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Performance of Corrosion Inhibitor Admixed Slag Cement Mortar Exposed to Aggressive Corrosion Environment

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ABSTRACT

The objective of the investigation is to study the effect of inhibitor addition on strength and durability performance of Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC) mortar exposed to aggressive corrosion environment. The variables involved in the study are type of cement (53 grade PPC and PSC), type of corrosion inhibitor (sodium nitrite (SN) based and calcium nitrite (CN) based) and dosage of corrosion inhibitor (1%, 2% and 5% by weight of cement). The strength properties were studied by conducting compressive strength, splitting tensile strength, flexural strength and shear strength tests. The durability tests conducted are sorptivity test and chloride penetration test. It is found that there is a similar compressive strength values at the age of 28 day and 56 days for control and inhibitor admixed mortar specimens irrespective of type of cement, type of inhibitor and dosage levels. There is an appreciable increase in tensile strength, flexural strength and shear strength for inhibitor admixed mortar as compared to control mortar irrespective of type of cement. Sorptivity test results revealed an improved performance of SN and CN inhibitor admixed mortar specimens irrespective of type of cement. There is an appreciable reduction in chloride penetration depth in the range of 10-40% for inhibitor admixed PPC and PSC mortar as compared to control mortar. It is concluded that addition of sodium nitrite and calcium nitrite based inhibitor enhances the durability properties of PPC and PSC mortar without affecting the strength properties.

Keywords: Corrosion inhibitor; durability properties; strength properties; slag cement mortar; sorptivity test

INTRODUCTION

Reinforced concrete is the most commonly used construction material worldwide. Reinforcement corrosion is the widespread damage mechanism to which reinforced concrete structures are subjected to when they are exposed to aggressive environments. Among the existing corrosion protection methods, use of corrosion inhibitors as concrete admixtures is a very popular, feasible and a relatively economical method. In the recent times, slag is widely used in concrete either as a separate cementitious component or as a part of blended cement. It works synergistically with Portland cement to increase strength, reduce permeability, improve resistance to chemical attack and inhibit rebar corrosion. Calcium nitrite and sodium nitrite based corrosion inhibitors are also find wider application in the reinforced concrete construction. Kim et al. (1) studied the assessment of the inhibition effect of calcium nitrite-based corrosion inhibitor using a polarization method and its influence on the chloride transport, compressive strength and setting time of concrete. The influence of calcium nitrite based corrosion inhibitor on the corrosion of reinforcing steel embedded in 14 different mortars was studied by Sideris et al. (2). Accelerated corrosion tests of reinforcing steel in mortar containing chlorides were conducted by Han-Seung Lee et al. (3) using a lithium nitrite corrosion inhibitor focusing on the nitrite–chloride ion molar ratio as a test parameter. Investigation on the performance of high workability slag-cement mortar for ferrocement with varying quantities of GGBFS (50% and 60 %) as cement replacement and superplasticizer was performed by Memon et al. (4) with the water cement ratio fixed in such a way that the flow value is 136±3%. Investigations were performed by Shannag et al. (5) on high strength mortar with varying amounts of silica fume, fly ash and super plasticizer with different water cement ratios. They formulated 21 mortar mixes and investigated their flow characteristics and compressive strength development. David Darwin et al. (6) compared the performance of various corrosion inhibiting techniques such as epoxy coating on steel rebars, concrete admixed with calcium nitrite and two other organic inhibitors, bars with primer coating using micro-encapsulated calcium nitrite along with epoxy and coating of reinforcement with zinc prior to epoxy application. Haibing Zheng et al. (7) studied the effect of a surface-applied corrosion inhibitor on the durability of concrete by using capillary water absorption test, chloride penetration test, and accelerated carbonation test. Daniel Cusson et al. (8) conducted five year durability studies on concrete exposed to corrosive environments on bridge barrier walls and on accelerated electrochemical cells in the laboratory by using nine corrosion inhibiting systems including concrete admixtures, steel reinforcement coatings and concrete surface coatings or sealers. From the review of literatures, it is found that many researchers investigated the performance of calcium nitrite based inhibitors on corrosion protection of steel rebars in concrete and mortar. Sodium nitrite and migrating corrosion inhibitors also find many researchers interest. But scant studies are available to understand the strength and durability performance of slag cement mortar or concrete due to incorporation of sodium nitrite and calcium nitrite based inhibitor.

MATERIALS USED IN THE STUDY

The materials used in the study includes standard sand (Ennore sand), two types of cement viz. Portland Pozzolona Cement (PPC) and Portland Slag Cement (PSC), commercially available branded sodium nitrite and calcium nitrite based corrosion inhibitor and water. Mix proportion of cement mortar is 1:3 (1 part of cement: 3 parts sand) and the workability of mortar mix is fixed as 75-90% so that amenable for casting with minimum compaction and without bleeding. The corrosion inhibitors was added at 1%, 2% and 5% by weight of cement. Table 1 shows the properties of fine aggregate and Table 2 shows the physical properties of corrosion inhibitors used in the study. Since there is changes in the consistency values of cement due to addition of corrosion inhibitor, mini flow test (9) was conducted to ascertain the flow properties of inhibitor admixed mortar and accordingly water-cement ratio was fixed. Trial and error method was adopted to arrive the water-cement ratio for control and corrosion inhibitor modified mortar with a desired workability. Fourteen different combinations of mortar mixes were tested for its performance by varying type of inhibitor, dosage of inhibitor and type of cement. Table 3 shows the different types of mortar and corresponding water-cement ratio for the desired workability.

