



Influence of Inorganic Inhibitors on the Strength and Corrosion Resistive Properties of Quarry Dust Concrete

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Demand of quarry dust for making concrete is increasing day by day because availability of natural sand is getting depleted and it is becoming costly. This paper deals with an experimental study undertaken to investigate the use of quarry dust as fine aggregate in concrete. Experimental work has been carried out with calcium nitrite, calcium nitrate and sodium nitrate as corrosion inhibitors at the dosage of 1, 2, 3 and 4 % by weight of cement. The effectiveness of these inorganic inhibitors was studied using various electrochemical techniques such as rapid chloride penetration test (RCPT), accelerated corrosion test, A.C. impedance measurement and gravimetric weight loss measurement. The mechanical properties such as compressive strength, flexural strength, split tensile strength and bond strength in addition to water absorption were also studied and the optimum percentage addition of each inhibitor was determined. Results herein revealed that replacement of sand by quarry dust increases the strength of the concrete; with addition of inhibitor it offers lower permeability and greater density which enable it to provide better resistance to corrosion and durability in adverse environment.

Key Words: Quarry dust, Inhibitor, Chloride diffusion, Accelerated corrosion, Resistance.

INTRODUCTION

The demand for natural sand is quite high in developing countries since the available sand is not able to meet the demand of construction sector. Natural sand takes millions of years to form and it is not replenishable. In such a situation the quarry rock dust can be an economic alternative to the river sand. Quarry rock dust can be defined as residue, tailing or other non-volatile waste material after the extraction and processing of rocks to form fine particles less than 4.75 mm¹. Ilangoan and Nagamani^{2,3} studied the usage of quarry dust as 100 % substitute for natural sand in concrete and conducted experiments to judge the properties of fresh concrete and strength properties. It is found that the compressive strength, flexural strength and durability properties of concrete made of quarry dust are nearly 10 % more than conventional concrete. As reported by Hameed and Sekar⁴, the use of quarry dust as fine aggregate will also reduce environmental impact, if consumed by the construction industry in large quantities. Sahu and Kumar⁵ have reported that concrete containing quarry dust as fine aggregate is promising greater strength, lower permeability and greater density which enable it to provide better resistance to freeze/thaw cycles and durability in adverse environment. Murugesan and Chitra⁶ examined the effect of super plasticizer

in quarry dust replaced concrete and reported that the compressive strength of quarry dust concrete can be improved with admixture E. As suggested by Prachoom Khamput⁷, super plasticizers can be used to improve the workability of quarry dust replaced concrete. Nagaraj and Manning^{8,9} have observed that concrete using quarry fines shows improvement in higher flexural strength, abrasion resistance and unit weight which are very important for reducing corrosion or leaching.

Corrosion of reinforcing steel is a major problem facing the concrete infrastructures. Videm¹⁰ and Vedalakshmi *et al.*¹¹ 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. Brown *et al.*¹² and Luo *et al.*¹³ suggested that corrosion can be prevented by using certain corrosion inhibiting chemicals and coating to reinforcement. According to NACE (National Association of Corrosion Engineers) inhibitors are substances which, when added to an environment, decrease the rate of attack on a metal. Gu *et al.*¹⁴ have reported that corrosion inhibitors are becoming an accepted method of improving durability of reinforced concrete in chloride laden environments. Several researchers¹⁵⁻¹⁸ have concluded that corrosion inhibitors function by reinforcing a passive layer or by forming ox-

ide layer and prevent outside agents and reduce the corrosion current. Schutter *et al.*¹⁹ and Munteanu *et al.*¹⁵ have investigated the mechanism of inhibitors and reported that inhibitors can act as anodic inhibitors block the corrosion reaction of the chloride-ions by chemically reinforcing and stabilizing the passive protective film on the steel (*e.g.*, nitrites); cathodic inhibitors react with the steel surface to interfere with the reduction of oxygen (*e.g.* zinc oxide) or ambiodic inhibitors suppressing both anodic and cathodic sites by forming an adsorptive film on the metal surface (*e.g.*, amines and fatty acids). Prabakar *et al.*²⁰ evaluated the performance of sodium nitrate inhibitor in concrete and suggested that addition of 4 % sodium nitrate in concrete enhances the durability properties in addition to mechanical properties of concrete. Calcium nitrite has been used as a corrosion inhibitor against chloride attack and as a set accelerator in concrete for more than 20 years²¹⁻²³. Considerable data are available concerning its effects on corrosion inhibition, setting times, freeze-thaw resistance, strength and other properties^{24,25}. Both calcium nitrate and calcium nitrite may act as anodic inhibitors against chloride induced corrosion of rebars in concrete through a similar mechanism, although the kinetics of reaction may be different²⁶⁻²⁸. However, studies on the corrosion resistance performance of concrete having quarry dust as fine aggregate with inhibiting admixtures are not available in the technical literature. This paper deals with the experimental study to investigate the effect of inorganic inhibitors namely calcium nitrite, calcium nitrate and sodium nitrate at the dosage of 1, 2, 3 and 4 % by weight of cement in concrete containing quarry dust as fine aggregate in resisting corrosion.

