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EFFECT OF STEEL FIBER DOSAGE ON CORROSION RESISTANCE OF REINFORCED CONCRETE

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Key words: Steel fiber, corrosion current, half-cell potential, electrical resistivity and crack width

Abstract: Corrosion in conventional steel reinforced concrete is considered as one of the major threats to the durability of the structures. Hence, alternative reinforcements are attempted to replace steel reinforcement in concrete in the recent times. However, the main steel reinforcement cannot be entirely replaced for technical reasons and hence, steel fibers are used as complementary reinforcement in addition to main reinforcements. In this context, the combined influence of steel fibers and steel rebars on corrosion is investigated in this study. Tests are performed on control and steel fiber reinforced concrete (SFRC) lollipop specimens made with two different water to cement ratios (0.45 and 0.5) and corrosion is accelerated using impressed current. Five dosages including control such as 0%, 0.2%, 0.5%, 0.75% and 1% of steel fibers by volume of concrete is used. Parameters such as corrosion current, half-cell potential, electrical resistivity and crack width are obtained and plotted against the time period in order to investigate the influence of fiber dosage and water to cement ratio on corrosion. The accelerated corrosion tests performed in the laboratory scale indicate the usefulness of incorporating steel fibers in addition to steel rebar in mitigating the corrosion and controlling the crack width in real reinforced concrete structures, especially exposed to marine environment.

1. INTRODUCTION

Reinforced concrete (rc) structures are inevitable in the infrastructural development of the country. Some of the structures include bridges, off-shore structures, dams, tunnels, low and high rise buildings are constructed of reinforced concretes. Owing to the wide variety of applications, rc structures are exposed to different types of aggressive as well as non-aggressive environments. Some of the adverse conditions expected in the concrete are marine environment, carbon dioxide exposure, chemical and biological attack, etc.Reinforced concrete structures are prone to corrosion due to the presence of steel rebars. Hence, the improvement in durability of the structures depends upon the corrosion resistance of the concrete. Corrosion-induced damage in reinforced concrete structures can be reduced by various methods [3,4,5] as reported in the literature. One of the possible methods is the incorporation of fibers in the concrete [6]. Studies report the incorporation of different types of fibers into concrete to increase the cracking resistance to avoid corrosion of reinforcement [7,8]. In the recent years, hybrid reinforcement (main steel reinforcement and fibers) are coming into existence to increase the strength, toughness and cracking resistance of concrete [7]. Yang et al. [9] investigated the effect of incorporation of steel and synthetic fibers on the bearing capacity as well as cracking response of high-strength concrete beams made of fibre reinforced polymers (FRP). It is concluded that the addition of fibers improved the ultimate flexural moment, delayed the formation of first crack due to bending and decreased the size of the crack width. It is further observed that the incorporation of fibers increased the cracking resistance and reduced the corrosion rate.

It is reported that steel fibers bridge the cracks in the matrix to increase the cracking resistance which in turn improves the corrosion resistance. The short and discontinuous fibers dispersed in cement matrix of fiber-reinforced concrete improved the mechanical toughness owing to the diffused and stable cracking. As the permeability of the concrete is influenced by formation of cracks, the use of fibers for increasing the crack resistance greatly help in reducing the penetration of deleterious compounds that cause corrosion damage. The ingress of chlorides, water, and other chemicals can be avoided by the incorporation of fibers. However, few literature reports the contradictory statement against the goodness of incorporation of fibers in improving the crack resistance. It is stated that the steel fibers entrap more air during mixing, thus increases the permeability [11]. Further, some literature reports that the introduction of fibers increases the interfaces that typically weakens the concrete and allows water and ions [12,13].

Plenty of research works discuss the usefulness of adding steel fibers or any other fibers in cracking characteristics of fibre reinforced composites with steel reinforcements, however, most of the researches focus on shear and flexural behaviour and research that focusses on the effects of fibre reinforcement on corrosion control is very limited. In view of this, the present study focusses on the effect of hybrid reinforcement on the corrosion protection of concrete.

