

DEVELOPMENT OF REPAIRING METHODS FOR DAMAGED STRUCTURES DUE TO CHLORIDE ATTACK IN THE MARINE ENVIRONMENT

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Abstract

Many reinforced concrete structures around the world are deteriorated before their design life time due to environmental effects. Chloride attack is one of the major causes of deterioration of reinforced concrete structures. Chloride contamination can occur from the application of de-icing salts, from cast-in chlorides or from seawater as structures close to marine environment. In Sri Lanka there is no any type of repairing method to repair the damaged structures due to chloride attack. Most of the times the authorities replace the damaged bridges with new ones whenever there is a failure due to corrosion.

This research is mainly focused on developing a repairing method to repair the corroded bridges in the coastal belt. There are many methods are used to repair the corroded structures, by this the most appropriate method is selected.

There are several methods to repair damaged structure which is subjected to chloride attack. Electrochemical chloride extraction, applying a repair mortar and use of corrosion inhibitors are few of those methods. This research is mainly concerning about developing a repair mortar to repair the damaged reinforced concrete structures.

A repair mortar is developed with less permeability characteristics with fly ash and silica fume. Calcium nitrate is used as an inhibitor additive to the repair mortar. Rapid chloride permeability test is carried out to few cylindrical samples to test the permeability of the repair mortar. Accelerated corrosion test is used to provide an aggressive environment to the test specimens. Finally the chloride concentration variation with the depth of the specimen was measured by titrating concrete powder samples with silver nitrate. Standard bridge rating systems are used to rate the bridges in coastal belt. Most suitable method to the country is selected.

Keywords: chloride attack, corrosion, repairing methods, mineral admixtures, condition assessment.

1. Introduction

Reinforced concrete is one of the most widely used construction materials in the world. It is an economical material that generally performs its intended use well over its service life. The most important and costly deterioration mechanism affecting the reinforced concrete structures is the corrosion of steel reinforcement. In good quality concrete reinforcement steel is unlikely to corrode even if sufficient moisture and oxygen are available due to formation of a protective oxide film (passive film) in the highly alkaline environment. However, this passive film can be disrupted and corrosion initiated by chlorination due to the penetration of chloride ions into the concrete, which lowers the alkalinity of the reinforcement surface (Hansson et al., 2007). Therefore chloride attack is a major cause of deterioration of reinforced concrete structures. This chloride contamination can occur from the application of de-icing salts, from cast-in chlorides or from seawater as structures constructed in marine environment which leads to a huge reduction of service life.



Figure 1: Deteriorated bridge deck slab

By investigating about this deterioration and service life reduction of concrete structures due to chloride attack there can recognize mainly three different levels of deterioration, the initiation level, propagation level and the level of surface cracks to progressing into further damage and developing into spalls (Hansson et al., 2007). Using the mathematical models the service life can be predicted of these structures according to several figures of observations. By mathematical modelling the exact time of failure of the bridge can't calculated. But the level of deterioration and the time period that the repair of the bridge should carry out can be calculated.

Currently in Sri Lanka there isn't any type of repairing method using to repair the damaged structures due to chloride attack. Most of the times the authorities replace the damaged bridges with new ones whenever there is a failure due to corrosion. This replacement required a higher cost and there can be indirect costs to the country due to traffic delays and reduction of productivity.

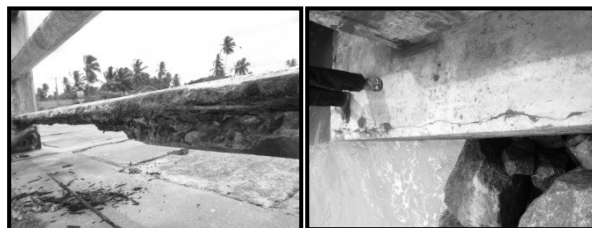


Figure 2: Other corroded parts of the bridges

As the corrosion of the reinforcement steel is a major issue in the world. This research is conducted to develop and test some already existing methods to prevent the corrosion of the reinforcement steel as well as to introduce more methods to repair the reinforcement steel which are already corroded. Furthermore this research is to suggest a new method which will be suitable to our country to apply in the field to reduce the effect of the corrosion due to severe environment around the coastal belt.

