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ScienceDirect

Procedia Structural Integrity 3 (2017) 11–17

Structural Integrity Procedia

www.elsevier.com/locate/procedia

XXIV Italian Group of Fracture Conference, 1-3 March 2017, Urbino, Italy

Improving the mechanical performance of cement composites by carbon nanotubes addition

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Abstract

The addition of high performance nano materials like carbon fibers, carbon nanotubes, graphene etc. in the cement and concrete is gaining attention for achieving multifunctional composite materials with enhanced mechanical, physical and electrical properties. The nano-metric size range and the exceptionally high mechanical properties of carbon nanotubes possess very great potential for their utilization in cementitious composites for obtaining remarkable properties. Billions of ton of concrete is used every year in construction industry and its quantity may be reduced to a large extent only by improving the mechanical and durability properties. One way of achieving the enhanced mechanical properties of cement composite is the utilization of thoroughly dispersed carbon nanotubes in the composite matrix. In the present research, small fractions of multiwall carbon nanotube (MWCNTs) i.e. 0.05 and 0.10 wt.% of cement have been incorporated into the cement concrete and their influence on the mechanical properties of the resulting composites have been studied. It is a well-known fact that the uniform dispersion of the MWCNTs in the composite matrix holds the key for the performance improvement. Therefore, special attention was paid to this aspect and uniform dispersion of MWCNTs was achieved through the use of high energy sonication in the presence of modified acrylic based polymer (acting as a surfactant). The concrete specimens were tested in splitting tensile, flexure and compressive strength after 3, 7, 28 and 56 days of immersed water curing. It was observed that the addition of 0.05wt.% MWCNTs increased the splitting tensile strength by 20.58%, flexural strength by 26.29% and compressive strength by 15.60% as compared to the control mix at 28 days of curing. The strength enhancements for the concrete mixes containing MWCNTs may be regarded to the phenomenon of bridging, pinning and branching of the cracks at nano/micro level due to the presence of MWCNTs. Beside strength enhancements, it was also

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Peer-review under responsibility of the Scientific Committee of IGF Ex-Co.
10.1016/j.prostr.2017.04.003

observed that the MWCNTs had tremendously enhanced the fracture energy and breaking strains of the concrete mixes as observed in three-point bending tests. The research concludes that very low amounts of MWCNTs incorporated in the cement concrete mixes improve their mechanical strengths and fracture behavior remarkably but the thorough dispersion of MWCNTs in the matrix have to be insured.

Peer-review under responsibility of the Scientific Committee of IGF Ex-Co.

Keywords: Fracture energy; MWCNTs; Concrete; Nanaotechnology; Toughness; Crack pinning; Micro cracking

1. Introduction

Cement and concrete composites are the basic construction materials which are extensively used around the globe. The production of cement involves generation of enormous amounts of anthropogenic carbon dioxide (CO_2) in the atmosphere, contributing approximately 5.0% CO_2 generation around the globe. Beside this, other environmental concerns are also associated with the use of cement and concrete composites such as depletion of virgin aggregates and its impact on the ecosystem. Ordinary cement and concrete composites offer much flexibility and cost effectiveness in their utilization but they are vulnerable to physical and chemical attacks affecting their performance in service life span; therefore, requiring costly repair and maintenance works. Construction of super-paves, tunneling, long span structural members and pre-stress technology demands the concretes of ultra-high strength and performance. For effective service life in different situations and under different loading conditions, ordinary concrete is not much beneficial. Therefore, the production of modified concrete with exceptional properties in terms of mechanical strength and with minimum amount of cement is highly desired so that economical and sustainable construction may be achieved along with reduction in CO_2 emissions in the atmosphere.

The idea of nanotechnology for the modifications of composite properties at nano scale is not new in relation to the construction materials. Nanotechnology deals with the synthesis, characterization, utilization and analysis of materials at nano scale. Several researchers have explained that the properties of cement and concrete composites may greatly be modified by using nano and micro sized particle inclusions in the matrix Raki et al. (2010); Lopez et al. (2013); Ferro et al. (2015); Ahmad et al. (2015); Khushnood et al. (2014); Khushnood et al. (2016); Ferro et al. (2014). The nano level inclusions in concrete have shown improved durability, mechanical strength, porosity reduction and economical construction Lothenbach et al. (2011); Lothenbach et al. (2008); Wu et al. (2016); Khushnood, Ahmad, Savi, et al. (2015); Barbhuiya et al. (2015); Abd Elrahman & Hillemeier (2014); Khushnood, Ahmad, Ferro, et al. (2015). The nano metric inclusions includes nano silica, graphene, multi walled carbon nano tubes (MWCNTs), nano $CaCO_3$, nano TiO_2 etc. Li et al. (2015); Li et al. (2005); Siddique & Mehta (2014); Wang et al. (2013); Chithra et al. (2016); Chuah et al. (2014); Vulic et al. (2013). The studies show that the inclusions improve the packing of particles and produce crack bridging phenomena by densifying the nanostructures. Nano particles control the C-S-H reaction and improves the concrete durability Singh et al. (2016); Kong et al. (2012); Hou et al. (2013); Fan et al. (2015); Hu et al. (2014).

Among above mentioned nano materials, MWCNTs possess unique and exceptional characteristics in terms of physical and mechanical properties. MWCNTs have tubular structure composed of folded layers of graphene with exceptionally high aspect ratios Mubarak et al. (2014); Broza (2010); Mamalis et al. (2004); Popov (2004). Several researchers have been reported the utilization of MWCNTs in preparing cement and mortar composites and studied the behavior but limited work is available describing the full scale utilization of the MWCNTs in the concrete matrix. Therefore, in the present research MWCNTs were utilized in the preparation of concrete matrix and their influence on the mechanical behavior of concrete is discussed in detail.

Nomenclature

C-S-H	Calcium silicate hydrate	CMOD	Crack mouth opening displacement
MWCNTs	Multi walled carbon nano tubes	w/c	Water to cement ratio