EXPERIMENTAL

The cement used was Ordinary Portland Cement (43 Grade) conforming to IS 8112-1989. Locally available well-graded quarry dust, conforming to Zone-II of IS 383-1970 having specific gravity 2.68 and fineness modulus 2.70 was used as fine aggregate. Natural granite aggregate having density of 2700 kg/m³, specific gravity 2.7 and fineness modulus 4.33 was used as coarse aggregate. High yield strength deformed 16 mm diameter bars of Fe 415 grade conforming to IS 1786 was used for pullout and corrosion tests. To increase the workability of quarry dust concrete commercially available super plasticizer ROFF 320 has been used. The inhibitors used were calcium nitrite-Ca(NO₂)₂, calcium nitrate-Ca(NO₃)₂ and sodium nitrate-NaNO₃ at the dosage of 1, 2, 3 and 4 % by weight of cement. To attain strength of 20 N/mm² a mix proportion was designed based on IS 10262-1982 and SP23:1982(21). The mixture was 1:1.517:3.38 with water cement ratio 0.45.

The following experiments were conducted to thoroughly investigate the strength, water absorption and corrosion resistance properties of the quarry dust replaced concrete with and without inhibitors. Tests were conducted on a minimum of three replicate specimens after 3 days, 7 days and 28 days curing and the average values are reported.

Strength tests

Compressive strength: The compressive strength of concrete is one of the most important tests conducted on hardened concrete because most of the desirable characteristic

properties of concrete are qualitatively related to its compressive strength. The compression test is carried out on cubic specimens of size 150 mm × 150 mm × 150 mm. Triplicate specimens were cast for each percentage of every inhibitor for 3, 7 and 28 days strength. After curing, the specimens were subjected to compressive force in a compression testing machine of capacity 2000 kN according to IS 516-1964. The ultimate load at which the failure occurs is noted. Then, the compressive stress value is obtained in N/mm².

Split tensile strength: This test is an indirect tensile strength test. This test is carried out on a cylindrical specimen of 150 mm diameter and 300 mm length. The cylindrical specimen is placed horizontally between the loading surface of a compression-testing machine and the load is applied until failure of cylinder along the vertical diameter occurs. The split tensile strength is given by the formula $2P/(\pi DL)$ and the stress value is obtained in N/mm². P is the ultimate load at which the cylinder fails. D and L are the diameter and length of the cylinder.

Flexural strength: Beams of size 100 mm × 100 mm × 500 mm were cast to measure flexural strength of concrete. The testing is carried out in UTM of capacity 40T and the system of loading is two point loading as per IS 516-1959. Flexural strength is expressed as modulus of rupture and is given by M/Z. M is the maximum moment that the beam can carry and Z is the modulus of section.

Bond strength: Bond strength between paste and steel reinforcement is of considerable importance and is mainly dependent on the blending materials used in making concrete. The blending materials used in this investigation are various inhibitors at various percentages. The corrosion rate has a direct effect on the bond strength and hence, it is one of the chief factors to be considered. Cylinders of size 150 mm diameter and 300 mm length with high yield strength deformed (HYSD) rods of 70 cm length kept at the centre, were used for determination of bond strength. Bond strength is given by the formula P/A , where P is the ultimate load and A is the total area of the rod *i.e.*, surface area and cross sectional area.

Water absorption (ASTM-C642-81): Water absorption of hardened concrete specimens was calculated based on ASTM C642-81. Cubes of size 150 mm × 150 mm × 150 mm were cast and after 28 days curing the cubes were taken out and dried in an oven at 105 °C for 24 h. The dried specimens were cooled to room temperature (25 °C), weighed accurately and noted as dry weight (W_d). Dry specimens were immersed in water and the weight of the specimens at predetermined intervals was taken after wiping the surface with dry cloth. This process was continued till constant weight is obtained in two successive observations (W_w). The water absorption percentage is given by,

$$W = (W_w - W_d) / W_d \times 100$$

where W_w is the weight of the saturated specimen and W_d is the weight of the dried specimen.

Durability tests

Rapid chloride permeability test (ASTM-C1202): The rapid chloride penetration test (RCPT) is used to determine the electrical conductance of concrete to provide a rapid indication

of its resistance to the penetration of chloride ions. The rapid chloride permeability test 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. 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 (0.3). The total charge passed through the cell in coulombs has been found in order to determine the resistance of the specimen to chloride ion penetration.