2. Methodology

2.1 Sample preparation for rapid chloride penetration test

Twenty one specimens were prepared with 100 mm diameter and 50 mm height as shown in the Figures 3 (a) and (b). Mortar mixture is used to prepare the specimens and compositions of the admixtures were varied according to the Table 1 .Specimens were allowed for the curing for 28 days submerged in water. After that the specimens are cured by moist curing for 90 days. Finally rapid chloride penetration test (RCPT) is carried out according to ASTM C 1202 to find the best mortar proportion for the minimum chloride permeability.

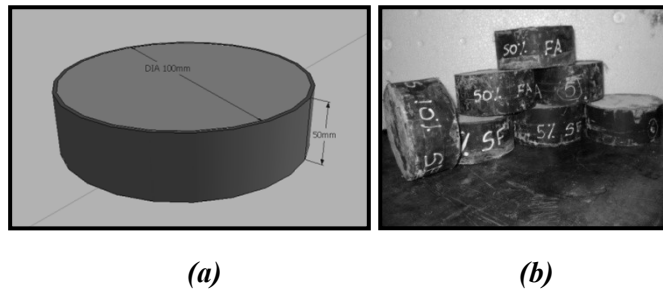


Figure 3: (a) Dimensions of the samples (b) Samples after casting

Table 1: Add mixture type and added percentage by mass of cement to specimens

Specimen No.	Admixture	Percentage (%)	Number of Samples
S1,S2,S3	Control Sample	0	3
S4,S5,S6	Fly Ash	25	3
S7,S8,S9		50	3
S10,S11,S12		75	3
S13,S14,S15	Silica Fume	5	3
S16,S17,S18		10	3
S19,S20,S21		15	3

2.2 Rapid Chloride Penetration Test (RCPT)

The mortar specimens were allowed for the curing for 28 days submerged in water. After that the specimens are cured by moist curing until 90 days for RCPT as per ASTM C 1202. The dried specimen was fixed to the apparatus as shown in the Figure 4. The positive reservoir of the cell was filled with 0.30 M NaOH solution while the negative reservoir was filled with NaCl with 3.0% Cl⁻ ion concentration solution. Two identical copper bars were used as anode and cathode. A direct current (DC) of 60 V was applied across the specimen faces as the anode to the NaOH and cathode to the NaCl. The current across the specimens were recorded at every 30 minutes interval, covering a total period of six hours. By knowing the current and time history, the total charge passed (CP) through the specimen was computed by Simpson's rule as given in the ASTM 1202. (Refer Eq. (1))

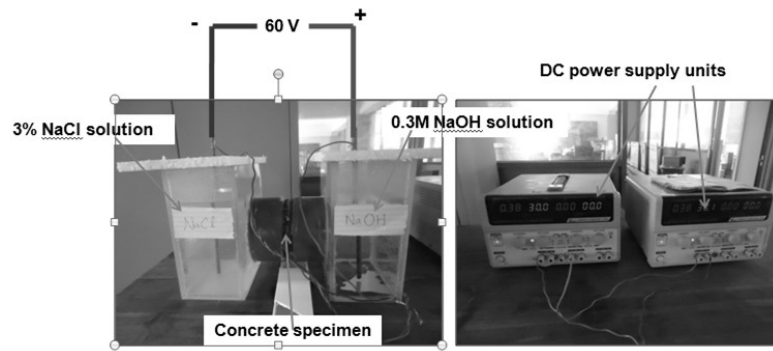


Figure 4: Rapid chloride penetration test apparatus

2.3 Calculating charge passed (CP) through the specimen

The current passed through the specimens were recorded every 30 minute interval in order to find the charge passed (CP) through the specimen according to Simpson's rule (Eq. 1) as given in the ASTM 1202. By referring to the Table 2 the level of chloride ion penetrability of the mortar mixer can be determined.

$$CP = 900 [I_0 + 2I_{30} + 2I_{60} + 2I_t + \dots + 2I_{330} + I_{360}] \quad (1)$$

CP - Total charge passed in coulombs, I_0 - Initial current in ampere, I_t - ampere at time t min

Table 2: chloride ion penetrability of the mortar according to CP Value (K.D. Stanish et al.,)

Charge Passed (coulombs)	Chloride Ion Penetrability
> 4,000	High
2,000-4,000	Moderate
1,000-2,000	Low
100-1,000	Very Low
< 100	Negligible

2.4 Preparing test specimens to apply repair mortar

Six specimens were prepared with identical parameters as shown in Figure 5 and allowed for curing for 14 days. Another one specimen was prepared as shown in Figure 6 to use as the control specimen and allowed for curing for 28 days. Three types of repairing mortar were applied as shown in Table 3 to each specimen and allowed for the curing. After another 28 days of curing, seven specimens were subjected to Accelerated Corrosion Test Method (ACTM) for 30 days period. Finally concrete dust samples were taken from the specimens in 20 mm, 40 mm and 60 mm depths for the titration process to measure free and total chloride ion concentrations. By comparing the result of chloride ion concentrations the most appropriate method will be proposed.

