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Cement and Concrete Research 33 (2003) 1357–1361

CEMENT AND CONCRETE RESEARCH

Research on improving the heat insulation and preservation properties of small-size concrete hollow blocks

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Received 3 September 1999; accepted 10 February 2003

Abstract

To solve the problems of poor thermal insulation and heat preservation properties that exist in the walls made of small-size concrete hollow blocks, a new type of compound small-size concrete hollow blocks has been developed. As shown in tests and calculations, the compound blocks not only improve significantly the thermal insulation effect, heat preservation properties, and impermeability of the walls, but also show good decorative results.

Keywords: Temperature; Concrete; Physical properties; Mechanical properties

1. Introduction

Sintered clay bricks have long been the main building materials in China. The clay bricks in Qin Dynasty and the tiles in Han Dynasty have become the symbol of Chinese building materials. However, with problems such as deficiency of energy, lack of land resources, and growth of population density being more and more prominent, the investigation on the replacement of the clay brick walls has become an important subject to building materials researchers. In recent years, the reform measures and policies to the wall materials have been strengthened and a series of laws and regulations has been issued. With these measures, opportunities for the development of new types of wall materials in China are provided.

Since small-size concrete hollow blocks have many advantages, such as soil saving, energy saving, high strength, convenience in construction, wide sources of materials, and simplicity in production technology, their application is rapidly spread. But in practice throughout the years, several problems have been found in this kind of materials. Poor heat preservation is one of the most marked problems. For example, the external walls with normal thickness of 240 mm in the southern warm areas of China, which use clay bricks plastered with common mortar, have a total heat resistance R_0 of 0.493 m^2 K/W. If the walls use small-size concrete hollow blocks with the same plaster, the value of R_0 is 0.369 m^2 K/W. It is clear that the heat preservation capability of concrete hollow blocks is poorer than that of clay bricks. Furthermore, in China, the Thermal Physical Design Code for Civil Buildings (GB50176-93) [1]—the design for thermal insulation of the external walls in the east or west side of the buildings—is demanded to satisfy the requirement that the highest temperature inside the surfaces of the walls be smaller than the calculated highest outdoor temperature in summer. Take Nanjing in China as an example. Here, the calculated highest outdoor temperature in summer is 37.10 °C, and the highest temperature inside the surfaces of the 240-mm-thick clay brick walls plastered both inside and outside is 37.24 °C. But for the walls made of small-size concrete hollow blocks, the highest temperature inside the surfaces is 39.84 °C. It can be concluded that the thermal insulation capability of concrete hollow blocks is inferior to that of clay bricks. Because no heating measure is taken in most houses of south China in winter, the maintenance of room temperature depends mainly on the external walls of the buildings, while the cooling in hot summer relies largely on air ventilation; thus,

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doi:10.1016/S0008-8846(03)00066-8

proper measures should be taken to improve the thermal physical properties of small-size concrete blocks. Otherwise, buildings made of this kind of materials will be difficult to accept by users due to their coldness in winter and heat in summer.

2. Research on improving the heat insulation and preservation properties of small-size concrete hollow blocks

2.1. Present conditions of small-size concrete hollow blocks

Generally speaking, small-size concrete hollow blocks are made of common crushed stone or cobble, sand, and cement. The overall thermal conductivity is 1.51 W/m K, which is twice the value for clay bricks. In order to resist forces properly, they are made to have concrete ribs with a certain width, which form the passageways for thermal convection (called "heat bridges") besides the air in the holes of the block convects due to the difference in temperature between the cold face and the hot face. The joint action of these factors results in the poor performance of heat insulation and the preservation of small-size concrete hollow blocks [2]. To solve this problem, several studies have been done. For example, Li [3] considered that (1) changing the arrangement of holes in the blocks will extend the original routes for heat flow and will greatly affect the thermal conduction coefficient of small-size concrete hollow blocks, thus improving their thermal physical properties. By means of a finite element method, Li carried out large amounts of calculation on heat resistance for small-size concrete hollow blocks with different sizes or different arrangements of holes. He found that the more rows of holes perpendicular to the direction of heat flow, the greater heat resistance for the blocks [4]. The value of heat resistance is increased by at least 20% with every additional row of holes. (2) Changing the raw materials for producing the small-size concrete hollow blocks was also considered. Some researchers [5] think that if crushed stone or cobble is replaced by lightweight aggregates such as pumice, coal cinder, and shale ceramic to produce the small-size concrete hollow blocks, the problem of poor heat insulation and preservation can be solved effectively. Since lightweight aggregates are small in their apparent density and good at heat preservation, if they are used raw materials, the produced concrete hollow blocks will show bigger values of heat resistance. (3) Blocking the routes for the heat flow can also be considered. The others [6,7] have made an attempt to block the routes for the thermal current. They proposed that if the outside or inside surface of the external walls of buildings is wrapped with high-performance heat insulation materials, the heat flow will be blocked in a relatively complete way [8,9], and better thermal physical properties will be obtained.

