RESTRAINING OF CHLORIDE INDUCED CORROSION IN RC STRUCTURES USING ION EXCHANGE RESIN

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ABSTRACT

Chloride ingress in Reinforced Concrete (RC) structures is probably the most aggressive phenomenon that causes the distress as well as structural deterioration and decrease the service life of structures. Like many other countries of the world, in Japan also, RC structures along the coastline deteriorate seriously due to chloride attack. The distinct feature of chloride attack is that, it causes corrosion of steel reinforcement bars and results in the formation of cracking, spalling or delamination which damages the surrounding concrete of RC structures. These types of damages warrant untimely expensive repair of the existing structures. The ingress of chloride ions into concrete mainly attributed by diffusion process and is primarily governed by concrete pore types and its orientation. The objective of this study is to develop high durable new type repair mortar with ion-exchange resin admixture to restrain chloride induced corrosion as well as to enhance the service life of RC structures by reducing chloride contents from matured concrete. Due to its excellent quality of chloride binding, ion exchange resin admixture with new repair mortar, might be the potentially effective option to restrain chloride induced corrosion and to enhance the life span of structures. Although the phenomenon is not yet well understood, this paper examined the effectiveness of using ion exchange resin with repair mortar for RC structures against chloride induced corrosion. A number of inverse diffusion tests were conducted using small mortar specimens of High-Early Strength Portland Cement (HESPC) and Polymer Cement (PC). The contents of ion-exchange resin in the repair mortar were 0 and 3 % by volume and were casted over the matured concrete specimens. The matured concrete specimens of 10cmX10cmX3cm & 10cmX10cmX5cm size were prepared with an initial chloride content of 2.5 kg/m^3 and after 14 days of casting, repair mortar were casted above the matured part. Chloride contents were measured by titration analysis after 2, 28 and 140 days and by EPMA after 140 days. From the test results, it was revealed that a significant amount of chloride has moved outward from matured concrete by inverse diffusion and bounded with ion-exchange resin of repair mortar. The test results signify the

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enhancement of chloride binding in mortar with 3% ion-exchange resin compared to 0% resin (normal mortar) for each type of cement. From this inverse diffusion study with repair mortar and resin, the effective reduction of chloride concentration at the reinforcement area of matured structures was clearly observed.

Keywords: Ingress, concrete, admixture, diffusion

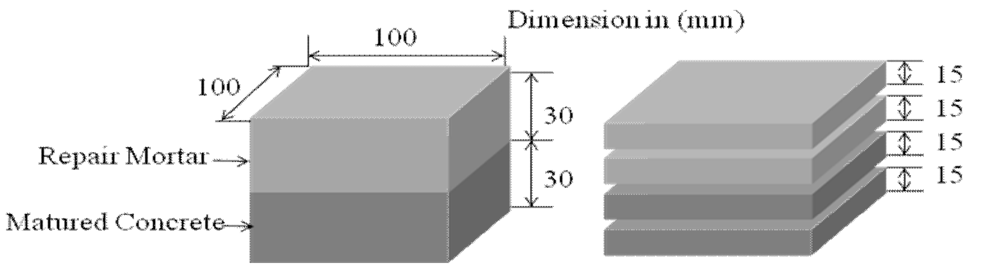
1. INTRODUCTION

Concrete is the most versatile and widely used construction material all over the world, but chloride-induced rebar corrosion is one of the major forms of environmental attack to concrete structures, which may lead to reduction in the strength, serviceability, and aesthetics of the structure. As a result, durability of RC structures in chloride laden environment is of great interest to design engineers, infrastructure owners and researchers (Shi et al. 2012). In case of RC structures, with passing of time, chlorides from the environment penetrate into the structures and get accumulated, what we call the matured concrete structures. The accumulation and ingress of chloride ion corrode the reinforcement (Elsener 2002). Due to chloride induced corrosion, structures require immediate repair and maintenance. The repair of damaged RC structures can be done, using some ready-mixed mortars (Batis et al. 2003), prepared by using different kinds of additives, such as ion exchange resin, silica fume or fly ashes. These admixture substances should have good characteristics quality compatible with concrete and should not alter the properties of concrete as well. In the present study, a typically available commercial Ion (anion) Exchange Resin (IER) has been examined with two types of cement to produce resin mixed repair mortar for the renovation and rehabilitation works of RC structures. IER are polymers of spherical beads of 0.5 to 1.0 mm diameter and insoluble substances, containing loosely held ions which are able to be exchanged with other ions. These exchanges take place without any physical alteration to the ion exchange material. In this research, basic type anion exchange resin was used as an admixture with repair mortar to remove chloride ions by exchanging with hydroxyl ions. The resin absorbs and binds chloride ions from the matured concrete and liberates hydroxyl ions into the pore solution. This paper examined the efficiency of resin mixed repair mortars in restraining chloride induced corrosion in RC structures through outward chloride movement from matured concrete using inverse diffusion tests.

