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Cellulosic fibers from rice straw and bamboo used as reinforcement of cement-based composites for remarkably improving mechanical properties

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ABSTRACT

The cement-based composites reinforced with cellulosic fibers isolated from rice straw were fabricated by a slurry vacuum de-watering technique. The physical structures and mechanical properties of the composites with fiber contents ranging from 2% to 16% by weight (wt.%) were investigated. Moreover, the composites reinforced with bamboo cellulosic fibers and the control cement paste, sample without cellulosic fibers, were also fabricated as reference materials. As a result, the cement-based composites reinforced by cellulosic fibers showed a remarkable improvement in the mechanical properties. The measurements of the flexural strength and the fracture toughness of the optimal sample were found to be increased by 24.3% and 45 times, respectively. The bulk density of the composites was decreased by 12.4–37.3% as a result of the introduction of cellulosic fibers. Additionally, the field emission scanning electron microscope (FSEM) observations and energy dispersive spectroscopy (EDS) analyses revealed that the hydration products of Portland cement migrated to the fiber lumens, resulting in mineralizing the cellulosic fibers and decreasing the fracture toughness of the composites.

1. Introduction

Nowadays, one of main challenges of construction industry is improvement of the sustainability [1]. Renewable resources are generally regarded as indispensable option to be used as building materials to improve the sustainability of the construction industry. As a renewable resource, the use of vegetable fibers in the production of cement composites has drawn an increasing interest [2–7], which is associated with the following two aspects. On the one hand, plant fibers has many advantages over most synthetic fibers, such as low density, low cost, widely available, excellent specific strength and high specific modulus, and especially, their renewability and biodegradability [8–11]. On the other hand, the event took place during the last decades of the last century when most developed countries prohibited the use of asbestos in building materials due to its hazardous effects on human health [10]. Many studies on wood [2,10], sisal [5,12,13], hemp [14,15], coconut [3,4,12,16] and bamboo [17] used in cement-based materials have been reported in references. However, the application of crop straws, such as wheat straw and rice straw in cement-based materials has not been comprehensively examined in the published literatures.

Crop straw is a kind of important renewable biomass resource, which has reached about 800 million tons in 2013 in China. However, the crop straw has not been got enough attention and widely utilized for a long time. At present, most of the crops straws are accumulated as waste or burned, resulting not only in wasting biomass resources but also in polluting the environment. So utilization of crop straw resources is a challenge. Accordingly, crop straw reinforced cement-based composites provide an effective way to utilize crop straw and to conform to the strategic objectives for the sustainable development of building materials.

However, there are many disadvantages affecting the application of crop straws in building materials, for example, the

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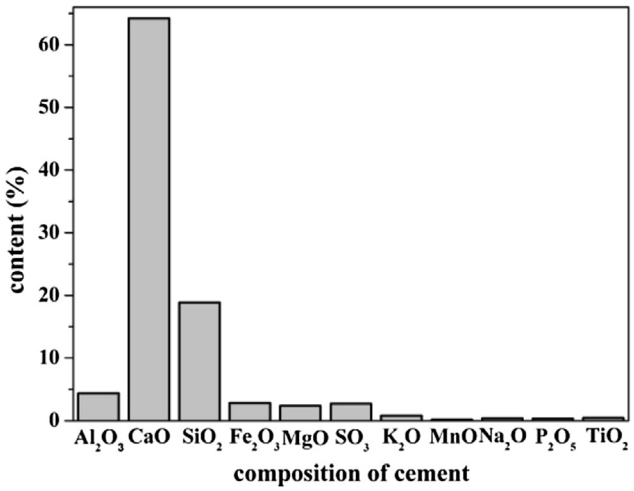

Fig. 1. Chemical composition of cement.

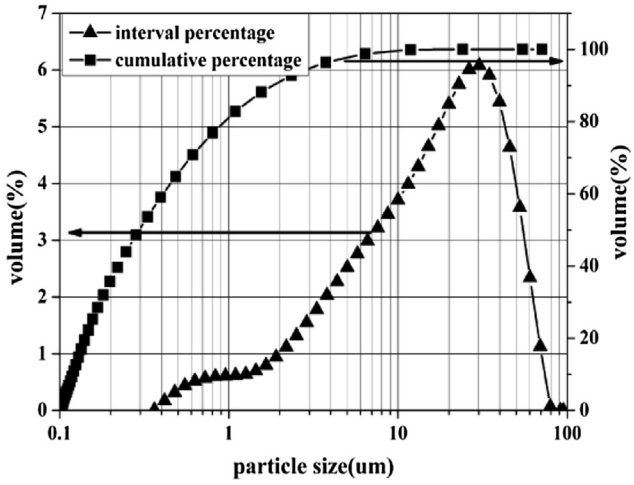

Fig. 2. Particle size distribution of cement.

