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Research on adaptability between crop-stalk fibers and cement

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Abstract

By analyzing the components of crop-stalk-fibers leachate, the effects of the leachate on the various properties of cement hydration such as water-reducing, slow-setting, hydration heat as well as the strength of hydrated cement were studied.

Keywords: Crop-stalk-fibers leachate; Process of hydration; Hydration heat

1. Introduction

Crop stalks belong to the agricultural surplus material. At present, the crop stalks in some areas have little rational applications except burning. This leads to the polluted environment. At the time of burning near the highway, smog influences sight, which can cause emergence of traffic accidents. In the last few years, the research about using crop stalks to process into fiber and producing composite have made relatively great progress. For example, these crop fibers and cement when compounding can produce products with good performance and low costs. Crop stalks of larger output are cotton stalk, wheat stalk, corn stalk, rice stalk, sorghum stalk, bagasse, peanut shell, etc. These crop stalks and cement when compounding have a unique characteristic because crop-stalk-fibers leachate have greater influence on hydration and stiffening of cement. Different properties of different crop-stalk-fibers leachate have different influence on hydration and stiffening of cement. By analyzing the components of crop-stalk-fibers leachate, this text has studied the influence of leachate on slow-setting, water-reducing, and hydration heat properties of cement, and expect effective action for using crop-stalk fibers.

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2. Experiment

2.1. Raw materials

The experiment adopts the slag Portland cement of 425#. Its chemical components are shown in Table 1.

Crop-stalk fibers that this experiment adopts include cotton stalk, wheat stalk, and corn stalk. The fibers were crushed with a feed grinder to 3–10 mm long, then weighted at 400 g each. They were then soaked for 24 h with 800 ml water, and the different types of crop-stalk-fibers leachate were made after filtering.

2.2. Components analysis of crop-stalk-fibers leachate

Refs. [1–3] show that the components of leachate are mainly polypentaglucose saccharide, lignin and inorganic salts ion if crop-stalk fibers were being sodden in cold water. We adopted a gaseous phase chromatogram to analyze quantitatively saccharide and lignin. But because their heat stabilities are relatively poor, and they carbonize easily, they must be treated before carrying on chromatogram analysis. Analysis outline is shown in Fig. 1, the test results are shown in Table 2.

2.3. Test of standard consistence, setting time and strength

Cement and quartz sand were mixed by the proportion of cement/quartz sand = 1:3, and leachate was added.

Table 1
Chemical components of slag Portland cement

Chemical components	Loss	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3
Quality percentage (%)	2.26	21.5	2.59	6.48	58.53	2.12	3.21

Table 2
Test results of crop-stalk-fibers cold leachate

Test items	Types of fibers		
	Cotton-stalk fiber	Wheat-stalk fiber	Corn-stalk fiber
Polypentaglucose ($\times 10^{-2}$ g/g fiber)	1.248	1.238	2.132
Lignin ($\times 10^{-2}$ g/g fiber)	1.238	1.422	1.580
Polypentaglucose ($\times 10^{-2}$ g/g H_2O)	0.624	0.619	1.066
Lignin ($\times 10^{-2}$ g/g H_2O)	0.619	0.711	0.790

These substances were mixed adequately and the consistency of the mortar was tested. If the consistency is too low, less leachate should be added until the standard consistency is achieved. The volume of leachate was recorded. Leachate was replaced with water to do the experiment to test the volume of water when the mortar is at standard consistency.

Cement and quartz sand were mixed by the proportion of cement/quartz sand = 1:3, and leachate was added to achieve a mortar of standard consistency. The setting time was tested according to GB 1346— the setting time test method of China. Accordingly, leachate was replaced with water to make a mortar of standard consistency to test the setting time of the blank sample. Average value of three test values of each type of leachate mortar was recorded. The results are shown in Table 3.

Cement and quartz sand were mixed by the proportion of cement/quartz sand = 1:3, and leachate was added to achieve a mortar of standard consistency. The mortar was poured into the mould of the size $40 \times 40 \times 160$ mm and was vibrated slightly to get rid of the air bubble inside the mortar. The test samples were cured for 24 h in standard room with a temperature of 20 ± 0.5 °C and a relative humidity of more than 90% before demolding. The samples were placed into the standard room for curing. Three samples were obtained to test for the compressive strength and three samples were taken to test for the bending strength, respectively, at 3, 7, 28, and 60 days. The average value of the three test values were recorded as the result. The test methods are according to the concrete relevant standard in China (GB J81-1985-Test methods of mechanics properties of concrete). The results are shown in Table 4.

