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Influence of pretreatment of rice straw on hydration of straw fiber filled cement based composites

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HIGHLIGHTS

- Effect of pretreatment of straw fiber on the fiber characteristics was investigated.
- Different kinds of straw fibers filled cement based composites were studied.
- Pretreatment of straw fiber eliminate amorphous hemicellulose and lignin.
- The pretreated rice straw fibers had less influence on the hydration of cement.

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ABSTRACT

The morphological and structural characteristics of four different fibers, the pristine rice straw (RF1) and three fibrous materials (RF2, RF3 and RF4) during the components separating process from rice straw, were investigated. The results indicated the pretreatment of rice straw could eliminate amorphous hemicellulose and lignin, increase the crystallinity and improve the thermal stability of rice straw fiber. Additionally, the effect of four kinds of straw fibers on hydration of the straw fiber filled cement based composites were studied using isothermal calorimetry, X-ray diffraction (XRD) and thermogravimetry (TGA) techniques. For this purpose, the composites containing 10 wt.% of the pristine and the pretreated rice straw fiber were prepared. As a result, the presence of both the pristine and the pretreated rice straw fiber delays and inhibits the hydration of cement. The composites containing RF1 showed the lowest rate of heat of hydration (almost 0 mW) and sustained the cumulative heat (7.9 J) compared to the composites containing RF2, RF3 and RF4 (240.1, 318.2 and 317.1 J, respectively) in the first 7 days. However, the cumulative heat of the composites with the pretreated rice straw fibers was still lower than the control cement paste (334.2 J). The XRD and TGA results revealed that the amount of calcium hydroxide is lower in the composites containing rice straw than in neat cement. This study recommends that the pretreated rice straw fibers had less influence on the hydration of cement.

1. Introduction

As a renewable and biodegradable resource, the use of plant fiber in construction materials dated from long before. In ancient Egypt and China, mixtures of straw and loam were employed as construction materials. However, an increasing interest was drawn on use of plant fiber in the application of cement based composites until the last two decades, due to the increasing environmental concern and awareness of industrial pollution [1–8]. The research results demonstrated that the addition of plant fiber can improve such properties of cement based composites as decrease of the density, increase of the flexural strength [3–5], control of the initiation and growth of microcracks [6,7], and improvement of the impact resistance [8].

In spite of the obvious advantages on the above characteristics of plant fiber as reinforcement of cement based composites, their long-term durability undergoes reduction in strength and toughness, resulting in limiting the application of plant fiber in cement matrix [2,9–11]. It has been suggested [2,10,11] that it is associated

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Table 1
The chemical composition of cement.

Components (wt.%)	Al_2O_3	CaO	Cl	Fe_2O_3	K_2O	MgO	Na_2O	P_2O_5	SO_3	SiO_2	TiO_2	BaO
Cement	4.83	62.4	0.01	2.85	0.81	2.39	0.41	0.35	4.73	18.9	0.47	0.14

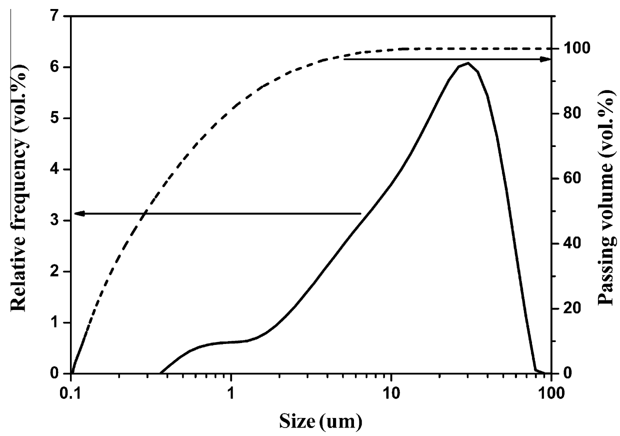

Fig. 1. Particle size distribution of the cement.

Table 2
The properties of the fibers.

Sample	DP	Components (wt.%)				
		Cellulose	Lignin	Hemicellulose	Ash	Moisture
RF1	–	35.6	16.8	20.5	15.2	12.1
RF2	295	50.6	20.5	7.9	12.5	8.5
RF3	325	67.4	8.5	7.2	8.5	8.3
RF4	385	78.5	2.6	6.9	3.1	8.9

with three main causes. Firstly, the alkaline pore water produced by Portland cement hydration dissolves the lignin and hemicellulose of the fiber, resulting in decrease of the strength of the fiber. Secondly, alkaline hydrolysis of cellulose molecules leads to degradation of molecular chains. Finally, the crystallization of lime in the lumen of the fibers decreases the fiber flexibility and strength.