hemicellulose and lignin in straw fibers prevent seriously the cement from hydrating, and the structure of straw fibers is damaged by alkaline cement, resulting in decreasing its strength [18,19]. At the same time, the pectin on the surface of the fiber also leads to a badly bonding between the crop straw fibers and the cement matrix. To overcome these drawbacks, much effort has been devoted to pre-treatments, adding chemical admixtures and improving manufacturing process. Bledzki and Gassan [20] pointed out that the elastic modulus of bulk natural fibers such as wood is about 10 GPa, and cellulose fiber with modulus up to 40 GPa can be separated from wood by chemical pulping processes. Jiang et al. [21] isolated cellulose from steam exploded rice straw by an efficiently and environment-friendly method, the selected dissolutions of cellulose and lignin in different ionic liquid.

On the basis of the above discussions, the main objective of this study is to examine the behavior of the cellulosic fibers isolated from rice straw in cement-based composites, and further assess the application feasibility of this kind of cellulosic fibers reinforced cement-based composites in construction industry. The present work provides mechanical and physical data of rice cellulosic fibers reinforced cement-based composites (RFRCC) by varying fiber contents. To evaluate the reinforcing effects of agricultural cellulosic fiber, the properties of bamboo-isolated cellulosic fibers reinforced cement-based composites (BFRCC) are comparatively investigated.

Table 1
Fiber properties.

Fiber type	Length (mm)		Diameter (um)		Aspect ratio
	Average[a]	S[b]	Average[a]	S[b]	
Rice cellulosic fiber	0.9	0.18	5.28	1.68	175
Bamboo cellulosic fiber	2.5	0.41	13.13	4.62	190

[a] Average length and diameter obtained from 30 fibers of each type.
[b] Standard deviation of each sample: $S = (\sum (x - \bar{x})^2/(n-1))^{1/2}$, n = 30.

2. Materials and methods

2.1. Materials

42.5 ordinary Portland cement was used as raw material in this paper, the chemical compositions and the particle size distribution of the cement were determined by X-ray fluorescence (XRF) and laser granulometry respectively, as shown in Figs. 1 and 2.

Rice cellulosic fibers (RF) and bamboo cellulosic fibers (BF, Sichuan Anxian Paper Co., Ltd.) were selected. RF was extracted from rice straw in the laboratory, the extraction process of which was described in detail by Jiang et al. [21]. SEM images of these fibers were shown in Fig. 3. The average values and standard deviation of length and diameter are provided in Table 1, for which the Layida method was used to determine whether data were accepted or omitted.

2.2. Composites preparation

Cellulosic fibers reinforced cement-based composites were fabricated in the laboratory by a slurry vacuum de-watering

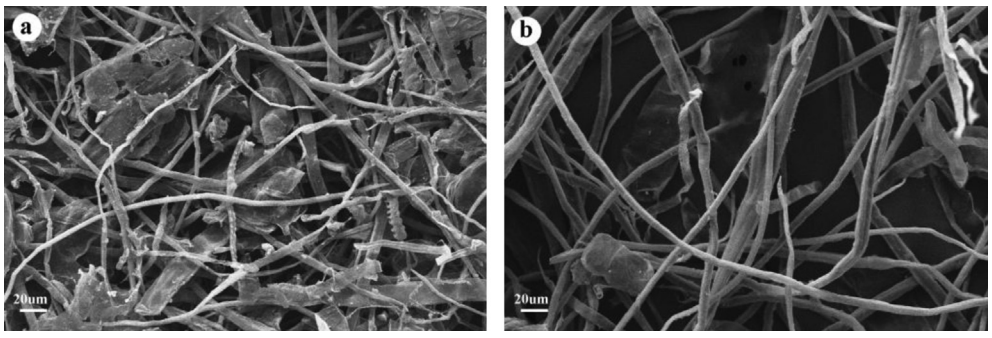

Fig. 3. SEM images of (a) rice cellulosic fiber and (b) bamboo cellulosic fiber.