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Microstructural investigation of glass fiber reinforced polymer bars

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ABSTRACT

Microstructural characteristics are crucial in understanding and predicting the behavior of glass fiber reinforced polymer (GFRP) bars used for concrete reinforcement. Considering the lack of extensive GFRP microstructural knowledge, the main purpose of this study is to provide a documentation of GFRP microstructure and demonstrate its contribution in the durability of GFRP bars. Scanning electron microscopy (SEM) imaging was performed at different magnification levels on the cross-section of four different commercially available pristine GFRP bars. As a result of differences in the production method by pultrusion, each pristine bar presented a unique microstructural pattern including voids, defects, and fiber distribution. Two of the bars which demonstrated the most different patterns were exposed to accelerated conditioning in alkaline solution. The horizontal shear test was performed and the results were compared with the pristine bars. The difference in microstructural patterns was found to significantly contribute to GFRP durability. These results can be used as a benchmark for the microstructure of commercially available pristine GFRP bars and serve as a base for monitoring possible changes after any conditioning or testing.

1. Introduction

Over the past two decades, glass fiber reinforced polymer (GFRP) bars have been demonstrated to be a practical alternative for black, epoxy-coated and stainless steel rebars in reinforced concrete structures (RC) especially in applications where durability and corrosion resistance are required such as bridge decks and marine structures. In addition, the use of GFRP is suitable for buildings that include equipment sensitive to electromagnetic fields such as magnetic resonance imaging (MRI) units or bases for large motors [1].

GFRP consists of glass fibers as load carrying elements and resin which transfers and distributes the load among the fibers. Microstructural patterns of the fibers and resin play a crucial role in understanding the GFRP behavior. Different manufacturing parameters (such as pulling speed and dye temperature) lead to various GFRP microstructural patterns including the presence of voids and defects at various locations of GFRP cross-section. These patterns present combinations of continuous defects and disconnected voids and lead to a unique pattern for each GFRP bar. Understanding the GFRP microstructural pattern may allow predicting the GFRP behavior under different loading conditions and states of stress.

Considering the lack of GFRP microstructural knowledge, the main purpose of this study is to provide a documentation of GFRP microstructure and investigate its possible contribution on GFRP durability. It is recognized that this study was limited to small sample size, a single bar diameter and four GFRP manufacturers; however, its findings are significant and provide a clear path for investigations to follow.

In the present study, four commercially available GFRP bars with a nominal diameter of 12.7 mm (0.5 in.), equivalent to No. 4 steel rebar, were investigated. First, samples were properly polished and prepared for the microscopic examination. Next, scanning electron microscopy (SEM) was employed at different magnification levels to capture different aspects of the microstructural pattern including i) existing defects and voids in the matrix; ii) fiber-matrix interface; and, iii) fiber distribution in the matrix. Panorama images of the entire cross-sections were provided to give a proper comparison between different bars.

As part of this study, the possible effect of microstructural patterns on GFRP durability was investigated [2–4]. Two types of the bar that demonstrated the most different microstructural patterns were exposed to accelerated conditioning. The horizontal shear test

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Table 1
GFRP nominal and measured cross-sectional areas.

Surface texture	GFRP		Area (mm^2)		Diameter (mm)	
			Nominal	Measured	Nominal	Measured
Ribbed surface	A		126.5	130.5	12.7	12.6
Fine sand coated & helically wrapped fiber	B		126.5	137.8	12.7	12.7
Double twisted fiber wrapped	C		126.5	152.6	12.7	13.9
Coarse sand coated	D		126.5	162.6	12.7	14.7

was performed and the results were compared with the pristine bars. Finally, SEM imaging was performed on conditioned bars to provide additional evidence of the effect of the microstructural patterns on durability.

2. GFRP samples

Four different GFRP bars all produced by pultrusion were selected in this study. Even Though, the production process is nominally the same, different process parameters and bar constituents including different surface characteristics have a profound effect on the result of the products. The selected GFRP bars were: Ribbed deformed surface (GFRP-A), fine sand coated with helically wrapped fibers (GFRP-B), double twisted fiber wrapped (GFRP-C) and coarse sand coated (GFRP-D). Table 1 provides the nominal and measured cross-sectional areas for all GFRP bar types. The nominal area is based on a circle with a nominal diameter of 12.7 mm (0.5 in.). The average measured area was computed based on a work by Claure and coworkers [5] following a standard test method for density and specific gravity (relative

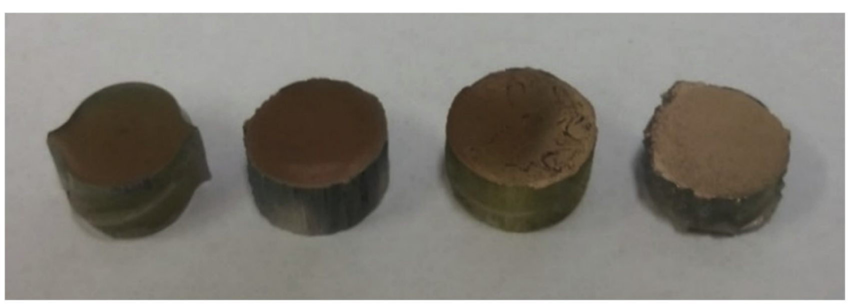

Fig. 1. Representative prepared samples (from left: GFRP-A, B, C, and D).

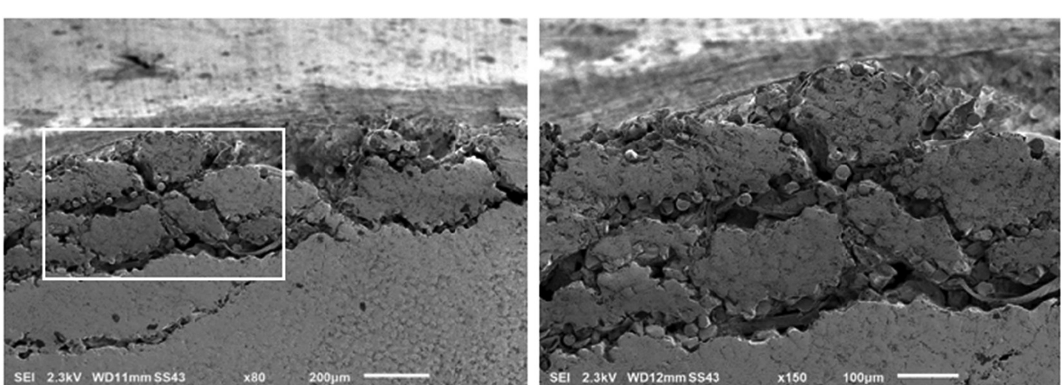

Fig. 2. A defect at the edge of GFRP-A at magnification levels of 80× (left) and 150× (right).