2 EXPERIMENTAL DETAILS

2.1 Materials

Ordinary Portland cement (OPC) conforming to IS 12269, crushed granite aggregates with maximum size of 20 mm and zone II fine aggregate as per IS:383. Two water to cement ratios of 0.45 and 0.5 are used. Mix proportions for two different water cement ratio concrete are presented in Table 1. Fe 550D grade thermo mechanically treated (TMT) deformed bars of 16 mm diameter are used as reinforcement.

Table 1. Mix proportions of concrete

Cement kg/m^3	Sand kg/m^3	CA kg/m^3	Water kg/m^3	Avg. compressive strength
400	630.70	1193.4	180	47.36
394	711.50	1107.79	210	42.00

2.2 Specimen preparation

Concrete cylindrical specimens of size 100mm dia. and 200mm height as shown in Fig.1. are made. Steel bar of diameter 16 mm is placed at the center of the cylindrical specimen during casting and extruded from the top surface for the length of 100 mm. The bottom cover provided for the specimen is 25mm. Concrete made with two different water to binder ratio (0.45 & 0.5) and 5 different dosages of steel fibers are used for the accelerated corrosion test. Three lollipop specimens are prepared for each mix. Total of 30 lollipop specimens 15 each for one water cement ratio is cast. Companion cubes of 100mm size is cast for compressive strength testing.

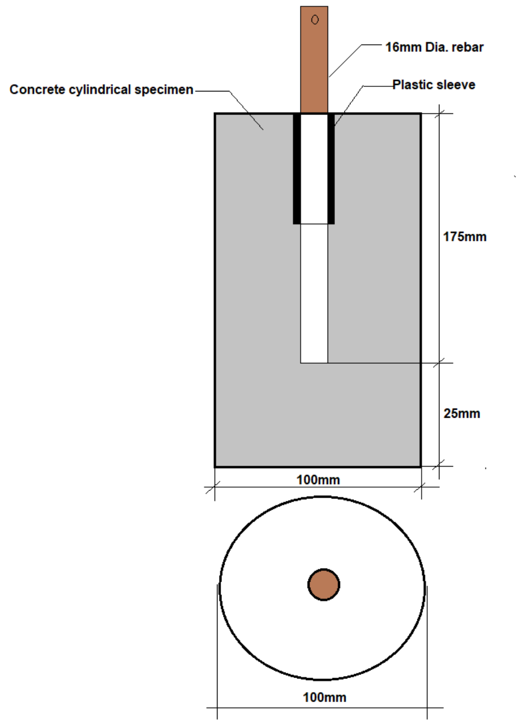

Fig 1. Schematic of test specimen with dimensions

2.3 Test Procedure

Impressed current technique is generally used to accelerate corrosion in concrete. In this study, anodic potential is impressed current technique is used to accelerate the corrosion process and the same is adopted in this study. It is stated that the use of low current density levels to induce corrosion was more realistic than using higher current density levels because a low current density allows the gradual dissipation of corrosion products, which is close to the real situation. In the present study, the corrosion process was accelerated by impressing an anodic potential between the steel reinforcement (anode) and steel plate cathode and recording the variation of current with time. Initially, the specimens were immersed in a 3.5% NaCl solution for 24 h to ensure full saturation of the test specimen. The level of NaCl solution is maintained well above the rebar portion. Later, a constant 2 V anodic potential was applied for the specified durations to attain a weight loss of about 20% in the reinforcement bars of the uncracked specimens. Fig. 2 shows the test set up for the accelerated corrosion.

Fig 2. Test set up for accelerated corrosion

3 MEASUREMENT PARAMETERS

3.1 Half-cell potential

Half-cell potential (HCP) is also known as corrosion potential (Ecorr) and open circuit potential (OCP). HCP is the widely used simplest method for corrosion measurement of reinforcement in the field. HCP works with two electrodes: steel reinforcement as working electrode and a reference electrode (copper sulphate electrode). From the HCP of the steel measured, the probability of corrosion risk can be indicated as prescribed in ASTM C876. However, the half-cell potential measurement can only indicate corrosion of the steel reinforcement qualitatively, and the information on the corrosion rate cannot be obtained.