Impressed voltage test (ASTM-C876): Impressed voltage test is based on electrochemical polarization principle. To assess the corrosion protection efficiency under accelerated test conditions, concrete cylinders of size 75 mm diameter and 150 mm length were cast with a high yield strength deformed (HYSD) steel bar of 16 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 and also the protruding rod was insulated by PVC sleeve. After 28 days curing, all the triplicate specimens were taken out and dried for 24 h 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 top is connected to the positive terminals of the power pack (anode) and the stainless steel plate is connected to the negative terminal (cathode). The test specimens were subjected to a constant voltage of 6 volts from the D.C power pack. This setup forms an electrochemical cell. The experimental setup is shown in Fig. 1. The applied voltage is kept constant continuously and the current response is monitored with respect to time.

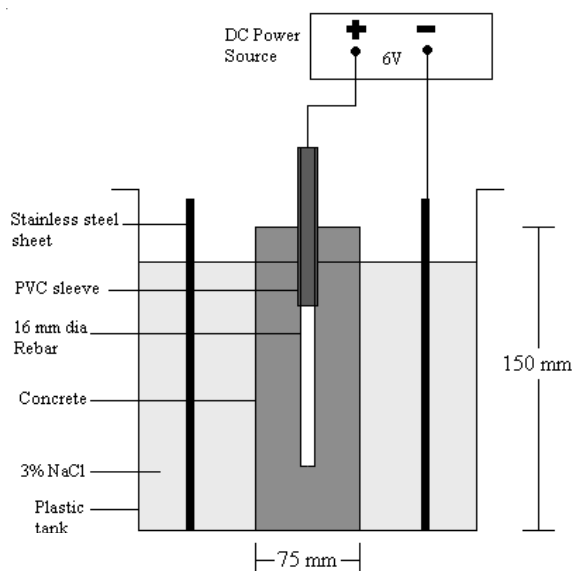


Fig. 1. Test set up for impressed voltage technique

AC Impedance technique: AC impedance spectroscopy is being used as non-destructive technique for quantifying corrosion of steel rebars embedded in concrete. In this technique an A.C. signal is applied to the embedded rebar and the response is monitored in terms of phase shift of the current

and voltage components and their amplitude. Cylindrical concrete specimens of size 75 mm diameter and 150 mm long were cast with centrally placed steel rod of diameter 12 mm. The steel rod is placed in such a way that an equal cover of 31.5 mm is maintained all-around. The potential of the rebar was measured periodically using a high input impedance multimeter. Impedance measurement was made using three electrode arrangements. Stainless steel electrode of size 10 mm × 80 mm was used as an auxiliary electrode and saturated calomel electrode was used as a reference electrode. Rebar embedded in concrete acted as a working electrode. The experimental set up is shown in Fig. 2. Chloride solution was used as a contacting solution to reduce the contact resistance between the electrode assembly and the concrete. A sinusoidal voltage signal of 20 mV was applied over a frequency range of 100 KHz to 10 mHz using a computer controlled electrochemical analyzer. The impedance values were plotted on the Nyquist plot. From the Nyquist plot, using the software 'z view' the resistance of concrete (R_c) and polarization resistance (R_p) values were calculated. By assuming Stern-Geary constant (B) as 26 mV (Andrade 1978), the corrosion current I_{corr} was calculated using the Stern-Geary relation (Stern 1975),

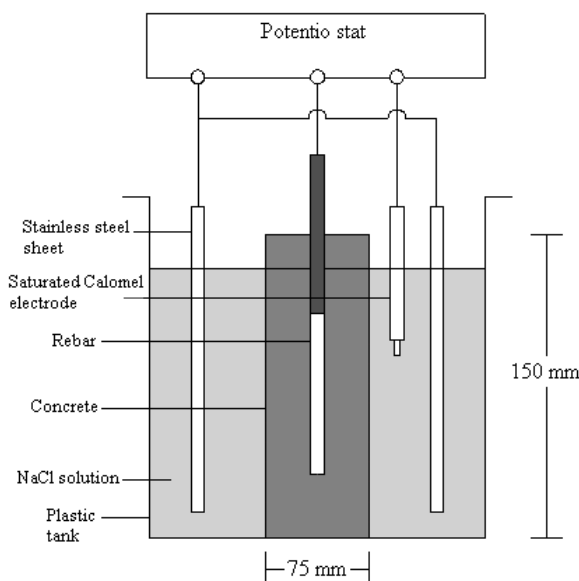


Fig. 2. Test set up for AC impedance technique

$$I_{corr} = \frac{B}{R_p}$$

where B = Stern-Geary constant, 26 mV, R_p = polarization resistance or Charge transfer resistance R_{ct} , ohms cm^2 , I_{corr} = corrosion current, $\mu A/cm^2$. From the I_{corr} , the corrosion rate of rebar was calculated using the following formulae,

$$\text{Corrosion rate in mmpy} = 0.0116 \times I_{corr}$$

where, I_{corr} is in $\mu A/cm^2$.