Table 1 : Properties of Fine Aggregate

Property	Test Procedure	Test Result
Specific gravity	BIS 2386: 1963, "Indian Standard Methods of test for Aggregates for concrete, Part 4 Specific gravity, density, voids, absorption and bulking"	3.03
% Water absorption		1.73
Bulk density		17.6 KN/m^3
Fineness Modulus		3.035
Grading zone	BIS 383 : 1970, "Specification for Coarse and Fine Aggregates from Natural sources for concrete"	Zone - III

Table 2 : Physical Properties of Corrosion Inhibitors

Property	Corrosion Inhibitor	
	Sodium Nitrite based	**Calcium Nitrite based**
Colour	Dark Brown	Pale White
pH	11.58	12.65
Specific Gravity	1.182	1.105

Table 3 : Details of Mortar Mix and w/c ratio as per Mini Flow test

Type of mix	Workability (% flow)	W/C Ratio	Type of mix	Workability (% flow)	W/C Ratio
PCM	82	0.55	SCM	80	0.50
PCM+1% SNI	87	0.50	SCM+1% SNI	81	0.50
PCM+2% SNI	79	0.45	SCM+2% SNI	89	0.50
PCM+5% SNI	86	0.40	SCM+5% SNI	82	0.45
PCM+1% CNI	80	0.50	SCM+1% CNI	87	0.40
PCM+2% CNI	89	0.45	SCM+2% CNI	76	0.40
PCM+5% CNI	85	0.45	SCM+5% CNI	81	0.40

Note : PCM : Portland Pozzolona Cement Mortar; SCM : Slag Cement Mortar; SNI : Sodium Nitrite based Inhibitor; CNI : Calcium Nitrite based Inhibitor

EXPERIMENTAL INVESTIGATION

The performance of corrosion inhibitor modified PPC and PSC mortar were assessed under strength and durability aspects. The strength related tests conducted includes compressive strength test, splitting tensile strength test, flexural strength test and shear strength test. Durability tests such as sorptivity test and chloride ion penetration test are also conducted. The compressive strength test was conducted as per BIS 516 (10) in a 500 kN capacity compressive testing machine to find the compressive strength of 70.6mm cube specimen at 7 days, 14 days, 28 days and 56 days of curing period. Split tensile strength test was carried out in a 150 ton capacity compression testing machine as per BIS 5816:1999 (11) and the specimen size is 150mm diameter and 300mm height mortar cylinder, tested at the age of 28 days. The specimens of size 160 x 40 x 40 mm cured for 28 days were subjected to flexural strength test as per BIS 516-1956 (10) in a Universal Wood Testing Machine of 2ton capacity. Figure 1 shows the flexural strength test in progress. The undistributed portion of the specimens subjected to flexural test was used for the shear strength test. The test was carried out in a 2 ton capacity Universal Testing Machine with selected loading range. The specimen is placed over the box type arrangement as shown in figure 2 and load is applied in a gradual manner without shock until failure of the specimen. Figure 2 shows the shear strength test in progress.

Figure 1 : Flexural strength test in progress

Figure 2 : Shear strength test in progress

The mortar disc specimen of size 100 mm diameter and 50mm length was used for water sorptivity test. The disc were cut from a mortar cylinder water cured for 28 days and dried in an oven at 50^0C for 3 days. The test was carried out as per ASTM 1585 (12). Figure 3 shows the sorptivity test in progress. For chloride ion penetration test (13), mortar cube specimens of size 70mm x 70mm x 70mm were cast, applied with polymer cementitious waterproof coating on all four sides leaving top and bottom surface. The specimens were kept immersed in 3% NaCl solution for 20 days, split open along uncoated top and bottom surface and sprayed with an indicator solution comprising of 0.1 N Silver Nitrate and 0.1% Sodium Fluorescein. The surface penetrated by chloride turns to white colour and the unaffected area remain in dark grey colour as shown in figure 4. The depth of penetration of chloride is measured at 8 locations along the periphery and averaged.

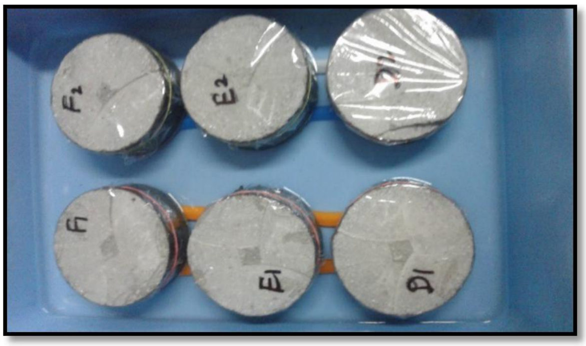

Figure 3: Water Sorptivity test in progress

Figure 4: View of specimens showing Chloride Penetration

RESULTS AND DISCUSSION

Figure 5 shows the comparison of compressive strength for control and SN inhibitor admixed PPC mortar. It can be seen that inhibitor admixed PPC mortar exhibits increase in compressive strength irrespective of dosage addition and age of test as compared to control PPC mortar. The 7 day compressive strength for PPC mortar admixed with SN based inhibitor at 1%, 2% and 5% revealed an significant increase in compressive strength of the order of 47%, 19% and 70% respectively as compared to control PPC mortar. The similar trend is observed for 14 day compressive strength test results. Whereas marginal increase in 28 day compressive strength of the order of 5%, 9% for inhibitor admixed PPC mortar at 1% and 2% respectively as compared to control mortar. But addition of inhibitor at 5% appreciably increases the 28 day strength of the order of 15% as compared to control PPC mortar. Figure 6 shows the comparison of compressive strength for control and CN admixed PPC mortar. It can be seen that addition of CN based inhibitor at 1%, 2% and 5% by weight of cement significantly increases the 7 day compressive strength of the order of 76%, 84% and 92% as compared to control PPC mortar. The similar trend is followed in the 14 day compressive strength test results. But addition of 1% CN based inhibitor marginally increases the 28 day compressive strength of the order of 5%, whereas addition at 2%, 5% significantly increases the compressive strength of the order of 17% and 26% respectively as compared to control PPC mortar.

