Construction and Building Materials 134 (2017) 220–227

Contents lists available at ScienceDirect

Construction and Building Materials

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

Technical note

Dispersion of carbon fibers in cement-based composites with different mixing methods

Jie Gao [a,b], Zhenjun Wang [c,d,*], Ting Zhang [c], Liang Zhou [c]

[a] School of Highway, Chang'an University, Xi'an 710064, China
[b] National and Local Joint Engineering Materials Laboratory of Traffic Engineering and Civil Engineering, Chongqing Jiaotong University, 400074, China
[c] School of Materials Science and Engineering, Chang'an University, Xi'an 710061, China
[d] Engineering Research Central of Pavement Materials, Ministry of Education of P.R. China, Chang'an University, Xi'an 710061, China

ARTICLE INFO

Article history:
Received 22 June 2016
Received in revised form 22 November 2016
Accepted 13 December 2016
Available online 30 December 2016

Keywords:
Carbon-fiber-reinforced cement-based composites
Carbon fiber dispersion
Carbon fiber bundles
Mixing methods

ABSTRACT

Mixing methods can significantly influence dispersion of carbon fibers in cement-based composites. In this work, pre-mixing method (carbon fibers were added before cement) and after-mixing method (carbon fibers were added after cement) were adopted to prepare carbon-fiber-reinforced cement-based composites (CFRC). X-ray computed tomography (CT) was used to obtain the cross-sectional images of successive layers in the composites. Scanning electron microscope (SEM) was adopted to capture microstructure images of the composites. The CT images were continuously identified through their grayscale peaks. The sub-mm pores were separated from carbon bundles to improve the accuracy of the identification results. Two-dimensional (2D) dispersion characteristics of two different mixing methods were quantitatively analyzed by extracting pixels area of each component. Meanwhile, three-dimensional (3D) models were established by means of optimized CT images to obtain the volume fraction of carbon fiber bundles. The results show that the average areas of uniformly dispersed area, which obtains through pre-mixing method, are higher than those with after-mixing method. The dispersion effect of pre-mixing method is superior than that with after-mixing method. In addition, the volume fraction of carbon fiber bundles in specimens prepared through pre-mixing method was lower than that prepared by after-mixing method. Thus, the contrast resolution of X-ray CT system can recognize materials with over 0.3% density difference in CFRC; and the pre-mixing method is recommended in the preparation of carbon-fiber-reinforced cement-based composites.

1. Introduction

Carbon-fiber-reinforced cement-based composites (CFRC) possess not only excellent mechanical properties [1–6], but also high conductive and electromagnetic performances [7–9]. In recent years, CFRC have been extensively used as smart civil engineering materials for structural monitors, intelligent buildings and deicing or snow-melting pavements [10–15]. However, carbon fibers tend to cluster during process of preparing the composites. Nowadays, pre-mixing method (carbon fibers were added before cement) and after-mixing method (carbon fibers were added after cement) are usually adopted to prepare carbon-fiber-reinforced cement-based composites [16]. However, mixing methods of carbon fibers can evidently influence their dispersion in cement matrix. It is difficult to achieve electric function roles of carbon fibers when they are poorly dispersed [17–19]. Therefore, it is necessary to quantitatively evaluate dispersion of carbon fibers in cement-based composites and recommend suitable mixing methods for preparing the carbon-fiber-reinforced cement-based composites.

To evaluate dispersion of carbon fibers in cement matrix, a traditional method was introduced in Technical Specification for Fiber Reinforced Concrete Structures in China (CECS38:2004) [20] and Standard Test Method for Determination of Glass Fiber Content in Glass Fiber Reinforced Concrete (ASTM C1229-94) [21]. Several specimens with equal mass were separated from the fresh fiber reinforced cement paste and numbered. Each specimen was placed on a square hole sieve with a diameter of 75 μm. The cement particles were washed out with water and carbon fibers were collected, dried and weighed. The dispersion can be evaluated by variation coefficient of carbon fiber mass. In addition, Yang et al. [22] introduced four methods to evaluate fiber dispersion, which were fresh mixture method, scanning electron microscope method,

* Corresponding author at: School of Materials Science and Engineering, Chang'an University, Xi'an 710061, China.
E-mail address: wangzhenjun029@163.com (Z. Wang).

http://dx.doi.org/10.1016/j.conbuildmat.2016.12.047
0950-0618/

measurement of electrical resistance and simulation experiment. The results showed that different methods could be used under different conditions. Woo et al. [23] compared conductivity of different specimens to determine the uniformity of steel fiber dispersion. Kim et al. [24,25] used graphics software and statistical analysis software to obtain the dispersion coefficient of polyvinyl alcohol fiber. However, the methods mentioned above can only achieved indirect analysis of dispersion but can not directly obtain the dispersion morphology of carbon fibers and the accurate volume fraction of carbon fiber bundles.

