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Properties and microstructures of plant-fiber-reinforced cement-based composites

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Abstract

The effects of microstructures and interface situation on the properties of plant fiber cement-based composite materials with steel slag were studied. The hydration mechanism of matrix materials adulterated with steel slag was discussed. Meanwhile, the mechanical properties of plant fiber cement-based composite materials have been effectively improved through treating the surface of plant fiber by urea–formaldehyde resin. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Cement; Plant fiber; Microstructures; Hydration mechanism; Interface

1. Introduction

In recent years, plant-fiber-reinforced cement composites have been considerably developed. Wood-fiber-reinforced cement and gypsum shaving boards have been broadly applied to many areas. In some developed countries, many companies have developed series of equipment and suitable technology for manufacturing these products.

In many areas of the world, however, wood resources are so deficient that cement and gypsum shaving boards are limited. Straw derived from crops is a kind of annual plant fiber that abounds in most areas of the world. So many investigators have been engaged in the studies of the replacement of wood fiber by annual plant fiber.

This paper chiefly discussed the effects of matrix microstructure and interface situation on properties of plant fiber cement-based composite materials with steel slag.

2. Experimental

2.1. Materials

Cotton straws were dried and smashed to 5–20 mm long. Ordinary Portland cement as specified in GBs (China national standards) was used in all the mixes.

Steel slag was ground to through 170 mesh. The chemical compositions of cement and steel slag are given in Table 1. Calcined gypsum powder, water glass (modulus is 2.6), lime powder and urea–formaldehyde resin are commercial goods.

2.2. Process technology and equipment

First, mix ordinary Portland cement, plant fiber and steel slag at a ratio of 5:2:3 in the mixer (JSI95a) under dry conditions. Secondly, add some water to put the mixtures into a uniform and semi-dry condition. After that, put the mixtures on the mold and then put the mold under the compressor. Finally, compress the mixtures for 4 h at a pressure of 2.8 MPa to prepare the specimens (10-mm-thick board).

Add calcined gypsum powder of 3% and lime powder of 2% to replace the equivalent quantity of cement, add water glass solution of 2%, and finally repeat the experiment as described in Ref. [1].

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Table 1
Chemical compositions of cement and steel slag (%)

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	IL
Cement	21.24	6.56	4.30	61.96	2.58	1.87	1.68
Steel slag	16.10	10.28	27.80	37.02	6.32	–	–

Treat the cotton fiber with urea–formaldehyde resin, and then repeat the experiment as described in Ref. [l].

In order to treat the plant fiber, the urea–formaldehyde solution is vaporized with an atomizer, and the pressure of the atomizer is controlled in the range of 0.2–0.25 MPa so that the urea–formaldehyde resin can be evenly sprayed on the surface of cotton straw fiber.

2.3. Method of testing

The flexural and tensile strength, the retained percentage of flexural strength after immersion in water for 24 h and the percentage of expansion in thickness after immersion in water for 24 h are tested by the standard (JC411-91) of the cement shaving board.

The microstructure of hydration products in the matrix of the board is observed with scanning electron microscopy (SEM; Hitacuis-2500).

3. Results and discussion

3.1. Mechanical properties and testing results

The mechanical properties of the specimens, tested by the methods in the above experiment, are given in Table 2.

3.2. Mechanism of matrix hydration

Polyose, alcohol and tannin, which are released from the cotton straw fiber, retard the hydration and hardening of cement in the reactive system that consists of cement, cotton straw fiber and steel slag. The test results show that in the presence of cotton straw fiber, setting time of cement is delayed for 1.2–1.5 h, long-term strength of the specimens is decreased by 8–10%. In general, in this system, steel slag does not react and only serves as a filler. In the system including gypsum, lime and water glass, gypsum and C_3A of cement reacted and formed ettringite as follows:

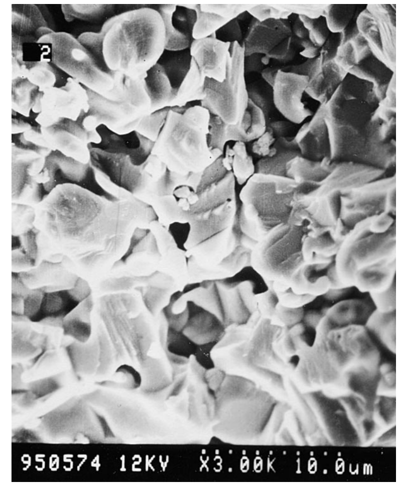

Fig. 1. Hydration of matrix without admixtures.

$$3CaO \cdot Al_2O_3 + 3(CaSO_4 \cdot 0.5H_2O) + 29.5H_2O = 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 31H_2O.$$

In this system, hydration products such as calcium silicate and CH were formed quickly. Meanwhile, the Ca^{2+}, OH^- and SO_4^{2-} ions quickly diffuse to the surface of steel slag grains. These ions destroy the glass structures and cause the activated SiO_2 and Al_2O_3 to be released from the surface of steel slag grains and then form CSH and CASH gel with other compositions. Due to the decreasing of $Ca(OH)_2$ formed from cement hydration, steel slag improves the hydration of C_2S in clinker. The gypsum in the matrix not only activates the steel slag, but also increases the early strength of specimens. Lime and water glass activate the reactivity of steel slag as an activator, and they also accelerate the formation of CSH gel in the system.

