Construction and Building Materials 152 (2017) 105–114

Contents lists available at ScienceDirect

Construction and Building Materials

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

Interlaminar shear capacity of thermally damaged GFRP bars under alkaline concrete environment

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HIGHLIGHTS

- Several GFRP reinforcing bars exposed to high temperature then immersed in the alkali concrete environment are tested.
- Inter-laminar shear strength and stiffness of the GFRP bars are investigated.
- The GFRP bars damaged by higher temperature show more apparent degradation in the shear stiffness and strength.
- Longer immersion period in alkali condition produces more rapid degradation in the shear stiffness and strength.

ARTICLE INFO

Article history:
Received 16 August 2016
Received in revised form 22 March 2017
Accepted 26 June 2017

Keywords:
GFRP reinforcing bars
Experimental test
Inter-laminar shear capacity
Interfacial strength
High temperature
Concrete alkalinity

ABSTRACT

The paper investigated the effect of alkaline concrete environment on thermally damaged glass fiber reinforced polymer (GFRP) reinforcing bars through an accelerated aging test in alkaline solution. In the experimental test, the GRFP bar specimens were exposed to high temperatures and then immersed in alkaline solution with a pH of 12.6 presenting the similar alkalinity of concrete. Other specimens, which were unexposed to high temperatures, were also immersed in the alkaline solution for the same period of time in order to compare the performance changes in inter-laminar shear strength and stiffness capacities (ILSS and ILSSf). From the test results, the bar specimens which were thermally damaged by high temperature showed more degradation in ILSS than the thermally undamaged ones; rapid performance degradation occurred for longer immersion periods. Analysis of scanning electron microscope images showed that the fine cracks on the surface and resin matrix damage developed during exposure to high temperature led to accelerate alkali penetration, thereby resulting in rapid performance degradation.

1. Introduction

In the event of fires in concrete structures, the mechanical degradation properties of concrete and reinforcing bars at high temperature have a significant impact on the possibility of collapse of structures. However, if the structures are damaged but do not collapse during fire accidents, the load carrying capacity of the structure "after exposure to high temperature" is directly related to post-fire strength of the materials of the structure. Normally the strength of reinforcing bars at high temperature is not the same as that of the reinforcing bars after high temperature exposure (post-fire strength). For example, the yield strength of conventional steel reinforcement at a high temperature of 300 °C is about 10% of its original yield strength. However, according to the recently published NCHRP 12-85 [1], steel reinforcement "exposed to 700–1000 °C and cooled down" can be conservatively estimated to have a 10% reduction in the yield strength. Therefore, the assessment of the load carrying capacity of fire-exposed reinforced concrete structures should be based on the post-fire strengths of the materials composing the structure.

Temperature effect on the mechanical properties of composite material has been investigated by many researchers. One recent study was done by Hawileh et al. [2], experimentally investigating the degradation of tensile mechanical properties (elastic modulus and strength) of carbon, basalt, and their hybrid-layered composite laminates at elevated temperatures. Among the tested composite types, the carbon laminates showed a greatest degradation in the mechanical properties. Also, Hawileh et al. [2] proposed empirical models based on the test data to predict the tensile properties of each laminate according to temperature variation. From the study [2], it can be recognized that thermal damage states and consequent

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http://dx.doi.org/10.1016/j.conbuildmat.2017.06.158
0950-0618/

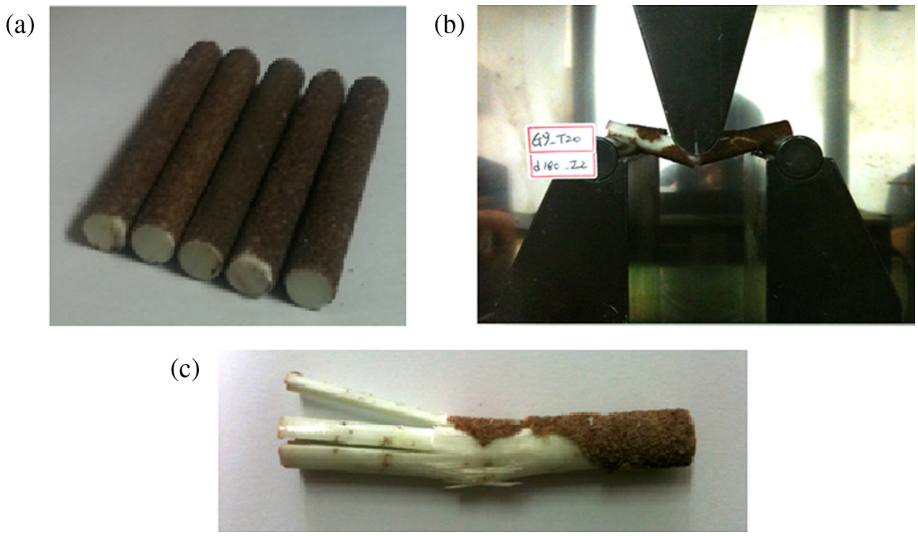

Fig. 1. GFRP rebar: (a) specimens, (b) inter-laminar shear tests, and (c) fractured specimens.

