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Properties study of cotton stalk fiber/gypsum composite

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Abstract

This manuscript addresses treating cotton stalk fiber surface with styrene acrylic emulsion, which improves the interfacial combined state of cotton stalk fiber/gypsum composite effectively and improves its mechanical properties notably. Mixes less slag, ordinary Portland cement, etc., to modify gypsum base. The electron microscope was utilized to analyze and research on the effect on composite properties of the abovementioned mixtures.

Keywords: Cotton stalk fiber; Gypsum; Composite; Interface; SEM

1. Introduction

Gypsum-base composites are receiving more and more extensive application in the development of new-type wall body materials. A lot of companies in other countries have put out new-type building materials that compound gypsum with wood shaving, and have successfully developed several kinds of production equipment. This kind of composite has the following merits:

1. Low density (1000–1200 kg/m^3), good properties of insulating against heat and sound and high rate of strength/density make it fit to be used as raw material of light partition wall.
2. Cheap price and wide source make the production costs very low.
3. Good technology property and simple manufacture technology make it suitable for producing in enormous quantities.
4. Low thermal expansion coefficient and absorbing water expansion coefficient are helpful in dealing with wall-board crack.

In China, [1,2] because timber resources are very limited, the researches on substituting crops fiber for wooden shaving as strengthening material have very important practical meanings and this work has attracted the attention of many material scientists. This article mainly discusses the properties of cotton stalk fiber/gypsum composite and the impact on microstructure of composite and interfacial combination by mixing slag, Portland cement and styrene acrylic emulsion.

2. Experimental

2.1. Raw materials, shape technology and equipment

The materials are prepared as follows. Mix β-hemihydrate gypsum powder, slag that was ground through 170 mesh and cotton stalk fiber that was crushed by disintegrator first, and then press with wheel, with a length of 5–20 mm and a diameter of 0.5–3 mm at a ratio of 5:3:2 by weight, and mix evenly in JS195A glue sand blending machine, then add the right amount water and mix evenly again. The material is at half-dried state at this moment. Spread the material evenly on the mould, then send onto 50-C-1 pressing shaping machine. Hold for 40 min under 2.8 MPa pressure then get the board, which has a thickness of 10 mm.

Mix 3% lime powder and 2% ordinary Portland cement among base body material, substituting the gypsum powder of equal weight, then repeat the abovementioned experiments.

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Repeat the abovementioned experiments after treating cotton stalk fiber with styrene acrylic emulsion in advance. The method of treating cotton stalk fiber is by using empty press machine and spray gun to make styrene acrylic emulsion atomization, and then spraying on the surface of the cotton stalk fiber evenly. Generally speaking, 120 g of styrene acrylic emulsion can spray evenly 1000 g of cotton stalk fiber.

After doing these three groups experiments, put them into room with temperature [3] of 20 ± 0.5 °C and relative humidity of more than 95% for 14 days.

2.2. Sample testing

(1) Adopt HITACHI S-2500 scanning electron microscope to examine the hydration products and the microstructure of base body material.

(2) Process the panel into 30 samples respectively, per treatment with $250 \times 50 \times 10$ mm, and test bending strength, modulus, absorption ratio and thickness expand ratio after absorbing water with five samples each and strength after absorbing water/strength before absorbing water with five samples, respectively, of the panel consulting the standard JC411-9l—the People's Republic of China board of saw dust of cement. Examine the fracture state of samples, which have been bended to be destroyed with S-2500 SEM.

3. Results and discussion

3.1. Test results

Physical and mechanical properties of test results of various kinds of modified gypsum-based composites are shown in Table 1.

