# INVESTIGATION ON THE DURABILITY OF FIBRE REINFORCED CONCRETE (FRC) EXPOSED TO MARINE ENVIRONMENT

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**Key words:** Fibre reinforced concrete, Polymer-concrete composites, Durability, Marine environment, Corrosion time, Accelerated chloride-induced corrosion test

**Abstract:** This experimental investigation presents an improvement on the mechanical properties and durability of conventional concrete (CC) exposed to marine environment using synthetic fibre-concrete composites incorporating Polypropylene fibres. Conventional concrete (CC) as a reference specimen; and polypropylene fibre reinforced concrete (FRC) specimens with various proportions of polypropylene (PP) fibres were cast and exposed to simulated marine environment in the laboratory for 24 months. An accelerated corrosion experimental program carried out to measure the time to concrete cover cracking and anodic current. According to the results, a considerable enhancement on concrete durability in terms of increasing the time to crack initiation and reducing the anodic current for FRC was observed.

## 1 INTRODUCTION

Premature deterioration of reinforced concrete (RC) structures exposed to marine environment has become a worldwide problem with serious economic consequences due to maintenance, repair, and replacement of the RC structures and also environmental impact and safety issue[1, 2]. 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 [3, 4].

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 [5, 6]. 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 [7].

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 [8].

Generation of cracks relates to low tensile strength and strain of conventional concrete. To help overcome to these imperfections, there has been a steady increase in use of the fibre reinforced concrete (FRC) over the last 40 years. The main role of fibres is to control the numbers and width of cracking in the concrete[9].

Synthetic fibres have become increasingly important to the civil and structural engineering over the last decade and now have a broad range of applications. Different kinds of synthetic fibres like polypropylene, aramid, polyvinyl alcohol etc. are utilized in cementitious materials to enhance mechanical properties of concrete such as tensile and flexural strengths, toughness, impact load resistance, and fracture energy [10]. Among the various types of fibres, polypropylene fibres (PP) have become more and more important in engineering application due to their low cost, light weight, good bond with matrix and high corrosion resistance.

It has been shown earlier that cracking resulted from shrinkage and differential settlements during the fresh state can be effectively inhibited by monofilament type of polypropylene (PP) fibres reinforcement. Because of the large numbers involved, fibres can be properly distributed throughout the mortar matrix, around the coarse aggregate particles, and even in boundary layers of concrete elements.

In this paper, the mechanical properties and durability assessment of FRC incorporating PP fibres exposed to simulated marine environment utilizing Accelerated Chloride-Induced Corrosion Test are investigated.

## 2 MATERIALS AND METHODS

### 2.1 Materials

a. A Portland cement type General Purpose (GP) based on Australian Standard which is equivalent to ASTM C 150 Type (I) was used in this study.
b. Monofilament type of PP fibres with a length of 18 mm and a diameter of 20 µm were employed.
c. Crush coarse aggregate with maximum size of 20 mm, specific gravity of 2.71, and water absorption capacity of 1.48% was used. Table 1 presents the sieve analysis of coarse aggregate based on Australian Standard (AS2758.1).

**Table1**: Coarse aggregate grading

| Sieve Size(mm) | 26.5 | 19 | 9.5 | 4.75 |
|---|---|---|---|---|
| Passing (%) | 100 | 91.30 | 9.21 | 0.34 |

d. Natural fine aggregate with specific gravity of 2.62 and water absorption capacity of 1.67% was used. Table 2 reveals sieve analysis of fine aggregate according to Australian Standard (AS2758.1).

**Table2**: Fine aggregate grading

| Sieve Size (mm) | Passing (%) |
|---|---|
| 9.5 | 99.74 |
| 4.7 | 93.64 |
| 2.3 | 82.33 |
| 1.18 | 55.20 |
| 0.600 | 34.27 |
| 0.300 | 16.67 |
| 0.150 | 6.74 |

### 2.2 Methods: Mechanical Properties

In this investigation, Conventional Concrete (CC) as a reference specimen; and Fibre Reinforced Concrete (FRC) specimens with various proportions of PP Fibres, 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 (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.

### 2.3 Methods: 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 [11, 12]. 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 for 24 months.

After this period, the specimens were tested under Accelerated Chloride-Induced Corrosion Test to measure the corrosion time of each category of the concretes. In this electrochemical test the embedded steel in concrete acts as an anode and steel bar acts as a cathode and the electrolyte is 15% sodium chloride solution. 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 digital 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.

