EFFECT OF STYRENE-ACRYLIC EMULSION ON MECHANICAL PROPERTIES OF CEMENT-BASED COMPOSITES

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Cement-based composites were prepared from rice husk and styrene-acrylic emulsion (SAE) with a semi-dry production process. The dosage of SAE, the rice husk content, and alkali treatment on the mechanical properties of the composites were studied. The mechanical test of the rice-husk cement composites proved that SAE is an effective additive for reinforcing the composites, and the mechanical properties improved significantly by alkali treatment and adding SAE. The composites were characterized by FT-IR, SEM, and XRD. The results indicated that SAE can be beneficial for the hydration of the composites.

Keywords: Rice Husk; Styrene-Acrylic Emulsion; Mechanical Properties; Composite

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INTRODUCTION

Cellulose fibers are widely used in developing countries from annual plants, woods, *etc.* Vegetable fibers in the application of cement-based composites have received great attention (Abdel-Kader *et al.* 2010; Bilba *et al.* 2008; Coutts *et al.* 1990; Ferraz *et al.* 2011; Frybort *et al.* 2008; Ghavami 2005; Li *et al.* 2003; Li *et al.* 2006; Savastano *et al.* 2003; Sedan *et al.* 2008; Yue *et al.* 2000). Nature fiber cement composites are exceptional in this respect, not only for their eco-friendly nature but also because they are an economic and socially useful outlet for wood residues and agricultural wastes. Several treatments on vegetable fibers (Bilba *et al.* 2008; Blankenhorn *et al.* 2001; Gonzales *et al.* 1999; Lin *et al.* 1994) confirmed that the compatibility with cement was improved. Alkali treatment to plant fiber can reduce the coagulation components effectively and improve the fiber-cement bonding, which then improves the mechanical properties of the composites (Carvalho *et al.* 2010; Thiruchitrambalam *et al.* 2010). Flexible fibers with a hydrophilic nature have been developed with high tensile strength. These fibers typically have a diameter of 10 to 20 μm and a tensile strength of 2,000 to 2,500 MPa (Kandal *et al.* 1998). Polyvinyl alcohol (PVA) fibers are expected to show a strong bond with cementitious matrix due to their hydrophilic nature. Fibers with a hydrophilic nature generally show high bond strength with cement matrix. This high bond strength is attributed to hydroxyl groups on the carbon backbone and resulting strong hydrophilic characteristics of PVA fibers (Akers *et al.* 1989). The hydroxyl groups lead to a strong hydrogen intermolecular bond (Akers *et al.* 1989) and therefore contribute to strong chemical bonding between PVA fibers and cement hydration products.

In this article, the rice husk was treated with 5% Na_2SiO_3 solution. Volume fractions of PVA fiber (1%) were considered in this study. The composites were manufactured at different process conditions after crushing rice husk, and SAE was used as a modifier. Its mechanical properties were studied. The composites were characterized by FT-IR, SEM, and XRD.

EXPERIMENTAL

Materials

Rice husk and cement (P·O42.5R) were provided by Harbin Cement Factory of Heilongjiang, China. Sodium Silicate (C.P.) was purchased from DIBO Chemical Co. of Tianjin, China. Styrene-acrylic emulsion (solid content 47%) and PVA fiber (length 6 mm) were purchased from ShanDong Future Chemical Technology Co., Ltd and Tai'an Tongban Fiber Co., Ltd, respectively.

Method for Preparation of the Rice Husk Cement Composites

The ratio of rice husk/cement and water/cement was 1:4 and 1:3, respectively. The target of the composites was 1200 kg/m^3; styrene-acrylic emulsion/composites ratio were 0, 1%, 3%, 5%; volume fractions of PVA fiber were 1% (material proportion for the composites were shown in Table 1). Prior to the pasting preparation, the rice husk were minced to pieces smaller than 5 mm. Rice husk, an amount of SAE, and water were loaded into a blender. After mixing for 20 min, cement was put into the blender. After completely mixing, the mixture was pressed to a board (420 mm×400 mm×15 mm) by a presser under the pressure of 2.5 MPa for 72 h. The rice husk cement-composites were made. The properties of the composites were tested after spraying water on the board for 28 days.

