are determined. Whereas the Slump flow and V-funnel tests show the filling ability of SCC mix, the J-ring and L-box tests show the passing ability of SCC mix, and the marsh cone tests show the viscosity of SCC mix The workability test results are categorized as Slump flow test results, V-funnel test results, L box test results, J-ring test results and marsh cone test results. The values of the test results for determining the fresh properties of SCC mixes are given in the Table 2, Table 3 and Figure 2.

From the Figure 2, the test could be carried out for cement with 0.5% of superplasticiser with % of corrosion inhibitor (sodium nitrite) at design mix W/C ratio. For the selected water cement ratio (0.40) the optimum dose is SN3%.

3.2 Tests Conducted on Hardened M25 SCC

Compressive, split tensile and flexural strength tests were done on the concrete specimen casted on different days, to examine the mechanical properties. Different specimens were used for the respective tests.

3.2.1 Compressive Strength

In order to determine the compressive strength of the concrete, the Cube specimen of size 100 x 100 x 100mm is casted from the reference mix of SCC and let curing for about 90 days. As per IS 516-1959, the specimens were tested in a compression testing machine which has the capacity of 2,000 KN, at the time interval of 3, 7, 14, 28, 56 and 90 days respectively

Compressive strength fc = Load/Area…… (a)

The ability to resist the static load to a concrete specimen which tends to crush, is measured as its compressive strength. According to the increasing percentage of corrosion inhibitor (Sodium nitrite), differences in strength increasing or decreasing was examined by the compressive test performed on the specimen. According to IS516-1959 the different mixture proportions were determined by the compressive strength test on SCC. The empirical test values are plotted as shown in Figure 3.

The above figure implicit that the addition of sodium nitrate increase the compressive strength notably on 1%

Table 3. Marsh Cone Time in Seconds for SP and CI

0.5% of SP and % of SN by cement	Time in sec (T)
SN0	6.52
SN1	5.64
SN2	4.86
SN3	4.24
SN4	4.34
SN5	4.64

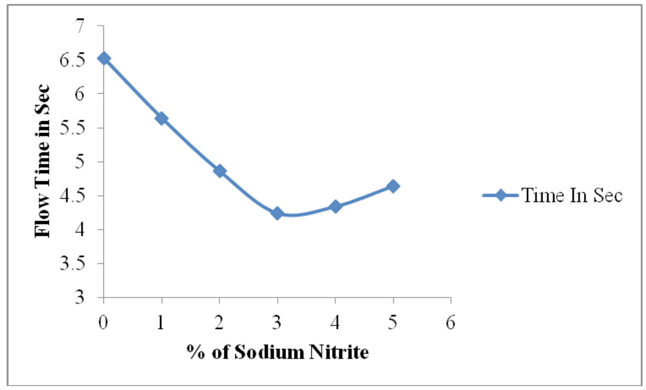


Figure 2. Optimization of dosage by cement.

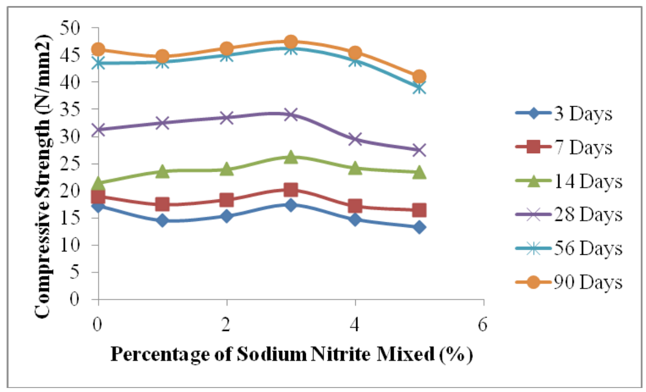


Figure 3. Compressive Strength with Inhibitor (MPa).

and 2% addition than in 4% and 7.2% comparatively. Also the compressive strength value hike to 8.8% (34 Mpa) than SN0 whiles the addition of 1% of the inhibitors. Further increase in % of sodium nitrite inhibitor result is decrease in value. Hence the optimum percentage of mix was seen in SN3 i.e. addition of 3% inhibitor shows the better improvement in compressive strength than the conventional concrete comparatively.

3.2.2 Split Tensile Strength

To determine the split tensile strength, cylinders of diameter 100 mm and 200 mm high are casted from the reference mixes. As per IS 5816-199, the specimen is tested after 28 days of curing with different techniques.

$$f_{split} = 2P/\pi DL, \ldots\ldots$$

Where, P=load, D= diameter, L=length of cylinder…… (b)

The test results were plotted as shown in Figure 4. With reference to figure 3, it is known that the strength value increased by 3.44% by adding 3% of sodium nitrate

3.2.3 Flexural Strength

For the determination of flexural strength, beams of size 100 × 100 x 500 mm are casted from the reference mixes. The specimens are checked after curing of about 28 days using different techniques. Universal testing machine is used for testing the specimens as per IS: 516-1959. The two-point loading method has been adopted.

$$frup = (WL)/(bd2)$$

Where, W = load at failure, L = Span of beam (400 mm), b = width, d = depth of beam …(c)

With reference to Figure 5, it is observed that better improvement in flexural strength has been found due to mix SN3 with addition of 3% inhibitor than the CC comparatively. From the results it is found that the inhibitor of 3% having 17.14% (5.33 MPa) gives more strength than conventional concrete.