2.2. The design principle of a new kind of compound blocks

To explore a more effective way of improving the heat insulation and preservation properties of small-size concrete hollow blocks, we took further studies. It is well known that one important measure of improving the heat preservation effect of walls is to raise the heat resistance, but there is no one single factor that influences the heat insulation effect. The index of examining the heat insulation effect of a wall is the highest temperature ($\theta_{\mathrm{i\ max}}$) on the internal surface of the wall when the highest calculated outdoor temperature in summer is reached. In GB50176-93, the formula to calculate $\theta_{\mathrm{i\ max}}$ is

$$\theta_{\mathrm{i\ max}} = \overline{\theta}_{\mathrm{i}} + \left(\frac{A_{t_{\mathrm{sa}}}}{\gamma_0} + \frac{A_{t_{\mathrm{i}}}}{\gamma_{\mathrm{i}}}\right)\beta \tag{1}$$

in which

$$\overline{\theta}_{\mathrm{i}} = \overline{t}_{\mathrm{i}} + \frac{\overline{t}_{\mathrm{sa}} - \overline{t}_i}{R_0\alpha_{\mathrm{i}}} \tag{2}$$

where t_{i}, A_{t_i}, t_{sa}, and $A_{t_{\mathrm{sa}}}$ are related to the outside environmental condition; α_{i} has a relation to the external shape of the wall; γ_0 and γ_{i} are affected by the heat inertial index and thermal storage coefficient; while $\overline{\theta}_{\mathrm{i}}$ depends on the total heat resistance R_0 and the environmental condition. Therefore, in order to decrease the highest temperature ($\theta_{i\ \mathrm{max}}$) on the internal surface of the wall, the heat inertial index and thermal storage coefficient of the wall should also be taken into account, except for the consideration of raising the total heat resistance R_0. So we designed a new kind of compound concrete hollow blocks with lightweight materials outside and heavyweight materials inside, which are applied to meet this demand. The compound concrete block is structurally composed of three layers—load-bearing layer, heat insulation layer, and decoration layer. The load-bearing layer is made of heavyweight materials, with three rows of holes arranged in it. The heat insulation layer is made of lightweight materials, and named CPS with polystyrene or CPI with expanding pearlite concrete. The lightweight materials outside of the blocks will increase effectively the total heat resistance, while the heavyweight materials inside not only have the capability of load bearing and improving thermal storage coefficient, but also have the strong points of wider resource of raw materials and lower price. The decoration layer can be made with certain colors, lines, or relief patterns to improve the aesthetic perception of the buildings. The decoration layer also works well in resisting corrosion, permeation, and cracking.

2.3. The physical and mechanical properties of the compound blocks

A main size of compound block is 390 × 240 × 190 mm. The principal physical and mechanical properties of the compound concrete hollow blocks are listed in Table 1. It

Table 1
The principal properties of the compound concrete hollow blocks

Item	CPS block	CPI block
Apparent density (kg/m^3)	1170	1230
Mass of a single block (kg)	20.8	22.0
Water absorptivity of face layer (%)	3.1–3.5	
Compressive strength (MPa)	7.9–11.1	
Impermeability	Qualified	Qualified
Freeze–thaw resistance	>D15	>D15

can be seen that the two kinds of compound concrete hollow blocks show good physical and mechanical properties as well as duration.

2.4. Test method of thermal physical properties for block walls

According to the method in GB50176-93, calculations were first carried out on the heat insulation and preservation effects for walls made of different kinds of blocks. Then thermal physical properties tests for these walls sized 1200 × 1200 mm were made on a device designed and assembled by us. The test device was a typed cold–warm room, controlled by an automatic thermostat. Constantan copper thermocouples and potential difference instruments measured the temperature at each point. The temperature induction parts on the test points of air temperature thermocouples were heat-treated with radiation protection. A heat screen to ensure a relatively uniform temperature field and radiation environment for the specimens separated the heater. The temperatures and the rates of heat flow on the holes and ribs were measured, respectively. The relative weighted averages were then calculated according to the area. The thermal physical properties of walls made of different blocks were evaluated by calculation and test results.