Figure 7 shows the comparison of compressive strength for control and SN inhibitor admixed slag cement mortar. It can be seen that addition of inhibitor at 2% and 5% appreciably increases the 7 day compressive strength of the order of 14% as compared to control slag cement mortar. Whereas 1% inhibitor addition produced similar compressive strength values. The 14 day compressive strength results exhibits an significant increase in compressive strength for inhibitor admixed slag cement mortar irrespective of dosage levels as compared to control mortar. The 28 day and 56 day compressive strength test results revealed an similar compressive strength values irrespective of inhibitor dosage addition as compared to control slag cement mortar. Figure 8 shows the comparison of compressive strength for control and CN inhibitor admixed slag cement mortar. It can be exhibited that addition of inhibitor at 1%,2% and 5% increases the 7 day compressive strength of the order 14%, 48% and 30% respectively as compared to control slag cement mortar. Whereas 14 day compressive strength values revealed an significant increase as compared to control mortar irrespective of dosage levels. The 28 day and 56 day compressive strength values suggested that there is no major variation due to addition of CN based inhibitor in cement mortar irrespective of dosage levels.

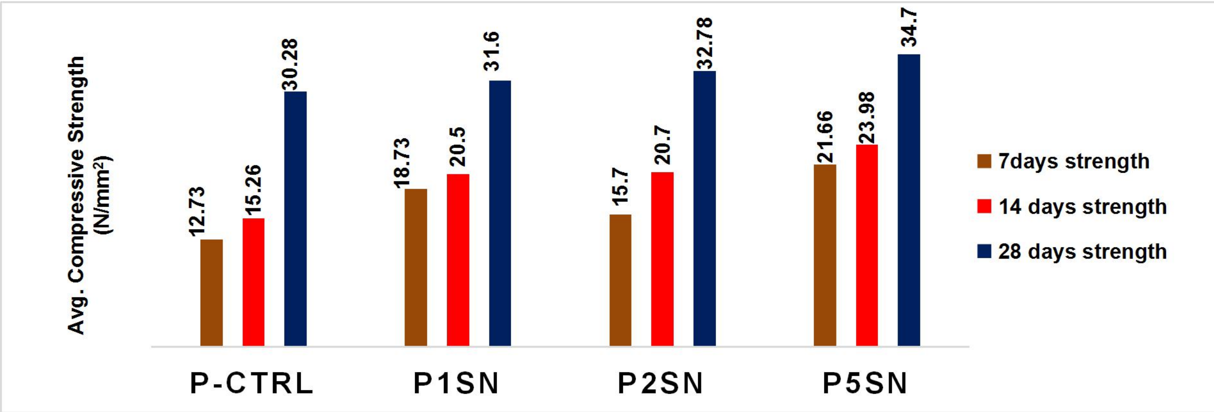

Figure 5 : Comparison of Average Compressive Strength for control and SN inhibitor admixed PPC mortar

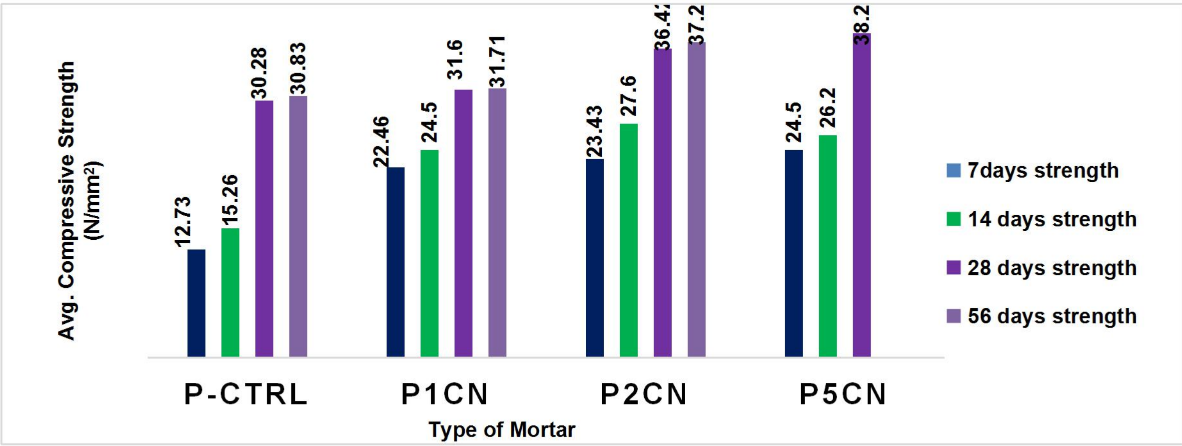

Figure 6 : Comparison of Average Compressive Strength for control and CN admixed PPC mortar

It can be concluded that addition of SN and CN based inhibitor in PPC mortar exhibits increased early strength gain as compared to control. There is a marginal increase in 28 day compressive strength for SN admixed mortar of the order of 5-15% and CN admixed mortar of the order 5-26% as compared to control PPC mortar when inhibitor was added at 1%,2% and 5% by weight of cement. Slag cement admixed with SN and CN based corrosion inhibitor exhibited appreciable increase in early strength at 7 day and 14day as compared to control mortar. Whereas similar compressive strength when tested at 28 day and 56 day as compared to control mortar. The increase in early strength development for SN and CN based inhibitor may be due to set acceleration property exhibited by the corrosion inhibitor. Afterwards strength development is in par with control mortar irrespective of type of cement used. There is no negative influence due to incorporation of corrosion inhibitor in slag cement and PPC mortar.