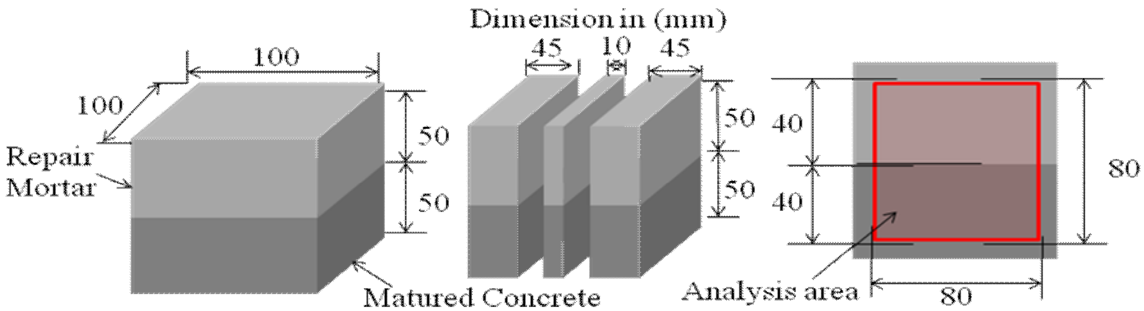
2. OUTLINE OF EXPERIMENT

2.1. Materials and mix proportions

Two types of specimens were prepared both using HESPC and PC, one type for potentiometric titration analysis and the other one for Electron Probe Micro Analyzer (EPMA), whose geometry and dimensions are shown in **Figure1**. A strongly basic & typical commercially available anion exchange resin (AMBERLITETM IRA402 Cl), has been used in this study. The total exchange capacity of resin is greater than 1.25eq/L (Cl^- form) and the moisture holding capacity is 49 to 55% with 660 g/L-R apparent density. The physical properties and chemical compositions of HESPC and PC are listed in **Table 1**. The specimens and their mix proportions are listed in **Table 2**, where IER (0%) indicates control specimen and IER (3%) indicates test specimen.



(a) Main Specimen for Titration analysis (b) Sliced Specimen for Titration



(c) Main Specimen for EPMA (d) Sliced Specimen for EPMA (e) EPMA analysis Area

Figure 1: Geometry and dimensions of specimens for titration analysis in (a) & (b) and for EPMA in (c), (d) & (e)

Table 1: Physical properties and chemical compositions of HESPC and PC

Cement Type	Density (g/cm^3)	Chemical Composition (% by mass)							
HESPC	3.14	(Na_2O+K_2O)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	NaCl
		1.624	20	5.01	2.79	65.9	1.55	3.12	0.006
PC	3.15	Latex fibre	(SiO_2 +NaCl)		Al_2O_3	Hydraulic cement (OPC)			
		12-23	40-50		6.00	20-25			

Table 2: Test specimens and their mix proportions (kg/m3)

Specimen Type	Matured Concrete				Resin Mixed Repair Mortar			
	W	C	S	Cl	W	C	S	IER
HESPC-IER (0%)	289	586	1290	2.5	293	586	1290	0
HESPC-IER (3%)					293	586	1213	35
PC-IER (0%)					315	1750	—	0
PC-IER (3%)					315	1673	—	35

2.2. Exposure conditions and analysis of test specimens

After casting, all specimens went under a cyclic dry and wet condition of 4 days dry and 3 days wet at a temperature of 40℃ with 60% and 95% RH respectively (JCI Diagnostic Technology of Concrete, JCI 2010). The specimens were exposed to the above mentioned exposure conditions for a period of 2 days, 28 days and 140 days. For titration analysis, after each exposure regime, specimens were sliced into the layers from 0 to 15 mm, 15 to 30 mm, 30 to 45 mm & 45 to 60 mm as shown in **Figure 1(b)** and grounded separately for potentiometric titration analysis against $AgNO_3$. For EPMA, specimens were sliced into layers and analyzed as shown in **Figure 1(d) & (e)**.

