Construction and Building Materials 159 (2018) 205–212

Contents lists available at ScienceDirect

Construction and Building Materials

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

Mechanical behavior of multilayer GO carbon-fiber cement composites

Zeng-shun Chen [a,b], Xiao Zhou [a], Xu Wang [a,c,*], Peng Guo [a]

[a] The National and Local Joint Engineering Laboratory of Traffic Civil Engineering Materials, Chongqing Jiaotong University, Chongqing 400074, China
[b] Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China
[c] Department of Civil and Environmental Engineering, University of Illinois Urbana-Champaign, Urbana, IL 61801, USA

HIGHLIGHTS

- The mechanical properties of GO carbon-fiber cement paste were experimentally analyzed.
- The mechanical properties of GO cement composites were obtained for comparison and explanation.
- The SEM test of GO cement paste was carried out for explanation.
- The flexural strength of the GO carbon-fiber cement paste was greatly improved by GO and carbon-fiber.

ARTICLE INFO

Article history:
Received 25 June 2017
Received in revised form 3 September 2017
Accepted 21 October 2017

Keywords:
Graphene oxide
Carbon-fiber
Mechanical behavior
SEM

ABSTRACT

Graphene oxide (GO) has attracted much attention due to its dispersibility in water, high aspect ratio and excellent mechanical properties. In this study, the mechanical behaviors of multilayer GO carbon-fiber cement composites were experimentally investigated. The experiments of compressive strength and the flexural tensile strength of the composites were performed. For the purpose comparison and explanation, the mechanical properties of GO cement and carbon-fiber cement were also investigated. The results show that the compressive strength of the GO carbon-fiber cement composite with adding 0.06% GO and 1% carbon-fiber was increased by 23.89%, whereas the increment of the flexural tensile strength of the composite was increased by 138.44%. The results were explained with respect to the mechanical behavior of GO cement specimens with incorporating different percentages of GO, and the microstructures of the composites observed by Scanning Electron Microscopy (SEM). The present study not only advanced our understanding of mechanical behaviors of multilayer carbon-fiber cements, but the results can be utilized for civil and transportation structures to improve the performance of the structures.

1. Introduction

Cement is the principal binder material in the production of concrete and has been widely utilized for buildings and structures [1]. However, both the cement and concrete are prone to crack due to their quasi-brittle nature, leading to poor tensile strength and strain capacity [2]. To improve the tensile strength of cement, reinforcing fiber materials, such as steel fibers [3], carbon fibers [4], polymeric fibers [5], etc., have received considerable attention. These fiber materials can greatly improve the mechanical properties of concrete and cement-based materials, but cannot inhibit the formation of crack of these materials.

With the development of science and technology, nanotechnology has provided nano-scale particles or fibers that are introduced to numerous materials to improve their properties. Graphene is one of the most popular nanomaterials, and has attracted much attention for its many unusual properties, e.g. 200 times stronger than steel, outstanding heat and electricity conductivities, nonlinear diamagnetism, etc. [6]. Despite its excellent properties, the incorporation of graphene in cement-based materials has been proven to be rather complex and very hard because it is hard to be dissolved with water and is very expensive. As a graphene derivative, graphene oxide (GO), has been extensively investigated by researchers and been widely used in many subjects due to its dispersibility in water, high aspect ratio and excellent mechanical properties [1,2,7,8]. The recent research indicated that GO exhibits high values of strength, aspect ratio and large surface area [9]. In addition, GO can be easily obtained from natural flakes by chemical oxidation and exfoliation of graphite. The extraordinary

* Corresponding author at: The National and Local Joint Engineering Laboratory of Traffic Civil Engineering Materials, Chongqing Jiaotong University, Chongqing 400074, China.

E-mail addresses: zchenba@ust.hk (Z.-s. Chen), xuwang@cqjtu.edu.cn (X. Wang).

https://doi.org/10.1016/j.conbuildmat.2017.10.094
0950-0618/

mechanical properties make GO a promising nano reinforcement in cement-based materials.