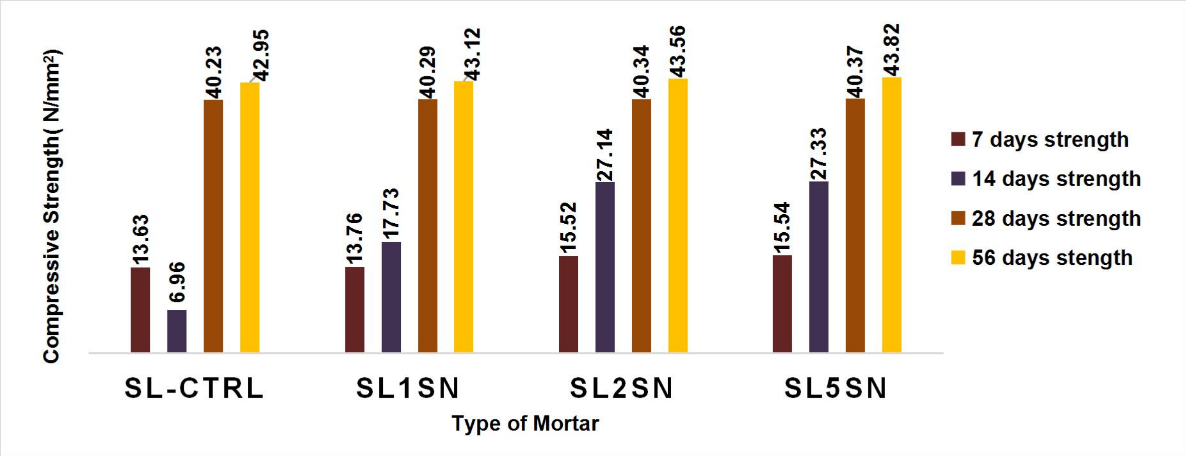

Figure 7: Comparison of Average Compressive Strength for Control and SN Inhibitor Admixed Slag Cement Mortar

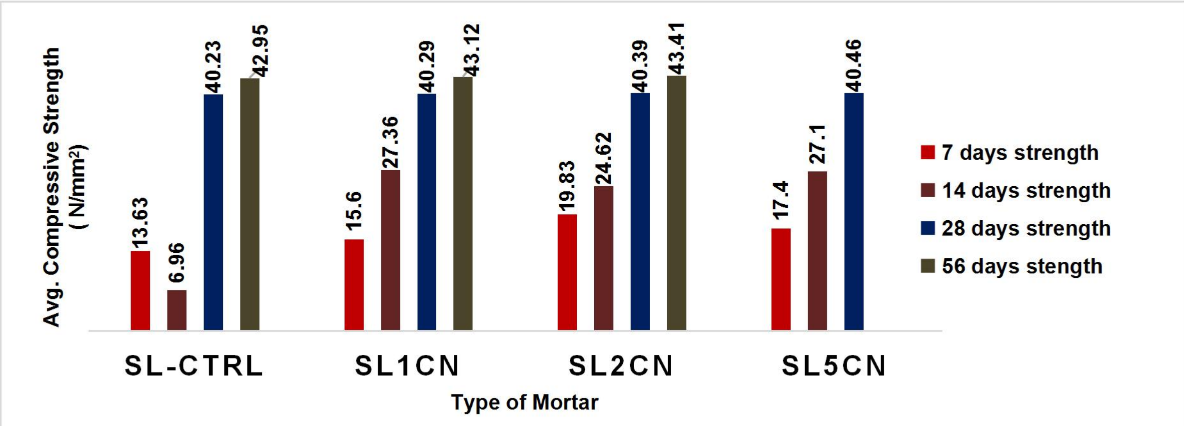

Figure 8 : Comparison of Average Compressive Strength for Control and CN Inhibitor Admixed Slag Cement Mortar

Figure 9 shows the comparison of splitting tensile strength for control and corrosion inhibitor admixed PPC mortar. It can be seen that addition of SN and CN based inhibitor in PPC mortar significantly increases the splitting tensile strength irrespective of the dosage addition. Addition of SN inhibitor at 1%, 2% and 5% significantly increases the tensile strength of the order of 19%, 36% and 91% respectively as compared to control PPC mortar. Whereas addition of CN inhibitor drastically increases the splitting tensile of the order of 2.04 times and 2.17 times upon inhibitor dosage at 1%, 2% respectively as compared to control mortar. Addition at 5% exhibits similar value as that of control mortar. Figure 10 shows the comparison of splitting tensile strength for control and corrosion inhibitor admixed Slag cement mortar. It can be seen that splitting tensile strength development for control slag cement mortar is 65% more as compared to PPC mortar. Addition of SN inhibitor in slag cement mortar further increases the tensile strength of the order of 19%, 24% upon dosage addition at 2% and 5% respectively. Addition of CN based inhibitor at 1%,2% and 5% significantly increases the tensile strength of the order of 26%, 34% and 37% respectively as compared to control slag cement mortar. It can be concluded that slag cement mortar offers increased tensile strength values as compared to PPC mortar. Addition of SN inhibitor at 5% and CN inhibitor at 2%, 5% offers significant increase in splitting tensile strength of PPC mortar. There is also a significant increase in tensile strength for SN and CN admixed slag cement mortar in the range of 19-37% as compared to control mortar. The increase in splitting tensile strength values for inhibitor admixed mortar specimens may be due to good workability offered by the SN and CN based inhibitor in the reduced water-cement ratio as compared to control mortar.