3.2.4 Water Absorption Test

The water absorption test for the hardened concrete specimens is determined based on ASTM C-642 - 81. The

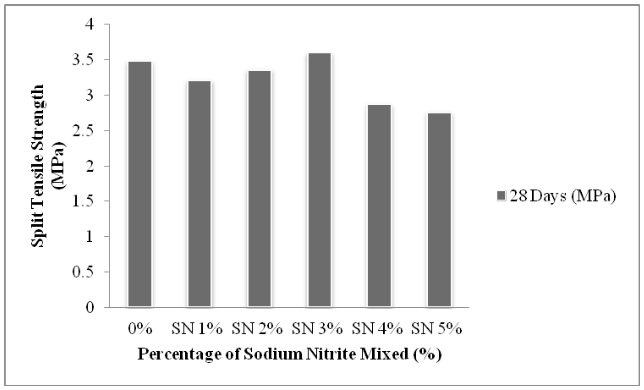


Figure 4. Split tensile strength with Inhibitor (MPa).

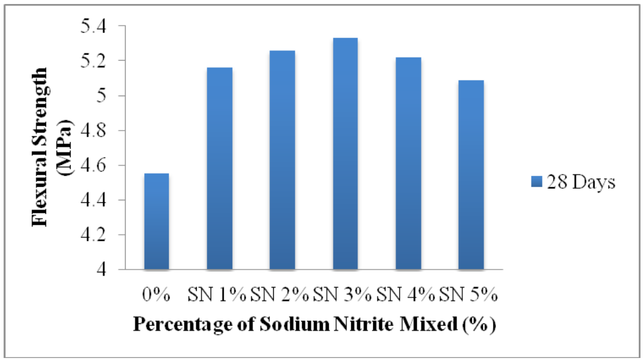


Figure 5. Flexural strength with Inhibitor (MPa).

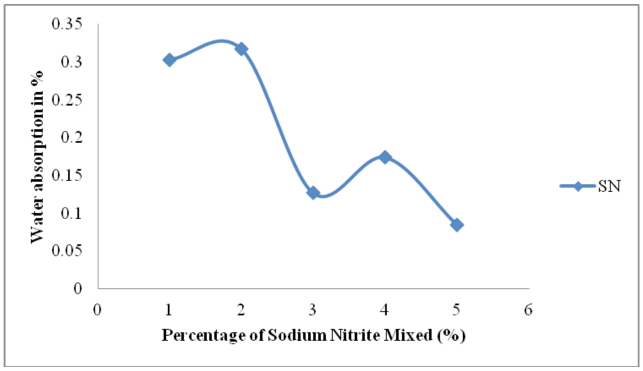


Figure 6. Water Absorption.

concrete cube specimens of size 100 x 100 x 100 mm are used. Concrete cubes were casted for each mix proportion and are tested after 28 days curing. The value of water absorption is given by the ratio weight of water (difference between wet and dry weight) to the dry weight of the specimen.

Water Absorption (%) = {(Saturated weight – Dry weight) / (Dry weight)} X 100

From the observed results, the values of water absorption are plotted against the percentage of inhibitors for all mixes. Comparing to all mix ratios, sodium Nitrite 1% shows higher value than conventional concrete. For all the mixes the water absorption values was decreases upto SN3%. Addition of 1% SN4% was relatively higher absorption than the optimal percentage.

4. Conclusion

The following conclusions were made based on the experimental studies:

- Designed for a selected water cement ratio (0.40) the most favorable dose are SN3%. The test could be accepted out for cement with 0.5% of superplasticiser and % of corrosion inhibitor (Sodium Nitrite) at design mix W/C ratio.
- The most favorable doses inferred from the above tests fall within the range suggested.
- Amongst the various percentages of corrosion inhibitors added such as SN1%, SN 2%, SN 3%, SN 4% and SN 5%, the self compacting concrete with 3% addition of inhibitor shows highest values of compressive strength, split tensile strength, and flexural strength than that of conventional concrete specimen.
- The self compacting concrete casted with 40% fly ash and SN3% attains higher values of compressive

strength, split tensile strength and flexural strength, showing increased percentage of about 8.8%, 3.44%, and 17.14% respectively.

- Addition of corrosion inhibitor reduces the water absorption properties considerably.
- The optimum percentage of sodium nitrite to get added in SCC comprising fly ash admixture is that SN3%, which increases the strength and durability of the concrete.

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