Table 1
Specimen preparation.

Specimen ID.	Exposure to high temperatures	Immerged in alkali solutions (40 °C, pH 12.6)
TA_120	for 8 min. to reach 120 °C	30 days, 60 days, 100 days, 180 days
TA_150	for 9 min. to reach 150 °C	30 days, 60 days, 100 days, 180 days
TA_200	for 11 min. to reach 200 °C	30 days, 60 days, 100 days, 180 days
TA_270	at 270 °C for 60 min	30 days, 45 days, 60 days, 80 days, 180 days
A	None	30 days, 45 days, 60 days, 80 days, 180 days
T_120	for 8 min. to reach 120 °C	None
T_150	for 9 min. to reach 150 °C	
T_200	for 11 min. to reach 200 °C	
T_270	at 270 °C for 60 min	
NN	None	None

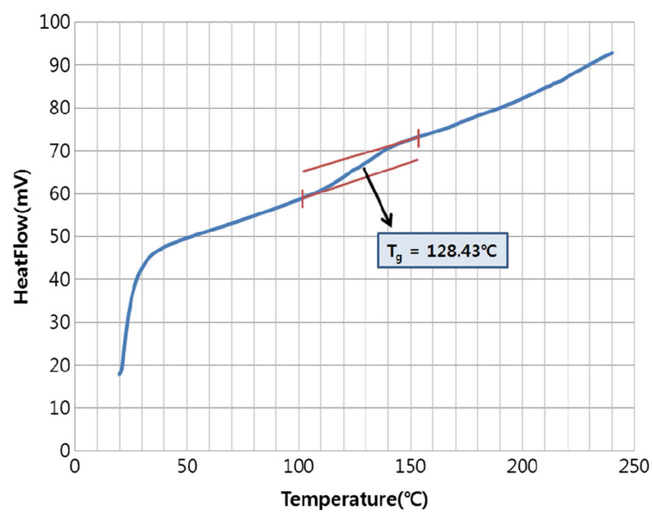

Fig. 2. DSC results (T_g: glass transition temperature).

mechanical properties are considerably different depending on the exposed temperature levels and types of composite materials. Glass fiber reinforced polymer (GFRP) reinforcing bar considered in the present study is one of representative composite construction materials and has been increasingly used in concrete structures to replace existing conventional steel reinforcement. This is especially true in North America and Northern Europe where winters are long and snowy and the GFRP reinforcing bars are well known for suffering little corrosion, being lightweight, and having excellent mechanical properties [3]. However, the low resistance to fire of GFRP reinforcing bars has still remained an issue for decades. It has been reported that the fiber, one of the components of GFRP reinforcing bars, does not show any degradation in mechanical performance at temperatures in the range from 100 to 500 °C, while the performance of the resin matrix of the GFRP bars degrades critically, reducing significantly the mechanical performance of the GFRP bars [4]. Such phenomenon occurs because the glass transition temperature of epoxy and vinyl ester, widely used as the resin matrix, is only 80–120 °C [5,6,7]. Previous studies on the fire resistance performance of GFRP reinforcing bars have mostly focused on changes in their performance at high temperature conditions [8–11]. For example, Robert and Benmokrane [9] measured the shear strength of GFRP reinforcing bars at high temperature in a specially constructed heating chamber. However, no experimental studies related to the interface shear performance or capacity, which is the one of failure mechanism of GFRP reinforcing bars after high temperature exposure, have been conducted. The state of GFRP reinforcing bars after exposure to high temperatures during fire accidents should be assessed for the structural safety and durability of concrete structures. It should be noted that GFRP reinforcing bars damaged by exposure to high temperature are still exposed to strong alkaline concrete environments with a pH over 12.6. Alkali is one of the main factors that degrade the mechanical performance of GFRP reinforcing bars, leading to debonding and delamination between the fiber and the resin matrix. Therefore, the exposure conditions of GFRP reinforcing bars can be considered more practically by taking into consideration the alkaline concrete environment of GFRP reinforcing bars after high temperature exposure when evaluating thermally damaged concrete structures with GFRP reinforcement.

In this study, the changes of the shear capacity such as Inter-Laminar Shear Strength (ILSS) and Stiffness (ILSSf) were observed of GFRP reinforcing bars exposed for long period of time to alkaline solution after high temperature exposure. In the experimental test,