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Waterproof properties of thermal insulation mortar containing vitrified microsphere

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HIGHLIGHTS

- Effect of the content of vitrified microsphere on the waterproof properties.
- Effect of hydrophobically-modified aggregate on the waterproof properties.
- Effect of hydrophobically-modified cementing material on the waterproof properties.
- Comparison of two methods of hydrophobically-modified.

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ABSTRACT

The waterproof indicators including water absorption, impermeability and wettability were evaluated in this paper. First, the optimum vitrified microsphere (VM) content was determined according to the fundamental performance, water absorption and impermeability of the thermal insulation mortar. The influence of water to cement ratio (w/c) on consistency of the mortar was then investigated. The results indicated that when w/c was 1.4, the mortar was favorable in terms of workability, strength and durability. The test results showed that the hydrophobic treatment of VM surface was beneficial to the reduction of water absorption. Two hydrophobic treatment methods, i.e., coating with organosilicon hydrophobic agent (OHA) on VM or blended OHA with cement were compared. According to the testing results of water absorption, the water level decline and water seepage depth, blending OHA with cement was more effective to improve the waterproof performance of the thermal insulation mortar.

1. Introduction

Unlike the traditional heat insulation lightweight aggregate involved in architecture engineering, i.e., expanded perlite and polystyrene particles, vitrified microsphere (VM) is characterized by relatively higher strength and better fire resistance. Due to its favorable overall performance, the VM thermal insulation mortar has attracted increasing attention [1–3]. The researches related to the VM thermal insulation mortar primarily focused on mechanical properties, thermal characteristics, and fire resistance. S.P. McBride et al. [4] studied the mechanical properties of lightweight concrete using VM. The results indicated that the high content of VM significantly lowered the density and strength of concrete. Li et al. [5] analyzed the mix proportion and mechanism of VM thermal insulation mortar and the results demonstrated that the VM content was responsible for the reduction of thermal conductivity and compressive strength. Md. Akhtar Hossain [6] found that in the absence of a superplasticizer, when the temperature was less than 200 °C, both the compressive strength and tensile strength of the cement mortar containing fly ash increased as the temperature increased, and the cement mortar was optimally resistant to high temperature when fly ash replaced 50% of the cement. Derek Kramar and Vivek Bindiganavile [7] explored the effects of the dry density of lightweight mortar using expanded VM on its mechanical properties. Fang et al. [8] revealed the correlations among the dry density, compressive strength and thermal conductivity of the thermal insulation mortar. Recently, the fire resistance of thermal insulation mortar containing VM has been attracted increasing attention [9].

As indicated above, thermal insulation mortar containing VM is generally characterized by favorable thermal insulation and relatively high strength when compared to thermal insulation mortar made with other types of traditional lightweight aggregate. However, there have been few studies carried out on its waterproof properties. Actually, the hydrophilicity of VM and cement and

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the porous structure of VM affect negatively the waterproof performance of the thermal insulation mortar. Consequently, high water absorption and permeability can often be observed, which is devastating for the exterior thermal insulation wall [10,11]. Water exists in thermal insulation mortar in the phase of solid, liquid or gas, and the existence and migration of these three forms of water can seriously weaken the thermal insulation system, which then manifests as such problems as freezing, leakage, and water vapor diffusion [12–17]. When a leak occurs in an external thermal insulation system, the decline of thermal insulation can often be observed. Additionally, in case of temperature rise or even fire, the migration of water vapor that is intended to be restrained by the thermal insulation mortar, can produce enormous stress inside the mortar, thus resulting in the mortar cracking or even falling. In winter, in process of freezing, the 9% volume expansion produces considerable tensile stress in the thermal insulation mortar, thus causing the entire thermal insulation system to crack or even fall off. In addition, water can serve as a carrier that triggers the chain reaction of a thermal insulation system, e.g., the chemical and physical erosion. Therefore, improving the waterproof performance of VM thermal insulation mortar can help improve the stability and durability of its thermal insulation in the presence of moisture [18].

This paper mainly aims to study the waterproof performance of the thermal insulation mortar containing VM. First, the thermal insulation mortar was prepared which could meet the physical and mechanical requirements of the specification. Then, the water absorption, impermeability and wettability were researched. Methods to improve the waterproof performance of the thermal insulation mortar, coating organosilicon hydrophobic agent (OHA) with VM, or blending OHA with the cement was compared.

2. Experimental program

2.1. Raw materials

The raw materials involved in this study is listed in Table 1. The vitrified microsphere was employed as the major thermal insulation component. Organosilicon hydrophobic agent was used to improve the impermeability, reduce the water absorption and wettability, and thus contribute to the moisture resistance of the thermal insulation mortar. The properties of VM and OHA are illustrated in Tables 2 and 3, respectively.