3. RESULTS AND DISCUSSION

3.1. Titration analysis

The trend of chloride movement by inverse diffusion method from matured concrete to newly added repair mortar for different time intervals are shown in **Figure 2**. Although the trend did not show a good level of consistency with the progress of time but a clear picture was depicted of the ability of resin mixed mortar to bind and absorb chloride than non resin mixed mortar. In this case, chloride ions from matured concrete layer (30~60mm) moved outward to repair mortar layer (0~30mm) by

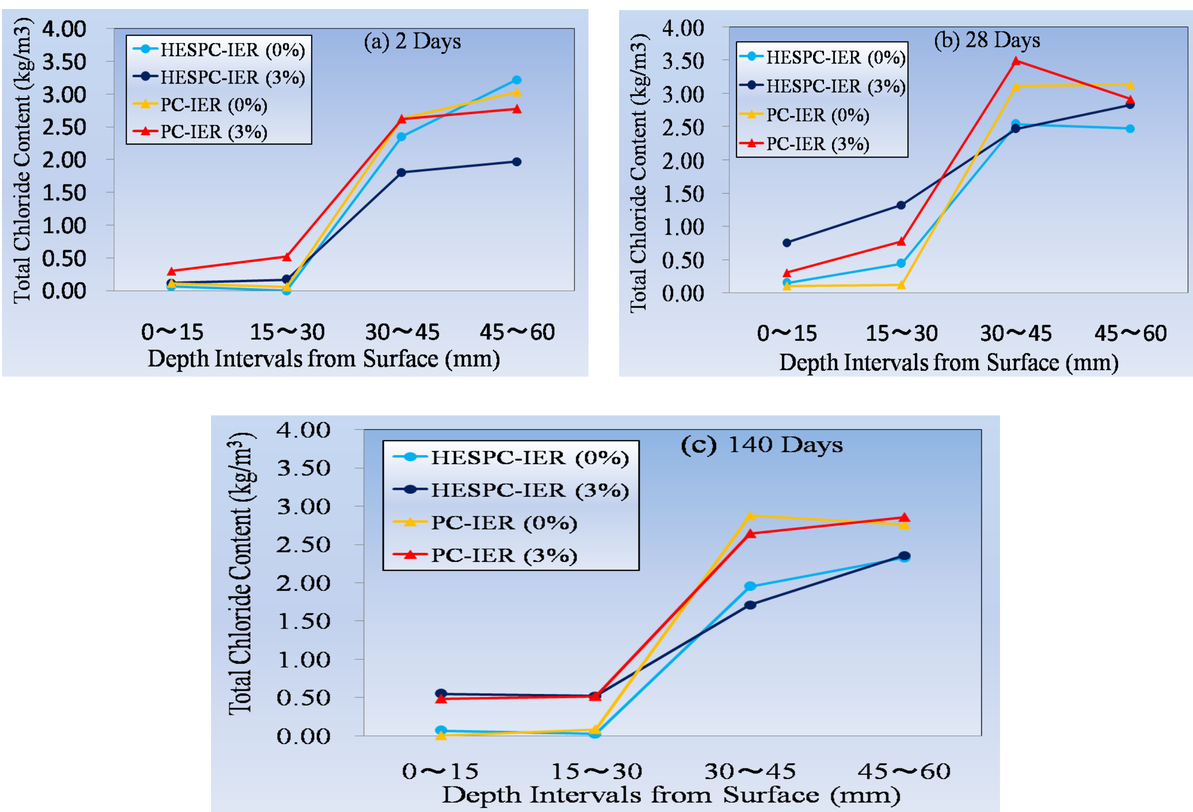


Figure 2: Chloride content at different depths for HESPC & PC in (a) 2 Days, (b) 28 Days and (c) 140 Days

inverse diffusion method due to the existence of resin in mortar and the phenomena were observed in both HESPC and PC. The phenomena became much understandable after 140 days time period, if chloride content of different depths (layer) are compared as shown in **Table 3** and graphically represented in **Figure 3.** As per the results, inverse diffusion of chloride ions was clearly identified

Table 3: Chloride contents at different depths after 140 days

Depths (mm)	HESPC-IER (0%)		HESPC-IER (3%)		PC-IER (0%)		PC-IER (3%)	
0～15	0.068	0.096	0.549	1.072	0.007	0.092	0.485	1.002
15～30	0.027		0.523		0.086		0.517	
30～45	1.952	4.277	1.710	4.067	2.875	5.631	2.643	5.497
45～60	2.326		2.357		2.756		2.853	

