Construction and Building Materials 133 (2017) 57–64

Contents lists available at ScienceDirect

Construction and Building Materials

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

Multi-walled carbon nanotube reinforced mortar-aggregate interfacial properties

Xiaobin Song, Susu Shang, Dandan Chen, Xianglin Gu *

Department of Structural Engineering, Tongji University, 1239 Siping Road, Shanghai 200092, China

HIGHLIGHTS

- Carbon nanotube reinforced mortar-aggregate interfacial properties were tested.
- Relationship between CNT dosage and the interfacial properties was established.
- Correlation between different interfacial strength properties was identified.
- Optimized CNT dosage for different strength properties was determined.

ARTICLE INFO

Article history:
Received 1 September 2016
Received in revised form 17 November 2016
Accepted 10 December 2016

Keywords:
Multi-walled carbon nanotube
Mortar-aggregate interface
Tensile strength
Shear strength
Industrial grade

ABSTRACT

This paper presents the test results of the mortar-aggregate interfacial strength properties considering six dosages of industrial grade pre-dispersed multi-walled carbon nanotube paste. Mechanical and ultrasonication dispersion were carried out and scanning electron microscope was taken for dispersion inspection. The test results indicated a stable yet negative effect of carbon nanotube paste on the mortar compression strength; while a widely scattered (coefficient of variation up to 23.6%) positive effect on the interfacial tensile strength (maximum 8.4% increase at 0.2 wt% carbon nanotube) was observed. It was also found that the increase of the interfacial shear strength was much more significant (maximum 51.5% at 0.05 wt% carbon nanotube) with a medium variation. Analysis of the mortar strength, interfacial tensile strength and shear strength showed no solid correlation amongst the three strength properties, which implies that the reinforcing mechanism of the carbon nanotube to the mortar-aggregate interface along various directions can be substantially different. The generated knowledge will be incorporated in a meso-scale analysis of carbon nanotube reinforced concrete, in which the aggregate, mortar and interface will be considered separately.

1. Introduction

Concrete has long been the most widely used construction material for its good structural integrity, fire resistance, easy mold-ability and cost effectiveness. However, due to its weak tensile strength and strain capacity, concrete is prone to crack, which can lead to durability issues in steel reinforced off-shore structures and bridges. The resulting maintenance and repair cost can be astronomical considering the vast use of concrete structures around the world.

Micro and macro fibers turn out to be the remedy as they can improve the strength and deformability of concrete. Carbon nanotubes (CNTs) have been increasingly promising for its high strength and aspect ratio, and desirable chemical, thermal and electrical properties [1]. Since the first report on CNTs by Iijima [2], numerous attempts have been made on reinforcing ceramic, metal and cementitious materials, with nanotubes. Detailed review can be found in Siddique and Mehta's work [1].

However, the results of CNTs on reinforcing cementitious materials have not always been encouraging. There are two major technical obstacles to a satisfactory reinforcing effect: the uniform dispersion of the nano particles as they are prone to agglomerate due to the van der Waals forces; and the sufficient bonding with cementitious material which may be hindered by the hydrophobic nature of the fibers. Various physical and chemical treatments of CNTs have been tried via experimental studies [3–16], and yet the achieved strength improvements in cement paste, mortar or concrete from use of CNTs have been rather different from one research to another, as partially shown in Fig. 1, where the strength

* Corresponding author.
E-mail addresses: xiaobins@tongji.edu.cn (X. Song), 2014_sssu@tongji.edu.cn (S. Shang), 1195318687@qq.com (D. Chen), gxl@tongji.edu.cn (X. Gu).