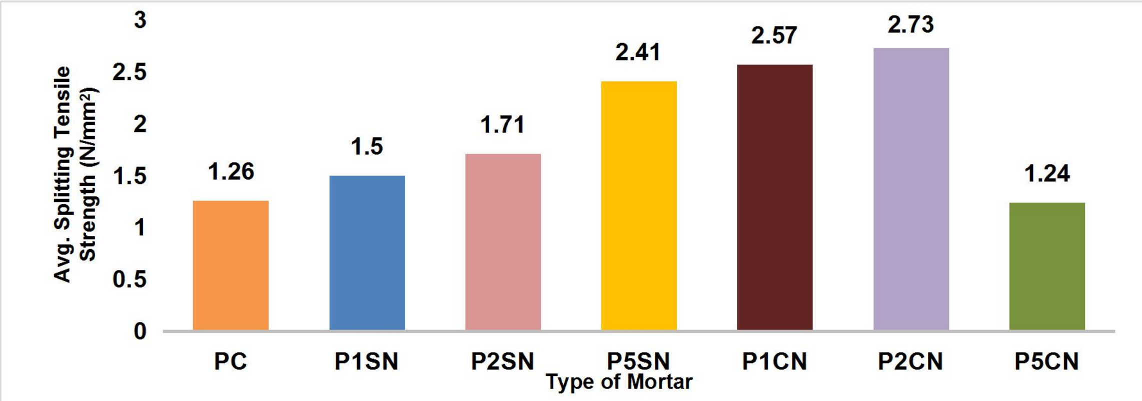

Figure 9 : Comparison of Average Splitting Tensile Strength of Control and Corrosion Inhibitor Admixed PPC Cement Mortar

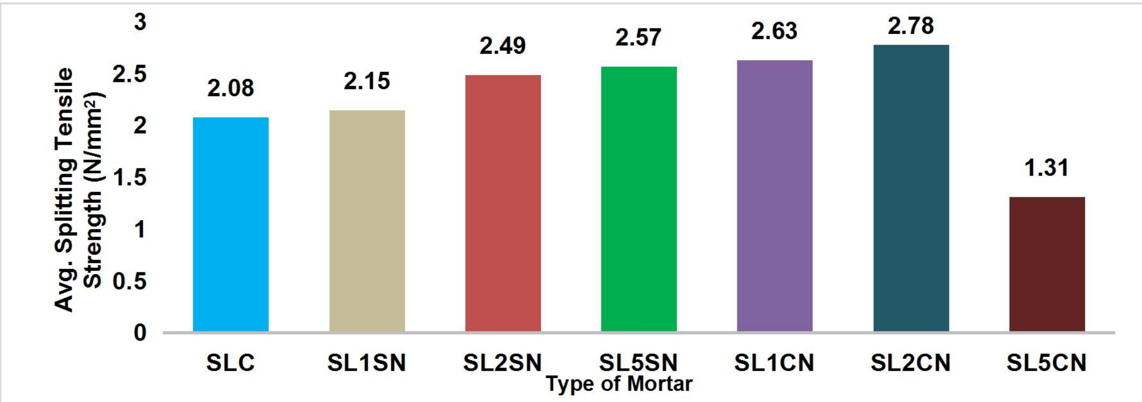

Figure 10 : Comparison of Average Splitting Tensile Strength of Control and Corrosion Inhibitor Admixed Slag Cement Mortar

Figure 11 shows the comparison of flexural strength of control and inhibitor admixed PPC mortar. It can be seen that flexural strength offered by control PPC mortar is 6.23 MPa which is marginally less than the 1% SN inhibitor admixed mortar. But SN inhibitor modification at 2% and 5% significantly increase the flexural strength of the order of 31-33% as compared to control mortar. Addition of CN based inhibitor also significantly increases the flexural strength of the order 30% irrespective of the dosage levels as compared to control PPC mortar. Figure 12 shows the comparison of flexural strength of control and inhibitor admixed slag cement mortar. It can be seen that the flexural strength of control slag cement mortar is 5.70 MPa which is 8.5% less than the flexural strength obtained for PPC control mortar. Addition of SN based corrosion inhibitor only marginally increases the flexural strength of slag cement mortar in the range of 2-7% as compared to control slag cement mortar irrespective of dosage level addition. Whereas CN inhibitor addition at 1% and 2% significantly increases the flexural strength of the order of 40%; and 5% addition marginally increases the flexural strength of the order of 10% as compared to control slag cement mortar.

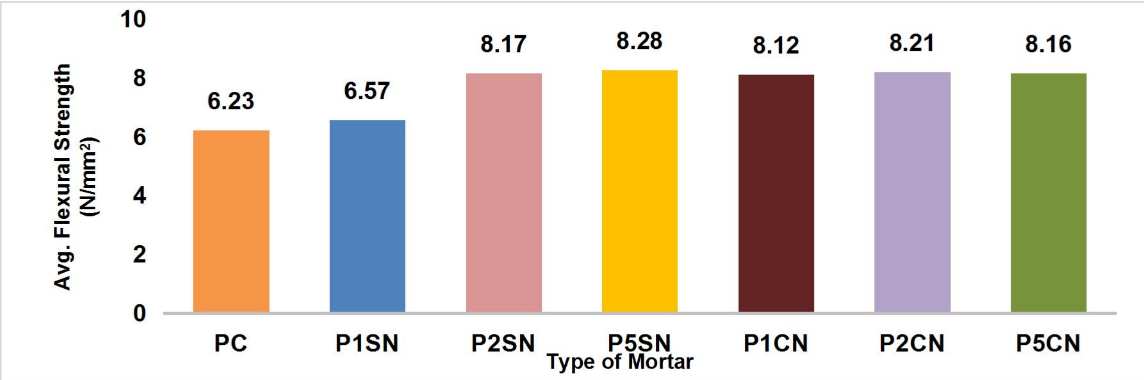

Figure 11 : Comparison of Average Flexural Strength of Control and Inhibitor Admixed PPC Mortar