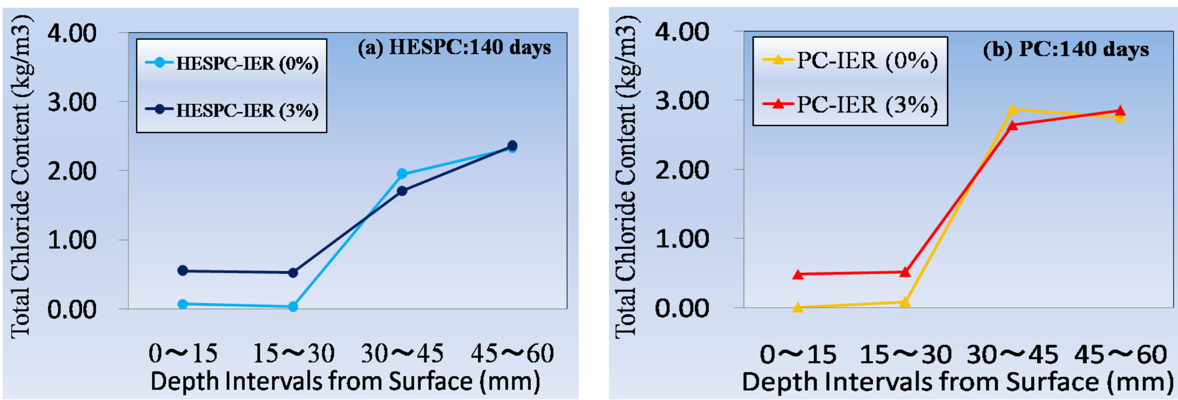


Figure 3: Outward movement of chloride in (a) HESPC: 140 days & (b) PC: 140 days

by comparing the total chloride content of 0~30 mm and 30~60 mm, because after 140 days:

Total chloride content (0~30 mm zone): control specimen (0% resin) ‹ test specimen (3% resin)

Total chloride content (30~60 mm zone): control specimen (0% resin) › test specimen (3% resin)

This phenomenon happened because, when resin (admixture) mixed repair mortar was attached to the matured concrete, due to adsorption and fixing of chloride ions by resin, more chloride moved outward from the matured concrete by inverse diffusion and bound with the resin beads. A little amount of chloride movement was observed in control specimens even without the resin (admixture) and this might be due to the velocity gradient between the two layers. Although the time period was not much enough to understand the phenomena well, the results showed that, as a repair mortar, resin mixed HESPC mortar performed slight better than PC mortar.

3.2. EPMA

Total chloride ion distribution in the cement mortar specimens were also obtained through EPMA technique. The EPMA results of ion distribution after 140 days for both HESPC and PC were shown in **Figure 4** and **Figure 5**. For both the cement cases, the same phenomena were observed as observed in titration analysis. It was observed that a considerable amount of ions have been diffused outward to repair mortar part from matured concrete in test specimen (3% resin) than control specimen (0% resin). It is well known that as an admixture, ion exchange resin has wonderful capacity of binding and absorbing chloride ions into resin beads, when chloride ions come in contact with them. In this case, inverse diffusion was more spontaneous and much noticeable in test specimen due to the existence of resin (admixture) in the mortar. On the contrary, in control specimen, as there was no resin, an insignificant amount of ions diffused outward only due to velocity gradient between two layers. As per the EPMA results, the inverse diffusion of chloride ions is clearly identified through eye vision by comparing the chloride content of repair mortar and