2.4. Measure of hydration heat

Cement 400 g and quartz sand 400 g were weighed separately and then mixed and stirred for 1 min in a pan wiped with wet cloth first. Leachate 110 ml was added to the mixture which was mixed for 3 min before hydration heat was measured. The temperature was recorded every hour for 40 h, then every 2 h for 68 h. The effects of crop-stalk-fibers leachate on hydration heat of cement are shown in Fig. 2.

2.5. Analysis hydration products by SEM

The hydrated products were examined after 7 days by SEM.

3. Analysis and discussion

3.1. Properties of water-reducing and slow-setting of crop-stalk-fibers leachate

In can be found from Table 3 that the volume of water when the mortar is at standard consistency for blank

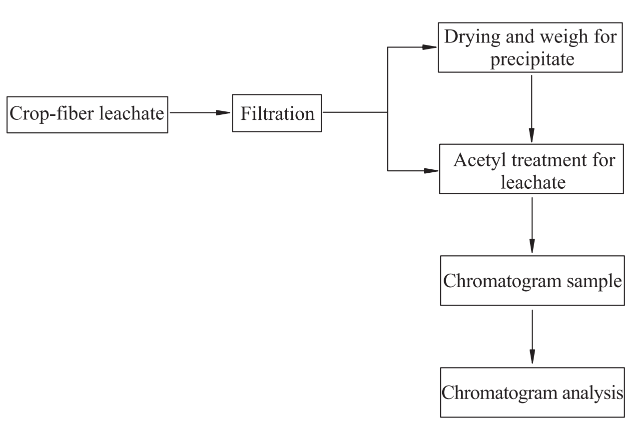

Fig. 1. Analysis outline of crop-stalk-fibers leachate.

Table 3
Results of the volume of leachate when mortar is at standard consistence and setting time of mortar

Sample types	Test items		
	The volume of leachate when mortar is at standard consistency (ml)	Initial setting time	Final setting time
Blank sample	140.8 ± 1.5	3 h 11 ± 7 min	5 h 51 ± 9 min
Cotton-stalk leachate	137.0 ± 1.0	4 h 16 ± 6 min	7 h 16 ± 10 min
Wheat-stalk leachate	136.2 ± 0.8	4 h 15 ± 7 min	7 h 10 ± 9 min
Corn-stalk leachate	129.0 ± 0.8	5 h 26 ± 5 min	8 h 30 ± 12 min

Table 4
Effects of crop-stalk-fibers leachate on concrete strength

Sample types	Test items							
	Bending strength (MPa)				Compressive strength (MPa)			
	3 days	7 days	28 days	60 days	3 days	7 days	28 days	60 days
Blank sample	3.90 ± 0.26	5.51 ± 0.23	7.31 ± 0.30	7.31 ± 0.25	24.72 ± 1.27	32.37 ± 1.85	46.10 ± 2.23	47.00 ± 1.72
Cotton-stalk leachate	2.70 ± 0.18	3.94 ± 0.20	6.16 ± 0.25	6.20 ± 0.28	12.10 ± 0.83	19.86 ± 1.07	38.75 ± 2.07	39.00 ± 1.50
Wheat-stalk leachate	3.18 ± 0.15	4.10 ± 0.19	6.15 ± 0.21	6.21 ± 0.19	16.11 ± 0.80	24.54 ± 1.40	42.30 ± 2.45	43.10 ± 1.75
Corn-stalk leachate	2.30 ± 0.14	3.15 ± 0.18	6.20 ± 0.22	6.18 ± 0.20	11.75 ± 0.75	17.80 ± 0.95	37.13 ± 2.12	38.60 ± 0.90

sample is the greatest, but the initial setting time and the final setting time are the shortest. Different types of crop-stalk-fibers leachate have different effects on standard consistency, initial setting time, and final setting time of the mortar. Among them, corn-stalk-fiber leachate has the most heavy influence, with a water-reducing volume of 11.8 ml when the mortar is at standard consistency, an initial setting time of 2 h and 15 min, and a final setting time of 2 h and 39 min. Cotton-stalk-fiber leachate and wheat-stalk-fiber leachate have approximately the same influences on standard consistency, initial setting time and final setting time of the mortar. The water-reducing volume are 3.8 and 4.6 ml, respectively, when the mortar is at its standard consistency; the initial setting time are 65 and 64 min, respectively; the final setting time are 85 and 79 min, respectively.

