Study on a New-Type Thermal Storage Aerated Concrete

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***Abstract*—In this study, the Paraffin/Silicon dioxide phase change materials PCM was mixed into the aerated concrete to prepare thermal storage aerated concrete. The thermal performance, compressive strength, dry density and thermal conductivity were measured. The microstructure of the thermal storage aerated concrete was observed with a Scanning Electron Microscope. The results showed that the compressive strength of the thermal storage aerated concrete was decreased with the increase of the amount of the composite PCM. The existence of composite PCMs makes the crystallinity of the tobermorite decreased. The aerated concrete with the composite PCM shows notable thermal storage performance.**

***Index Terms*—aerated concrete, phase change material, thermal storage, energy saving**

I. Introduction

Phase change material (PCM) is a kind of thermal energy storage material which can store and release heat under specific temperature [1], [2]. By combining the PCM with the traditional building materials, the composite building materials have the function of heat storage and the temperature-control function. PCM has already received extensive attention of the researchers [3]-[8].

In the 1970s, American researchers firstly prepared a broadly applicable phase change material capsule applied them in the brick and floor, which showed good energy saving effect [9]. Hawex et al. [10] studied the thermal performances of the concrete block in which paraffin, butyl stearic acid, lauryl alcohol, tetradecyl alcohol et al. were mixed into. It was found that the heat storage capacity of concrete was increased by twofold. Shazim Ali Memon *et al.* [11] prepared a kind of energy saving heat storage building materials by mixing light aggregate concretes with paraffin, the mix proportion between the light aggregate concrete and paraffin was 1.0:0.7. The study found that this kind of material can significantly reduce the room temperature and the indoor temperature fluctuation. In addition, it can transfer the load temperature peak. Zongjin Li *et al.* [12] produced paraffin/diatomite composite PCM and mixed it into the cement based material. The results showed that, although the mechanical property, the dry shrinkage strain and the thermal conductivity of the cement based material were dramatically decreased; the paraffin/diatomite PCM can keep good compatibility with the cement based material.

The above researches are all under the room temperature condition. However, the data of the applications of PCM in the condition of high temperature and high pressure are very lack. The varitey of the performance and the modified mechanism after incorporating PCM into the autoclaved aerated concrete (1.25MPa, 190℃) were investigated in this study. The effect of the mixed composite PCMs on the mechanical properties and the thermal conductivity of aerated concrete were studied. The microstructure, phase change and heat storage effect of the thermal storage aerated concrete were analyzed.

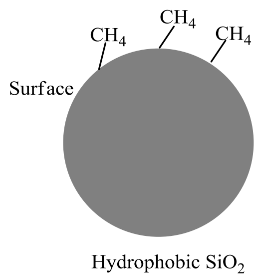

Figure 1. Molecular model diagram of hydrophobic nano silicon dioxide

II. Experimental

A. Materials

Cement used in this experiment was P Ⅱ 52.5, produced by Onoda cement LTD., Nanjing. Lime was supplied by Dongsheng lime CO.,LTD., Zhenjiang. Fly ash was supplied by China resources power plant, Nanjing. Silica fume was supplied by Jihe micro silicon powder CO.,LTD., Luoyang. Gypsumwas supplied by Shanghai Sinopharm chemical reagent CO.,LTD.. The chemical compositions of above raw materials are given in Table I. Aluminum powder was supplied by Discoverer Aluminum co., LTD., Luoyang. Waterreducingagent was the BASF 2651F. Foam stabilizer was supplied by Jiangsu Jiechengkaixin material technology CO., LTD.. Sodium citrate was supplied by Shanghai Sinopharm chemical reagent CO., LTD.. Paraffin was obtained from Rubitherm PCMS CO.,

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Ltd., China. Hydrophobic nanosilicon dioxide was supplied by Evonik Industries. The components and properties of the hydrophobic nano silica used in this study were presented in Table II and the molecular model diagram of the hydrophobic nano silica was presented in Fig. 1.

TABLE I. CHEMICAL COMPOSITIONS OF MAIN RAW MATERIALS (%)

Raw materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	TiO_2	SO_3	LOI
Cement	20.57	8.32	3.83	61.40	2.39	0.51	−	2.24	2.83
Fly ash	39.07	48.52	3.37	9.96	1.32	0.07	1.41	0.46	4.15
Silica fume	98	−	−	−	−	0.29	−	−	0.80
Hydrophilic nano silicon dioxide	99.8	0.05	0.003	−	−	−	0.03	−	0.01

TABLE II. PROPERTIES OF HYDROPHOBIC NANO SILICON DIOXIDE

Performance	SiO2	Drying loss 105℃	L.O.I 1000℃	Surface area(m2/g)	density (kg/m3)
Hydrophilic nano silicon dioxide	99.8%	≤1.5%	≤2.5%	200±25	50±20

B. Preparation of Thermal Storage Aerated Concrete

The nano silica was adsorbed with paraffin at the mass ratio of 2:1 by using vacuum adsorption method. Then , the Paraffin/Silicon dioxide composite PCMs were obtained. 0%, 10%, 20% and 30% of Paraffin/Silicon dioxide composite PCM (by the weight of cement) were incorporated with the AAC, respectively. The four groups of AAC were marked as AAC1, AAC2, AAC3 and AAC4, respectively. The mix proportion of raw materials of AAC1 is given in Table III. The compressive strength and thermal conductivity of the original AAC1 are 2.51MPa and 0.0807 W/(m.K), respectively.