3.2 Electrical Resistivity

The electrical resistivity of a material describes its ability to withstand the transfer of charge. The resistivity of concrete principally depends on factors such as degree of saturation, porosity, pore volume, pore solution characteristics, distribution and connectivity of pores etc. Corrosion in steel reinforcement is an electrochemical process in which concrete act as an electrolyte. In order to electric circuit to close, electron transport through steel as well as an ionic current through the dissolved ions in the pore solution need to happen. Hence, concrete’s resistivity controls the corrosion process kinetics. In concrete with high electrical resistivity, the corrosion process is slow because the current cannot easily pass between the anodic and cathodic areas of rebars. Since corrosion is an electrochemical phenomenon, the electrical resistivity of concrete will influence the corrosion rate of the embedded steel.

4 RESULT AND DISCUSSION

Parameters such as corrosion current, half-cell potential, electrical resistivity and crack width are obtained and plotted against the time period in order to investigate the influence of fibre dosage and water to cement ratio on corrosion. Half-cell potential and corrosion current help to identify the corrosion initiation time of reinforced concrete. Similarly, electrical resistivity measurements and crack width are used to correlate the corrosion rate. Higher electrical resistivity of concrete indicates the lower corrosion rate in the reinforced concrete.

4.1 Effect of dosage of steel fiber on half-cell potential

Half-cell potential measurements help in identifying the location of corrosion in reinforcement based on the presence of most negative zones in a potential field. However, corrosion rate cannot be obtained from the half-cell potential. Fig.2 presents the evolution of corrosion potential of the SFRC test specimens exposed to NaCl solution for a duration of about 400 days and the results are plotted. Fig 3. shows the half-cell potential of mixes with various dosages of steel fibers with the water to cement ratios of 0.45 (Fig 2a) and 0.5 (Fig 2b).

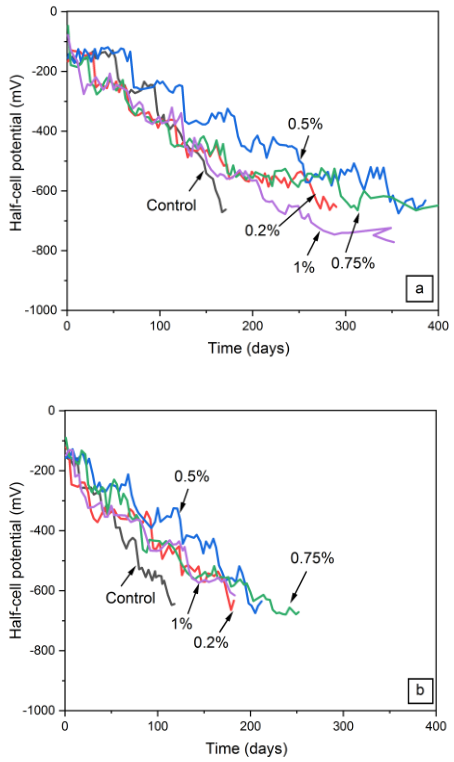

Fig 3. Half-cell potential a) 0.45 b) 0.50

From the Fig 3a, it is observed that the control concrete cracked before 170 days in 0.45 w/c specimens while the concrete with fibers measured readings even beyond 170 days. This shows that the incorporation of fibers delayed and controlled the cracking of concrete specimens. Comparing the half-cell potential readings at the same day, it is shown that negative potential is higher in control than the SFRC. For instance, at 170 days, when the control specimen cracked, the negative potential is -660 mV in control specimens without fibre and negative potential of -515 mV, -320 mV, -510 mV, -560 mV respectively are observed in 0.2%, 0.5%, 0.75% and 1.0% SFRC specimens. Among the SFRC specimens, 0.5% SFRC showed lesser negative potential than other concretes. Further, it is noticed that in 0.5 w/c concrete specimens (Fig 3b), the control specimen cracked at 118 days. It is observed that higher water cement ratio increases the corrosion risk in the concrete as expected. Even in the concrete without fibers (control), specimens cracked and failed at early age (118 days) in 0.5 w/c mixes against 170 days in 0.45 w/c mixes indicating water cement ratio plays a significant role in the formation of corrosion cracks.