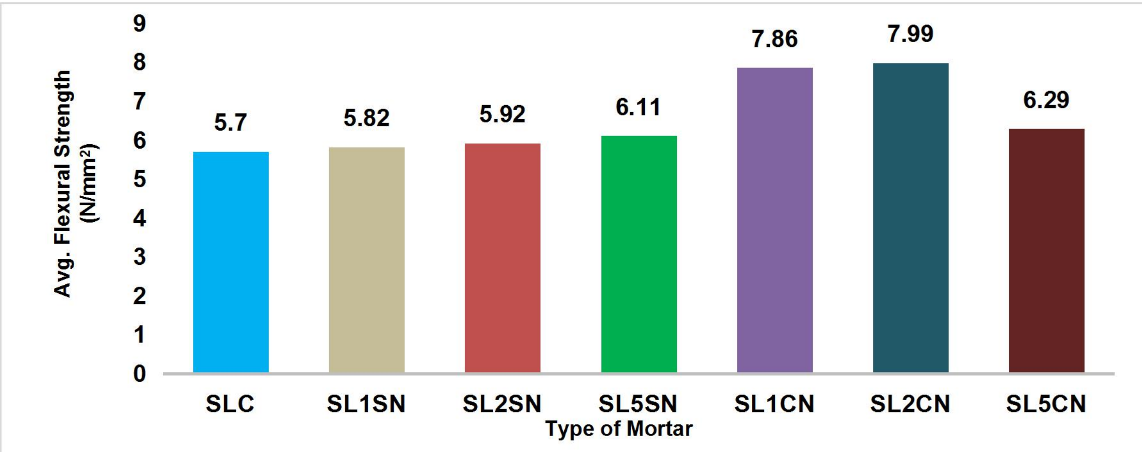

Figure 12 : Comparison of Average Flexural Strength of Control and Inhibitor Admixed SLAG Cement Mortar

It can be concluded that addition of SN and CN based inhibitor in PPC mortar significantly increases the flexural strength of the order of 30% as compared to control PPC mortar. Whereas addition of SN based inhibitor in slag cement mortar marginally improves the flexural strength; and addition of CN based inhibitor significantly improves the flexural strength of the order of 40% at 1% and 2% dosages as compared to control slag cement mortar. The increase in flexural strength for inhibitor admixed mortar specimens may be due to improved workability in the fresh state of mortar and subsequent well formation of micro structure of the mortar matrix.

Figure 13 shows the comparison of shear strength of control and inhibitor admixed PPC mortar. It can be seen that SN and CN based inhibitor addition in PPC mortar significantly increases the shear strength as compared to control mortar irrespective of the dosage levels addition. There is significant increase in shear strength in the range of 25 - 33% upon increasing the SN inhibitor dosage from 1% - 5%. Addition of CN based inhibitor also significantly increases the shear strength of PPC mortar of the order of 29-32% as compared to control mortar irrespective of dosage levels. Figure 14 shows the comparison of shear strength of control and inhibitor admixed slag cement mortar.

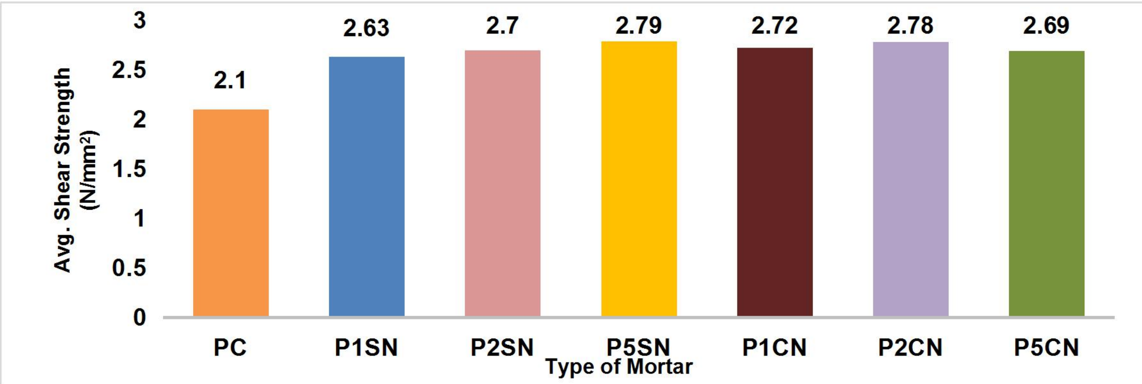

Figure 13 : Comparison of Average Shear Strength of Control and Inhibitor Admixed PPC Mortar

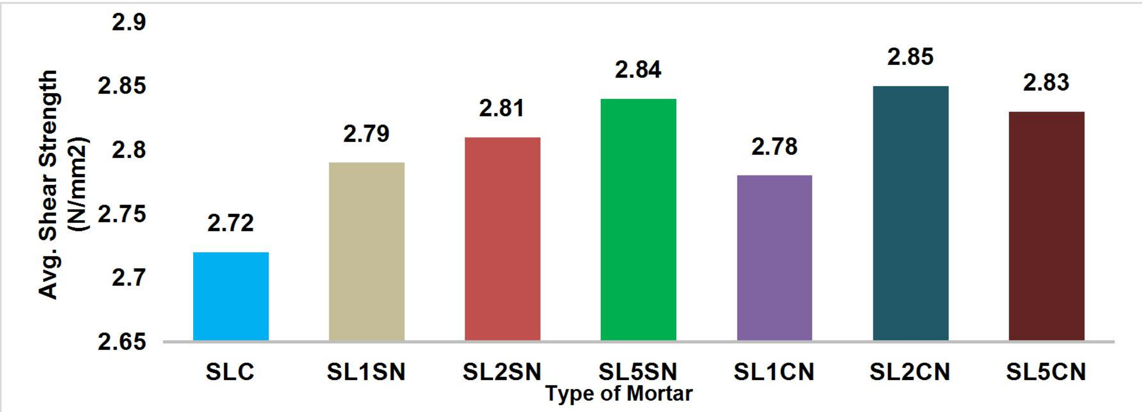

Figure 14 : Comparison of Average Shear Strength of Control and Inhibitor Admixed Slag Cement Morta