Gravimetric weight loss measurement: Steel embedded concrete cylinders were cast with various percentages of inhibitors and also without inhibitor. High yield strength deformed (HYSD) rods of size 16 mm diameter and 150 mm long, were immersed in the pickling solution (hydrochloric acid + water in equal parts) for 15 min to remove the initial

rust. The initial weight (W_1) of the rod was measured and embedded in the center of cylindrical concrete specimens of size 75 mm diameter and 150 mm long. The specimens were subjected to 28 days curing in fresh water. After the curing period was completed the cylinders were immersed in 3 % NaCl solution under alternate wetting (3 days) and drying (3 days) conditions over a period of 90 days. At the end of 90 days the cylinders were broke open and the final weight of the specimens was taken. The difference between the initial and final weight gives the weight loss of the specimen. From the weight loss obtained corrosion rate can be calculated using the following formula:

$$\text{Corrosion rate in mmpy} = 87600 \times \frac{W}{\text{DAT}}$$

where W = weight loss in grams ($W_1 - W_2$), D = density of steel g/cm^3 , A = area of the embedded rebar in cm^2 , T = time in hours.

RESULTS AND DISCUSSION

Compressive, split tensile, flexural and bond strength:

The compressive strength results after 28 days curing are shown in Fig. 3. From the figure it is evident that 1 % addition of calcium nitrite shows 8.82 % increase in the compressive strength, while the addition of 2 % of this inhibitor gives hike of 20.68 % and this yields the maximum increase in the strength value. Further, addition of calcium nitrite (3 %) gives 7.57 % increase and (4 %) gives 2.62 % increase in compressive strength. Considering the addition of calcium nitrate and sodium nitrate, the maximum strength value is obtained by adding 3 % of the inhibitor to the concrete which yields about 10.75 and 7.64 % improvement, respectively. Addition of 4 % yields a comparatively lower value than the control specimen. The split tensile strength test results at the age of 28 days are shown in Fig. 4. In accordance with Fig. 4, it is understood that addition of 2 % calcium nitrite and the addition of 3 % calcium nitrate and sodium nitrate shows the maximum increase in the strength value by 26.32, 19.03 and 16.62 %, respectively. The concrete with 4 % addition of calcium nitrite, calcium nitrate and sodium nitrate shows the reduction in split tensile strength by 10.9, 41.7 and 21.86 %, respectively than the control specimen. Fig. 5 shows the flexural strength test results after 28 days curing. Considering Fig. 5, it is observed that the maximum increase in the strength is given by 2 % addition of calcium nitrite and 3 % addition of calcium nitrate and sodium nitrate. The strength values are increased by 21.24, 18.58 and 16.82 %, respectively. The Bond strength test results at 28 days are shown in Fig. 6. The specimens with 2 % addition of calcium nitrite, shows a maximum increase in the bond strength by 29.13 %. In the case of calcium nitrate and sodium nitrate, 3 % addition of inhibitor shows 28.38 and 26.61 %, respectively. However, further addition of inhibitor to 4 % accelerates concrete setting time and cause a slight reduction in the strength values.

From the results of the strength tests, it is observed that in the case of nitrite based inorganic inhibitors, the specimens with 1, 2 and 3 % addition of inhibitors display slightly a higher strength than the control specimen since the total porosity of

