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Bond Strength of GFRP Reinforcing Bars in Concrete Containing Seawater

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Abstract

There is a growing problem of freshwater shortages in various areas around the world. The use of potable water in construction, including as mixing water in concrete, implies that less water is available for agriculture and human consumption. These same areas often have an abundant supply of seawater, which is known to change some fresh and hardened properties of concrete if used in the concrete mix. Furthermore, seawater contains a high concentration of chlorides which results in rapid deterioration of internal steel reinforcement. The main purpose of the present research was to investigate the effects of replacing concrete mixing water with seawater on the bond behaviour of corrosion-resistant GFRP reinforcing bars. A total of 20 standard pull-out tests were conducted on sand-coated GFRP bars embedded in either a control concrete mix or a similar mix made with seawater. The preliminary results show that GFRP reinforcement may present a promising and sustainable solution for concrete structures in areas with freshwater shortages.

Keywords: GFRP, Seawater, Concrete, Corrosion, Bond, Sustainability

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Introduction

The use of fibre-reinforced polymer (FRP) bars in concrete structures has been shown to be a viable alternative to conventional steel reinforcing bars in applications where corrosion-induced deterioration is likely, such as marine environments or where de-icing salts are used. FRP bars are corrosion-resistant, which enables structural elements like bridge decks to maintain their performance over long periods of time in aggressive environments. This feature, as well as other unique advantages, have encouraged engineers to employ FRP bars in concrete structural members. Glass FRP (GFRP) is the most well-known type used in industry due to its acceptable properties and low cost.
At the same time, there is a growing problem of freshwater shortages in various areas around the world. According to the World Health Organization, by 2025 more than half of the world's population will be living in water-stressed areas [1]. Freshwater accounts for only 2.5% of the Earth's water, and most of it is frozen; thus water available for drinking is very limited. The problem is intensified due the growing agricultural industry, urban and industrial developments, and increased pollution in rivers and lakes. As a result there is a global scarcity of clean water [2]. Particularly in the north of Chile, in the vicinity of the Atacama Desert, the scarcity of fresh water is critical and it should be preserved for human consumption and agriculture. In contrast, there is an abundance of seawater on Earth, representing approximately 97.5% of the total Earth's water. However, when seawater is used as mixing water in Portland cement concrete (PCC), several undesirable chemicals will be incorporated into the PCC microstructure such as chloride, sodium, magnesium, calcium, and potassium ions. In order to move towards a more sustainable future for the construction industry, the consumption of freshwater will need to be reduced, and thus alternative applications which take advantage of the abundance of seawater should be explored.
The presence of chloride ions in seawater can accelerate steel corrosion in reinforced concrete members because they can penetrate and destroy the non-corroding protective oxide film, (i.e. the passivating layer). Corrosion of the steel reinforcement can lead to cracking, spalling, and delamination of concrete, a loss of structural integrity, and various other problems which can significantly reduce the service life and functionality of the structure. Hence, FRP reinforcement may present a suitable and sustainable alternative in these cases; however, to date, the use of FRP-reinforced concrete containing seawater has not been investigated in detail.
In reinforced concrete structures, the forces are transferred between the concrete and rebar based on the bonding mechanism which mainly relies on bar surface deformation characteristics and embedment environment. Therefore, the bond mechanism between concrete and rebar is a key element in determining the flexural behaviour of reinforced concrete members at the serviceability and ultimate levels [3][4]. This mechanism controls the deflection, the width and distribution of cracks and the ultimate strength of a reinforced concrete member [3][4]. As a result, the bond mechanism between concrete and rebar has been the subject of many different studies; however, the effect of seawater on bond behaviour has not been investigated.

Experimental Program

A total of 20 standard concrete pull-out specimens were casted with normal mixing water and seawater (Figure 1a). The test matrix is shown in Table 1. The specimens were fabricated and tested according to the provisions of ASTM D7913/D7913M−14 and ASTM D1141-98 [5][6] with an embedment length of five times the nominal bar diameter and a loading rate of 0.02 mm/sec using a Universal Testing Machine (Figure 1b). The aforementioned cubic concrete specimens had dimensions of 20x20x20 cm. Moreover, the bar was pulled by employing a wedge anchor system at the opposite end of the embedded bar. The slip was measured at both the loaded and unloaded ends using LVDTs and the applied force was recorded using the internal load cell of the testing machine.