It can be understood that shear strength of control slag cement mortar is 2.72 MPa which is 30% mortar than the shear strength values obtained for control PPC mortar. Inhibitor addition at 1%, 2% and 5% in the slag cement mortar marginally increases the shear strength of the order of 2-5%, irrespective of type of inhibitor as compared to control slag cement mortar. It can be concluded that addition of SN and CN based inhibitor significantly increases the shear strength of PPC mortar of the order of 25-32% as compared to control mortar. Whereas addition of SN and CN based inhibitor in slag cement mortar increases the shear strength only marginally.

Figure 15 shows the time versus rate of water absorption of control and inhibitor admixed PPC mortar in the sorptivity test. It can be seen that control PPC mortar exhibits improved water absorption as compared to inhibitor admixed mortar irrespective of type of inhibitor and dosage levels during the test period. Addition of calcium nitrite based inhibitor at 2%, 5% and sodium nitrite based inhibitor at 5% exhibits significantly improved performance against water absorption as compared to other inhibitor dosage levels irrespective of type of inhibitor. Figure 16 shows the time versus rate of water absorption of control and inhibitor admixed slag cement mortar. It can be visualized that control and 5% CN inhibitor admixed mortar offers improved water absorption as compared to other types of mortar. SN based inhibitor addition at 5% and CN based inhibitor addition at 2% exhibits significantly reduced water absorption as compared to other tested inhibitor admixed mortar. It can be concluded that slag cement mortar exhibits appreciable reduction in rate of water absorption as compared to PPC mortar. Addition of SN and CN inhibitor at higher dosages offers significant durability enhancement in case of PPC mortar. Whereas for slag cement mortar addition of SN inhibitor at higher dosages offer improved durability performance. The observation of similar performance of CN inhibitor as compared to control slag mortar when added at higher dosage needs further investigation.

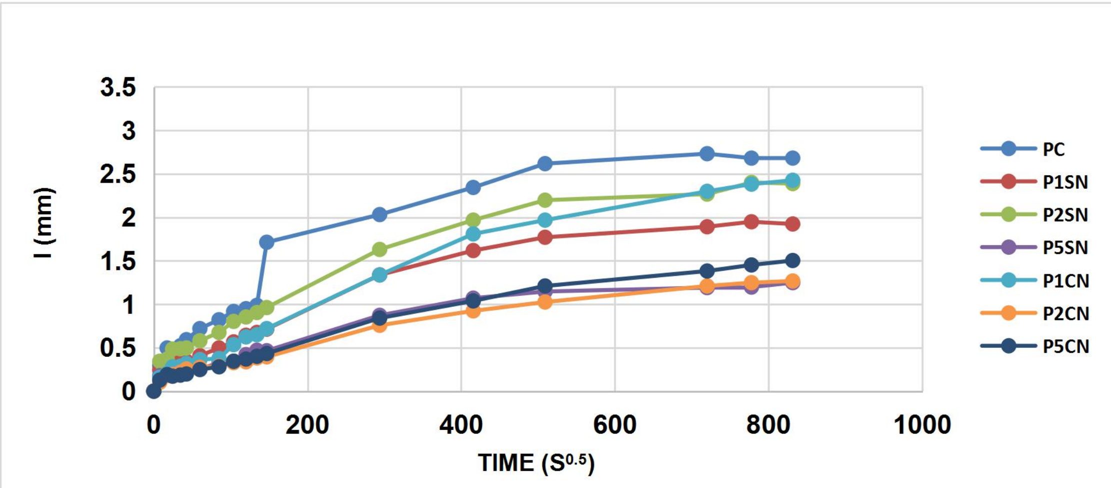

Figure 15 : Time Vs Rate of Water Absorption of Control and Inhibitor Admixed PPC Mortar

Figure 17 shows the comparison of average depth of penetration of chloride ion in the control and inhibitor admixed PPC and SC mortar. It can be inferred that there is a 32% reduction in chloride ion penetration for control slag cement mortar as compared to PPC mortar. Addition of SN inhibitor in PPC reduces the chloride ion penetration in the range 14 - 33% whereas CN inhibitor incorporation in cement mortar offers 10-40% reduction as compared to control mortar. The appreciable durability performance was obtained for SN inhibitor modification at 2% and CN inhibitor modification at 1% as compared to other tested dosages. The similar trend was observed in case of CN and SN inhibitor admixed slag cement mortar. The reduction in chloride ion penetration is 7-34%, 14 - 21% for SN and CN inhibitor admixed slag cement mortar respectively as compared to control mortar.