Polyose, alcohol, tannin, etc., which are released from cotton straw fiber, are good for uniform diffusion of hydration products; the actions of all the abovedescribed reduce the induction time and increase the diffusion rate of various ions. At this time, steel slag not only acts as a filler but also has high reactivity, so the reaction of the whole system is more complete.

Table 2
Mechanical properties of the specimens

	Properties			
Specimens	Flexural strength (MPa)	Tensile strength (MPa)	Retained percentage of flexural strength[a]	Percentage of expansion[a]
Cement:plant fiber steel slag = 5:2:3	7.86	0.34	76.2	2.4
With gypsum, lime and water glass	9.28	0.52	82.0	2.0
With fiber treated by urea–formaldehyde	11.83	0.58	90.1	1.2

[a] The specimens are immersed in water for 24 h.

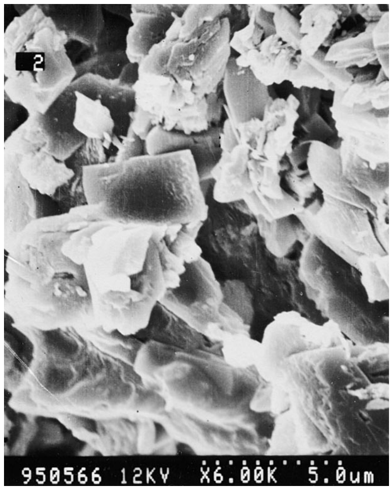

Fig. 2. Hydration of matrix with admixtures.

The large quantities of CSH gel formed from the above reaction fill the cracks between ettringite, cement and steel slag. They act as a coupling agent; the inner structure of matrix has been improved and the density of the matrix has been increased. Thus, the mechanical strength is increased by 18%, and the water-resistant ability is considerably improved, which agrees well with the observed microstructured characteristics (Figs. 1 and 2).

3.3. Interface analysis

The SEM of interfaces between matrix and untreated fiber is illustrated in Fig. 3. The SEM shows that the interface layers are loose and some cracks appear between matrix and fiber.

The SEM of a broken section with treated fiber is show in Fig. 4. The SEM image shows that the surface of the fiber is smooth. It is indicated that adhesion between fiber and matrix is not good; the fiber and matrix appear to have separated before breaking. This interface situation will result in lower mechanical strength.

Fig. 3. Interface between matrix and untreated fiber.

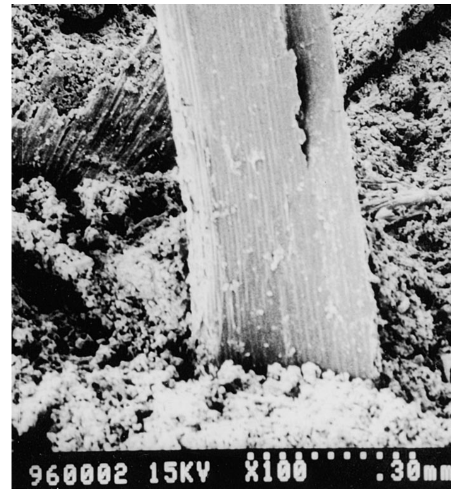

Fig. 4. The SEM of section with untreated fiber.

A SEM image of the interface situation with fiber treated by urea–formaldehyde resin is given in Fig. 5. It is indicated that the fiber and matrix combine tightly with gel embedded into the space and small holes appearing on the concave surface spots of the fiber that cause the fiber ‘anchor’ in the matrix.

The SEM of a flexural broken section is shown in Fig. 6, indicating that the surface of the fiber adheres tightly to the matrix materials.

The study results show that urea–formaldehyde resin and treated fiber have good properties in adhesion. When fiber and matrix combine, organic compositions and hydration products in the matrix diffuse each other. These cause more complete hydration reaction, and form solid and densified interface layers. When the specimens are broken, the cracks do not develop through the interface but transfer to the interior matrix. In this mechanism of breaking, more energy will be consumed, and the flexural strength will increase by 50%. Meanwhile , because the plant fibers, which have high

Fig. 5. Interface between matrix and treated fiber.

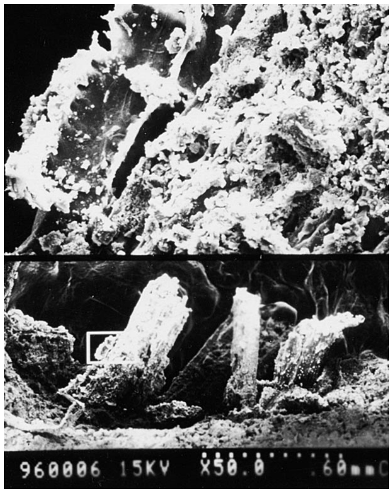

Fig. 6. The SEM of section with treated fiber.

water absorption, are embraced by densified interface layers, the properties of water resistance and water absorption expansion have been considerably improved (Table 2).

4. Conclusions

The properties of plant-fiber-reinforced cement composite materials depend upon the structures of matrix and interface layers.

In the plant-fiber-reinforced cement composite materials with steel slag, the reactivity of steel slag has been effectively activated through adding just the right amount of gypsum, lime and water glass. Due to the large amount of formation of CSH, which fills the space of the structures between grains, the microstructures and the properties of matrix have been improved.

The resin and fiber adhere tightly when the fiber is treated with urea–formaldehyde. Due to the formation of solid and densified interface layers, the strength and water-resistant ability have been remarkably increased.

References

[1] L. Wei, J Shandong Univ Build Mater 6 (3) (1992) 43–46.