In this work, the first purpose is to evaluate the dispersion of carbon fibers with different mixing methods, which influences design, preparation, property and application of CFRC. The second purpose is to describe the distribution morphology of carbon fiber bundles in the cement matrix, which plays vital roles in the functional sensitivity and mechanical property enhancement of CFRC.

2. Experimental

2.1. Raw materials

In this work, ordinary Portland cement was used and its properties are shown in Table 1, which can meet requests in *Standards of Common Portland Cement in China* (GB 175-2007) [26]. Polyacrylonitrile (PAN)-based carbon fibers were adopted and their properties are shown in Table 2. Tap water was used.

2.2. Sample preparation and tests

2.2.1. Preparation of the specimens

In specimens, the proportion of various materials set as: cement:water:carbon fiber = 1:0.55:0.025 (in mass). Then the volume content of carbon fiber (V_{cf}) in specimen can be calculated by Eq. (1).

$$v_{cf} = \frac{m_{cf}\rho_{cf}}{m_c\rho_c + m_w\rho_w + m_{cf}\rho_{cf}} \times 100\% \tag{1}$$

where m_c, m_w, m_{cf} – mass of cement, water and carbon fiber. ρ_c, ρ_w, ρ_{cf} – density of cement, water and carbon fiber, which are shown in Table 1 or Table 2.

In this work, two mixing methods were used to prepare the composites. For the pre-mixing method, the mixing water was weighed firstly. Then, carbon fibers were added and stirred for 60 s by a JJ-1/1A forced electric mixer with the rotation rate 1000r/min. In the following, cement was added and stirred by a JJ-5 cement mortar mixer in accordance with the pattern of fast (120 r/m) – slow (60r/m) – fast (120 r/m), and each pattern was stirred for 30 s, respectively. The process of pre-mixing method is illustrated in Fig. 1.

For the after-mixing method, the mixing water and cement were first stirred by a JJ-5 cement mortar mixer (60 r/m) for 30 s. Then, the carbon fibers were added and stirred for 120 s (fast-slow-fast pattern, 40 s each). The detail process of after-mixing method is illustrated in Fig. 2.

The stirred mixtures were poured into 40 mm × 40 mm × 40 mm steel models and vibrated for 30 s in a vibration platform. The specimens were placed in a curing room with the temperature of 20 ± 2 °C and the relative humidity >90%. After curing for 7 days, the specimens were used for tests. In CT image acquisition and identification, the large density difference between carbon fiber and water or air makes them easily-distinguished. Therefore, capture of CT images and recognition of carbon fibers can not be influenced by the present of free water in specimens. Moreover, considering the grayscale varies with curing age significantly, the

Table 1
Properties of ordinary Portland cement.

Fineness	Density	Initial setting time (h)	Final setting time (h)	Flexural strength (MPa)		Compressive strength (MPa)	
(m^2/kg)	(g/cm^3)			3 d	28 d	3 d	28 d
320	3.105	3.1	4.9	5.9	7.9	21.7	55.4

Table 2
Properties of carbon fiber.

Diameter (μm)	Length (mm)	Density (g/cm^3)	Tensile strength (MPa)	Young's modulus (GPa)	Carbon content (%)
7.1	2–5	1.742	3900	230	95.3

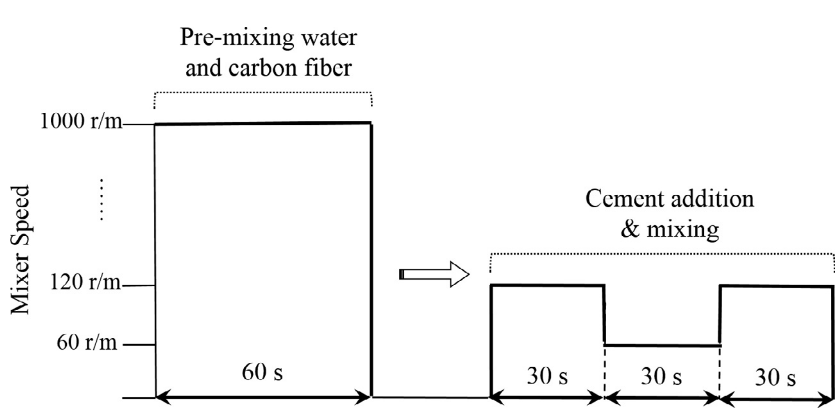

Fig. 1. The process of pre-mixing method.