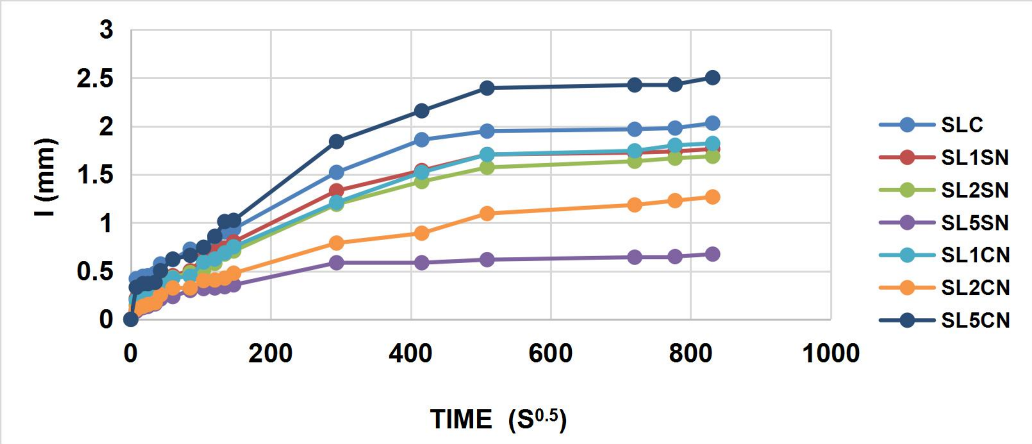

Figure 16 : Time Vs Rate of Water Absorption of Control and Inhibitor Admixed Slag Cement Mortar

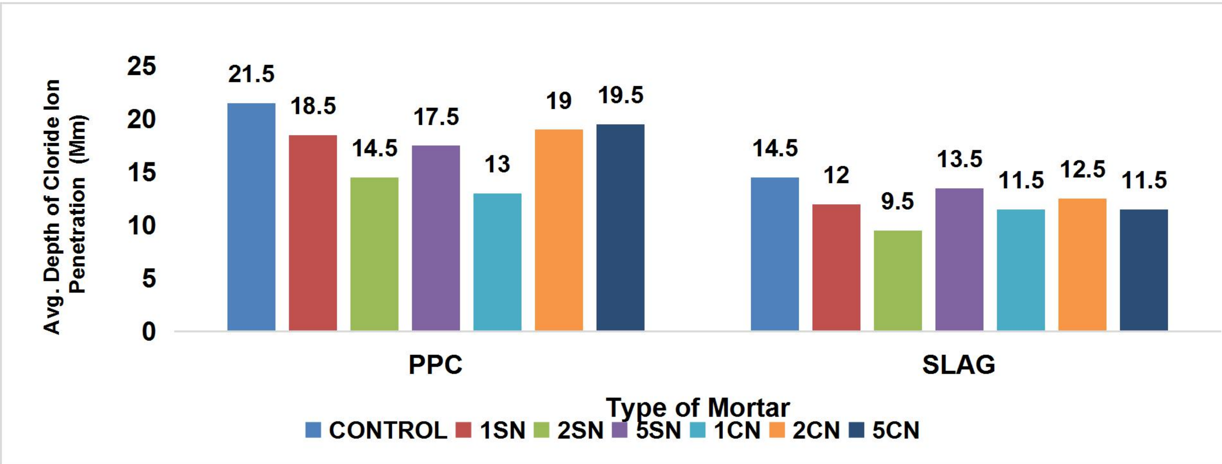

Figure 17 : Comparison of Average Chloride Ion Penetration for Inhibitor Admixed PPC and SLAG Cement Mortar

CONCLUSIONS

Based on the test results and further analysis following conclusion are drawn:

- The water cement ratio is reduced marginally due to addition of SN based and CN based corrosion Inhibitor for the same workability of control mortar.

- Addition of SN and CN based inhibitor at 1%, 2% and 5% by weight of cement did not appreciably influence the fresh properties of PPC and Slag cement such as initial and final setting time but marginal reduction in consistency of cement.

- There is an marginal increase in 28 day compressive strength for SN admixed PPC mortar of the order of 5-15% and CN admixed mortar of the order 5-26% as compared to control PPC mortar.

- Slag cement admixed with SN and CN based corrosion inhibitor exhibits similar compressive strength values when tested at 28 day and 56 day as compared to control mortar.

- Control slag cement mortar offers increased tensile strength as compared to PPC mortar. Addition of SN and CN inhibitor offers significant increase in tensile strength of PPC and slag cement mortar as compared to control mortar.

- Addition of SN and CN based inhibitor in PPC mortar significantly increases the flexural strength of the order of 30% as compared to control PPC mortar. Whereas addition of SN based inhibitor in slag cement mortar marginally improves the flexural strength; and addition of CN based inhibitor significantly improves the flexural strength of the order of 40% at 1% and 2% dosages as compared to control slag cement mortar.

- There is a significant increase in shear strength due to addition of SN and CN based inhibitor in PPC mortar of the order of 25-32% as compared to control mortar. Whereas addition of SN and CN based inhibitor in slag cement mortar increases the shear strength only marginally.

- Slag cement mortar exhibits appreciable reduction in rate water absorption as compared to PPC mortar irrespective of inhibitor addition. Incorporation of SN and CN inhibitor at higher dosages offers significant durability enhancement of PPC mortar. Whereas for slag cement mortar addition of SN inhibitor at higher dosages offer improved durability performance.

- There is a 32% reduction in chloride ion penetration for control slag cement mortar as compared to PPC mortar irrespective of inhibitor addition.

- Addition of SN inhibitor in PPC reduces the chloride ion penetration in the range 14 - 33% whereas CN inhibitor incorporation in cement mortar offers 10-40% reduction as compared to control mortar. The reduction in chloride ion penetration is 7-34%, 14 - 21% for SN and CN inhibitor admixed slag cement mortar respectively as compared to control mortar.

- It is concluded that addition of sodium nitrite and calcium nitrite based inhibitors enhances the durability properties of PPC and slag cement mortar without affecting the strength properties.

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