A few studies have focused on the characteristics of GO composites. Pan et al. [10] pointed out that the mechanical properties of GO/chitosan nanocomposite films have been significantly enhanced without sacrificing the optical transparency, and with incorporation of 1 wt% GO, the fracture strength and tensile modules of the nanocomposites were greatly enhanced by 93% and 51%, respectively. Afterwards, Pan et al. [8] has investigated the mechanical properties of a graphene oxide cement composite by introduction of 0.05% GO. The study found that the compressive strength and the flexural tensile strength were significantly improved by 15–33% and 41–59%, respectively, indicating that GO has potential for being used as nano reinforcement in cement-based materials. Subsequently, Sun et al. [11] has found the flexural strength of cementitious composites containing 0.05% GO increased from 5.52 MPa to 12.61 MPa. Kang et al. [12] reported that GO cement mortars displayed a higher average of compressive, bending and tensile strengths than ordinary cement mortars. Also, an increased coherence inside the cement due to powerful covalent bonds with C—S—H has been pointed out by using Field Emission Scanning Electron Microscopy (FE-SEM). Mokhtar et al. [1] has studied the mechanical performance of graphene oxide nano platelets reinforced cement by adding different percentages of graphene oxide nanoplatelets (GONPs) of 0, 0.01, 0.02, 0.03, 0.04 and 0.05 wt% of cement. Considerable enhancements both in compressive and tensile strengths by 13 and 41% have been achieved by incorporating 0.02 and 0.03 wt% GO, respectively. Most recently, the effect of GO on different properties (e.g. workability, hydration, electricity, etc.) has also been comprehensively studied [2,13–18]. Additionally, the effect of additives (e.g. fly ash, silica fume, etc.) on mechanical properties of graphene oxide cement composites has been investigated, and the additives can considerably enhance the properties of the composites [7,19,20]. All these studies are important to advance our understanding of mechanical behaviors of graphene oxide cement composites. Despite the progress, little attention has been devoted to understanding the mechanical properties of integrated GO carbon-fiber cement composites.

The purpose of this study is to investigate the mechanical behaviors of integrated multilayer GO carbon-fiber composites. Section 1 provides background information on recent progress of GO cement composites. Section 2 introduces the experimental setups of the multilayer GO carbon-fiber cement composites. Section 3 presents the results of mechanical behaviors of GO carbon-fiber cement composites. Section 4 gives the explanations of the results obtained in Section 3 with respect to mechanical behavior of GO cement pastes, the Scanning Electron Microscope (SEM) of GO paste, and the effect of carbon-fiber. Section 5 summarizes the major findings of this study.

2. Experimental setups

2.1. GO carbon-fiber cement paste

The dimensions of the GO carbon-fiber cement specimens are 40 mm × 40 mm × 160 mm. The were made of Ordinary Portland Cement, carbon fiber, GO and water purified by a GG328-Molatom1810a pure water device.

2.1.1. Cement paste and GO solution

The Ordinary Portland Cement is conforming to the requirements of type P.O 42.5R with 28-day compressive strength of no smaller than 42.5 MPa and 28-day flexural strength of no smaller than 6.5 MPa. The chemical components of the P.O R42.5 are shown in Table 1. The multilayer GO is synthesized from the oxidation of graphite based on the modified Hummer's method including three steps: oxidation, purification and exfoliation, and details can be found in a previous study [20]. The GO is laminated structure with the features of relatively large diameter, small thickness. The parameters and components of the multilayer GO in the present study are given in Table 2. The GO power was dissolved well with the purified water to get the GO water solution. The microstructures of the GO sheet observed by Scanning Electron Microscopy (SEM) and Transmission Electron Microscope (TEM) are displayed in Fig. 1. Fig. 1(a) indicates that the figure is filled with laminated structures of GO due to the large specific surface area of the GO. Fig. 1(b) shows that the surface of the GO sheet appears like a wrinkled paper that may be attribute to the strong acid treatment and the high aspect ratio, which is also explained in previous studies [1,21].

Table 1
The components of the P.O. R42.5.

Components of P.O. R42.5	Percentage (%)
CaO	65.16
SiO_2	21.25
Al_2O_3	4.21
Fe_2O_3	3.35
MgO	2.90
K_2O	0.97
SO_3	0.72
Na_2O	0.50
TiO_2	0.21
P_2O_5	0.10
MnO	0.07
Loss on ignition	0.56

2.1.2. Carbon-fiber

The carbon-fiber with the length of 3 mm was incorporated into the GO carbon-fiber cement paste specimens. Details of the carbon-fiber are presented in Table 3.

2.1.3. GO carbon-fiber cement paste

By incorporating the GO with percentages of 0.06 wt%, and 1 wt % carbon-fiber into the cement, the GO carbon-fiber cement specimens were made. The water-cement ratio of all mixtures specimen was kept at 0.37. It should be noted that the percentages of GO were selected based on the results in previous studies [1,8,11], which pointed out that with incorporating a relative low percentage of GO (e.g. 0.05 wt%) into a cement paste specimen, the flexural and compression strength of specimen will be increased considerably.

It should be emphasized that the cement paste, 0.06 wt% GO cement paste and 1 wt% carbon-fiber cement paste are also made for the purpose of comparison. Additionally, for the purpose of explanation, the mechanical behaviors of GO cement paste with different percentages (i.e. 0.04, 0.06, 0.08, 0.2, 0.4, 0.6, 0.8, 1.0 wt %) of GO are also investigated. The experiments for the GO cement pastes were carried out following the same procedure with that of GO carbon-fiber cement pastes.

Table 2
The parameters and components of GO power.

GO power	Specification	Contents
Parameters	Purity	>95 wt%
	Thickness	3.4–8 nm
	Lamellar diameter	10–50 μm
	Layers	5–10
	Specific surface area	100–300 m^2/g
Components (from XRD test)	C	68.44%
	O	30.92
	S	0.63%