PERFORMANCE OF POLYMER-CONCRETE COMPOSITES EXPOSED TO SEVERE ENVIRONMENT

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ABSTRACT

This paper presents a comprehensive experimental and theoretical investigation on the performance of polymer modified concrete (PMC) and fibre reinforced concrete (FRC) exposed to aggressive environmental conditions. Chloride-induced corrosion of steel in concrete is the main cause of premature deterioration of off-shore or on-shore reinforced concrete (RC) structures exposed to marine environment. For service life evaluation and prediction, the time of crack initiation in concrete cover can be considered as the most important criteria. Thus, the corrosion-induced crack initiation time and maximum anodic current intensity generated by corrosion process of embedded steel reinforcement in concrete were investigated in this paper. The specimens made of different categories of the concrete subjected to high concentrated Sodium Chloride solution and continuous cycles of wetting and drying for 24 months. Later, the accelerated electrochemical test was conducted to measure the time to concrete cover cracking and also anodic current intensity. Results proved that due to remarkable increase in time to cracking, the polymer-concrete composites increased the durability and service life of RC structures significantly.

Keywords: concrete durability, polymer modified concrete, fibre reinforced concrete, steel corrosion in concrete, accelerated electrochemical test,

1. INTRODUCTION

The subject of the reinforced concrete structures durability has extensively been studied and investigated for the last four decades. But, premature deterioration of reinforced concrete structures is still widely recognized problem in the world (Shaker et al., 1997). This phenomenon has generated worldwide serious economic impacts regarding to maintenance, repair and in some cases replacement of structures. Also, the environmental impact in terms of raw materials consuming as well as carbon dioxide emission; and safety issue should be considered as the consequences problems (Ann et al., 2009, Song and Kwon, 2009). According to the vast investigations, it is found out that the dominant factor of this process is the chloride-induced corrosion of the steel reinforcement in concrete due to the chloride diffusion into the concrete (Zornoza et al., 2009, Costa and Appleton, 1999).

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Chloride diffusion into the concrete occurs through the concrete permeability and surface cracks resulted from different sources such as loading and shrinkage. Increasing the number and the width of cracks will not only accelerate the diffusion process but also enhance the probability of the steel corrosion leading to decreasing the service life of structures. When the concentration of chloride ions around the steel reinforcement surface reaches to chloride threshold, depassivation of high alkaline protective layer leads to corrosion initiation (Koleva et al., 2007). The surface of the corroding steel functions as a mixed electrode that is a composite of anodes and cathodes electrically connected through the body of steel itself, upon which coupled Anodic and Cathodic reactions take place. Concrete functions as an aqueous medium, i.e., a complex electrolyte. Therefore, a reinforcement corrosion cell is formed (Maruya et al., 2007). Since concrete in the corrosion process contributes as an electrolyte (solid electrolyte) then electrical resistivity (or conductivity) of concrete is of importance to certain diffusion of aggressive ions and corrosion process (Hansson, 1984).

Increasing the ductility and tensile strength from one side and reducing the permeability of concrete by confining the interconnected pores from the other side, the polymer-concrete composites can be an applicable solution to overcome this problem.

The results from this comprehensive experimental investigation confirm that the polymer-composites systems are able to improve he concrete durability significantly.

2. MATERIALS AND METHODS

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2.1. Materials

- Portland cement type General Purpose (GP) based on Australian Standard which is equivalent to ASTM C 150 Type (I)
- Polypropylene (PP) monofilament fibres with length of 18 mm and a diameter of 20 μm
- Styrene Butadiene Rubber (latex) as aqueous polymer
- Crushed coarse aggregate with maximum size of 20 mm, specific gravity of 2.71, and water absorption capacity of 1.48%
- Natural fine aggregate with specific gravity of 2.62 and water absorption capacity of 1.67%

2.2. Methods

2.2.1. Mechanical Properties

In this investigation, Conventional Concrete (CC) as a reference concrete; Fibre Reinforced Concrete (FRC) with various proportions of PP Fibres, and Polymer Modified Concrete (PMC) with various proportions of latex were cast and examined. According to Australian standard (AS4997), "Guidelines for Design of Maritime Structures", a minimum characteristic compressive strength of 40 MPa, minimum cement content of 400kg/m3, and maximum water to cement ratio of 0.4 were taken into account as the basic and initial assumptions of concrete mix design.

2.2.2. Mix Design, Specimens Characteristics, Mixing Procedure

The mean concrete compressive strength of 60 MPa and water-cement ratio of 0.35 with a cement content of 400 kg/m^3 and slump of 80 ± 10 mm were fixed to design of the concrete mix. The concrete mix design is reported in Table 1.