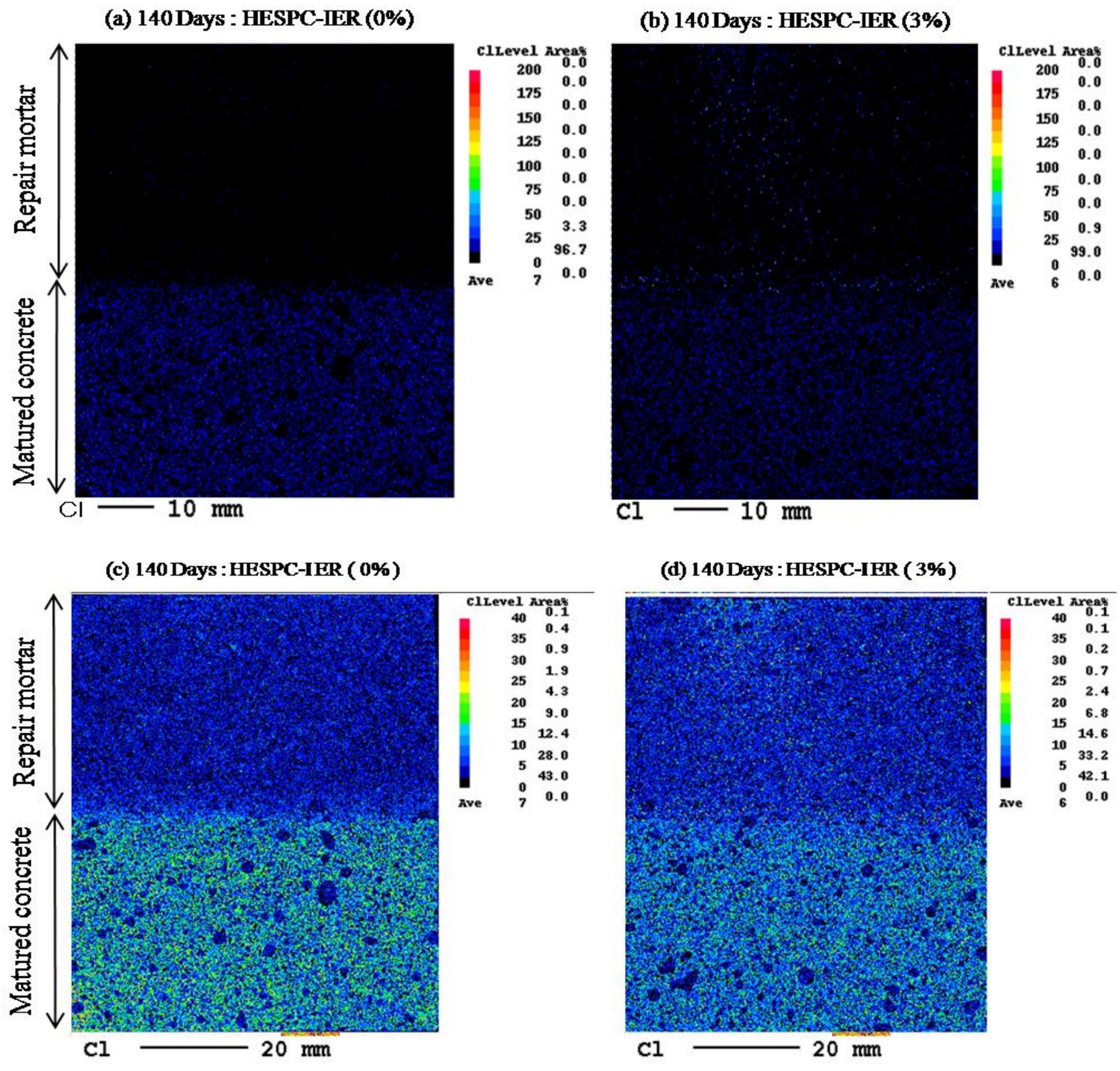


Figure 4: Chloride ion distributions after 140 days for HESPC in (a) & (b) in 100 scale (considering 8cmX8cm area) and in (c) & (d) in enlarged scale (considering 2cmX2cm area)