Typically, less negative potential values correspond to higher corrosion resistance, whereas more negative corrosion potentials indicate higher susceptibility to corrosion. In view of the negative potential obtained for concrete specimens with and without fibers, the results of half-cell potential indicates that the incorporation of fibers delays the corrosion. It is observed that the measured half-cell potential is comparatively lower for steel fiber reinforced concrete (SFRC) than the control concrete without steel fibers. The incorporated steel fiber prevents the cracking of concrete which in turn controls the crack width. From the potential measurement it is interpreted that the addition of steel fibers in concrete protect the main reinforcement from corrosion.

4.2 Effect of dosage of steel fiber on corrosion current

The corrosion initiation of steel in concrete can be determined by monitoring the corrosion current in the specimen. Fig. 3 shows the corrosion current versus time in days for the reinforced concrete specimens subjected to accelerated corrosion. It is noticed that during early ages, the current is low indicating there is no corrosion observed at the beginning of the accelerated corrosion test. Fig. 3a and 3b show that the corrosion current is less in 0.5% SFRC specimens.

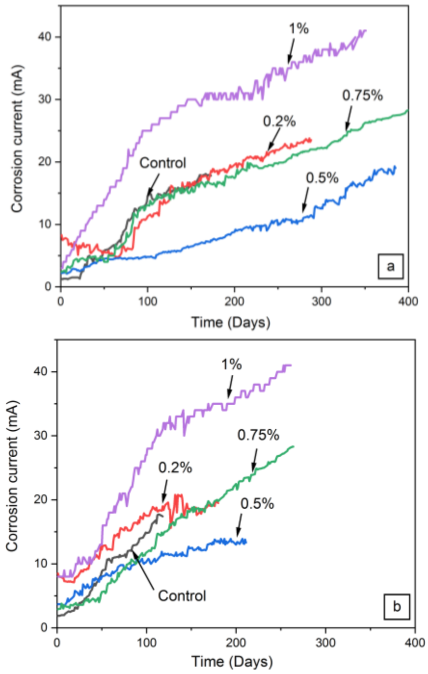

Fig 4. Corrosion current versus time a) 0.45 b) 0.50

Fig. 4a shows that except for 1% fibre specimens, all the SFRC specimens showed delayed corrosion initiation. The corrosion current indicates that in SFRC specimens the corrosion is delayed, especially when water to cement ratio is less. As observed from HCP, corrosion current also indicates the faster cracking in high water cement ratio mixes. cracki

4.3 Effect of dosage of steel fiber on electrical resistivity

Many literature [14,15] reports the importance of electrical resistivity as a parameter in measuring the corrosion rate in reinforced concrete structures. In this study, electrical resistivity is measured for a period of 400 days during the accelerated corrosion test and results are plotted in Fig.5. From the results, it is observed that the 0.5% fiber incorporated specimens are having higher electrical resistivity indicating the decreased corrosion rate. Especially in the low water to cement ratio specimens, at the same day of measurement, the electrical resistivity is high in 0.5% SFRC than control specimens.