Table 1. Material Proportion for Rice Husk-Cement Composites

No	Cement/g	Rice Husk/g	SAE/g	PVA fiber	Na_2SiO_3
1	2400	600	—	—	—
2	2400	600	64	—	—
3	2400	600	192	—	—
4	2400	600	320	—	—
5	2400	600	—	1% volume fraction	—
6	2400	600	64	1% volume fraction	—
7	2400	600	192	1% volume fraction	—
8	2400	600	320	1% volume fraction	—
9	2400	600	—	—	5% Na_2SiO_3 solution treated
10	2400	600	64	—	5% Na_2SiO_3 solution treated
11	2400	600	192	—	5% Na_2SiO_3 solution treated
12	2400	600	320	—	5% Na_2SiO_3 solution treated
13	2400	600	—	1% volume fraction	5% Na_2SiO_3 solution treated
14	2400	600	64	1% volume fraction	5% Na_2SiO_3 solution treated
15	2400	600	192	1% volume fraction	5% Na_2SiO_3 solution treated
16	2400	600	320	1% volume fraction	5% Na_2SiO_3 solution treated

Mechanical Properties and Characterization of the Composites

The density, flexural strength, and elastic modulus of the composites were tested according to the China building material standard JC411-2007. X-ray diffraction (XRD) measurements were performed on a Rigaku-Dmax 2500 diffractometer using Cu Kα radiation (λ = 0.15405 nm). The Fourier transform infrared (FT-IR) spectroscopy was measured by the Perkin-Elmer 580 B infrared spectrophotometer with the KBr pellet technique with a resolution of 4 cm^{-1}. The morphology of the samples were inspected on a JEOL 2010 scanning electron microscopy (SEM) operating at 20 kV. All the measurements were performed at 25 °C.

RESULTS AND DISCUSSION

Mechanical Properties of the Rice Husk-Cement Composites

Mechanical properties of rice husk-cement composites were shown in Table 2, and Figures 1 and 2 show the effect of the content of SAE on the mechanical properties of the composites.

Table 2. Mechanical Properties of Rice Husk-Cement Composites

No	1	2	3	4	5	6	7	8
Flexural Strength /MPa	2.21	2.79	4.48	5.58	2.35	3.06	4.97	6.12
Elastic Modulus /GPa	1.47	2.22	3.32	4.21	1.78	2.56	3.46	4.51
No	9	10	11	12	13	14	15	16
Flexural Strength /MPa	2.86	4.13	6.59	7.13	2.98	4.63	6.98	7.52
Elastic Modulus /GPa	2.19	2.96	4.56	5.11	2.14	3.11	4.79	5.19

As shown in Fig. 1 and Fig. 2, when the content is up to 3%, the properties can meet the requirement of the China building material standard (JC411-2007). With the content of SAE increasing, the mechanical properties of composites increased gradually. From Fig. 1 and Fig. 2, its mechanical properties improved significantly from 0 to 3%, its flexural strength increased from 2.21 MPa to 6.98 MPa, and its elastic modulus increased from 1.47 GPa to 4.79 GPa. However, in small margin from 3% to 5%, its flexural strength increased from 6.98 MPa to 7.52 MPa, and its elastic modulus increased from 4.79 GPa to 5.19 GPa. SAE can fill the gap of the composites, reduce its shrinkage, and form a network structure in the composites to improve the rupture strength. The pH value of cement hydration is about 13, but the rice husk contains many carbohydrates which go against the hydration of cement, and even lead to cement setting (Wei *et al.* 2001). After treatment on rice husk with 5% sodium silicate solution, the Sodium Silicate can be coated on its surface, form a dense layer of protection, and prevent carbohydrate exudation from improving the mechanical properties of the composites. PVA fibers had poor dispersion in the cement matrix, so mechanical properties of the composites were not improved evidently after adding PVA fiber. But mechanical properties of the composites were enhanced in a certain degree, because PVA fibers contained many hydroxyl, which can improve the bond force between the PVA fiber and cement composites and reduce the cracks in the cement matrix.