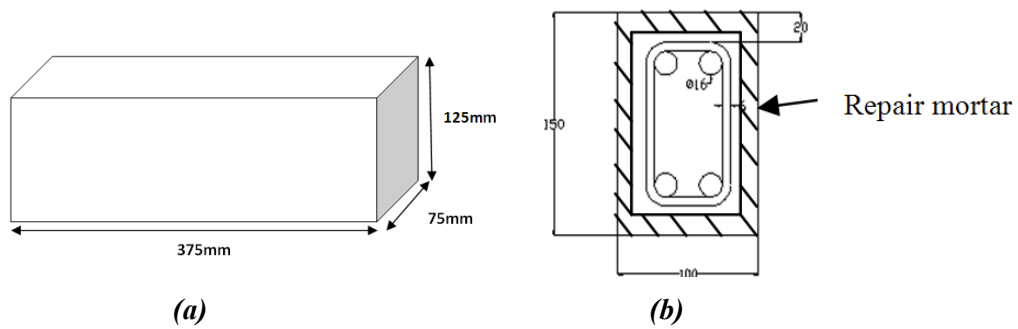


Figure 5: (a) Specimen dimensions (b) Cross section

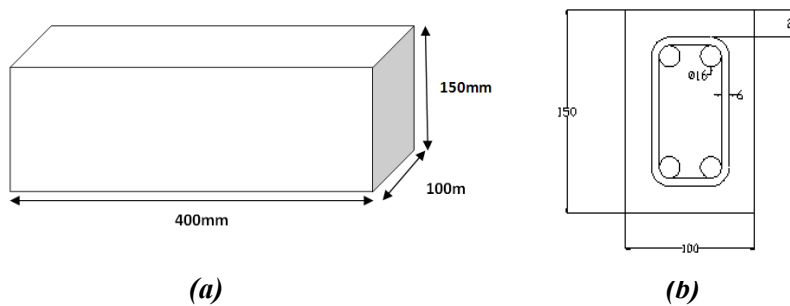


Figure 6: (a) Control specimen dimensions (b) Cross section

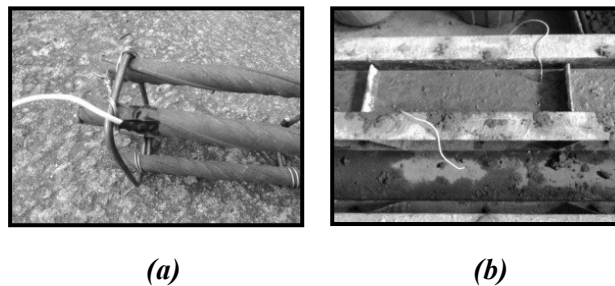


Figure 7: (a) Reinforcement and attached wire (b) Concreting specimens

Table 3: Add mixture type and added percentage by mass of cement to specimens

Specimen No.	Admixture	Percentage (%)	Number of Samples
S1	Control Sample	0	1
S2,S3	Fly Ash	50	2
S4,S5	Silica Fume	10	2
S6,S7	Calcium nitrite	-	2

2.5 Accelerated Corrosion Testing Method (ACTM)

NaCl solution of Cl⁻ ion concentration with 5% was used as the electrolyte for ACTM and the specimens were subjected to 5V voltage by a DC power source. The negative terminal of the DC power source was connected to the copper bars and the positive terminal is connected to the reinforcement bars of the specimens as shown in the Figure 8. Because of the voltage difference between two ends the chloride ions are deposited on the reinforcement bar and make it corroded. Because of this transverse mechanism of the cathodic protection, produce the corroded reinforced concrete samples faster. In this study the repaired samples and the control sample is subjected to accelerated corrosion test for a known period of time. The free and total chloride ion concentrations were measured in 20 mm, 40 mm and 60 mm depths of the specimen.

