Construction and Building Materials 68 (2014) 26–30

Contents lists available at ScienceDirect

Construction and Building Materials

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

Technical Note

Quantitative evaluation of carbon fiber dispersion in cement based composites

Zhenjun Wang [a,b,*], Jie Gao [a], Tao Ai [a,b], Wei Jiang [c], Peng Zhao [a,b]

[a] School of Materials Science and Engineering, Chang'an University, Xi'an 710061, PR China
[b] Engineering Research Central of Pavement Materials, Ministry of Education of PR China, Chang'an University, Xi'an 710061, PR China
[c] School of Highway Engineering, Chang'an University, Xi'an 710064, PR China

ARTICLE INFO

Article history:
Received 11 February 2014
Received in revised form 20 June 2014
Accepted 23 June 2014

Keywords:
Carbon fiber cement based composites
X-ray CT
Dispersion of carbon fibers
Dispersion coefficient
Variation coefficient of fiber dispersion

ABSTRACT

To date, carbon fiber cement based composites are gaining popularity in the field of civil engineering. Dispersion degree of carbon fibers (CFs) in the composites plays a significant role in the property improvements. However, it is extremely challengeable to evaluate quantitatively the dispersion of CFs because of their random distribution and low contrast with cement paste. In this paper, X-ray computed tomography (CT) scanner was adopted to capture the images; Optical Microscope (OP) was used to determine the thresholds of different components and mathematical calculation was conducted to compare the degree of fiber dispersion. The dispersion coefficient was introduced to evaluate quantitatively dispersion of the CFs. The higher value of dispersion coefficient, the more uniform distribution the CFs. The value range of dispersion coefficient is concentrated from 84% to 94%. There is no rule for changes of dispersion coefficient with the changes of scanned slices. Meanwhile, variation coefficient was calculated as an index to effectively compare the fiber dispersion for the different scanned slice with the same dispersion coefficient. In addition, the lower variation coefficient of fiber dispersion, the more uniform distribution the CFs.

1. Introduction

Compared with ordinary cement materials, carbon fiber cement based composites have the characteristics, not only light weight, but also high durability and excellent mechanical properties [1,2]. In addition, carbon fibers (CFs) are incorporated in cement based composites to improve both crack resistance and thermal property [3,4]. On the other hand, CFs are advantageous in their superior ability to increase the conductivity and improve the electromagnetic behavior of cement. Therefore, the composites are also used as smart structural materials in the field of civil engineering, such as health monitoring and intelligent building [5,6].

However, dispersion of CFs can affect rheology and mechanical performance of the composites [7]. In addition, the workability of the mixture during the preparation decreases with the increasing carbon fiber contents. Therefore, effective use of CFs in cement requires their uniform dispersion in the mixture [8]. The carbon fiber dispersion also affects greatly the air void content. The high air void content tends to have a negative effect on the compressive strength of the composites [9]. Wang et al. [8] concerned with the influence of carbon fiber dispersion on the mechanical properties of the composites. Their studies showed that the reinforcing ability of CFs depended on how the fibers were dispersed throughout the composites. Poorly dispersed fibers provided little or no reinforcement in some regions, which then acted as flaws in the composites. Therefore, the uniform dispersion of CFs is important to property improvement of the composites. For example, study of Cao and Chung [10] showed that cement mortar reinforced by short carbon fibers was improved by using acrylic dispersion as an admixture in the amount of 15% by mass of cement. The improvement of the tensile properties (particularly strength and ductility) was more than those attained by using methylcellulose, styrene acrylic, or latex as admixtures.

Because of the importance of fiber dispersion, the evaluation of fiber dispersion has seen greater attentions and has become a hot topic. Shui and Stroeven [11] used impedance measurements to test uniformity assessment of carbon fibers dispersion in cement paste. Ozyurt et al. [12] and Woo et al. [13] investigated the ability of AC-impedance spectroscopy to non-destructively monitor the fiber dispersion of conductive fiber-reinforced cement-based materials. In addition, X-ray CT is a completely nondestructive technique for visualizing features in the interior of opaque solid

* Corresponding author at: School of Materials Science and Engineering, Chang'an University, Xi'an 710061, PR China. Tel.: +86 02982339328.
E-mail address: wangzhenjun029@163.com (Z. Wang).

http://dx.doi.org/10.1016/j.conbuildmat.2014.06.035
0950-0618/

objects to obtain digital information on their properties. Wang and Xiao [14] used X-ray CT to quantify air void ratio, air void area, and air void size in cement asphalt emulsion mixtures. Cosmi and Bernasconi [15] used micro-CT to investigate the fatigue damage evolution in short fiber reinforced polymers. Liu et al. [16] established the characterization method of fiber distribution in 3D space by micro-CT imaging, and presented the effect of aggregate on fiber orientation distribution and fiber spacing distribution. Lee et al. [17] employed a watershed segmentation algorithm to examine a single fiber image detected by the proto-type thresholding algorithm. Torigoe et al. [18] adopted a fluorescence technique on the composites to capture the fluorescence image through a microscope and found the relationship between the degree of distribution and the ultimate tensile strain of the composites.