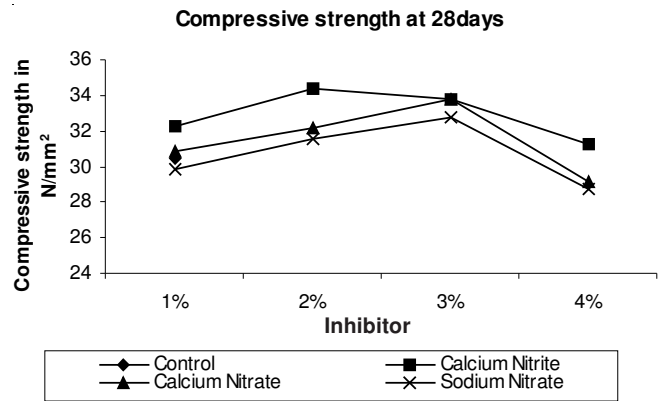


Fig. 3. Compressive strength

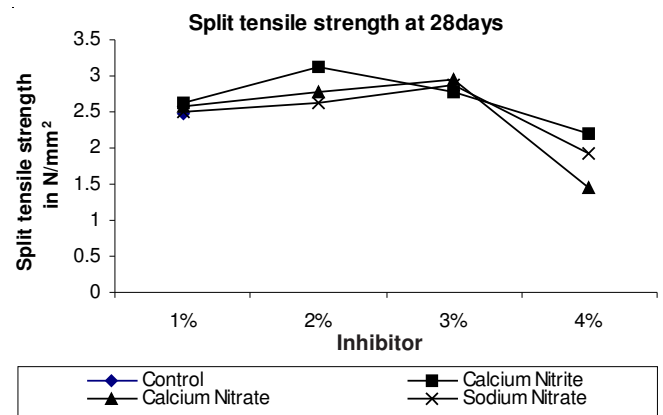


Fig. 4. Split tensile strength

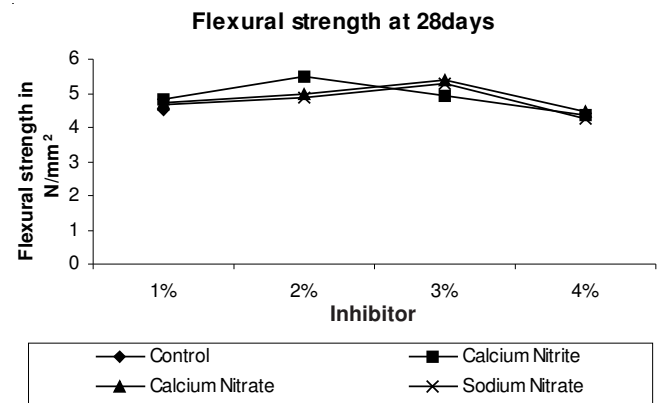


Fig. 5. Flexural strength

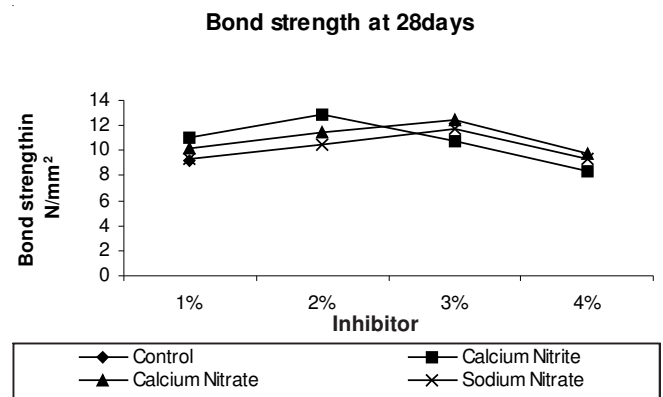


Fig. 6. Bond strength

the paste was lower in these percentages. Further increase in dosage, resulting in decrease in the strength due to decrease in the degree of hydration and therefore a higher capillary porosity in the cement micro structure. The increment caused by the nitrite based inhibitor is higher than the nitrate based inhibitors because of its compatibility with concrete properties.

Water absorption test: Fig. 7 shows the water absorption versus percentage of inhibitors after 28 days curing. It is observed that for all the inhibitors the absorption decreases as the concentration of inhibitor increases up to 3%. But, a concentration of 4% of calcium nitrite, calcium nitrate and sodium nitrate produces relatively higher absorption than other percentages. However, when compared to the control specimens, the addition of inhibitors definitely produces lower absorption values.

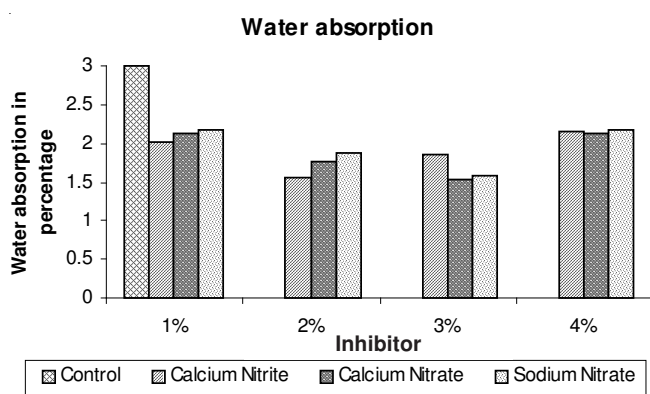


Fig. 7. Water absorption

Durability tests

Rapid chloride permeability test: Fig. 8 shows the chloride diffusion results of the different percentages of inhibitors. The performance of the quarry dust concrete with 1, 2, 3 and 4% addition of calcium nitrate are observed to be 1.62, 1.98, 1.51 and 0.98 times than the control specimen. Similarly, the performance of calcium nitrate are found to be 1.41, 1.64, 1.92 and 0.86 times and the effect of addition of sodium nitrate are found to be 1.32, 1.59, 1.89 and 0.74 times. From the figure it is observed that addition of 2% calcium nitrite and addition of 3% calcium nitrate and sodium nitrate show lower coulomb values than the other mixes.