It can be found from Table 2, in the cold leachate of crop-stalk fibers, that the amount of polypentaglucose and lignin is greatest in corn-stalk fiber, and they are approximately the same in cotton-stalk fiber and wheat-stalk fiber. Polypentaglucose and lignin are both surface active materials with absorbing water performance, which has surface adsorption, orientation arrangement and reducing surface tension performances. When mixing the crop-stalk-fibers leachate and cement, the particle surface of hydration products adsorb lignin and polypentaglucose, which allow the cement particles and the hydrated particles of cement to have the same electric charges on the surface. The same nature function that electric charge repels each other makes it tend towards the state of dispersing, weakens parcel ability of water and shows water-reducing function on macroscopic.

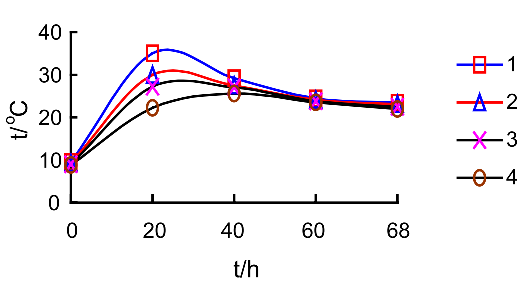

Fig. 2. The effects of crop-stalk-fibers leachate on hydration heat of cement. Curve 1 is the hydration heat curve of cement with blank sample; curve 2 is the hydration heat curve of cement with cotton-stalk-fiber leachate; curve 3 is the hydration heat curve of cement with wheat-stalk-fiber leachate; curve 4 is the hydration heat curve of cement with corn-stalk-fiber leachate.

Setting time and stiffening time of concrete are relational with mineral components of cement and gel structure of the cement gel system. However, crop-stalk-fibers leachates contain the active surface materials, such as saccharide, lignin, etc., which change the property of the particle surface of the glue gel system. Upon ion exchange, pairs of electricity layers of electric potential increase adsorption, surface tension among particles increase, thus increasing the stability of cement congeal system and showing the slow-setting of concrete on macroscopic.

Analyzing the strength experiment results as shown in Table 4, it indicates that the addition of various types of crop-stalk-fibers leachate has effected the strength development at 3 and 7 days of concrete, playing an obvious slow-setting function. Strengths on 28- and 60-day concrete samples containing various types of crop-stalk-fibers leachate are lower than the strengths of 28- and 60-day concrete samples without leachates. It shows that the crop-stalk-fibers leachates have a certain hindering setting function to the cement.

3.2. Effects of crop-stalk-fibers leachate on cement hydration

For the blank sample without the crop-stalk-fibers leachate, the highest hydration temperature that the hydration reaction could reach is 35.3 °C, and the time to reach the maximum temperature is 20 h, as shown as curve 1 in Fig. 2. But for the samples added the cotton-stalk-fiber leachate, the wheat-stalk-fiber leachate and the corn-stalk-fiber leachate, the maximum hydration temperature that the hydration reaction could reach are respectively 31.5, 29.1 and 26.3 °C. Correspondingly, the time to reach the maximum temperature are respectively 24, 27 and 33 h, as shown in curves 2, 3, and 4 in Fig. 2. It can be found that the maximum temperature of samples with crop-stalk-fibers leachate are obviously lower than that of the blank sample and the time to reach the maximum temperature lags obviously, too. Among them, the influence of corn-stalk-fiber leachate is the most remarkable, followed by the cotton-stalk leachate and the wheat-stalk leachate. Combining the test results in Table 2 that the content of polypentaglucose and lignin is the highest in corn stalk, and then in wheat stalk and cotton stalk, we find the main factor in the experiment that affects hydration heat is the content of polypentaglucose and lignin. Furthermore, as the content increases, the time of the peak of temperature comes later and the temperature of the peak becomes lower.

The hydration speed of the cement is very important to the forming process of the cement stone. It is known from the stiffening mechanism of cement that the hydration of cement can be interpreted from the following three stages. At the initial hydration stage, by adding the crop-stalk-fibers leachate, which plays a good scattering function to cement particle, effective areas of contact among cement increase, which accelerates hydration trend. The reaction is mainly on liquid phase at this moment, cement particles on surface that suspend in water are dissolved, hydration products begin to form, and the solution reaches saturation quickly. At the middle hydration stage, the hydration of the products increase, the solution becomes supersaturated from saturated, gel particles condense and separate out crystal gradually, crystal and gel precipitate around the cement, and a hydration product gel layer is formed. Saccharide and lignin contained in crop-stalk-fibers leachate can form adsorption layer on cement surface and influence abovementioned hydration products and reduce the hydration speed. At the last stage of hydration, hydration speed is controlled by the speed of diffusion of the products layer, hydration speed slows down gradually. This is why the peak value of hydration heat lags and the maximum temperature of hydration reduces on curves 2, 3, and 4 in Fig. 2.