In summary, dispersion degree of the CFs in the composites plays a decisive role on physical mechanics and durability. However, it is not easy to evaluate the dispersion degree quantitatively. In the present work, the authors introduced X-ray CT to capture the images and adopted optical microscope to help determine the thresholds of different components in the composites. The dispersion coefficient was introduced to evaluate quantitatively the fiber dispersion after using image processing technique. In addition, variation coefficient was calculated as an index to compare the fiber dispersion at the different slice with the same dispersion coefficient. This paper puts forward an accurate method for the evaluation of the dispersion of CFs in the composites, which is greatly significant to guide design, preparation and performance optimization of carbon fiber cement composites.

2. Experimental procedures

2.1. Raw materials

A Chinese 32.5R composite Portland cement was used and its properties were satisfied with requests of *Standards of Common Portland Cement in China* (*GB 175-2007*) [19]. Chopped short carbon fibers were adopted, whose density was 1.751 g/cm^3, length 3–5 mm and carbon content 94.2%. The mixing water was tap water. Sodium carboxymethyl cellulose and tributyl phosphate were used as a dispersion agent and a deforming agent, respectively.

2.2. Sample preparation and test

2.2.1. Preparation of the composites

Cement: water: carbon fiber: sodium carboxymethyl cellulose and tributyl phosphate (in mass) = 1:0.4:0.02:0.008:0.0016. The mixing sequence is shown in Fig. 1. The water in a beaker was heated to the temperature of 60 °C for easy dissolve of dispersion agent. Sodium carboxymethyl cellulose was added and was stirred for 60 s by hands. Carbon fibers were then added and the dispersion agent was continuously stirred for another 60 s. Afterwards, ultrasonic vibration was conducted for 120 s for further dispersion and tributyl phosphate was added for anti bubbles. The mixture and cement were mixed by a NJ-160A cement paste mixer for 120 s. The stirred mixture was poured into a 40 mm × 40 mm × 40 mm steel model and vibrated for 30 s in a vibration platform. The samples of the composites were placed in a curing room with the temperature 20 ± 2 °C and the relative humidity 90%. After curing 28 days, the specimens were prepared for tests.

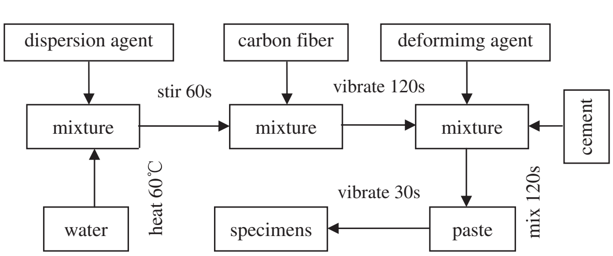

Fig. 1. Flow chart of preparation of the composites.

2.2.2. Image acquisition

A spiral X-ray CT scanner was adopted for image acquisition of the composites, whose settings were 225 kV (maximum tube voltage), 150 mA (X-ray tube current) and 1024 pixels × 1024 pixels (gray scale images). 19 slice scans were carried out for 40 mm cubic specimens based on the length of carbon fiber and one of CT images was shown in Fig. 2a. LWT150PT optical microscope was used to capture optical images of the composites, for determining gray thresholds of different components.

3. Results and discussion

3.1. CT image enhancement

CT image enhancement is the improvement of digital image quality, without the degradation of image information. The X-ray energy attenuation in the composites can result in relatively high absorption coefficient and grayscale differences for different components because different material possesses different X-ray absorption coefficient. Therefore, the original CT images were processed as follows with software: (a) Filtering: a median filter in spatial filter group was adopted to remove image noise and make the image keep the prospects for the smooth edges. (b) Sharpening: 7 × 7 mode in the sharpen filter was used to enhance the detail representation of fuzzy parts. (c) Image enhancement: to improve the accuracy of carbon fiber identification, image contrast enhancement was conducted to improve the perceptibility of fibers in the image through highlighting the characteristics of the component morphology and enhancing the brightness difference between fibers and cement paste. One enhanced CT image of the composites is shown in Fig. 2b.

3.2. Categorization of CT images

CT number in the images essentially reflects the density of material. The material with higher density displays the higher

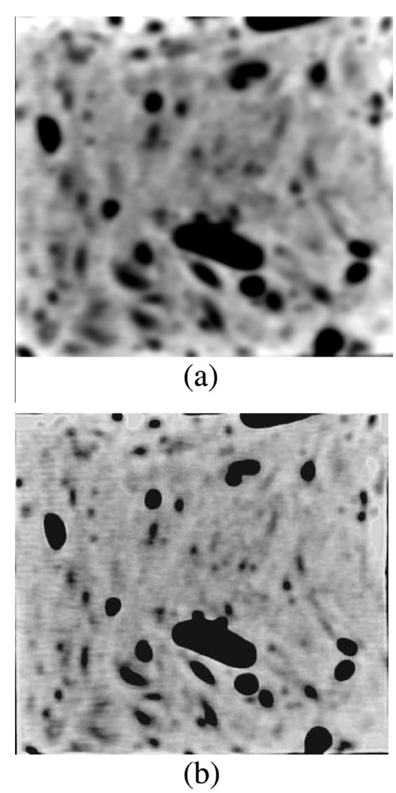

Fig. 2. CT image of the composites: (a) original CT image; (b) Enhanced CT image.