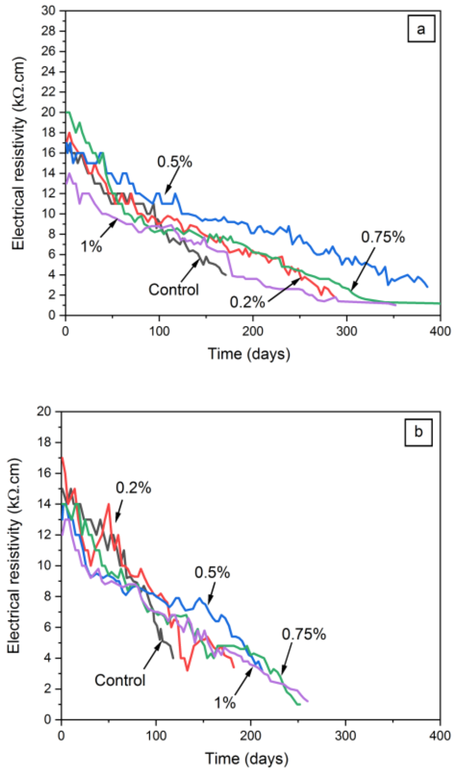

Fig 5. Electrical resistivity versus time a) 0.45 b) 0.50

4.4 Effect of dosage of steel fiber on Crack Width

Fig 6. shows the crack width versus time of the corroded lollipop specimens. It is noticed that in the control specimens (0.45 w/c), it took 150 days to attain the crack width of 1mm whereas in steel fiber reinforced specimens it took at least 260 days to attain a same 1mm crack width even with the minimum dosage of 0.2% fibers. Further, it is noticed that in 0.5% & 0.75% dosage of fiber in concrete with 0.45 w/c, the time taken to attain 1 mm crack width is delayed upto 400 days. The incorporation of fiber delayed the corrosion initiation as well as prolonged the time of maximum crack width. Further, it is noticed that the formation of crack is gradual in low w/c specimens and steep in high w/c. This indicates that using low w/c, crack width can be minimized.

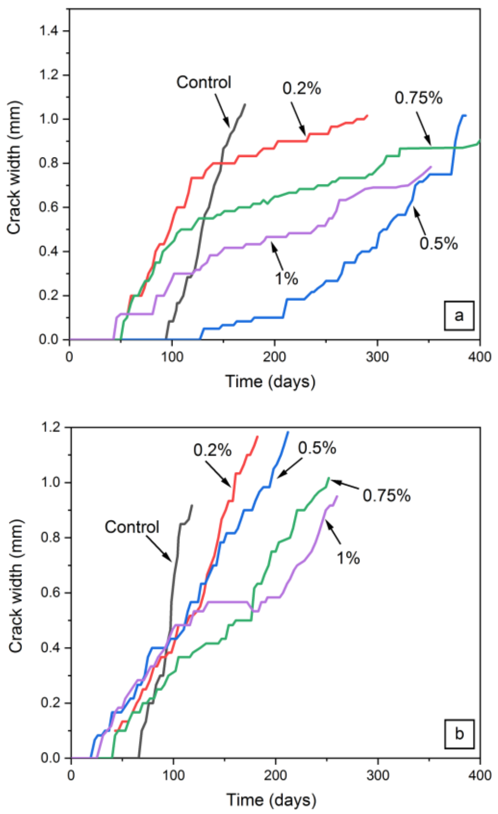

Fig 6. Crack Width versus Time a) 0.45 b) 0.50

Fig 7. shows the typical corroded lollipop specimens till it attains at least the crack width of 1mm.

Fig 7. Typical cracked specimens a) 0.2 b) 0.50 c) 0.75 % of steel fibers in concrete

5 CONCLUSIONS

In the present study, the corrosion risk of reinforced concrete lollipop specimens is studied. Accelerated corrosion test is carried out on reinforced concrete specimens with and without fibers for a period of 400 days and various parameters such as corrosion current, electrical resistivity, half-cell potential, crack width is measured. All the parameters measured indicate that the incorporation of fibers improved the corrosion resistance of the reinforced concrete specimens. Especially, the 0.5% dosage fiber in concrete had better corrosion resistance. It is also concluded that the optimum dosage of fiber needs to be used for efficiently controlling the crack as 0.75% and 1% fiber concrete are not consistently providing good results in terms of corrosion resistance. Further, the study concludes that the low water to cement ratio concretes perform better in terms of corrosion resistance. Combining both half-cell potential and electrical resistivity measurement techniques makes it possible to examine corrosion probability and corrosion rate once it is initiated

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