3.2. Solidification mechanism of matrix materials

The solidification mechanism [4] of gypsum-base cotton stalk fiber composite is comparatively complicated. Firstly, gypsum cementation material has comparatively obvious air-hardening characteristic. Secondly, calcium aluminate crystal is formed with the reaction of gypsum and C_3A in cement, and the react equation is as follows:

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

Among the multicomponent system of gypsum, slag, Portland cement, lime and the organic additives, the silicate component part of the cement can form hydrate rapidly, such as calcium silicate and calcium hydroxide. At the same time, Ca^{2+}, OH^- and SO_4^{2-} that exist in the system spread to the surface of the slag particle rapidly, destroy vitreous body structure of slag particle further, make active SiO_2 and Al_2O_3 dissolved from the surface of slag particle and then form CSH and CASH gel with other components. Because of the abovementioned reaction, it consumed $Ca(OH)_2$ produced by cement hydration. On one hand, cement plays the alkaline-exciting function to the slag. On the other hand, slag promotes the hydration reaction of C_2S and C_3S in cement clinker. The gypsum of matrix material plays the sulphate function of exciting the slag. The common result of the abovementioned several reactions is to shorten the time of induced period, and to make the diffusion ability of different ions in the system strong and the reaction complete.

The organic component in the system helps the matrix of hydration products scatter evenly, which pack into the gaps among gypsum crystal, calcium aluminate crystal and slag particle with CSH gel finally, and plays a function of coupling agent. The pore structure of matrix improves, the close-knit degree increases and the bending strength improves by about 20%. At the same time, it makes the matrix more water-resistant and penetration-resistant. Scanning electron microscope pictures of the matrix hydration products illustrate this situation, which are shown in Figs. 1 and 2.

3.3. Fracture state analysis of a sample board which has been bended to destroy

In a composite formed by different materials, the interface exists between different phases. The function of an interface has a very important influence on macroscopic properties of the composite. Fig. 3 is the fracture state of bended sample that the fiber surface has not treated. It shows clearly that the fiber's surface is smooth, and matrix

Table 1
Physical and mechanical properties test results of various kinds of modified gypsum-based composites

Sample kind	A	B	C
Bending strength (MPa)	5.60 ± 0.52	6.86 ± 0.71	10.08 ± 0.79
Bending modulus (GPa)	3.22 ± 0.28	3.87 ± 0.45	3.65 ± 0.30
Absorbing water ratio (%)	20.20 ± 2.34	18.61 ± 1.56	14.36 ± 1.34
Absorbing water thickness expansion ratio (%)	2.32 ± 0.22	1.68 ± 0.17	0.86 ± 0.11
Strength after absorbing water/strength before absorbing water (%)	66.25 ± 2.37	76.14 ± 3.25	91.41 ± 3.10

Results of a set of 5 samples for bending strength, bending modulus, absorbing water ratio and absorbing water thickness expansion ratio, and 10 samples for strength after absorbing water/strength before absorbing water.

(A) Sample of gypsum:slag:cotton stalk fiber at 5:3:2. (B) Sample of adding 3% of lime and 2% of ordinary Portland cement. (C) Sample of adding 3% of lime and 2% of ordinary Portland cement. Furthermore, the fiber was treated with styrene acrylic emulsion in advance.

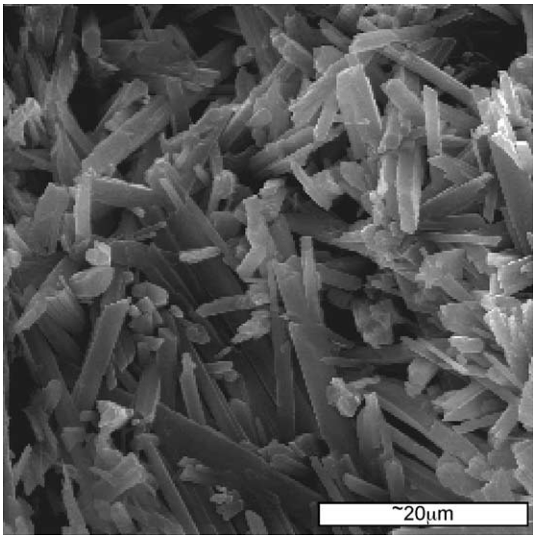

Fig. 1. Structure of the matrix of hydration products without adding lime and cement.