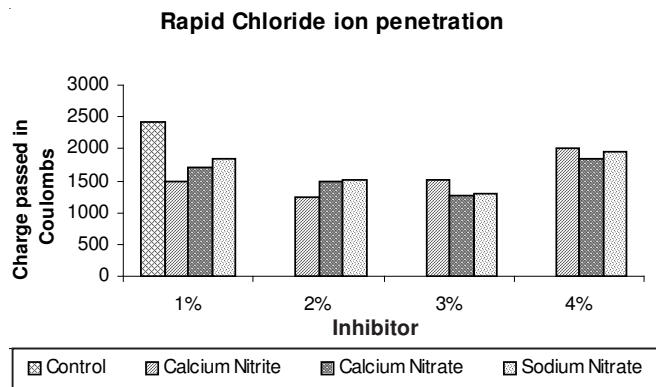


Fig. 8. Rapid chloride permeability test

Accelerated corrosion test-impressed voltage method:

The experimental studies conducted on rebar corrosion with 1, 2, 3 and 4% addition of calcium nitrite, calcium nitrate and sodium nitrate in concrete containing quarry dust as fine aggregate prove that the corrosion initiation time has been increased while using inhibitor in concrete. The performance of various inhibitors was investigated using electrochemical monitoring techniques while the concrete was immersed in 3% NaCl at ambient temperatures. The current intensity with respect to time for various percentages of inhibitors are shown in Figs. 9-12 and the corrosion resistance performances of the inhibitors at various percentages with respect to time is shown in Fig. 13. The corrosion initiation time for control concrete is found to be 158 h. In accordance with Fig. 13, it is to be noted that even the minimum value of the corrosion initiation time with respect to the addition of inhibitors is slightly higher than that of the control specimens. Among all the percentages added, 2% addition of calcium nitrite shows 97.46% improvement and 3% addition of calcium nitrate and sodium nitrate show 88.6 and 82.23% improvement, respectively which proves to be more effective in resisting corrosion. However the corrosion resistance is slightly reduced for 4% addition of inhibitors. The reasons for decrease in resistance are formation of C-S-H with higher C/S ratio, rapid initial setting followed by large heat development and a more porous structure (26). The effect is similar to the other nitrite inhibitors which accelerate set but retard cement hardening. The impressed voltage test results show that due to the addition of inhibitors permeability of the concrete was considerably reduced and the time taken for initiation of corrosion in concrete with respect to accelerated chloride penetration has been increased significantly.

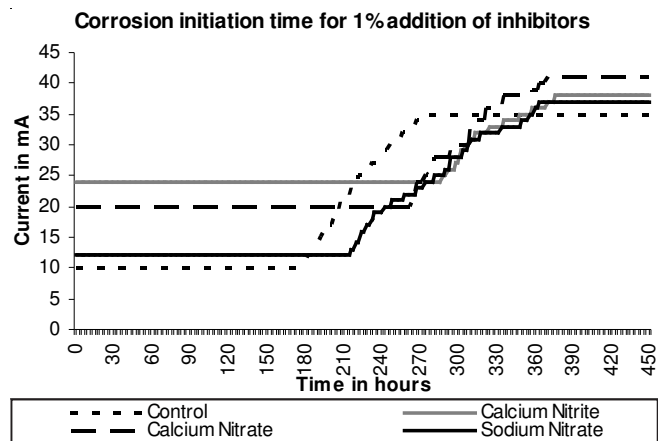


Fig. 9. Corrosion initiation time for 1% addition of inhibitors

AC Impedance technique: Table-1 lists the impedance parameters charge transfer resistance R_{ct} derived from Nyquist plots and I_{corr} values calculated using Stern-Geary relation. A good inhibitor system should show greater R_{ct} values and lesser I_{corr} values when compared with the system without inhibitor. Among all the percentages of inhibitors the specimens with 2% addition of calcium nitrite and 3% addition of calcium nitrate and sodium nitrate show higher R_{ct} values and lesser I_{corr} values. Fig. 14 shows the corrosion rates of all the specimens measured by AC impedance technique. The corrosion rate of the control specimen is 0.193 mmpy. From the figure it