TABLE III. THE MIX PROPORTION OF RAW MATERIALS OF AAC1 (WT%)

Component	C	FA	L	CS	NS	SF	A	B	D/ml	E/ml	Al
Quality/g	107	604	223	20	33	40	35	2.4	2	1.94	1.0

(Note: C–cement; FA-fly ash; L - lime; CS - gypsum; NS-hydrophilic nano silicon dioxide; SF- silica fume; A-water reducing agent; B-sodium citrate; D-water soluble oil (oleic acid: triethanolamine: water=1:3:36); E-sodium silicate; Al-aluminium)

C. Testing and Characterization

The microstructure of the aerated concrete is observed by the scanning electron microscope (Sirion field emission, FEI company, Holland). The compressive strength of the thermal storage aerated concrete was measured according to GB/T10294-2008 with the pressure testing machine (YAW-300C, Zhong Te Instrument Co., Jinan). The size of the specimen is 100mm×100mm×100mm. The thermal conductivity was measured by the thermal conductivity meter (DRH-300, Gelaimo Inspection according to GB/T10294-2008. The size of the specimen is 300mm×300mm×30mm. The test device of the thermal storage effect of aerated concrete (the thermal storage box) was mentioned in literature [13]. The size of the thermal storage aerated concrete board is 300mm×300mm×30mm. The multi-channel temperature recorder (TP9008U, Shanghai Ruiqin electronics co., LTD.) was used to record the change of the center temperature of the thermal storage box.

III. RESULTS AND DISCUSSION

A. Compressive Strength, Dry Density and Thermal Conductivity

The compressive strength and dry density and thermal conductivity of the thermal storage aerated concrete are presented in Table IV.

TABLE IV. COMPRESSIVE STRENGTH, DRY DENSITY AND THERMAL CONDUCTIVITY OF THE THERMAL STORAGE AERATED CONCRETE

Performance	AAC1	AAC2	AAC3	AAC4
Dry density /Kg/m^3	442.4	458.1	470.4	483.6
Compressive strength /MPa	2.51	2.23	2.01	1.61
Thermal conductivity /W/(m•K)	0.0807	0.0847	0.0865	0.0898

It can be seen from Table IV that the compressive strength of thermal storage aerated concrete decreased with the increase of the content of composite PCM. However, the dry density and the thermal conductivity increased with the content of composite PCM. When the composite PCM is mixed into AAC, the slurry consistency becomes larger. The gas forming process was hindered and the pore structure was affected. Therefore, the dry density increased. Because the composite PCM are hydrophobic and have poor compatibility with the aerated concrete, the weak interface between the composite PCM and the aerated concrete are formed. Thus, the compressive strength was decreased. The thermal conductivity is increased with the increase of dry density. So the thermal conductivity of thermal storage aerated concrete is increased.

Although the phase change materials have some adverse effect on the properties of aerated concrete, the appropriate dosage of composite PCM still can make the aerated concrete meet the requirements of the standard. When the content of the composite PCM is 20% (by the weight of cement), the thermal conductivity was increased by 7.2%. However, the compressive strength of the aerated concrete still had 2.01MPa, which can satisfy the requirements for B04 level aerated concrete block.

B. *Water Absorption Rate*

If the water absorption rate of the aerated concrete is high, the thermal insulation performance and the strength of the aerated concrete will be decreased. So, the water absorption rate of aerated concrete is characterized in this paper. The water absorption rate of aerated concrete with the size of 100mm×100mm×100mm is tested according to the GB/T10294-2008. The water absorption rate of the aerated concrete in 24h, 48h, 72h and 120h are showed in Table V.