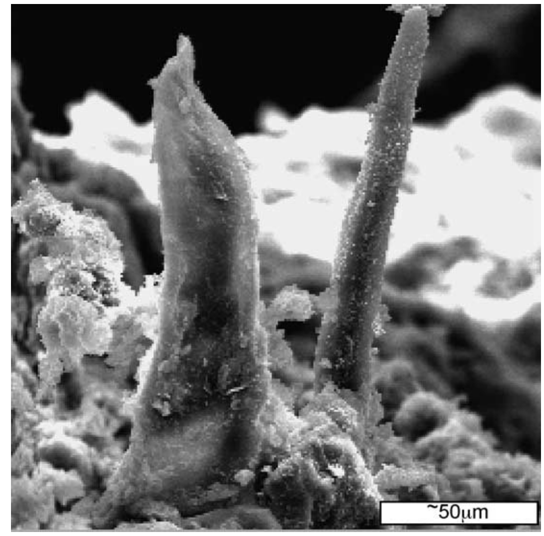

Fig. 3. Fiber fracture state of an untreated sample.

material does not glue and enclose with it, which proved that fiber and matrix material glue and enclose relatively poor, therefore, the strength of the sample is relatively low.

The samples prepared with fiber, which was treated with styrene acrylic emulsion, the state of which was pulled out from the matrix in its destroyed section, is shown in the Fig. 4. From the figure, we can see that a lot of matrix material remained on the pulled-out fiber's surface. This kind of interface bonding is firmer than the interface bonding in Fig. 3. So when samples are destroyed, cracks could not take place first at the interface of fiber and matrix, but at the interior of the matrix, which raised the whole compound effect of two materials. Thus, it shows an improved mechanical strength on macroscopic properties.

It is believed that fibers treated with styrene acrylic emulsion have good bonding properties. When the fiber and matrix are combined, organic emulsion on the interface and the hydration products of the matrix material diffuse reciprocally, and the organic emulsion density of this area is relatively high, which makes hydration reaction of the matrix more effective. It forms interfacial combining layer whose strength is higher than the strength of the matrix material itself.

3.4. Probing into structure of interfacial layer

Through the compound board's bending modulus experiment, it can be found that the bended modulus of Sample B

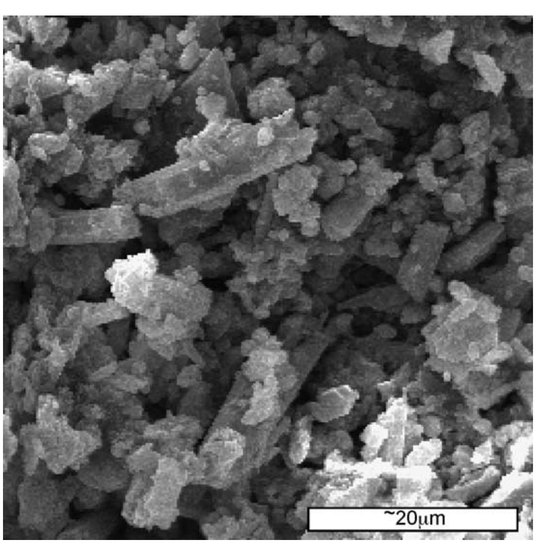

Fig. 2. Structure of the matrix of hydration products after mixing with lime and cement.