Table 1: Conventional concrete mix design

Material	Magnitude (kg/m3)
Cement	400
Water	140
Coarse aggregate	1173
Fine aggregate	781

Three types of FRC and five different types of PMC with different PP fibres and latex proportions respectively were cast to be investigated. The characteristics of the polymeric concrete are depicted in Table 2.

Table 2: FRC and PMC specimens' characteristics

Specimen Code	Fibre Proportion	SBR Proportion (p/c ratio)
	% by the vol. of concrete	% by the wt. of cement
FRC1	0.1	-
FRC2	0.2	-
FRC3	0.3	-
PMC1	-	3
PMC2	-	5
PMC3	-	7
PMC4	-	10
PMC5	-	15

The mixing process for conventional concrete was conducted according to Australian Standard (AS 1012.2). For FRC after finishing the mixing process for conventional concrete, PP fibres were added to the mix and another four minutes was took into account for mixing time to uniformly distribution of the fibres in the concrete mix. Increasing the proportion of fibres causes the reduction in fresh concrete workability leading to use more Superplasticizer. For PMC the mixing procedure can be conducted same as conventional concrete with considering two following points before start mixing (a) antifoaming agent should be added to the latex and mix for at least one minute, (b) latex should be added to the mixing water and mix for at least one minute.

2.2.3. Curing Method

FRC specimens can be cured with the same method as CC specimens one day in the covered moulds and 27 days in submerged situation. Since PMC is very susceptible to the moisture especially in early ages. The method and duration of curing have significant influence on the ultimate and rate of strength development of PMC. The polymer is in liquid form and it needs some time to lose the water and to be solidified. During this period, PMC should not be exposed to moisture otherwise, the solidification of polymer can not been completed. The most appropriate curing for latex modified concrete is 2 days in 100 percent relative humidity, 5 days in wet followed by 21 days dry conditions. Air curing of PMC allows any excess water to evaporate and allows formation of the latex film; this is desirable because latex film formation in the internal structure is the main reason for the improved properties in PMC.

2.2.4. Accelerated Chloride-Induced Corrosion Test

Since the corrosion of reinforcing steel bars is a long-term electrochemical process, the electrochemical accelerated methods can help to obtain the results in relatively shorter time for laboratory investigation. In this investigation, the Accelerated Chloride-Induced Corrosion Test (constant impressed voltage technique) was performed to compare the corrosion time of embedded steel bar in different categories of concrete.

The corrosion time of reinforcing steel bars was considered as a criterion for durability assessment of the concrete. The greater corrosion time indicates the more durable concrete. The procedure for this test can be illustrated as follows: the specimens for the corrosion resistance test consist of concrete beams (400×100×100 mm) with one embedded 12 mm diameter reinforcing steel bar. The specimens were exposed to simulated marine environment conditions consisting of high concentrated sodium chloride solution (15%) and wetting-drying cycles for 24 months.

After this period, the specimens were tested under Accelerated Chloride-Induced Corrosion Test to measure the concrete cover cracking and anodic current intensity. In this electrochemical test the embedded steel in concrete acts as an anode and steel bar acts as a cathode and the concrete performs as an electrolyte (solid electrolyte). A constant voltage of 30 V is applied from the external DC source between anode and cathode. The intensity of electrical current versus time is continuously recorded by using high resolution data logger. Based on the concept of this method, any impulsive raise in electrical current indicates corrosion induced cracking in concrete cover. The time to initiate a first crack on the concrete was observed and corresponding anodic current was noted. The schematic of the test arrangement is shown in Figure 1.