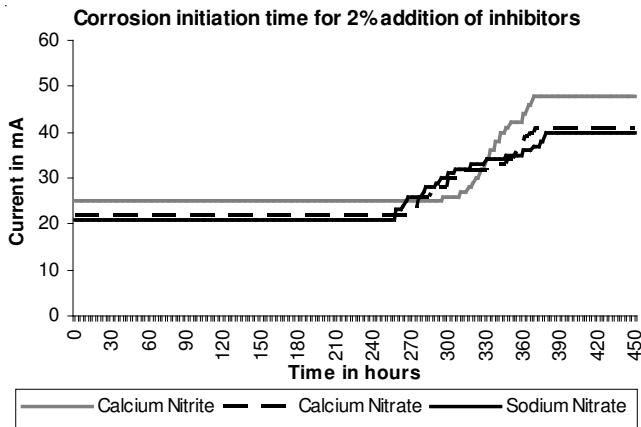


Fig. 10. Corrosion initiation time for 2 % addition of inhibitors

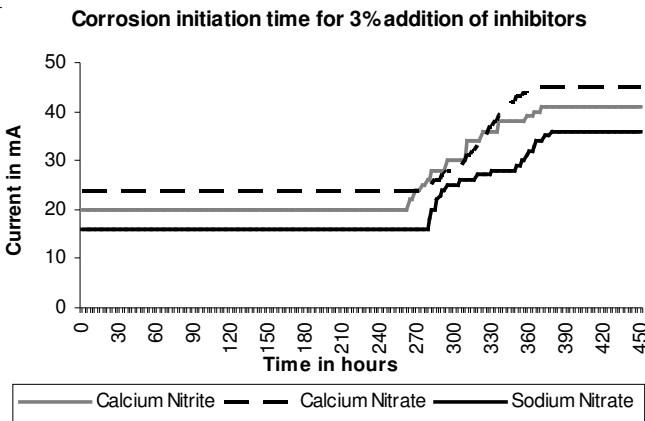


Fig. 11. Corrosion initiation time for 3 % addition of inhibitors

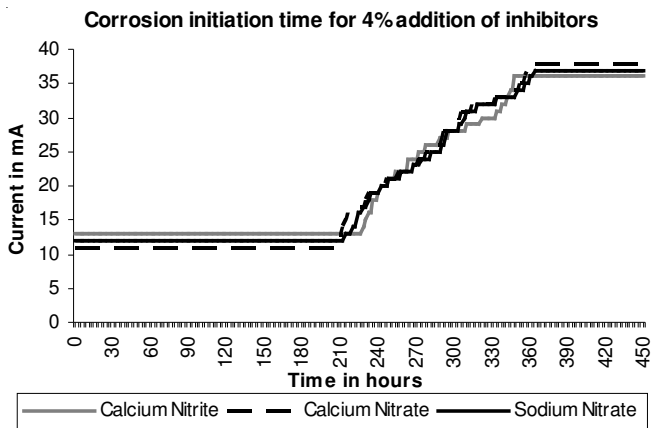


Fig. 12. Corrosion initiation time for 3 % addition of inhibitors

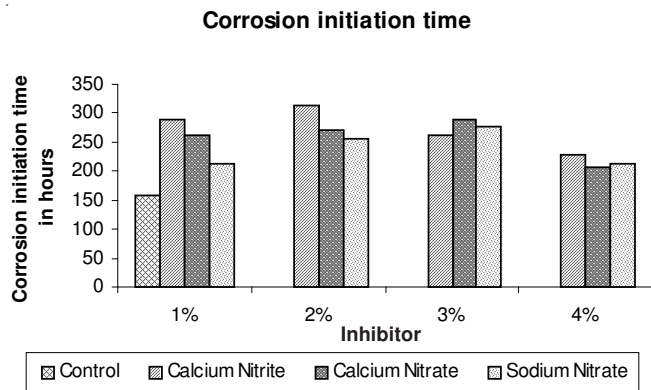


Fig. 13. Corrosion initiation time

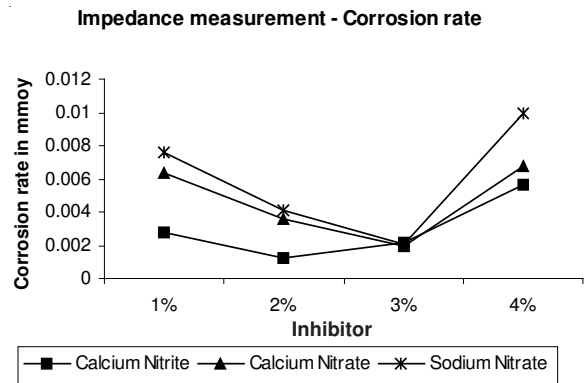


Fig. 14. AC impedance-corrosion rate of specimens

can be observed that, 2 % addition of calcium nitrite and 3 % addition of calcium nitrate and sodium nitrate were found to be more effective in controlling the corrosion rate of steel in 3 % NaCl solution. However, the corrosion rates are increased for 4 % addition of inhibitors which indicates that the tolerable limit of concentration is less than 4 %.

Alonso and Andrade²⁶ have related the values of corrosion current, I_{corr} , to the corrosion state in concrete. An $I_{corr} \leq 0.1-0.2 \mu A/cm^2$ indicates negligible corrosion, whereas greater values mean active corrosion. In terms of service life, an $I_{corr} > 1 \mu A/cm^2$ indicates high corrosion rate, while an $I_{corr} > 10 \mu A/cm^2$ is severe corrosion rate. According to this statement, the corrosion rate of 2 % addition of calcium nitrite and 3 % addition of calcium nitrate and sodium nitrate were found to be within 0.1-0.2 which indicates negligible corrosion and proves to be more efficient. The results of AC impedance show reasonable agreement with rapid chloride permeability test, impressed voltage technique and weight loss measurement.

