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Effects of compression ratio on water resistant properties of biomass brick

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HIGHLIGHTS

- Water resistance of brick is decreasing with the increasing compression ratio.
- Water resistance of brick is increasing with the expanding time from 0 to 168 h.
- Water absorption rate of brick is decreasing with the increasing compression ratio and the expanding time from 0 to 12 h.
- Deformation rate and expansion coefficient in thickness of brick is the greatest in the three directions.

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ABSTRACT

In order to study effects of compression ratio on water resistant properties of biomass bricks, which are made from poplar wood and corn stalk fibers and calcium hydroxide with different compression ratios, they are soaked for 168 h in warm water at 30 °C. The results show that water resistant and dimensional stability of bricks are good. Water absorption contents of bricks are decreasing with the increasing compression ratios, and they are increasing with expanding time. Water absorption rates of bricks are decreasing with the increasing compression ratio and expanding time. Dimensional deformation rates of bricks in thickness are greater than ones in width and length.

1. Introduction

There are about 0.549 billion m^3 poplar wood stock volume in the world, and 0.25 billion tons corn stalk in China [1]. Calcium hydroxide is an inorganic binder as the earliest adhesive in history[2]. Calcium hydroxide is used as an adhesive to manufacture the light biomass brick with poplar wood and corn stalk fibers for indoor partition wall, which provides an effective way to utilize the poplar wood and corn stalk and realizes the merger of the stalk and architecture industries, solves the problem about the serious resources and energy and environmental pressure of construction industry and explores a new way for agricultural economy [3–5]. New brick is similar to the properties of the wood, which is good sense in touch and warmth and decoration surface. It can adjust the relative humidity of indoor air, improve the indoor environmental quality and increase the housing habitability with the characters of moisture desorption and absorption. It follows the lightweight trend for wall material development in the world [6].

Biomass brick is molded from the loose accumulation body to dense entity [7]. The mixture is squeezed and moved and bonded, the interspaces between fibers becomes smaller, and the contact area increases, so that fibers can be connected each other. There are hydrogen bond, Van der Waals' force, glue nail and interwoven friction, and chemical bond in the brick, which is contributed to the compressive strength [8,9]. At the same time, carbon dioxide reacts with calcium hydroxide to produce calcium carbonate, which can increase the strength of the brick [10–18].

Biomass brick is made from wooden fibers, its dimensional stability is affected by the water, and the utilization of brick is decided by the dimensional stability. Compression ratio is an important process parameter, which affects the compressive degree and the water resistance. Therefore, effects of compression ratio on water

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resistant properties of biomass brick including water absorption and dimensional deformation rate and density, are studied in the article, which provide a basic theory for manufacture and application of biomass brick.

2. Materials and methods

2.1. Materials

Properties about poplar wood and corn stalk fibers and calcium hydroxide are shown in Table 1. The ratio of poplar wood fiber, corn stalk fiber, calcium hydroxide in one brick is equal to 7:1:44. Compression ratios between the mixture and the loaded brick, absolute drying mass and dimensions of biomass bricks are shown in Table 2. The test process of biomass brick is shown in Fig. 1.

Brick is molded in the press machine (Model MY 50B, Qingdao Jilongchang Equipment Machine Co., Qingdao, China), in which the press is equal to the greatest load when the head is pressed into the bucket completely, the keeping press time is equal to 1 min, and the temperature is equal to room temperature. It is dried for 48 h in the hot air drying house (Model 4.5 m × 2.8 m × 3.0 m (length and width and height), Jinan Longxiang Painting Equipment Co., Jinan, China), where it is 50 °C in air temperature, 32.2% in relative humidity of air and 0.12 m/s in air velocity. The heating rate is 1.2 °C/min and the precision is 0.1 °C. The relative humidity and temperature of air are measured using a temperature humidification electrical meter (Model 310 RS-232, Center Technology Co., Taiwan, China), and the velocity is measured using a thermo ball electrical wind velocity meter (Model QDF-3, Inspection Equipment Co., Beijing, China).

Then, biomass brick is dried to the absolute drying in a hot air drying box (Model DUG 9123A, Shanghai Jinghong Experiment Instrument Co., Shanghai, China) with the precision of 0.1 °C, where the hot air temperature is 50 °C. Mass of absolute drying brick is measured using an electrical balance (Model JA21002, Shanghai Jingtian Electrical Instrument Co., Shanghai, China) with a precision of 0.01 g. The dimensions of absolute drying brick are measured with three-keyboard digital calipers (Wuxi Kaibaoding Tool Co., Model Rohs Rorm 2002/95/EC, Wuxi, China) with a precision of 0.01 mm.

Absolute drying brick is soaked for 168 h in the thermostat water bath (Model DKB-600B, Shanghai Yiheng Science Instrument Co., Shanghai, China), where the temperature of water is 30 °C with the precision of 0.1 °C. During the soaked time stage between 0 and 12 h, mass is balanced and dimension is measured once every 2 h. However, during the soaked time stage between 12 h and 168 h, mass is balanced and dimension is measured once every 12 h.