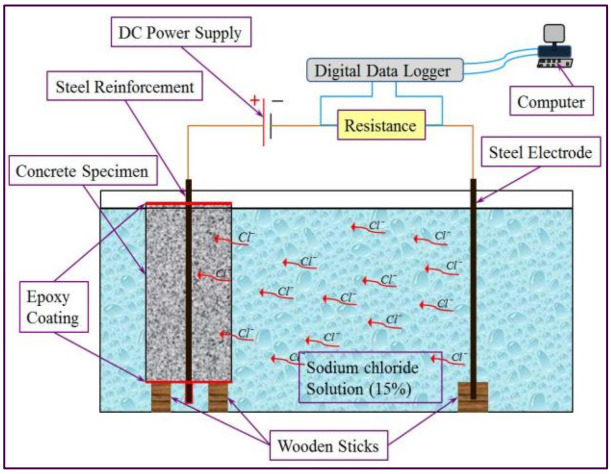


**Figure 1**: Accelerated Chloride-Induced Corrosion Test Set up

## 3 EXPERIMENTS

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 between 60 and 80 mm were fixed to design of the concrete mix. After that, the aggregate proportions were found out according to some trial mixes.

The concrete mix design is reported in Table 3.

**Table3**: Concrete mix design

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

Three types of fibre reinforced concrete with different polypropylene fibres proportion were selected to be investigated. The amount of 0.1%, 0.2%, and 0.3 % by the concrete volume was selected as the PP fibers proportions. The characteristics of these PP fibre reinforced concrete samples are depicted in Table 4.

**Table4**: Characteristics of concrete categories

| Concrete Category | Fibre Content (%)* | Superplasticizer (%)** |
|---|---|---|
| CC | 0.0 | 0.6 |
| FRC1 | 0.1 | 1.0 |
| FRC2 | 0.2 | 1.3 |
| FRC3 | 0.3 | 1.8 |

*by the volume of concrete
**by the weight of cement

### 3.1 Mixing procedure

The mixing process was conducted according to Australian Standard (AS 1012.2). After finishing the mixing process for conventional concrete, the PP fibres were added to the mix and another four minutes was added to the mixing time to disperse the fibres in the concrete mix uniformly. Increasing the proportion of fibres causes the reduction in fresh concrete workability leading to use more Superplasticizer.

### 3.2 Curing and exposure conditions

The wet curing system was utilized to all specimens for 28 days. Then, all reinforced concrete specimens were exposed to a simulated marine environment consisting of high concentrated Sodium Chloride solution (15%) with equal time interval (seven days) wetting and drying cycles at about 23± 3ºC for the period of 24 months.

## 4 RESULTS AND DISCUSSIONS

### 4.1 Mechanical characteristics

In this experimental study, compressive strength test based on Australian Standard (AS 1012.9) and flexural test based on Australian Standard (AS 1012.11) for different categories of concrete were conducted. The 7-day and 28-day compressive strength and also modulus of rupture test results are summarised in Table 5 and Table 6, respectively. Three specimens (samples 1,2, and 3) for each concrete category were cast to estimate the final results more accurately by using the average of the results.

**Table5**: Compressive strength results

| Concrete Category | 7-day MPa | Average MPa | 28-day MPa | Average MPa |
|---|---|---|---|---|
| CC1 | 40.5 | | 61.7 | |
| CC2 | 41.4 | 41.0 | 62.8 | 62.3 |
| CC3 | 41.2 | | 62.5 | |
| FRC1-1 | 43.6 | | 64.8 | |
| FRC1-2 | 45.3 | 44.5 | 65.3 | 64.7 |
| FRC1-3 | 44.6 | | 63.9 | |
| FRC2-1 | 46.8 | | 68.3 | |
| FRC2-2 | 45.3 | 46.5 | 67.9 | 67.9 |
| FRC2-3 | 47.4 | | 67.4 | |
| FRC3-1 | 49.2 | | 68.4 | |
| FRC3-2 | 47.8 | 48.5 | 70.5 | 69.4 |
| FRC3-3 | 48.8 | | 69.2 | |

The results confirm that PP fibres can improve the compressive strength of concrete due to bridging effect. Increasing the amount of fibres increases the compressive strength. Fibre proportions of 0.1, 0.2, and 0.3% by the volume of concrete improved the compressive strength by 4, 9, and 13%, respectively.

**Table6**: Flexural test results

| Concrete Category | MOR MPa | Average MPa | Change (%) |
|---|---|---|---|
| CC1 | 6.81 | | |
| CC2 | 6.71 | 6.73 | 0.0 |
| CC3 | 6.68 | | |
| FRC1-1 | 7.02 | | |
| FRC1-2 | 7.33 | 7.17 | +6.5 |
| FRC1-3 | 7.17 | | |
| FRC2-1 | 7.78 | | |
| FRC2-2 | 7.75 | 7.78 | +15.6 |
| FRC2-3 | 7.81 | | |
| FRC3-1 | 6.7 | | |
| FRC3-2 | 6.81 | 6.75 | +0.3 |
| FRC3-3 | 6.75 | | |

To better comparison of the above discussions, the average of compressive results for 7-day and 28-day test is shown in Figure2. All FRC specimens show an improved compressive strength compare to CC.

