Proceedings of the 9th International Conference on Civil Structural and Transportation Engineering (ICCSTE 2024)
Chestnut Conference Centre - University of Toronto, Toronto, Canada – June 13-15, 2024
Paper No. 232
DOI: 10.11159/iccste24.232

Investigating the Durability of Bent and Straight Glass Fiber Reinforced Polymer (GFRP) Rebars: Pilot Study

Ahmed Khalil[1], Rami Hawileh[1], Mousa Attom[1]
American University of Sharjah
Sharjah, UAE
First. b00079152@aus.edu; Second. rhaweeleh@aus.edu; Third. mattom@aus.edu

Abstract **-** This pilot study investigates the durability of bent and straight glass fiber reinforced polymer (GFRP) rebars in challenging marine environments. The reduction in tensile strength observed in bent rebars compared to the strength of the straight rebars is on average lower by 40%, which is considered significant. In addition, there is a lack of studies in the literature that examined the durability of bent FRP bars in harsh environments, as encountered in the UAE and Gulf region. To address this gap, an outdoor set of durability test was conducted with a specific focus on performance in saline environment. A comparative analysis will be conducted among the results of unconditioned (control) samples with those exposed to outdoor saline environment of the UAE. The output from this warranted study will answer many questions related to the utilization of such GRRP rebars in RC structural members when exposed to harsh marine environments.

Keywords**:** FRP Durability; Marine Environment; Bent; Straight; GFRP Rebars; Sustainability.

1. Introduction

The use of Fiber-reinforced polymer (FRP) rebars has gained interest as a potential replacement for traditional steel reinforcement in concrete structures. This is due to their notable characteristics such as high strength, lightweight nature, and resistance to corrosion. However, the performance of FRP materials tends to decline when exposed to combined stresses rather than pure axial tension. Recent research has highlighted that curved FRP reinforcements in Reinforced Concrete (RC) structures are prone to premature failures at bent corners due to reduced tensile strength under combined tensile and shear stresses [1]–[3]. While various types of FRP bars exist, carbon (CFRP) and glass (GFRP) are the most prevalent in both practical RC applications and ongoing research efforts. CFRP boasts superior properties, whereas GFRP stands out for its affordability compared to other composite materials [4-6].

Nevertheless, it's crucial to recognize that FRP rebars experience gradual degradation of mechanical properties over time due to environmental factors and sustained loading. This degradation is especially evident in bent FRP rebars, where localized stress concentrations at bends can cause microcracking and fiber breakage, leading to reduced strength. Studies such as [7-9] have shown a significant decrease in tensile strength when composite rebars are bent, with some reporting values as low as 25-40% [10] of the maximum tensile strength achievable in a straight bar. These findings emphasize the importance for designers to consider the impact of rebar curving on the strength of FRP rebars when incorporating these materials into structural designs. The reduction in strength at the bend of FRP rebar was measured using the empirical equation provided by the Japanese code [11] as follows:

$$\frac{f_{fb}}{f_{fu}} = \left(\alpha \frac{r_b}{d} + 0.3\right) \tag{1}$$

where f_{fb}/f_{fb} represents ratio of the bend portion strength to the uniaxial tensile strength of the composite. Additionally, r_b/d is a ratio of bend radius to bar diameter. The symbol α represents a probability factor. ACI 2015 [12] recommending a value of 0.05 for α.

The mechanical properties of FRP rebars are primarily influenced by the type of fiber reinforcement used. Inorganic fibers such as basalt, broken glass fibers, and carbon fibers are generally not water-absorbent but can develop micro-cracks when exposed to deionized or salty water for extended periods [13-16]. Chemical corrosion processes result in the formation of etching-like spots on fiber surfaces, reducing their local cross-sectional area and leading to stress concentration [13], as observed in SEM images shown in Fig.1. This corrosion increases the chances of the load redistribution during fiber load-bearing processes. Furthermore, the operational state of FRP rebars becomes more sophisticated [17].