Compressive strength is tested with the electrical strength test machine (Model DTH-300B, Shandong Luda Test Measurement Machine Co., Taian, China) when the brick is soaked for 168 h. The brick is loaded vertically in the thickness direction by the movement velocity in 1.0 mm/min. It is the compressive strength when the deformation reaches 2.5 mm in thickness direction. The brick can recovery its dimension as same as before testing when it is unloaded.

3. Results and discussion

3.1. Studies on the water absorption contents of biomass bricks

3.1.1. Effects of compression ratios on the water absorption contents of biomass bricks

Water absorption content of brick is decreasing with the increasing compression ratio between 0 and 168 h when the soaked time is same in Fig. 2. It ranges from 46.93% to 58.69% between 0 and 12 h when the compression ratio is same, however, it ranges from 0.75% to 4.14% between 12 h and 168 h. Therefore, the stage between 0 and 12 h is very important for the water absorption content.

Water absorption content of brick is decreasing with the increasing compression ratio excluding out 2.8 between 0 and 12 h when the soaked time is same in Fig. 3. It ranges from 31.60% to 56.07% between 0 and 2 h when the compression ratio is same, however, it ranges from 2.62% to 12.38% between 2 h and 12 h. Therefore, the stage between 0 and 2 h is very important for the water absorption content.

When the compression ratios are different in Fig. 4, water absorption content of brick ranges from 31.60% to 56.07% with the difference of 24.47% for 2 h. It ranges from 38.93% to 57.84% with the difference of 18.92% for 4 h, 42.51–58.21% with the difference of 15.71% for 6 h, 44.57–58.40% with the difference of 13.52% for 8 h, 46.37–58.35% with the difference of 11.98% for 10 h, 46.93–58.69% with the difference of 11.76% for 12 h. The relationship between water absorption content and compression ratio is in accordance with mathematical function (1), (2), (3), (4), (5) and (6) when the soaked time is equal to 2 h, 4 h, 6 h, 8 h, 10 h, 12 h separately.

$$y = -0.6651x^5 + 11.771x^4 - 78.417x^3 + 244.22x^2 - 356.2x + 235.36 \qquad R^2 = 1 \tag{1}$$

$$y = -0.6012x^5 + 10.521x^4 - 690.017x^3 + 210.22x^2 - 297.34x + 204.06 \qquad R^2 = 1 \tag{2}$$

$$y = -0.4588x^5 + 7.9844x^4 - 52.052x^3 + 157.6x^2 - 222.38x + 167.52 \qquad R^2 = 1 \tag{3}$$

$$y = -0.329x^5 + 5.7203x^4 - 37.343x^3 + 113.77x^2 - 163.19x + 139.77 \qquad R^2 = 1 \tag{4}$$

$$y = -0.1945x^5 + 3.4266x^4 - 22.818x^3 + 71.668x^2 - 107.92x + 114.19 \qquad R^2 = 1 \tag{5}$$

$$y = -0.1155x^5 + 2.1016x^4 - 14.631x^3 + 48.785x^2 - 79.401x + 101.95 \qquad R^2 = 1 \tag{6}$$

where, y is water absorption content, %; and x is compression ratio.

When the compression ratios are different in Fig. 5, water absorption content of brick ranges from 47.63% to 58.43% with the difference of 10.80% for 24 h. It ranges from 47.93% to 58.29% with the difference of 10.36% for 36 h, 48.30–58.29% with the difference of 10.88% for 48 h, 48.48–59.04% with the difference of 10.55% for 60 h, 48.67–59.49% with the difference of 10.82% for 72 h, 48.63–59.17% with the difference of 10.54% for 84 h, 48.87–59.41% with the difference of 10.54% for 96 h, 48.88–59.48% with the difference of 10.60% for 108 h, 48.95–59.55% with the difference of 10.60% for 120 h, 49.01–59.33% with the difference of 10.32% for 132 h, 49.04–59.59% with the difference of 10.55% for 144 h, 49.03–59.38% with the difference of 10.35% for 156 h, 49.12–59.45% with the difference of 10.33% for 168 h.

The relationship between water absorption content and compression ratio is in accordance with mathematical function (7), (8), (9), (10), (11), (12), (13), (14), (15), (16), (17, (18) and (19) when the soaked time is equal to 24 h, 36 h, 48 h, 60 h, 72 h, 84 h, 96 h, 108 h, 120 h, 132 h,144 h, 156 h and 168 h separately.

Table 1
Moisture content and density of raw materials.

Raw materials	Poplar wood fiber		Corn stalk fiber		Calcium hydroxide	
	Range	Mean	Range	Mean	Range	Mean
Moisture content (%)	8.31–11.76	10.19	15.56	15.56	47.06–52.28	50.78
Density (g/cm^3)	0.053–0.075	0.067	0.073	0.073	1.271–1.340	1.311