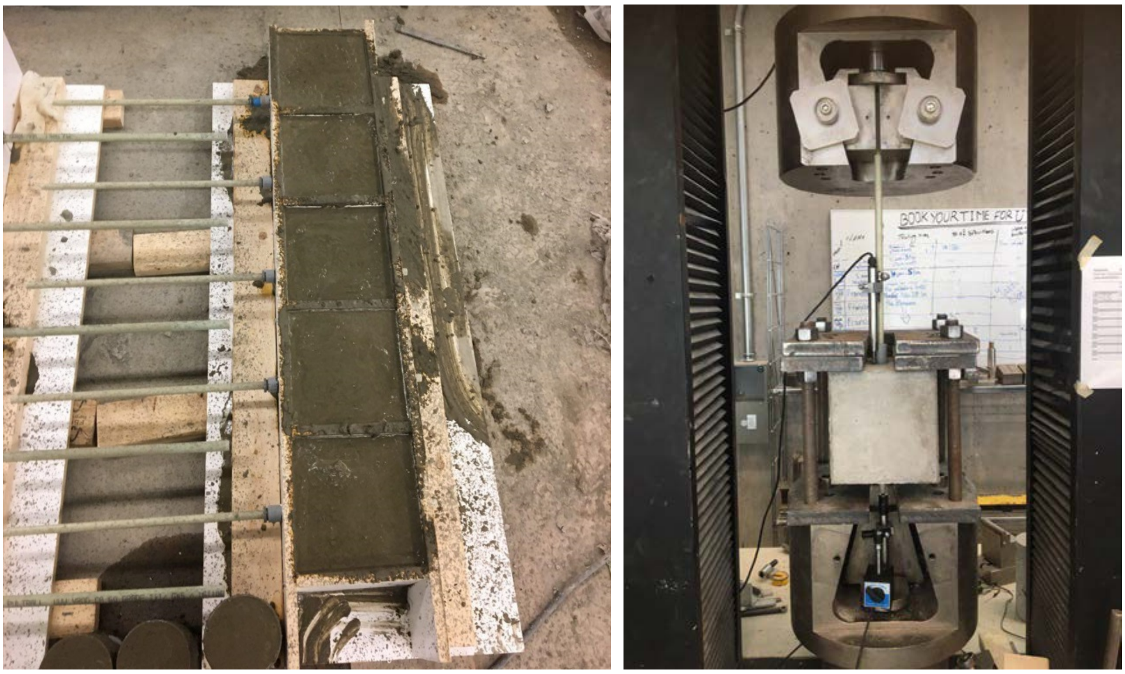

Figure 1a (left): Specimen fabrication, and 1b (right): test setup

Table 1: Test matrix

Concrete type	Nominal bar diameter (mm)	Number of specimens
Normal	12	5
Normal	16	5
Seawater	12	5
Seawater	16	5

All of the GFRP reinforcing bars had an external sand coating layer intended to enhance bond with the surrounding concrete. Two different nominal bar diameters were considered, namely 12 mm and 16 mm, which are commonly used in industry. The elastic moduli of the bars were 62.7 and 61.9 GPa for the 12 mm and 16 mm bars, respectively, with ultimate tensile strengths in excess of 1000 MPa.
Two concrete mixes were used for this study, which were identical except for the water used for mixing. In the control set, normal tap water was used. In the second set, artificial seawater was prepared according to ASTM standards [6]. The concrete had a target 28-day compressive strength of 30 MPa. The mix design is provided in Table 2. All of the samples were wet-cured for 28 days before testing.

Table 2: Concrete mix design

Material	**Quantity (kg/m^3)**
Cement	340
Water/cement ratio	0.58
Coarse aggregate	1050
Fine aggregate	750

Experimental Results

After 28 days, the samples were tested under displacement control in a universal testing machine. The concrete compressive strength measured from cylinder tests ranged from 39 to

45 MPa at the time of testing. The strengths measured from mixes with seawater were slightly lower on average than those made with normal water.
The pull-out test results are summarized in Table 3. The samples made with seawater showed very similar behaviour to those made with normal mixing water. Although slight decreases in average strength are observed for mixes made with seawater, the discrepancies are within the range of typical experimental variability and generally correspond to slightly lower measured compressive strength values. The larger bars had slightly lower average bond strengths than the smaller bars, as expected. The bond strength is calculated according to the following formula:

$$\boldsymbol{\tau} = \frac{\boldsymbol{F}}{\pi \boldsymbol{d}_b 5 \boldsymbol{d}_b}$$

Where:

$\boldsymbol{\tau}$ = Bond stress (MPa)
$\boldsymbol{F}$ = Bond force (kN)
$\boldsymbol{d}_b$ = Bar diameter (mm)

Table 3: Pull-out test results

Mixing water	Nominal bar diameter (mm)	Average bond strength (MPa)	Standard deviation (MPa)
Normal	12	17.8	1.50
Seawater	12	17.1	1.97
Normal	16	16.3	3.61
Seawater	16	14.3	1.49

Representative load-slip curves are shown in Figures 2 and 3. All of the tested samples had peak bond strength values ranging from 13 to 20 MPa, regardless of concrete type or bar diameter. Following the peak load, the stress decreased gradually and reached a relatively stable residual strength of approximately 8-10 MPa.