The corresponding studies have been conducted on the mechanical behavior of plant fiber reinforced cement based composites [3–5,7,8,12,13], the durability and improvement methods of plant fiber reinforced cement based composite [9,14,15], and degradation mechanism of plant fiber in cement matrix [10,11,15]. However, the investigation was reported rarely about the effect of plant fiber on cement hydration, as characterized by hydration process, hydration degree, setting and hardening of cement. As discussed in Ref. [16], the strength of the composites is influenced by a number of factors, including the strength of the matrix and the matrix/fiber interfacial bond, in addition to the fiber strength. For cement based composites, the strength of the matrix depends on hydration degree and hydration products of cement.

Table 3
Mix proportions of the composites.

Sample	Composition	W/S	Components (wt.%)			
			Cellulose	Lignin	Hemicellulose	Ash
Reference	100%OPC	1	0	0	0	0
OPC-RF1	90%OPC + 10%RF1	1	3.56	1.68	2.05	1.52
OPC-RF2	90%OPC + 10%RF2	1	5.06	2.05	0.79	1.25
OPC-RF3	90%OPC + 10%RF3	1	6.74	0.85	0.72	0.85
OPC-RF4	90%OPC + 10%RF4	1	7.85	0.26	0.69	0.31

Crop straw as well as other plant fiber is a kind of abundant and renewable biomass resource, which has many advantages over most wood species, such as short growing period, annual harvest, sustainable utilization and no damage to ecological environment. In China, millions of tons of crop straw are produced from agricultural process every year. However, disposal of rice straw poses serious problems to the government and farmers. Although the straw is partly used as an agricultural amendment, most has to be accumulated or burnt, resulting not only in wasting biomass resources but also in polluting the environment. Moreover, there is a remarkable lack of research on use of crop straw in cement matrix [17,18]. With the purpose of avoiding the seasonal environmental pollution and improving sustainability of construction industry, using crop straw to produce fiber filled cement based composite appears to be the most attractive choice.

Rice is the main agricultural product grown in China and worldwide. In the previous work [19], we have studied the effect of cellulosic fibers isolated from rice straw as reinforcement of cement based composites, which leads to remarkably improving the mechanical properties of fiber filled cement based composite.

In the present work, we have adopted four different fibers from rice straw: one was pristine rice straw and the others were fibrous materials in different stages of isolation [20]. In order to determine variation of the main chemical compounds presented in the rice straw fiber after the different pretreatment process, systematic characterizations were carried out by X-ray diffraction (XRD) and thermogravimetric analysis (TGA) Furthermore, the composite, with 10 wt.% partial cement replacement by different rice straw fiber, were fabricated and then tested at ages ranging from 7 to 180 days. Isothermal microcalorimetry, XRD, and TGA of rice straw fiber filled cement based composite were used to assess the effect of pretreatment of rice straw fiber on cement hydration.

2. Materials and methods

2.1. Raw materials

The cement used in this paper is 42.5 ordinary Portland cement (OPC). 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 Table 1 and Fig. 1.

The rice straw fibers were obtained from the laboratory cultivated in farms located in Province Sichuan, China. The pretreatment process of the fibers was described in detail by Jiang et al. [20]. Four different fibers in the pretreatment process were selected, including pristine rice straw (RF1), steam exploded rice straw fiber (RF2), once bleached rice straw fiber (RF3) and twice bleached rice straw fiber (RF4). The properties including chemical component were shown in Table 2. The results of Table 2 show that pretreatment of rice straw increases cellulose content, and decreases hemicellulose and ash content. The chemical composition of rice straw fiber comprehends approximately 35.6–78.5% cellulose, 3.1–20.1% hemicellulose, 2.6–20.5% lignin, and 3.1–15.2% ash. The degree of polymerization (DP) of the fiber increases with the increase of degree of pretreatment.

2.2. Analysis methods for rice straw fiber

The morphological observations of the different rice straw fiber were carried out on an EVO 18 scanning electron microscope (SEM), the SEM images were obtained by the electronic micro-scope model with 20 kV electron beam. The structural characteristics were analyzed by XRD (X'Pert PRO, copper target, angular