TABLE V. WATER ABSORPTION RATE OF THE AERATED CONCRETE

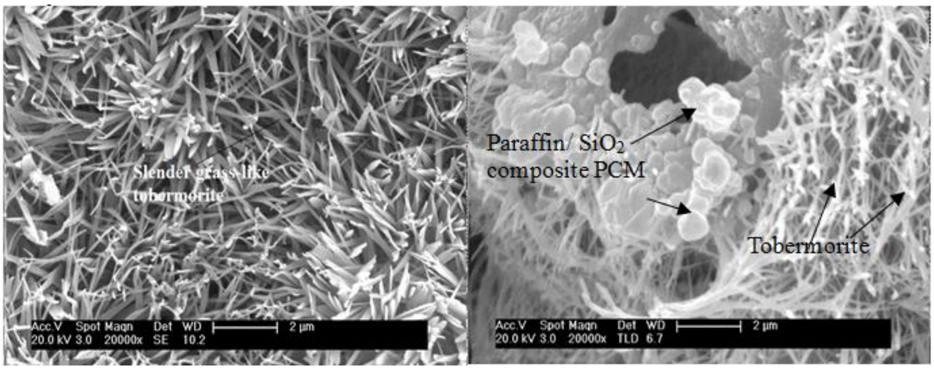
Samples	Dry density(g/cm^3)	Water absorption rate(24h) (%)	Water absorption rate(48)	Water absorption rate(72)	Water absorption rate(120)
AAC1	442.42	56.5	68.9	79.4	79.5
AAC2	461.51	52.6	58.5	65.2	65.6
AAC3	477.54	43.5	51.7	60.9	61.1
AAC4	486.56	37.7	45.6	56.8	57.1

Table V showed that the water absorption rate of the thermal storage aerated concrete is decreased with the content of the composite PCM. When the content of the composite PCM was 30% (by the weight of cement), the water absorption rate of the aerated concrete was reduced by 28.2% at 120 h. This is because that the dry density of the aerated concrete was increased. It is not easy for water to penetrate into the thermal storage aerated concrete. In addition, the composite PCM itself has hydrophobic properties.

C. *Micro-Morphology Analysis*

Fig. 2 (a) and Fig. 2 (b) show the SEM morphology of AAC1 and AAC3, respectively. It can be seen from Fig. 2 (a), the well crystallized needle-like tobermorites which were about 1 to 2μm in length were closely interwoven. They formed a mesh skeleton with high strength.

As shown in Fig. 2 (b), the crystallinity of the tobermorite was obviously decreased after the composite PCM were mixed into. In addition, there was poor crystallinity CSH (B) gel around the tobermorites. The composite PCM located in the surrounding of needle-like tobermorites. In the process of hydrothermal reaction, the composite PCM attached on the surface of partial mineral grains, it hampered the further hydrothermal reaction and lowered the crystallinity of the tobermorite. Consequently, the strength of the thermal storage aerated concrete was decreased.



(a) (b)

Figure 2. SEM morphologies of the aerated concrete ((a)AAC1, (b) AAC3)

D. *Thermal Storage Performances*

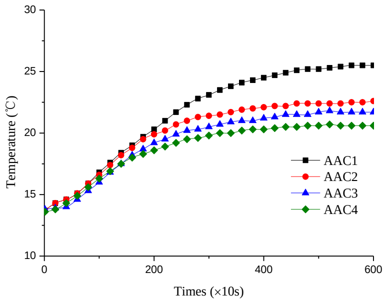


Figure 3. Time-temperature curve of the incubator center

Fig. 3 shows the time-temperature curves of the center of the thermal storage box with AAC2, AAC3 or AAC4 as one of the board. The test box with AAC1, AAC2, AAC3 and AAC4 as one of the board are marked as Box1, Box2, Box3 and Box4, respectively. It can be seen that the heating rate of the thermal storage box (Box2, Box3, Box4) is lower than that of the contrast box (Box1) during the process of heating. When the heating time is 600s, the center temperature of Box1, Box2, Box3 and Box4 achieves equilibrium. The equilibrium temperature of them were 25.5 ℃, 22.6 ℃, 21.7 ℃ and 20.6 ℃, respectively. The center temperature of Box2, Box3 and

Box4 is 2.9℃, 3.8℃ and 4.9℃ lower than that of Box1, respectively.

The result showed that adding of the composite PCM can lower the center temperature of the test box through heat storage. The more the content of composite PCM, the lower the center temperature of the test box. So, the thermal storage aerated concrete can be used as the building wall materials to improve the indoor comfortable degree and play a role of energy saving.

IV. CONCLUSIONS

1. The SEM morphologies showed that the existence of the composite PCM hampered the further hydrothermal reaction and lowered the crystallinity of the tobermorite. Consequently, the strength of the thermal storage aerated concrete was decreased.

2. The compressive strength of thermal storage aerated concrete decreased with the increase of the content of composite PCM. The dry density and the thermal conductivity increased with the content of composites PCM. However, the appropriate dosage of composite PCM still can make the aerated concrete meet the requirements of the standard.

3. The aerated concrete with the composite PCM shows notable thermal storage performance. The center temperature of the test box with AAC2, AAC3 or AAC4 as one of the board is more than 2.9℃ lower than that of the test box with AAC1.

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