Construction and Building Materials 134 (2017) 520–529

Contents lists available at ScienceDirect

Construction and Building Materials

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

Self-sensing damage assessment and image-based surface crack quantification of carbon nanofibre reinforced concrete

Savaş Erdem [a,*], Serap Hanbay [a], Marva Angela Blankson [b]

[a] Department of Civil Engineering, University of Istanbul, Avcilar Campus, Istanbul, Turkey
[b] School of Engineering, The University of Technology Jamaica, Kingston, Jamaica

HIGHLIGHTS

- Monitoring damage and deformation on the concrete column.
- Crack profiles by means of 3D image analysis and fractal theory.
- Composites with carbon nanofibre, carbon fibre and steel fibre.
- Carbon nanofibre maintains the compactness in a fractured concrete.

ARTICLE INFO

Article history:
Received 28 August 2016
Received in revised form 22 November 2016
Accepted 29 December 2016

Keywords:
Self-sensing
Concrete
Compressive damage
Carbon nanofibre
Crack analysis

ABSTRACT

Concrete is used extensively in the construction of civil infrastructures such as bridges. The development of cracks can however, undermine the integrity of such facility. In this research, the self-sensing damage of cementitious composites with three different types of fibres (carbon nanofibre, carbon fibre and steel fibre) were experimentally investigated. In addition to, the crack profiles were digitized and analyzed by means of 3D image analysis and fractal theory. The results show that, with the exception of steel fibre, the fibre reduced the strength of concrete. The modulus of elasticity of concrete were all minimised with the use of the different types of fibres. Most importantly, it was shown that the carbon nano fibre was not very effective in minimising the development of micro cracks but was effective in maintaining the compactness of concrete; the carbon nanofibre and steel were effective in mitigating the development of high volume of micro cracks but the latter was not quite as effective in maintaining compactness. The carbon nanofibre on the other hand, not only reduces development of fracture but contributes to the maintenance of compactness in the fractured concrete.

1. Introduction

The use of concrete on most construction project is inevitable as this material has a number of favourable properties. However, concrete is a brittle material and is susceptible to development of cracks within the matrix. The manifestation of minute cracks sometimes serves as warning of stress concentration in specific areas, but the cracks may propagate and contribute to sudden collapse. This situation represents one of the biggest disadvantages of the concrete. Durability is an important aspect of concrete bridge design, especially for bridges that will be subjected to continuous dynamic loading and the involuntary establishment of cracks can compromise this characteristic of the concrete. Therefore, monitoring of concrete that will result in the avoidance or mitigation of harmful cracks during the construction and the service life stages should be pursued at all times. This process underscores the necessity of a structural health monitoring programme.

Minnesota Transportation Department, in a report published in 2009 [1], defined the aim of the structural monitoring as bringing forth awareness to integrity of in-service structures continuously in real-time. Scheduled maintenances and periodic inspections provides only limited data about the structural health of concrete bridges and these methods are not cost-effective in terms of cost associate with labor and downtime of these structures. Nevertheless, through innovations in detection technology, material and structural damage characterizations is made possible with special diagnostic technology that provides continuous monitoring and real-time control of the structure of interest [2]. From this point of view, the core mandates of structural health monitoring are detection of damage and control of structures which are done by minimum labor-force through the provision of autonomous

* Corresponding author.
E-mail address: savas.erdem@istanbul.edu.tr (S. Erdem).

http://dx.doi.org/10.1016/j.conbuildmat.2016.12.197

systems for continuous monitoring. Structural health monitoring is used specifically to improve the safety and sustainability of critical structures. Examples of these critical structures are hospitals, firehouses, military control/monitoring centers, primary bridges, power plants and water systems [3].