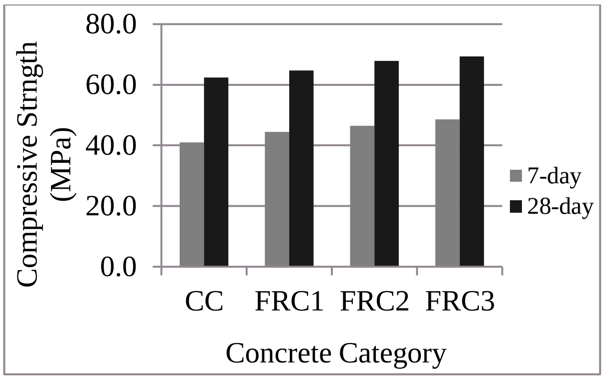


**Figure 2**: The average of compressive strength results

The results regarding to modulus of rupture are represented in Figure 3. Considering the results, it can be stated that by increasing the proportion of Polypropylene up to 0.2% by the volume of concrete, MOR will be enhanced by approximately 16%. But, by increasing the amount of fibre more than 0.2% in the concrete, the MOR compare to other PP FRC will be reduced but it is still around the modulus of rupture for CC.

The reason can be stated as reduction in bond strength between PP fibres and matrix due to increasing ITZ area which results the increasing of porosity of concrete.

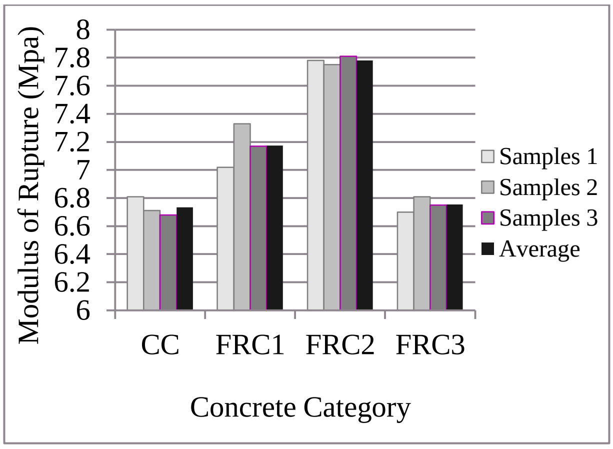


**Figure 3**: MOR results

## 4.2 Constant impresses DC voltage technique

In this experiment a constant 30V DC voltage is applied and the current intensity is continuously measured by a digital data logger and is sent to computer to save the data as MS Excel spread sheet as well as graphical output.

The results time to crack initiation test for conventional concrete and polypropylene fibre reinforced concrete with different proportions of fibres are reported in Table 7.

**Table7**: Impressed voltage test results, Time to cracking

| Concrete Category | Time to Cracking (h) | Average of Time to Cracking (h) |
|---|---|---|
| CC1 | 68 | 70 |
| CC2 | 71 | |
| CC3 | 70 | |
| FRC 1-1 | 73 | 74 |
| FRC 1-2 | 74 | |
| FRC 1-3 | 76 | |
| FRC 2-1 | 77 | 77 |
| FRC 2-2 | 78 | |
| FRC 2-3 | 76 | |
| FRC 3-1 | 80 | 81 |
| FEC 3-2 | 83 | |
| FRC 3-3 | 81 | |

The results indicate that generally FRC has a greater time to crack initiation which proves that permeability of FRC is less than CC. Also, it can be stated that by increasing the fibres proportion, the time to cracking is increased. For instance, adding 0.1% PP fibres to the concrete mix can improve the time to corrosion by approximately 6% and using 0.3% of fibre proportion can enhance the time to cracking up to approximately 15% compare to CC. The summarized of time to cracking results are illustrated in Figure 4.

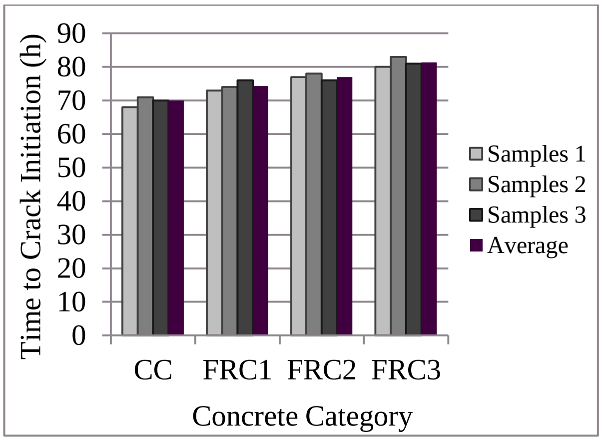


**Figure 4**: Time to cracking for different categories of concrete

The maximum values of anodic current for all concrete categories are expressed in Table8.

