Construction and Building Materials 137 (2017) 307–316

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Effect of cement based coatings on durability enhancement of GFRP-wrapped columns in marine environments

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HIGHLIGHTS

- This paper investigates the durability of GFRP sheets in tidal zone of marine environment.
- A marine simulator environment was designed and constructed similar to the real conditions.
- Ultimate strength and strain of confined specimens were affected after exposure.
- Polymeric and self-compacting mortar coatings can improve the durability of GFRP in marine environment.

ARTICLE INFO

Article history:
Received 28 August 2016
Received in revised form 28 January 2017
Accepted 30 January 2017

Keywords:
GFRP
Wrapping
Marine environment
Durability
Cement based coating

ABSTRACT

The main objective of this paper is to study the effects of marine environments on cement based coatings for enhancing the durability of Glass Fibre Reinforced Polymer (GFRP) sheets. Despite of durability degradation in harsh environments, GFRP sheets are widely used to repair the existing structures in the marine environment. Mean while there is no comprehensive analysis has described how the environmental conditions affect these sheets, and there is no any appropriate solution has been provided to date. In this research, a marine environment simulator was designed and constructed similar to the real conditions. Mechanical properties of wrapped specimens were studied after placing them inside the simulator. Two types of cement based mortar, namely polymeric and self-compacted, were applied on the sheets. The polymeric mortar increased the ultimate strength of the specimens wrapped with one and two layers of GFRP by 5.4% and 4.7% respectively, compared with similar specimens in the marine environment without the protective mortar. The ultimate strength was increased by 2.4% and 1.8% in specimens with self-compacted mortar coatings. Marine environments caused better curing of the self-compacted mortar and conversely a slight reduction of polymeric mortar's durability. Also, the bond strength of the polymeric mortar to GFRP sheets was more than those with self-compacted mortar.

1. Introduction

The application of Glass Fibre Reinforced Polymer (GFRP) sheets in the repair and rehabilitation of concrete structures has significantly grown in recent years. This is due to their high tensile strength, light weight, easy and fast installation, high resistance to electro-chemical corrosion, and lower price compare to other types of FRP [1–4]. Despite their interesting properties, GFRP sheets are still under investigation to assess their durability when exposed to the aggressive environment. Furthermore, the durability of FRP sheets can be improved through the use of protective coating [5–7]. A number of studies on the durability of GFRP materials in marine environments are represented in the followings:

Micelli et al. placed some concrete columns wrapped with GFRP sheets in 15% saline solution for 120 days and observed an ultimate strength reduction of 27% which was almost three times more than the reduction caused by wrapping them with CFRP [8]. Bae and Belarbi proceeded to investigate the effects of environmental conditions on the long-term properties of reinforced concrete columns strengthened with CFRP and GFRP sheets. In their study, a significant reduction in the ultimate load and ductility of the specimens which were strengthened by GFRP was observed after saltwater exposure [9]. Cromwell examined the changes in the mechanical properties of FRP sheets, and observed an ultimate strength reduction of 6% after 10,000 h of immersion in saline [10]. In a study con-

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http://dx.doi.org/10.1016/j.conbuildmat.2017.01.119
0950-0618/

ducted by Gharachorlu and Ramezanianpour on concrete specimens confined by CFRP and GFRP sheets, the highest reduction in strength was observed in GFRP-wrapped specimens exposed to high temperature environments combined with wet-dry cycles of saline solution [11]. Having put GFRP coupons at relative humidity of 30%, Nardone et al. concluded that an increase in the temperature was associated with a reduction in the durability of GFRP sheets, and increasing the temperature to 36 °C reduced the specimens' tensile strength by 3.4%. They also found that the destructive environmental effects could be reduced by increasing the number of layers [12]. In a study on the durability of FRP materials by Böer et al. it was found that the exposure to saline caused a sharp decrease in the strength and ductility of the columns which were strengthened with GFRP sheets. Also, humidity was found to have the primary destructive effect, while salt crystals expanding over time in the micro cracks exacerbated the deteriorating effect on the sheets [13]. Silva et al. found that the mechanical properties of FRP sheets, and particularly the ultimate strength of GFPR sheets, have been affected by saline water in such a way that the higher the temperature, the more destructive the effect of the environment [14].