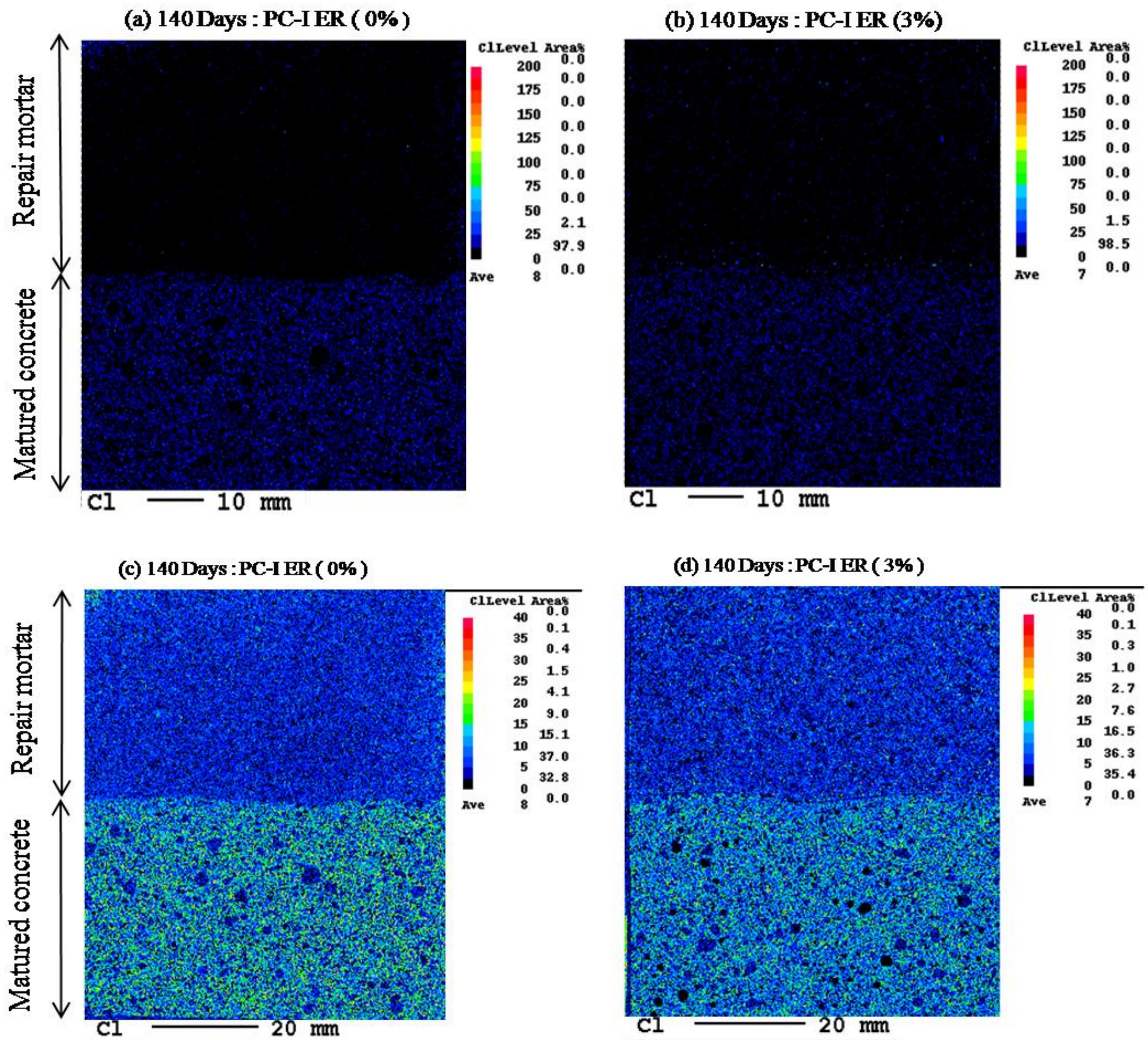


Figure 5: Chloride ion distributions after 140 days for PC in (a) & (b) in 100 scale (considering 8cmX8cm area) and in (c) & (d) in enlarged scale (considering 2cmX2cm area)

matured concrete, because after 140 days:

Total chloride content (repair mortar): control specimen (0% resin) ‹ test specimen (3% resin)

Total chloride content (matured concrete): control specimen (0% resin) › test specimen (3% resin)

In addition, according to the Cl level scale beside each figure it was revealed that, deeper chloride concentration area has been decreased in test specimen than control specimen for both the cement cases. In case of PC, resin mixed specimen showed a clear demarcation line between repair mortar and matured concrete than HESPC which was an indication that, mixing with resin, HESPC performed slight better than PC as a repair mortar. Through the analysis of EPMA images, a clear comparison was depicted about the inverse movement of chloride ions in control and test specimens.

4. CONCLUSIONS

According to the analysis, some major conclusions can be derived: **Firstly**, in case of titration analysis, although the results did not show a consistent trend for 2, 28 and 140 days but it was revealed that inverse diffusivity of ions was a direct function of resin (admixture) contents in the specimen, i.e. much the resin contents, much the diffusivity. Same phenomenon was also observed in EPMA results. The inconsistency in the results might be due to improper curing, moisture condition, w/c ratio, delay of cement hydration and slight variations in exposure conditions. **Secondly**, the experimental results of the chloride content at repair mortar and matured concrete were validated by EPMA analysis and the outward movement of chloride ions from matured part to repair mortar part was confirmed by EPMA. In both cases, mixing with resin, HESPC showed a slight better performance than PC. And **finally**, it can be concluded that, 140 days is not so much time to understand the phenomena at all. So further investigations are required with much effective observation and time trend to justify and establish the matter. As it was observed that existence of resin in mortar could reduce the chloride concentration at reinforcement area, it might be potentially and effectively useful in reducing and restraining chloride induced corrosion probability in RC structures. This technique could ultimately enhance the durability and service life of RC structures.

5. ACKNOWLEDGEMENT

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