**Table8**: Maximum anodic current for different categories of concrete

| Concrete Category | Maximum Current (mA) | Average of Maximum Current (mA) |
|---|---|---|
| CC1 | 93.6 | 91.4 |
| CC2 | 89.2 | |
| CC3 | 91.4 | |
| FRC 1-1 | 87 | 84.8 |
| FRC 1-2 | 84.8 | |
| FRC 1-3 | 82.6 | |
| FRC 2-1 | 82.6 | 80.4 |
| FRC 2-2 | 78.2 | |
| FRC 2-3 | 80.4 | |
| FRC 3-1 | 76 | 77.5 |
| FEC 3-2 | 78.2 | |
| FRC 3-3 | 78.2 | |

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 property. The results from measuring the maximum anodic current reveal that totally PP FRC has more electrical resistivity compare to CC. Besides, it can be noted that increasing the fibre proportion in the FRC causes the improvement of concrete electrical resistivity. This discussion will be more clear by comparison the results displayed in Figure 5.

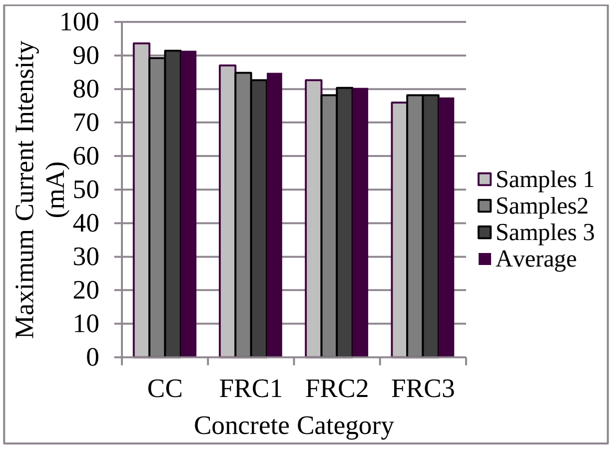


**Figure 5**: Maximum anodic current for different concrete categories utilizing impressed voltage technique

Finally, by combining the two measured factors including time to crack initiation and maximum current for all investigated concrete categories, a clear conclusion can be obtained. Figure 6 depicts the relation between the time to crack initiation and maximum anodic current for concrete categories.

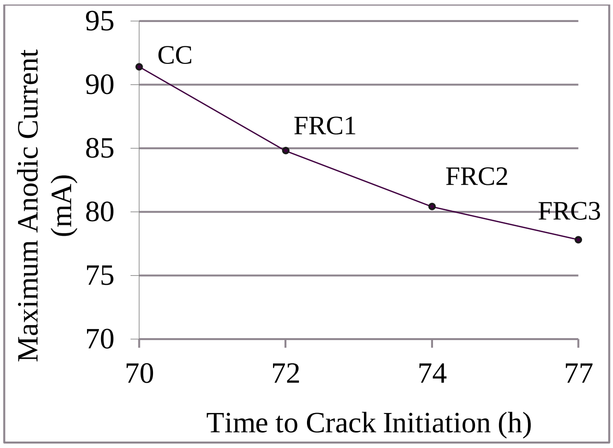


**Figure 6**: The average maximum anodic current versus the average time to crack initiation for concrete categories

Figure 6 illustrates that by increasing the fibre proportion in the FRC not only the time to crack initiation is increased, but also the maximum anodic current is reduced.

## 5 CONCLUSIONS

In this experimental study the mechanical properties and durability assessment of polypropylene fibre reinforced concrete exposed to marine environment have been investigated and following outcomes can be drawn:

- Increasing the proportion of PP fibres increases the air entrapped and decreases the workability of freshly concrete.
- PP fibres with proportion of 0.3% increase the concrete compressive strength approximately by 13%. But, flexural test results present that the magnitude of MOR beyond 0.2% of fibres proportion is decreased
- The electrochemical experiment results obtained from measuring the anodic current indicate that PP fibre reinforced concrete shows lower concrete conductivity.
- PP FRC shows reduction in permeability compare to CC considering results of time to crack initiation. Increasing the amount of PP fibres increases the time to cracking remarkably.
- By obtaining less maximum current intensity and more time to crack initiation in PP fibre reinforced concrete, it can be declare that the PP fibres increasing the durability of concrete which consequently prevents the premature deterioration of structure or in another hand, extends the structure service life of RC structures.

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