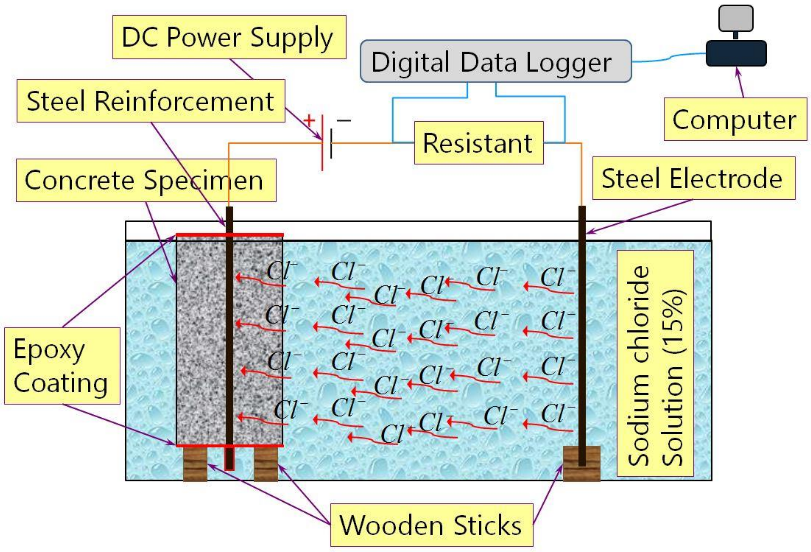

Figure 1 Accelerated chloride-induced corrosion test set up

3. RESULTS AND DISCUSSION

The results are presented in two types, mechanical properties and durability evaluation of all concrete categories.

3.1. Mechanical Properties

Compressive strength tests were carried out based on Australian Standard (AS 1012.9). The averages of 28-day compressive strength test results for each type of concrete are presented in Table 3. Each average result has obtained from nine specimens. The results show that increasing the fibres proportion improves the compressive strength for instances by adding 0.3% of PP fibres the compressive strength enhances by approximately 12%.

Table 3: Results of compressive test

Concrete Category	Codes of Specimens	The Average Of 28-day Compressive Strength MPa
CC	CC1 CC2 CC3	62
FRC1	FRC1-1 FRC1-2 FRC1-3	65
FRC2	FRC2-1 FRC2-2 FRC2-3	69
FRC3	FRC3-1 FRC3-2 FRC3-3	69
PMC1	PMC1-1 PMC1-2 PMC1-3	67
PMC2	PMC2-1 PMC2-2 PMC2-3	66
PMC3	PMC3-1 PMC3-2 PMC3-3	64
PMC4	PMC4-1 PMC4-2 PMC4-3	60
PMC5	PMC5-1 PMC5-2 PMC5-3	53

For PMC, it can be expressed that by increasing the polymer cement (p/c) ratio up to 0.7 the compressive strength enhances. But, increasing the polymer cement ration causes the reduction of strength. This phenomenon relates to generation of bubbles in PMC due to the reaction between polymer and cement ingredients.

3.2. Durability Evaluation

The results of time to crack initiation are reports in Table 4. For FRC, results indicate that by increasing the fibre proportion from 0.1% to 0.3% the time to crack initiation improves from 16% to 41% comparing to CC. This can be expressed as the reduction of the number and the width of the cracks especially the cracks resulted from plastic and dry shrinkage by forming the fibre-concrete composites. The results corresponding PMC’s specify a considerable enhancement in time to crack initiation due to reducing the diffusion coefficient of chloride into the concrete by confining the interconnected pores system. In PMC1 with p/c ratio of 0.03 the time to cracking increased to 119% and this increment for PMC5 with p/c ratio of 0.15 jumped to 204%.

Table 4: Time to crack initiation (corrosion time)

Concrete Category	Specimens Code	Time (h)	Average Time (h)	Increase (%)
CC	CC1	389	387	-
	CC2	392		
	CC3	379		
FRC1	FRC 1-1	447	447	16
	FRC 1-2	443		
	FRC 1-3	451		
FRC2	FRC 2-1	492	491	27
	FRC 2-2	486		
	FRC 2-3	496		
FRC3	FRC 3-1	543	547	41
	FEC 3-2	548		
	FRC 3-3	550		
PMC1	PMC1-1	853	847	119
	PMC1-2	849		
	PMC1-3	840		
PMC2	PMC2-1	977	973	151
	PMC2-2	969		
	PMC2-3	972		
PMC3	PMC3-1	1022	1027	165
	PMC3-2	1027		
	PMC3-3	1033		
PMC4	PMC4-1	1136	1132	192
	PMC4-2	1132		
	PMC4-3	1128		
PMC5	PMC5-1	1171	1177	204
	PMC5-2	1179		
	PMC5-3	1182		

These results are illustrated in the Figure 2.