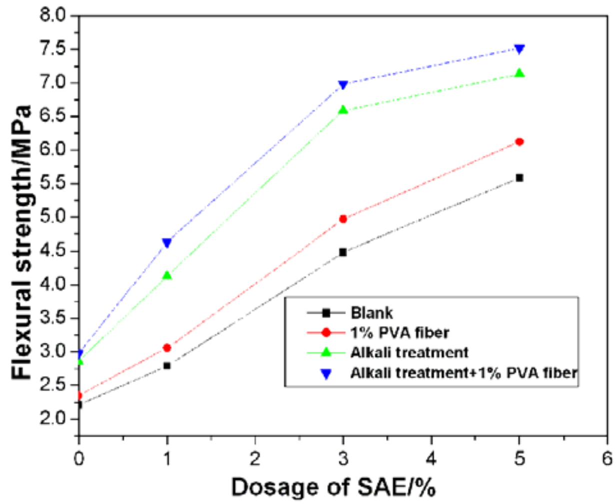

Fig. 1. Effect of content of SAE on Flexural Strength of the composites

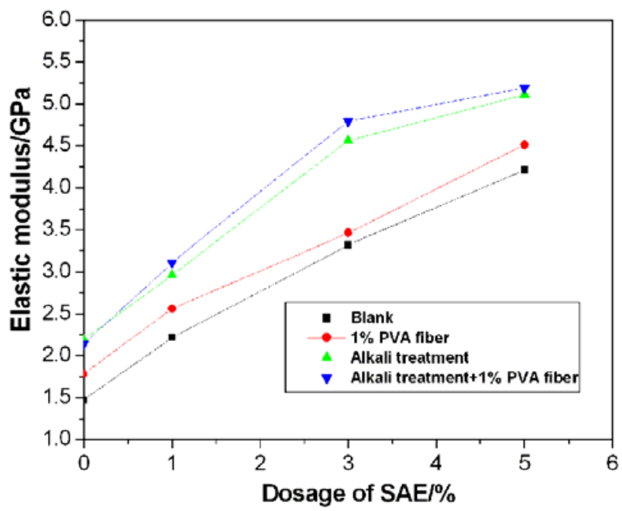

Fig. 2. Effect of content of SAE on Elastic Modulus of the composites

FT-IR Spectra

The bands at 470 and 870 cm^{-1} may be due to the Si-O and Al-O stretching vibration of silicate and aluminate-groups. The bands at 1634 and 3434 cm^{-1} were due to the presence of calcium sulfate in the form of ettringite (mono & trisulfate) in the cement (Bensted *et al.* 1974), which indicated the heterogeneous character of the materials involving cement components which were hydrated and their infrared bands overlapped. The band at 870 cm^{-1} was consistent with C_2S and C_2S phases (Singh *et al.* 2003) and/or the presence of $\nu_2(CO_3)$. The band at 1421 cm^{-1} showed the presence of carbon dioxide/$\nu_3(CO_3)$ (Singh *et al.* 2003). Position of the peak also shifted to 1458 cm^{-1} because of metal carboxylate formation in the mixes (Rodger *et al.* 1985). The bands at 1465 and 1100 cm^{-1} were due to the presence of C-S-H in the cement. The bands at 1635 and 3445 cm^{-1} were due to the presence of calcium sulphate in the form of ettringite (mono and trisulphate) in cement. The band at 1417 cm^{-1} showed the presence of carbon dioxide.

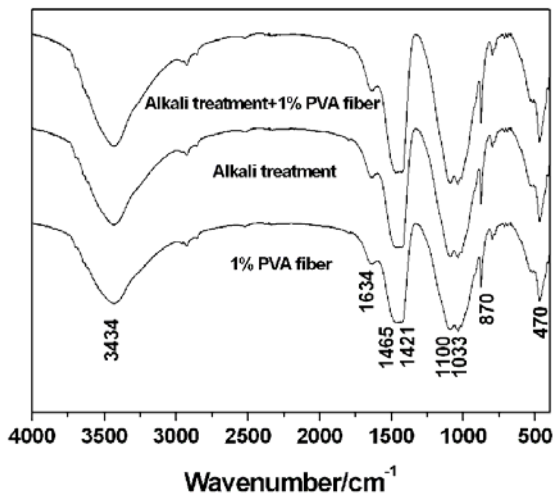

Fig. 3. FT-IR of rice husk-cement composites

X-Ray Diffraction Analyses (XRD)