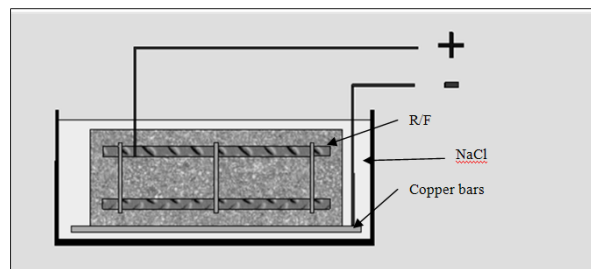


Figure 8: Accelerated corrosion test method

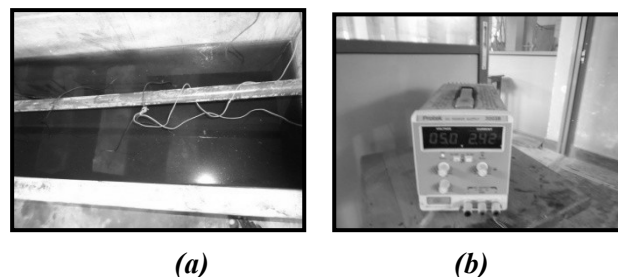


Figure 9: (a) Accelerated corrosion test tank (b) Power supply

2.6 Determination of chloride ion concentrations

2.6.1 Free chloride ion concentration

Concrete dust samples are taken from 20 mm, 40 mm and 60 mm depths of the specimen. These samples were sieved with the 0.25 mm sieve. The measured amount of 5 g, from each sample was mixed with 30 ml of distilled water initially and more distilled water added until 50 ml volume. Again the sample is mixed thoroughly. Then 25 ml sample was measured using a prepette and put in to a titrating flask. The K_2CrO_4 indicator is added and titrated against $AgNO_3$ until the colour changes to yellowish brown. By this method the free chloride ion concentration of the samples were measured.

2.6.2 Total chloride ion concentration

Concrete dust samples are taken from 20 mm, 40 mm and 60 mm depths of the specimen. These samples were sieved with the 0.25 mm sieve. The measured amount of 5 g, from each sample was mixed with 30 ml of 0.1M HNO_3 and more 0.1M HNO_3 added until 50 ml volume. Again the sample is mixed thoroughly. And then 25 ml sample is measured using a prepette and put in to a titrating flask and the K_2CrO_4 indicator is added and titrated with $AgNO_3$ until the colour changes to yellowish brown. By this method the total chloride ion concentration of the samples were measured.

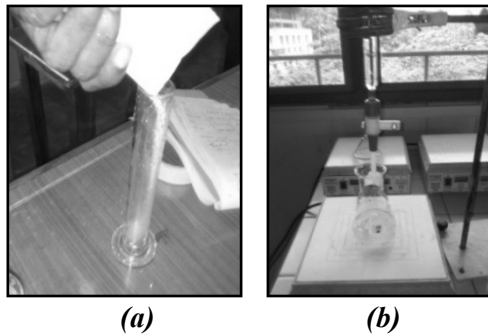
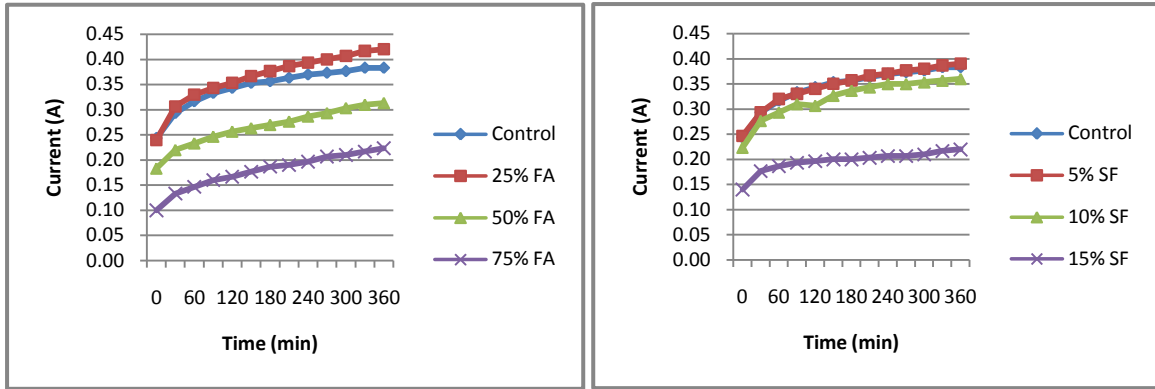


Figure 10: (a) Sample preparing (b) Samples titration

3. Results and Discussion

3.1 Rapid chloride permeability test results

The current across the specimens was recorded at every 30 min intervals, throughout a total period of six hours. Charge Passed (CP) through the specimen was calculated using above data. By comparing the charge pass across the specimen the lowest permeable admixture would be determined.