From the hydration SEM pictures of 7-day cement samples, we can also see that the hydration speed of the blank sample is the fastest, and the sample is full of CSH gel, as shown in Fig. 3a. Accordingly, Fig. 3b, c, and d are respectively the hydration SEM pictures of samples mixed with cotton-stalk leachate, wheat-stalk leachate, and corn-stalk leachate. We can see from the three SEM pictures that the cement hydrations are not all completed with a little CSH gel. The connections among CSH are very incompact, distributing sparsely in the samples, which is the main reason why the strength of crop-stalk-fibers leachate concrete declines. In Fig. 3b and c, a little CSH gel distributes in the sample asymmetrically, and clusters around CSH are very small, which explains why polypentaglucose and lignin hinder cement hydration at a certain degree and depress the cement hydration process. In Fig. 3d, as far as CSH gel is concerned, comparing with Fig. 3b and c, CSH is sparser and it distributes asymmetrically in samples. It is because contents of saccharide and lignin in corn-stalk-fiber leachate are higher than those in cotton-stalk-fiber leachate and wheat-stalk-fiber leachate, and they hinder cement hydration. It further shows the contents of saccharide and lignin have great influence on hydration and stiffening of cement.

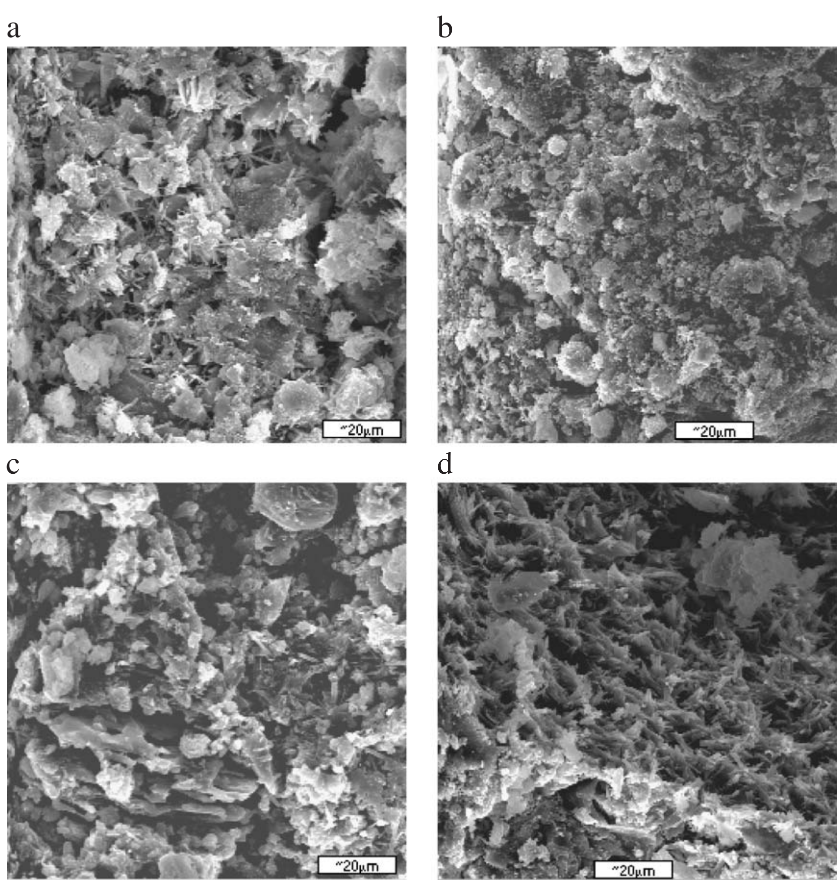

Fig. 3. The hydration SEM pictures of samples after 7 days.

4. Conclusions

We can draw the conclusions according to the research and discussion in the experiment:

1. The components of leachate of cotton-stalk fiber, wheat-stalk fiber, and corn-stalk fiber are roughly the same, but content is different, the main components are polypenta-glucose and lignin.
2. The leachate of cotton-stalk fiber, wheat-stalk fiber, and corn-stalk fiber has a slow-setting function and hindering setting function on hydration and stiffening of cement and reducing cement stone strength in various degrees. Experiment shows corn-stalk-fiber leachate has the greatest influence and wheat-stalk-fiber leachate and cotton-stalk-fiber leachate take second place.
3. The crop-stalk-fibers leachate has certain water-reducing capacity to cement. Under the concentration of leachate in the experiment, the water-reducing capacity of corn-stalk fiber is 7.9%, the water-reducing capacity of wheat-stalk fiber is 2.7%, the water-reducing capacity of cotton-stalk fiber is 2.1%.

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