Gravimetric weight loss measurement: Fig. 15 demonstrates average corrosion rate calculated in mmpy for various percentages of all the inhibitors from weight-loss measurements. From the figure it is inferred that 2 % addition of calcium nitrite show the lowest corrosion rate values. Further, increase in percentage of inhibitors increases the corrosion rates. Similarly calcium nitrate and sodium nitrate show lowest corrosion rate at 3 % dosage. On the other hand, 4 % addition of all the inhibitors slightly increases the corrosion rate. The same trend was observed in other tests. Values obtained by weight loss measurement are higher than AC impedance by 5 %. The results obtained from this study are in good agreement with the results of other researchers.

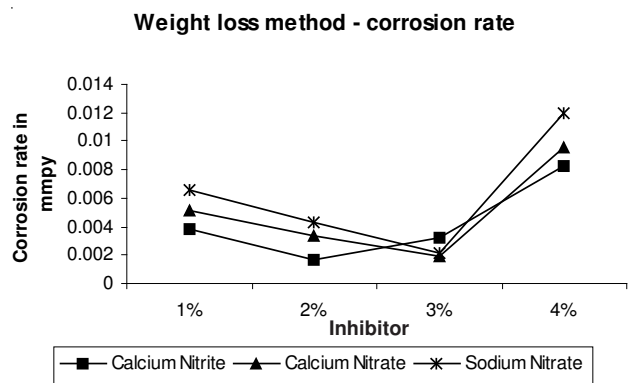


Fig. 15. Weight loss measurement-corrosion rate

TABLE-1
PARAMETERS OBTAINED FROM IMPEDANCE MEASUREMENTS

Systems	1 % inhibitor		2 % inhibitor		3 % inhibitor		4 % inhibitor	
	R_{ct} ($\Omega \text{ cm}^2$)	I_{corr} ($\mu\text{A}/\text{cm}^2$)	R_{ct} ($\Omega \text{ cm}^2$)	I_{corr} ($\mu\text{A}/\text{cm}^2$)	R_{ct} ($\Omega \text{ cm}^2$)	I_{corr} ($\mu\text{A}/\text{cm}^2$)	R_{ct} ($\Omega \text{ cm}^2$)	I_{corr} ($\mu\text{A}/\text{cm}^2$)
Control	15.66	1.66	-	-	-	-	-	-
Calcium nitrite	108.33	0.241	252.43	0.103	94.56	0.275	53.94	0.482
Calcium nitrate	47.10	0.552	83.87	0.314	151.16	0.172	44.36	0.586
Sodium nitrate	36.69	0.655	73.65	0.352	137.57	0.189	30.48	0.853

Conclusion

From the experimental studies, the following conclusions have been obtained:

(1) The concrete containing quarry dust as fine aggregate can be effectively utilized in the construction industry with good quality materials and appropriate dosage of super plasticizer; (2) The inorganic corrosion inhibitors investigated in this study did not adversely affect the strength properties of concrete. Among the various percentages of inhibitors added the specimens with 2 % addition of calcium nitrite and 3 % addition of calcium nitrate and sodium nitrate show maximum improvement in the compressive, split tensile, flexural and bond strength when compared with the control specimen; (3) The addition of inhibitors as admixture to concrete displays very low permeability and water absorption. Over dosing of corrosion inhibitor results in the acceleration of setting time which leads to a reduction in the ultimate strength of concrete; (4) All the corrosion test results revealed that 2 % addition of calcium nitrite and 3 % addition of calcium nitrate and sodium nitrate are found to be more effective in controlling the corrosion rate of steel. These inhibitors protect steel in concrete by keeping the chloride ions from reacting with the ferrous ions of ferric oxide defects; (5) Calcium nitrite delays the onset of corrosion in the concrete specimens contaminated with chloride and when it begins, the rate remains lower than that of the control specimen. It accelerates the setting times and also rate of development of strength. Thus, calcium nitrite is both accelerator and efficient corrosion inhibitor. Concrete with addition of 2 % calcium nitrite has got 1.92 times better performance as compared to control concrete; (6) Calcium nitrate is equally efficient as calcium nitrite as inhibitor and in addition to that it is cheaper, available in larger amount and less harmful. The corrosion resistance performance of concrete with addition of 3 % calcium nitrate was found to be 1.88 times more than control concrete; (7) Furthermore, it is proved that calcium nitrate and sodium nitrate had identical corrosion inhibiting properties. Sodium nitrate delays corrosion by reacting with ferrous ions from the rebar to strengthen the passive film on the surface of the reinforcement. Concrete with addition of 3 % sodium nitrate shows 1.82 times better performance than control concrete in resisting corrosion. The results obtained are in agreement with literatures²¹; (8) To conclude, considering strength as well as durability criteria, the optimum percentage addition of various inhibitors by weight of cement in concrete containing quarry dust as fine aggregate, is 2 % for calcium nitrite and 3 % for calcium nitrate and sodium nitrate.

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