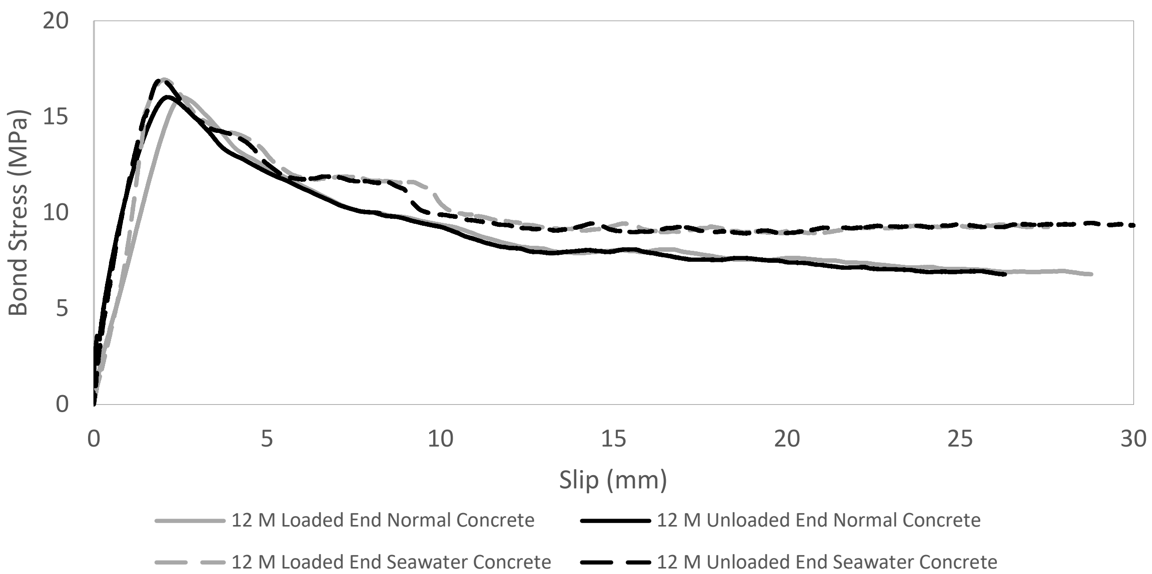

Figure 2: 12 mm bar with seawater and normal concrete

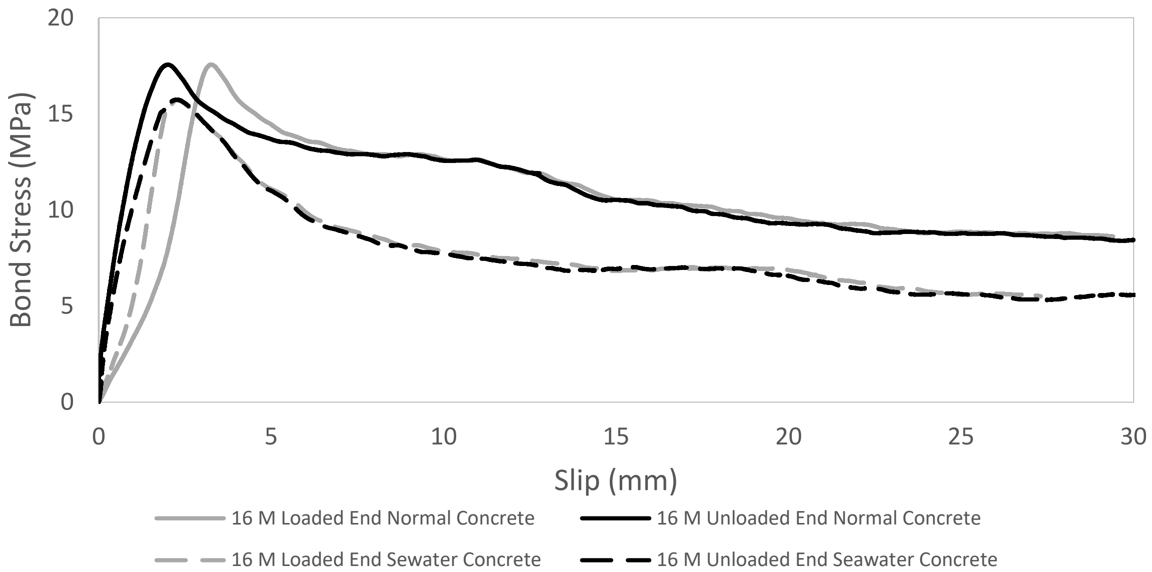

Figure 3: 16 mm bar with seawater and normal concrete

Conclusions

Based on the preliminary results obtained, it is observed that the use of seawater for mixing water in concrete had a small effect on the short-term concrete compressive strength and bond strength with sand-coated GFRP reinforcement at approximately 28 days. Additional testing and analysis are ongoing to determine if these discrepancies are statistically significant. This provides promising data for the potential use of GFRP reinforcement with seawater concrete in areas with freshwater shortages. Nevertheless, it is important to note that further research is still needed, particularly to assess the long-term performance characteristics and potential degradation of concrete due to sulphate content. This is the subject of ongoing research efforts.

Acknowledgments

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