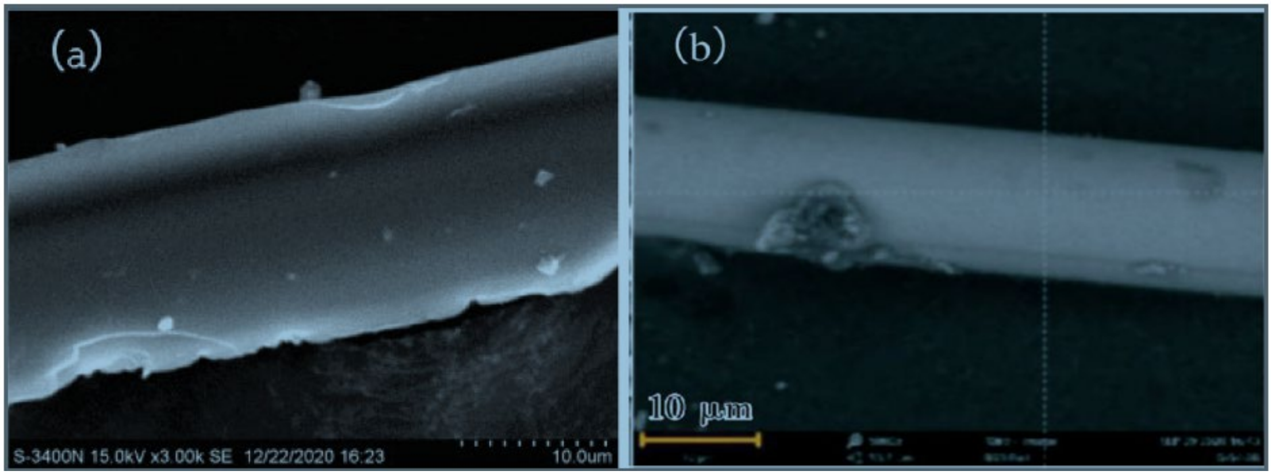


Fig. 1: SEM images depicting the condition of fibers after corrosion: a) Basalt fiber [18], and b) Glass fiber [19].

2. Research Objectives

The aim of this study is to bridge the existing research gap concerning the durability of bent GFRP bars through a comprehensive investigation of the impact of harsh marine conditions on both straight and bent GFRP rebars. Specifically, the study will focus on evaluating their performance in a typical saline environment of Gulf countries such as the UAE, which are characterized by high water salinity and aggressive weather conditions. The primary objectives of this research can be outlined as follows:

1. To assess the performance of bent GFRP rebars in comparison to straight GFRP bars in normal room temperature conditions.
2. To examine the durability of both straight and bent GFRP rebars in challenging environmental conditions.
3. To propose design strength reduction factors based on environmental conditions for the design of reinforced concrete beams utilizing GFRP reinforcement in harsh environments.
4. To analyze the microstructure of exposed GFRP rebars to understand the mechanisms of degradation.

3. Test Setup and Preliminary Durability Results

Fig. 2a illustrates the experimental setup employed to measure the strength of bent GFRP rebars. Fig. 2b shows the durability setup utilized to subject the bent GFRP samples to the typical harsh marine environment of the UAE. Fig. 3 presents the tensile strength of curved GFRP rebars, both before and after outdoor exposure of three months in a marine environment of the UAE. Although the reduction in strength is not significant, it is possible that the impact may amplify as the duration of exposure extends. In this research conducted at the American University of Sharjah, the impact of the duration of exposure on the strength of bent and straight GFRP rebars was conducted. Furthermore, a microstructure investigation was undertaken to determine the morphology of the exposed GFRP rebars. Fig. 4 shows the SEM image of an unconditioned sample, which reveals the presence of very few micro voids. However, as time progresses during the exposure of harsh marine environment, it is highly expected that these microstructures will experience an flood of excessive voids, which will correlate with the degradation of the mechanical strength. While these results provide valuable insights, it is important to acknowledge potential experimental errors, such as variations in sample preparation and environmental control.