(a) Fly Ash admixtures

(b) Silica Fume admixtures

Figure 10: Current variation with time

Figures 10 (a) and 10 (b) were revealed that in higher amount of admixture percentages in mortar specimens' causes' reduction of the penetrability. In the fly ash and the silica fume the average current measurements of each time interval was reduced. The CP value was calculated according to the Eq. 1. The performance of each admixture type and percentage amount added to mortar specimens were compared according to the CP value as shown in the Figures 11 and 12.

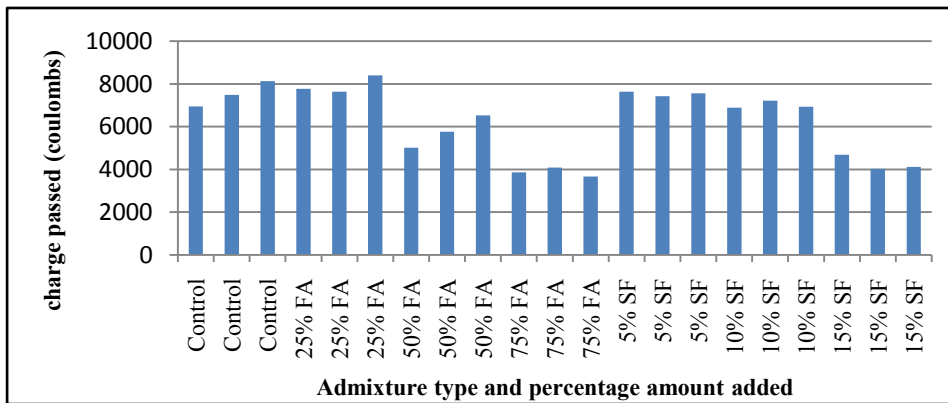


Figure 11: Charge passed variation with admixture type and percentage amount added to mortar sample

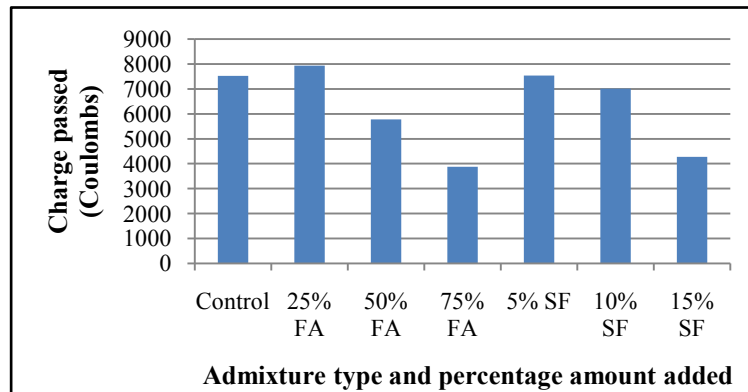


Figure 12: Average charge passed variation with admixture type and percentage amount added to mortar sample

4. Conclusions

In the study of the permeability variation of a concrete mix with different mineral admixture were investigated. The Silica Fume (SF) and Fly Ash (FA) were used as mineral admixtures. The optimum percentage of the Fly Ash was 40% - 50% and Silica Fume was 10% - 12% according to the previous literature. The permeability was increased with higher percentages of add mixtures, but strength of the mixture was reduced. Therefore three percentages of each admixture were used in order to determine the optimum percentage. As discussed in the results it is clearly shown that the samples used more admixture percentage gets lesser current values. Therefore it could say that when increasing the admixture percentage the chloride penetrability to the mortar is reduced.

For more comparable and descriptive presentation of the data the charge passed values were calculated. Therefore it can be discussed that lesser CP value represents the lesser penetrability of the chloride ions. As the CP values compared it was identified that the increasing the percentages of the admixture the penetrability was reduced. But only the 75% of the fly ash is lesser than the 4000 coulombs which gives a moderate penetrability. Therefore the results can be concluded as the Fly Ash with higher percentage is better admixture to the mortar other than Silica Fume.

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