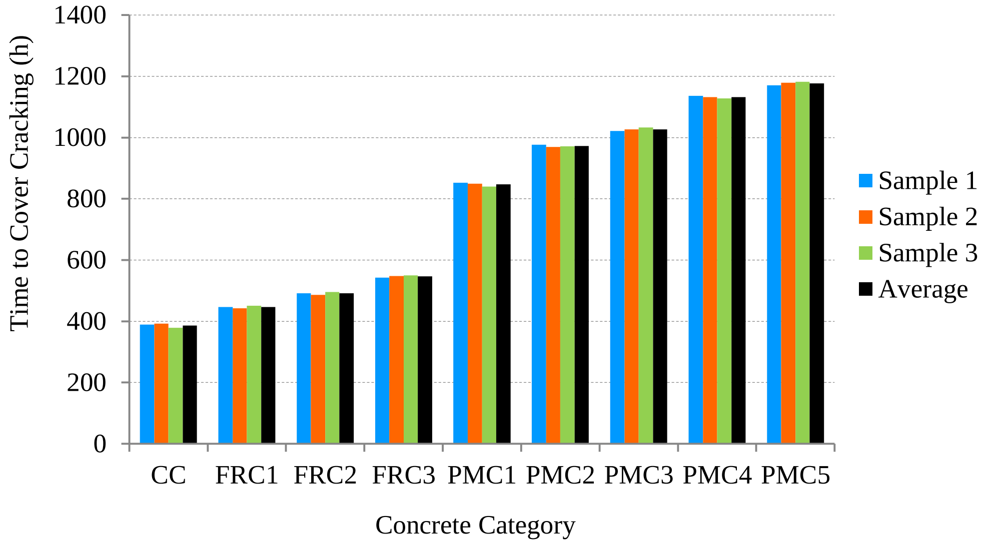

Figure 2: Time to cracking in different polymer-concrete composites

The results displaying in Figure 3 regarding to anodic current intensity demonstrates that by increasing the proportions of PP fibres or latex in concrete the current intensity reduces. The anodic current can be considered as a criterion to judge about the concrete conductivity/resistivity. The lower anodic current value shows the higher concrete resistivity. Thus, it can be noted that increasing the proportion of fibre and latex causes the improvement of concrete electrical resistivity.

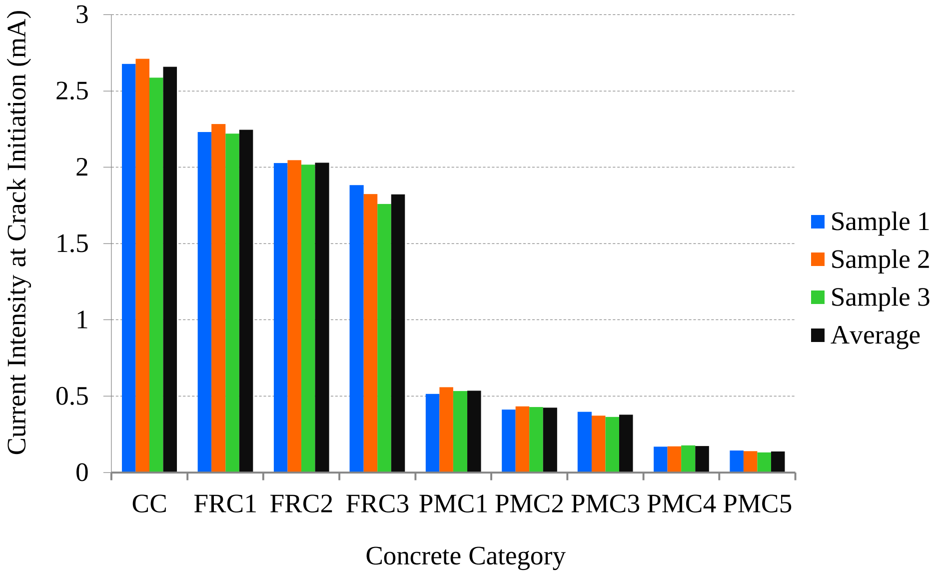

Figure 3: Maximum anodic current density in different polymer-concrete composites

4. CONCLUSIONS

In this experimental study the durability assessment of FRC and PMC exposed to simulated marine environment were investigated and following outcomes could be drawn:

- Increasing the proportion of PP fibres and latex increases the time to cover cracking.
- In FRC with proportion of 0.3% PP fibres, time to corrosion increases by 41%.
- In PMC with 15% latex proportion, approximately 200% increasing in time to cracking is observed.
- Considerable drop in current intensity in PMCs which indicates that PMCs have a significant lower conductivity compare to CC and FRCs. This property causes the larger corrosion propagation time.
- In general, polymer-concrete composites are able to get higher durability comparing to CC. The increase in service life in PMCs is considerably more than CC.

5. ACKNOWLEDGMENTS

It may acknowledge for sources of financial support from Centre for Built Infrastructure Research (CBIR) group as a part of the School of Civil and Environmental Engineering, University of Technology Sydney, Australia.

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