http://dx.doi.org/10.1016/j.conbuildmat.2016.12.034
0950-0618/

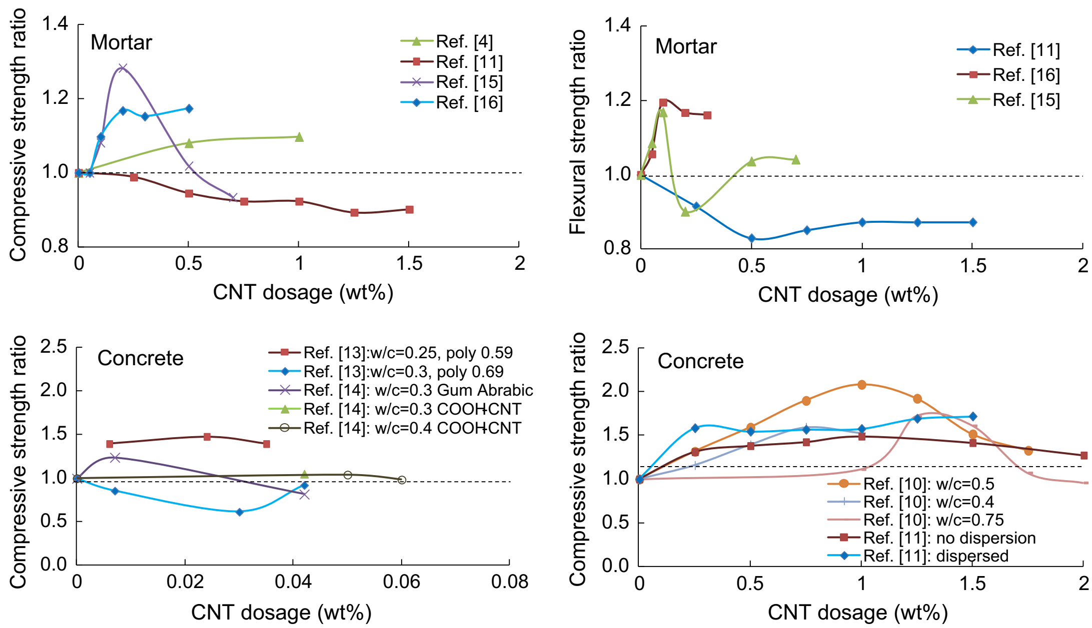

Fig. 1. Test results of CNT added mortar and concrete strength increases in literature.

ratio refers to the ratio of the nanotube added strength to a nanotube not added strength [4,10–11,13–16].

There may be a third explanation to this issue. It is well known that the concrete strength relies on the strength of mortar, aggregate, and, more importantly, the interfacial zone between the two [17–20]. The thin interfacial zone between the mortar and the aggregate, having the weakest strength properties due to its low density, can be significantly affected by the type and surface roughness of the aggregate used [21–23]. The reinforcing effect of the CNTs to the interfacial properties is complicated since, on one hand, even for uniformly distributed CNTs the chance of being present in the interfacial zone can be small; while, on the other hand, the reinforcement by unit volume of CNTs may be high considering the low strength of the loose mortar. The meso-scale discrete element models proposed in Gu et al.'s work [23] provides a promising tool to further analyze the contribution of the CNT reinforced interface to the overall properties of concrete.

The risk of fine CNT particles to human health is another unignorable obstacle to their wide application. The CNTs can cause inflammatory and fibrotic reactions once they get into human cells [24]. As a result, previous researches on CNT suspensions and cementitious samples all have to be carried out with fume hoods using appropriate safety precautions and in extremely clear environment, which significantly increased the research budget, not to mention the industry production cost. "As received" or industrial pre-dispersed CNT pastes have been used, although rarely, as to circumvent such problem [11,12]. However, more data are needed to be technically sufficient and convincing.

This paper presents the test results of multi-walled CNTs (MWCNTs) reinforced mortar-aggregate interfacial properties. The major objectives are to quantify the influence of MWCNTs on the interfacial strength properties as well as to determine the optimized dosage by adopting various dosages of MWCNTs in the tests. Industrial pre-dispersed MWCNTs paste has been used to simplify the material preparation and reduce the health risk to the operators, as well as to add to the existing database of as-received CNTs products. The generated results will be used for a meso-scale discrete modeling of CNT reinforced concrete by considering mortar, aggregate and interface separately.

2. Methodology and research significance

Industrial grade pre-dispersed MWCNT paste was added into mortar for reinforcing purposes. The so-made mortar and granite plates were sized and cast together to make standardized mortar-aggregate interfacial specimens. Pulling-off tests and combined compression and shear tests (slant shear tests) were conducted to measure the tensile and shear strength; the latter of which was further analyzed by means of Coulomb law of failure [25] to determine the cohesive strength and coefficient of internal friction of the interface. Various dosages of MWCNT paste were tried experimentally to establish its quantitative influence on the interfacial properties and the optimized dosage.

The presented research work explored the database of industrial grade CNT reinforced mortar-aggregate interfacial strength properties. The research results of the CNT reinforced interfacial properties can be used for meso-scale modeling of concrete via discrete element methods and thus can bring in new lights to the understanding of the reinforcing mechanism of CNT to concrete products. The experience of using industrial grade CNT pastes can also be useful to industry production in terms of cost reduction and health risk mitigation.

3. Experimental studies

3.1. Materials

Industrial grade pre-dispersed MWCNT paste was provided by a local supplier. The paste purity was larger than 97%. The CNT tubes were of 5–15 nm in diameter and 15–25 μm in length with an aspect ratio ranging from 150 to 210 m^2/g. The dispersant was Polyvinyl Pyrrolidone (PVP). Detailed parameters of the CNT paste are listed in Table 1.

Portland type I cement was used to make the mortar, together with ISO standard sand and tap water. The water/cement ratio was maintained constant at 0.486. The mix proportion of the mortar is as cement: water: sand = 1.0:0.486:1.543.

Natural granite plates and blocks bought from local market were used as aggregates. X-ray fluorescence (XRF) tests were con-