These studies indicate that the durability of GFRP sheets is reduced in exposure to aggressive environments, such as high humidity, saline solution and high temperature, highlighting the need to investigate the possibility and consequences of applying coatings to GFRP sheets. The main objective of this paper is to survey the performance of GFRP sheets used to strengthen compressive members located in the southern sea of Iran region. This area has extraordinarily harsh conditions such as presence of chloride ions in seawater, high temperature and humidity, the tidal phenomenon and also solar UV radiation. The durability of the specimens is investigated by applying two kinds of protective coating on the installed GFRP system.

2. Experimental program

2.1. Material properties

In this research, 4 concrete prisms (50 × 15 × 15 cm) and 42 concrete cylinders (10 × 20 cm) were prepared in total from type 2 Portland cement. After 28 days of water curing, strengthening by FRP sheets was carried out. In 50 × 15 × 15 cm concretes, strengthening process consisted of installing FRP sheets on two opposite sides of specimens and then applying protective coating on the surface of the layers. In 10 × 20 cm concretes, specimens were confined by one and two layers of FRP sheets. In some cylinders, protective coatings were applied on the surface of the sheets.

FRP sheets were prepared in type of Glass/Epoxy and installed on the specimens with the wet lay-up technique. Their tensile strength parallel to the fibre was determined following the standard ASTM D3039 [15]. Mix properties of the concrete, mechanical properties of the glass fibres and GFRP sheets are summarized in Tables 1, 2 and 3.

In this study two types of protective coatings were used to evaluate how the durability of GFRP sheets could be increased in the marine environment. The first type was a polymeric mortar coating commercially named WPM493, which was prepared by mixing cementitious and polymeric materials according to the manufacturer's instructions. The thickness of this coating was 2 mm and applied after the sheet curing process. The second type of protective coatings was a self-compacted mortar. In order to increase the bond strength between self-compacted mortar and GFRP sheets, the silica sand was spread onto wet resin in order to roughen the surface of GFRP and provide a better bonding. After curing GFRP sheets, the mortar was casted on them. Mix properties of the self-compacted mortar are summarized in Table 4. Slump flow test was carried out on the self-compacted mortar according to the EFNARC guideline [16]. The procedure of strengthening and applying protective coating in prismatic and cylindrical specimens are shown in Figs. 1 and 2, respectively.

Table 1
Mix properties of the concrete.

W/C	Cement (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Compressive strength (MPa)
0.51	341	804	974	29.8

Table 2
Mechanical properties of glass fibres.

Fibre type	Elastic modulus (GPa)*	Ultimate Strength (MPa)*	Weight per area (g/cm^2)
E-glass	90	2300	400

* According to the manufacturer's data sheet.

Table 3
Mechanical properties of GFRP sheets.

FRP type	Fibre volume ratio (%)	Thickness (mm)	Tensile strength (MPa)	Ultimate strain (%)	Tensile modulus of elasticity (GPa)
GFRP	35	1	190	1.21	15.6

2.2. Environmental conditions

Specimens were placed in two different environmental conditions. First one was normal condition in the laboratory and second one was marine environment similar to the real condition of south of Iran. This condition was selected as the environment condition as a case study in this research. In this region, there are numerous RC structures that needed to be strengthened and rehabilitated, due to deterioration and corrosion of steel bars. Environmental factors such as chloride ions in seawater, high temperature and humidity, tidal effects and UV radiations degrade the durability of materials to a serious danger. As it would take a very long time to conduct research on the application of new protective materials and their effects in such an environment, a marine simulator was constructed in the Concrete Laboratory at Amirkabir University of Technology to apply coastal region conditions on the specimens. The simulator was designed to allow researchers to control and monitor the air temperature and humidity, and water temperature, and schedule tidal and UV radiation cycles.

The exterior view of the simulator and specimens which were placed in the tidal pool are shown in Fig. 3. In order to simulate the coastal region in the south of Iran, the temperature inside the simulator was set to 40 °C, its humidity to 68%, and the salt concentration to 36.6 g per liter. The specimens were placed in the simulator for 3000 h and experienced 375 cycles of 8 h. One cycle consisted of 4hours Immersion in salt water (when the tidal pool was full of salt water) and 4hours exposure to UV radiation under dry condition (when the tidal pool was empty).

2.3. Test methods

Two test methods were used to evaluate the effects of marine environment on durability of the specimens. Pull-Off test according to ASTM D4541 [17] was carried out on 50 × 15 × 15 cm concrete prisms to evaluate the effect of marine environmental