2.2. Testing methods

The fundamental properties, e.g., dry density, compressive strength and thermal conductivity of the thermal insulation mortar were tested. The three major waterproof indicators, i.e., water absorption, impermeability and wettability were evaluated.

2.2.1. Dry density

Six 70.7 mm × 70.7 mm × 70.7 mm specimens in a group were made and cured in molds at (23 ± 2) °C and (50 ± 10)% relative humidity for three days. Subsequently, the molds were removed, and the specimens were cured for additional 25 days. Then, the cubic specimens were placed at (105 ± 5) °C and dried to a constant weight. The dry density of each specimen was tested and the average value was calculated as specified in GB/T 5486.3-2001 [19].

Table 1
Raw materials involved in the experimental program.

Raw materials	Abbreviation form
Vitrified microsphere	VM
Ordinary Portland cement	PO
Polypropylene fiber	PF
Redispersible emulsion powder	REP
Organosilicon hydrophobic agent	OHA
Hydroxypropyl methyl cellulose ether	HMCE

Table 2
Performance of the vitrified microspheres.

Bulk density (kg/m^3)	Thermal conductivity (W/m·K)	Size (mm)	Cylinder compressive strength (kPa)	Water absorption (%)	Volumetric floating (%)
90–110	0.037	0.5–1.5	188	39.5	93

Table 3
Main parameters of the water repellent agent.

Product name	Active ingredient	Appearance	Dilution ratio	Wetting angle after hydrophobic modification
BLA101	Surface-modified siloxane	Colorless, transparent liquid	1:4	100°–130°

2.2.2. Compressive strength

Three 70.7 mm × 70.7 mm × 70.7 mm specimens in a group were made and cured in molds at (23 ± 2) °C and (50 ± 10)% relative humidity for three days. The molds were then removed and the specimens were cured in standard condition (with relative humidity of 95% and temperature of 20 ± 2 °C) for additional 25 days). The compressive strength of the thermal insulation mortar was then tested as specified in GB/T 5486.3-2001 [19].

2.2.3. Thermal conductivity

Three 300 mm × 300 mm × 30 mm specimens were prepared in a group. The curing condition was the same as described for compressive strength test. The thermal conductivity was tested according to the method in GB/T 10294-2008 [20].

2.2.4. Water absorption

Three 70.7 mm × 70.7 mm × 70.7 mm cubes were made and cured for 28 days. Then, the cubes were dried at (105 ± 0.5) °C for (48 ± 0.5) h, and the mass (m_0) was measured. Each cube was then soaked in water. After being soaked for (48 ± 0.5) h, the cube was taken out and wiped with a wrung-out wet cloth to achieve saturated surface dry condition, and its mass (m_1) was measured. The water absorption of each test cube was calculated according to formula (1). Then, the average of the three test cubes' results was calculated as the water absorption of the mortar.

$$W_x = \frac{m_1 - m_0}{m_0} \times 100\% \tag{1}$$

2.2.5. Impermeability

The impermeability affects the durability of the thermal insulation mortar significantly. Two indexes to evaluate the impermeability of the thermal insulation mortar was proposed in reference [21], i.e., water level decline (h_0) and water seepage depth (h_1) within two hours (2 h) (Figs. 1 and 2). The specimens (70.7 mm × 70.7 mm × 70.7 mm) were prepared. The curing condition and testing steps were as following:

(1) The cube that had been cured for 28 days was put in an oven at a temperature of (105 ± 0.5) °C and dried to a constant weight.
(2) The dried cube was placed onto a test bench with its non-shaped surface facing upwards. An organic glass tube (diameter of 2 cm) with butter applied to its bottom was erected on the surface of the test cube and then sealed with hot melted wax. It is necessary to ensure that the sealing around the tube is firm and that the liquid wax does not enter into the tube from the bottom, as is shown in Fig. 1.
(3) (200 ± 1) mm of water was poured into the tube within 10 s, and then, the initial water level was recorded. The water level was recorded at specific intervals throughout the test for a total of 2 h, and then, the final water level was recorded. If all of the water in the tube had leaked out before 2 h, this step would be stopped and step 4 would be initiated. The untreated thermal insulation mortar had high water absorption. Therefore, the water should be poured quickly into the tube. It is advised to weigh the amount of water required to fill the 200 mm-high water column before pouring the water into the tube.
(4) The organic glass tube was removed, and a blade was used to scrape the wax and butter from the test cube's surface. A hacksaw blade was used to saw the test cube through the center of the installed organic glass tube, and then, the depth of the water seepage into the test tube was determined, as is shown in Fig. 2.