Studies relevant to high performance fibre reinforced concrete have increased as a result of the efforts made to find new construction materials that possess increased strength, ductility, toughness, and durability. When the fibres are distributed in a homogeneous way and used in appropriate quantity in a cementitious mixture, they reduce cracks and increase tensile strength, toughness, ductility and durability; and improve other mechanical properties of concrete [4]. In the study of Kim et al. [5], fibre/matrix bonding strength and flexural behaviour of bundle-type polyamide fibres reinforced concrete were measured, and the behaviour of the concrete upon impact with a high velocity projectile was investigated. The values that were obtained were compared with that of concrete containing hooked-end steel fibre that is commonly used in construction. The results about stiffness, flexural strength, toughness and fracture energy were accomplished. Apart from this, through several methods that were explored, it was confirmed that damage detection in concrete was possible in fibre reinforcement in concrete. Further, in the study of McCrory et al. [6], the use of acoustic emission (AE) to locate and classify the type of damage occurring in a composite carbon fibre panel during buckling was investigated and the results were positive. As stated in the study of Tashan et al. [7], previous research works attempted to determine a reliable method to detect cracks and recognize their properties by using different non-destructive testing (NDT) methods. In that study, infrared thermography (IRT) was used to detect the propagation of cracks and determine their width in concrete strengthened with carbon fibre reinforced plastic (CFRP) systems. Electrical conductivity property of fibres is a parameter used to detection damage. In the study of Bontea [8], the sensing of damage under increasing stresses was demonstrated in carbon fibre-reinforced concrete. Damage in concrete reinforced with short carbon fibres was monitored by measurement of the Direct Currents (DC) electrical resistance in the stress direction during repeated compressive loading at increasing and decreasing stress amplitudes. In the study of Athanasopoulos et al. [9], it was reported that the electrical conductivity of two-phase composite media has been studied by various researchers. More specifically, the electrical resistivity of the continuous dry carbon fibre (CF) performs and CFRPs were subject to the CF electrical resistivity, direction, and fiber's diameter, and thickness and fibre volume fraction. One of the significant attributes of fibres is crack bridging. In a study in

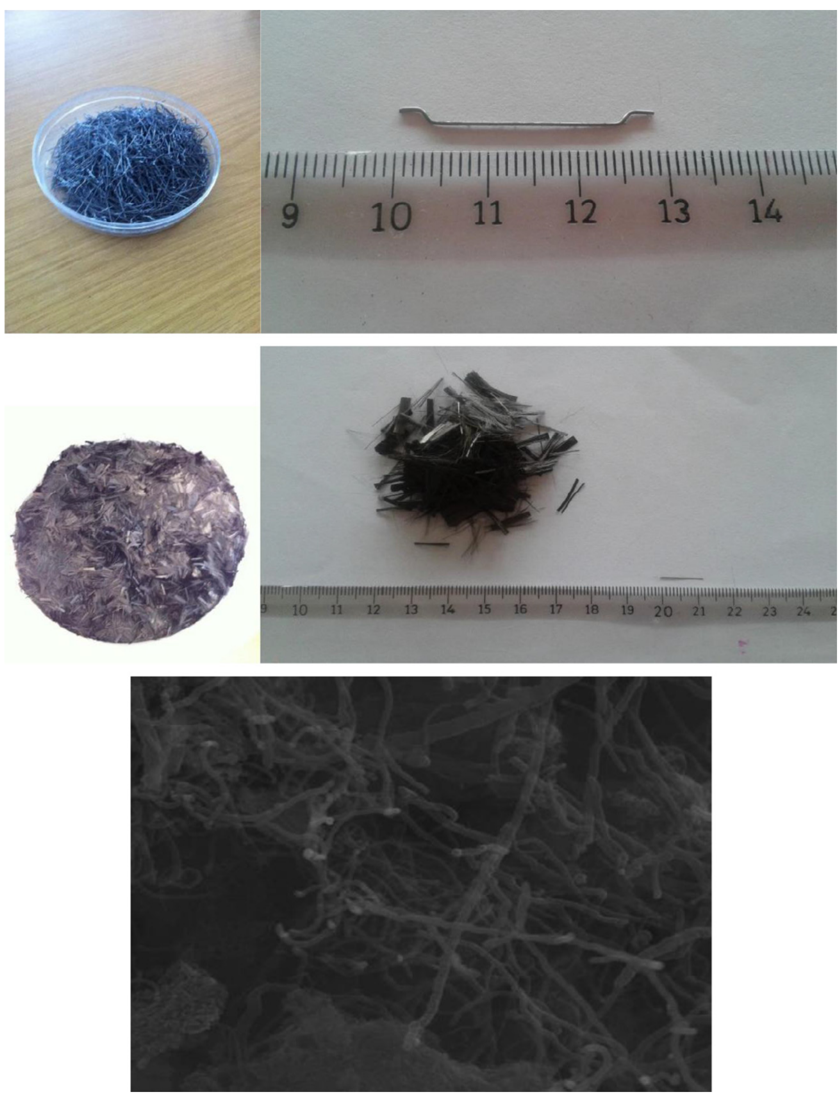

Fig. 1. The fibres used in this study: a) steel fibre; b) carbon fibre and c) carbon nano fibre.