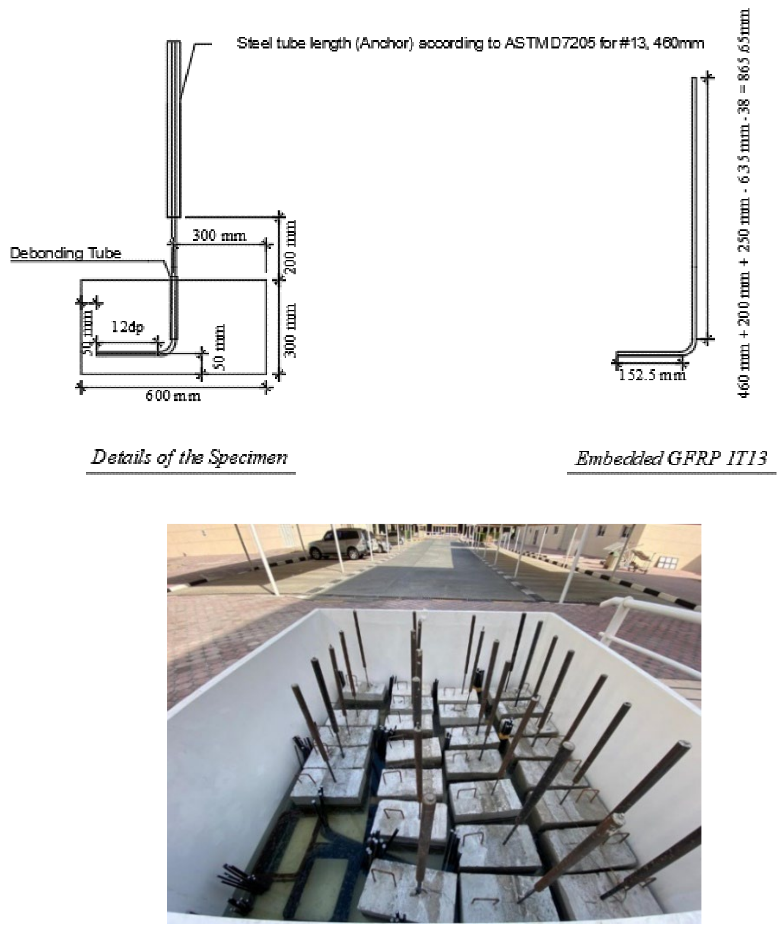
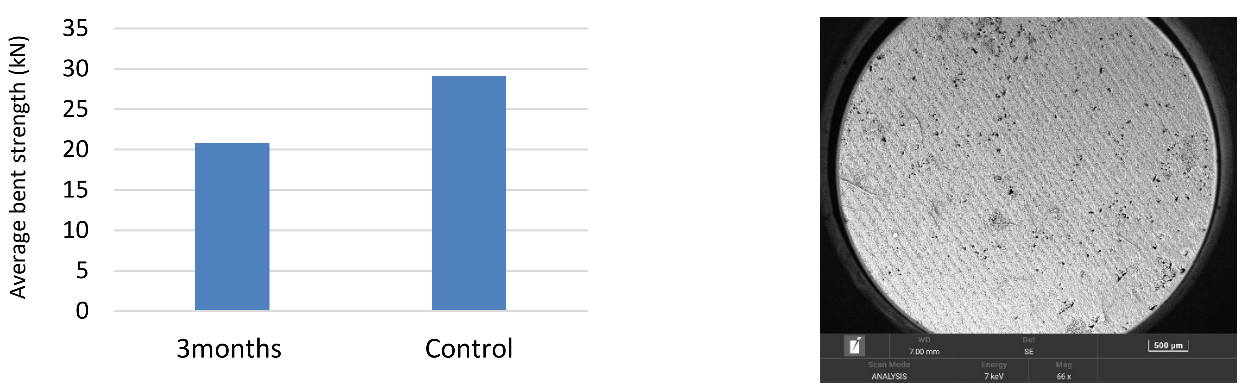


Fig. 2: Test Setup for a) bent GFRP test; b) Outdoor Marine.



(a) (b)

Fig. 3: a) GFRP rebar bent strength (in kN) of the unexposed (control) bent GFRP samples compared with the exposed bent GFRP samples of harsh marine environment of the UAE for 3 months. b) SEM image of unexposed GFRP rebar sample.

4. Conclusion

This study aims to address a significant gap in the realm of FRP, through investigating the impact of durability on strength of bent and straight GFRP rebars, particularly in challenging harsh environments prevalent in the UAE and Gulf region. The observed 40% reduction in tensile strength in bent rebars compared to straight rebars highlights the of understanding the durability effects for bent FRP rebars. Whereas the proposed durability setup of the experimental including the condition of saline environment, aim to provide a comprehensive analysis of the performance of GFRP in harsh environment conditions. By conducting a comparative analysis with the benchmark samples, unconditioned samples, with those exposed to saline environments, this study seeks to identify consistent patterns of strength deterioration in both straight and bent GFRP rebars. The derivation of strength reduction factors based on experimental results will offer valuable insights for the application of GFRP rebars in RC structural members exposed to harsh marine environments. This warranted study benefits structural engineering by enhancing the understanding of the preference of both longitudinal and shear reinforcement GFRP rebar in RC members built in harsh marine conditions.

Acknowledgements

The authors would like to acknowledge the fanatical support provided by the American University of Sharjah (AUS) for this research project. Additionally, the authors extend their appreciation for the financial support received through the Conference Travel Support program from the Office of Research and Graduate Studies at AUS.

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