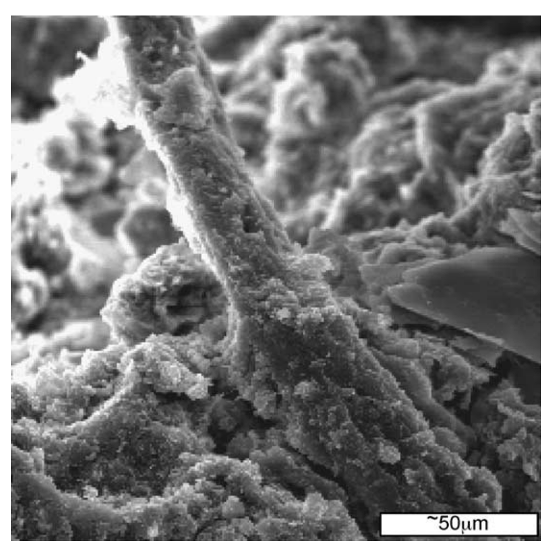

Fig. 4. Fiber fracture state of a treated sample.

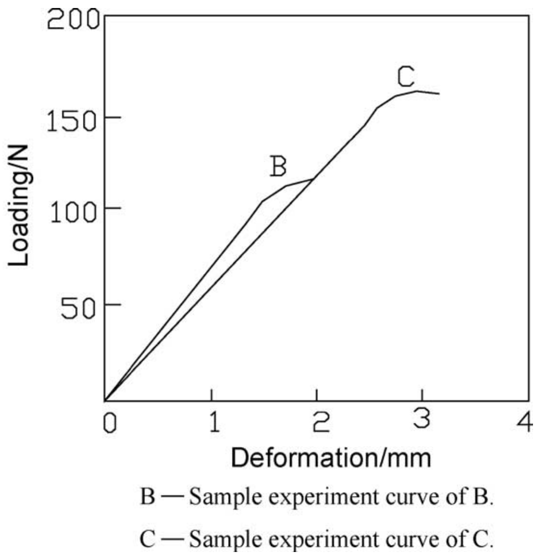

Fig. 5. Loading–deformation curves.

whose fiber is untreated is slightly higher than that of sample C whose fiber has been treated. Its bended loading–deformation curves are shown in Fig. 5.

The reason for this phenomenon is that a flexible interfacial layer was formed between the fiber treated with styrene acrylic emulsion and the matrix. When bearing loading takes places, the flexible interfacial layer deforms first, leading to the fact of the modulus on the low side. The existence of flexible interfacial layer is very helpful to the board's strength.

From the shaping process of cotton stalk fiber-reinforced gypsum-based composite, under the shaping press, along the pressure-loading direction, plastoelastic deformation and some parts of elasticity deformation take place on the cotton stalk fiber with different thickness. Because material in half-dried technology presents a disordered state, cotton stalk fibers must be in a state that allows some of them to be staggered across from each other. Under the loading pressure, the quantity of plasticity deformation and elasticity deformation produced in these interlock piles position is different from the other positions. After dispelling as shaping pressure, part of elasticity deformation of some cotton stalk fibers whose length–diameter ratio is smaller tends to return to its original shape, which causes "additional stress" in compound board, causing composites' trend to produce microcrackle inside, leading to the hidden danger of earlier breakage of the composites. Therefore, it has reduced their mechanical properties. When corroded by low molecular substance, such as water, the structure breakage will occur at stress-concentrated areas first.

After being treated with styrene acrylic emulsion, the deformable flexible interfacial layer between fibers and matrix, and among the fibers in the composites, relaxed the "additional stress" inside the composite, reduced some local stress concentration and improved macroscopic mechanical strength and the water-resistant property of the composite.

4. Conclusion

(1) The addition of ordinary Portland cement and lime, together with gypsum, plays a compound-exciting function to the activation of the slag. A large number of CSH gel formed in the system and packed into the gap of gypsum crystal, calcium aluminate and slag particle, which makes the structure of matrix become more and more compact and its mechanical strength and water-resistant property more improved.

(2) After being treated with styrene acrylic emulsion, the cotton stalk fibers can form a deformable flexible interfacial layer between fibers and matrix, the strength of which is stronger than that of the matrix. In addition, this interfacial layer has a certain flexibility. This flexibility will relax the additional stress in the course of shaping, and improve the whole strength and water-resistant property of the composites remarkably.

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