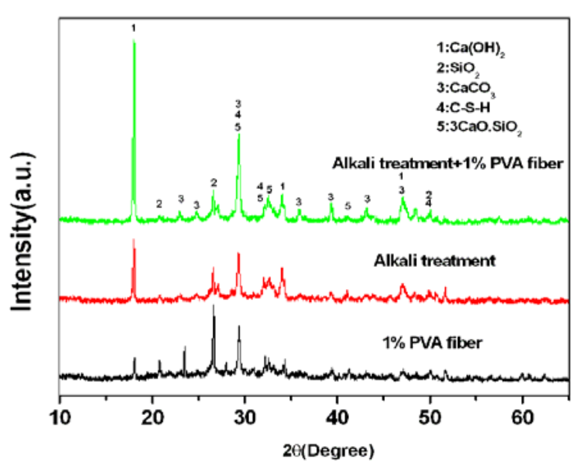

Fig. 4. XRD patterns of rice husk-cement composites

The XRD patterns indicating the hydration polymer modified cement were shown in Fig. 4. The expected crystalline hydration products are evident. Calcium hydroxide was formed with appreciable amounts and remained a good crystalline reaction product throughout the period of investigation. The amount of $Ca(OH)_2$ and C–S–H phase increased with alkali treatment and with the addition of PVA fiber. Calcium carbonate was formed after 28 days of curing age (Fig. 4). The relative amount of calcium carbonate in these XRD patterns can be attributed to the carbonation of $Ca(OH)_2$. In the case of C_3S phases, the peaks of maximum intensity overlapped with those of calcium carbonate, which made its evolution difficult to determine. The amount of C_3S phases decreased with alkali treatment and the addition of PVA fiber. The peak of SiO_2 may be from the rice husk.

Scanning Electron Microscopy (SEM)

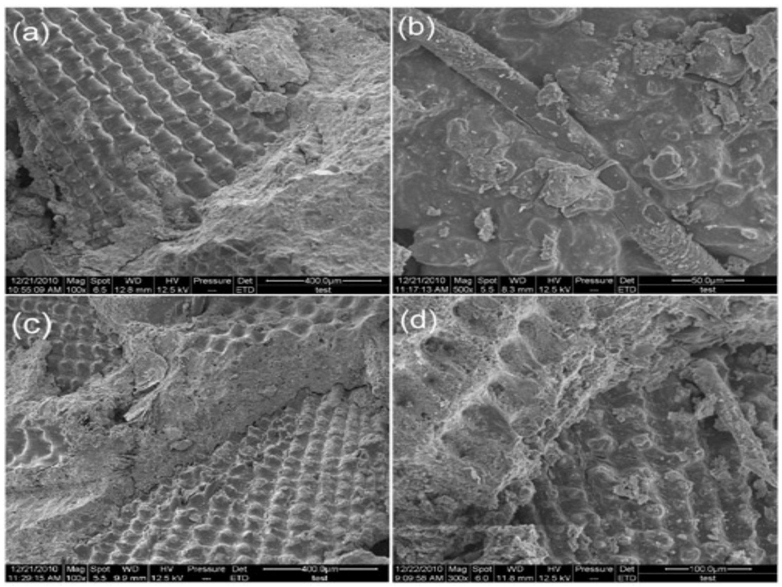

Fig. 5. SEM photographs of rice husk-cement composites

Fig. 5(a) shows the SEM of the control. Gaps existed in the cement composites, so the combination is unsatisfactory. Figure 5(b) is an SEM picture of the composites adding PVA fiber. PVA fiber had the tendency for conglobation with poor dispersion in the cement matrix. But PVA fiber has many hydroxyl groups, and in the process of hydration, the fiber combined with the cement and controlled the crack in the cement matrix to some extent to improve the microstructure of the composites. Fig. 5(c) is the SEM picture of the composites adding SAE. The styrene-acrylic emulsion formed the network structure in the cement matrix and controlled the fracture site structure effectively to improve the situation of rice husk and the combination of cement, so the mechanical properties of cement-based composites were improved. Fig. 5(d) is an SEM picture of the composites adding SAE and treated with sodium silicate. It can be clearly observed in the composites the rice husk and cement were integrated closely. Sodium

Silicate prevented leakage of carbohydrate and then formed a protective layer on its surface to improve the performance of the composites.

CONCLUSIONS

1. The styrene-acrylic emulsion formed the network structure in the cement matrix and controlled the fracture site structure effectively to improve the combination between rice husk and cement. So, styrene-acrylic emulsion can improve the flexural strength of cement composites and elastic modulus, thus SAE is an effective additive for reinforcing the composites.
2. Sodium Silicate can prevent leakage of carbohydrate and then form a protective layer on its surface to improve the performance of the composites. The mechanical properties of composites have been greatly improved with alkali treatment on rice husk.
3. The mechanical properties of the composites adding PVA fiber were not improved obviously. Maybe PVA fiber had the tendency for conglobation, so it had poor dispersion in the cement matrix.

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