2.5. Results and analyses of heat preservation effect for different walls

Table 2 shows the comparison results of heat preservation effect for the wall specimens made of different kinds of blocks between calculated and test results over a continuous 72 h under the condition of stable heat conduction. Table 2 shows that: (1) increasing the rows of holes in the small-size concrete hollow blocks is truly able to raise the total heat resistance and improve the heat preservation performance of the blocks; but for blocks with three rows of holes, the heat preservation effect is still inferior to that of 240-mm clay brick walls; (2) application of lightweight aggregate concrete to produce hollow blocks is also capable of improving the heat preservation effect of the blocks. However, the apparent density of lightweight aggregate should not be too small; otherwise, it cannot satisfy the mechanical requirement of the wall materials. Moreover, the applications of lightweight aggregate concrete hollow blocks is hindered by the limited source of lightweight aggregates; (3) the heat resistance is raised significantly by covering or wrapping the concrete hollow blocks, but this requires high-quality construction technique, and the cost of the walls will be three to five times of the original. Therefore, it is difficult to spread widely in the undeveloped areas; and (4) the heat preservation effect of the compound block walls is superior to other forms and also superior to the normal clay brick walls.

2.6. Test results and analyses of thermal insulation effect for different walls

Table 3 lists the comparison results between the calculated ones and the simulated periodic test results in thermal insulation effect over a continuous 14 h for walls made of different kinds of blocks under the condition of unstable heat conduction in an airtight room. It can be seen from Table 3 that: (1) increasing the rows of holes in the small-size concrete hollow blocks has no obvious effect on improving the thermal insulation property of the blocks. Even for blocks with three rows of holes, the heat insulation property is still inferior to that of clay bricks; (2) application of lightweight aggregate concrete does not show much improvement on heat insulation properties of the small-size concrete hollow blocks; and (3) for concrete hollow blocks wrapped by heat insulation materials, the improvement on thermal insulation effect is far less significant than improvement on the heat

Table 2
Calculated and test results of heat preservation properties for the walls made of various blocks

Index of thermal physical property		Total heat resistance (m^2 K/W)	
		Calculated results	Test results
Rows of holes in the concrete hollow blocks	One	0.369	0.353
	Two	0.426	0.415
	Three	0.480	0.469
Lightweight aggregate concrete hollow blocks	Cinder concrete	0.442	0.433
	Fly ash concrete	0.452	0.440
	Shale ceramic aggregate concrete	0.468	0.457
Blocks with single rows of holes, covered with 30-mm heat insulation board	Polystyrene board	1.226	1.210
	Mineral wool board	0.703	0.694
240-mm clay brick walls		0.493	0.487
New compound blocks	CPI	0.532	0.728
	CPS	0.521	0.719

All the walls are internally and externally plastered with a thickness of 20 mm.
The apparent density of the lightweight aggregate concrete is 1500 kg/m^2 for cinder concrete or fly ash concrete, and 1300 kg/m^2 for shale ceramic aggregate concrete.
The average temperature on the external surface of all walls is 58.5 °C.

preservation effect. It should be noticed that, by the use of this method, the room temperature will drop more slowly and there will be longer sultry room environment in the districts, which depend on air ventilation cooling in summer.

According to the test method described above, the highest temperature outside the walls was controlled at 55.5 °C, which can be reached after 3.5 h of heating, and then kept constant for 2 h. The tested temperature of internal surface of block walls can be seen in Fig. 1. Comparing the temperature of internal surface blocks with a single row and double rows of holes, not much improvement on thermal insulation effect was obtained; the difference is only 1 °C lower than that of the outside wall. The application of lightweight aggregate does not provide as high an enhancement on the heat insulation of the concrete blocks as the heat preservation effect, since the temperature of the internal surface of the wall only drops a little. This is disadvantageous to the buildings that depend on natural ventilation cooling. In contrast, the CPI and CPS compound concrete hollow blocks provide significant improvement on the heat insulation effect. For the CPI block walls, the highest temperature on its internal surface is about 3 °C lower than that of block walls with a single row of holes, and almost the same as that of clay brick walls. For the CPS block walls, the highest temperature on its internal surface is about 5 °C lower than that of block walls with a single row of holes, and 2 °C lower than that of clay brick walls. It should be noticed that for the two kinds of compound block walls, the temperature drops more quickly than that of clay brick walls when no there is no heating. It means that if the compound block walls are under natural ventilation, rather than in an airtight room, the thermal insulation effect will be much better. Thermal insulation properties were calculated by means of the summer thermal physical parameters in Nanjing, China. The calculated highest summer temperature on the internal surface is 37.5 °C for the CPI block walls and 36.0 °C for the CPS block walls. It can be seen from Table 3 that the calculated results are consistent with test results.

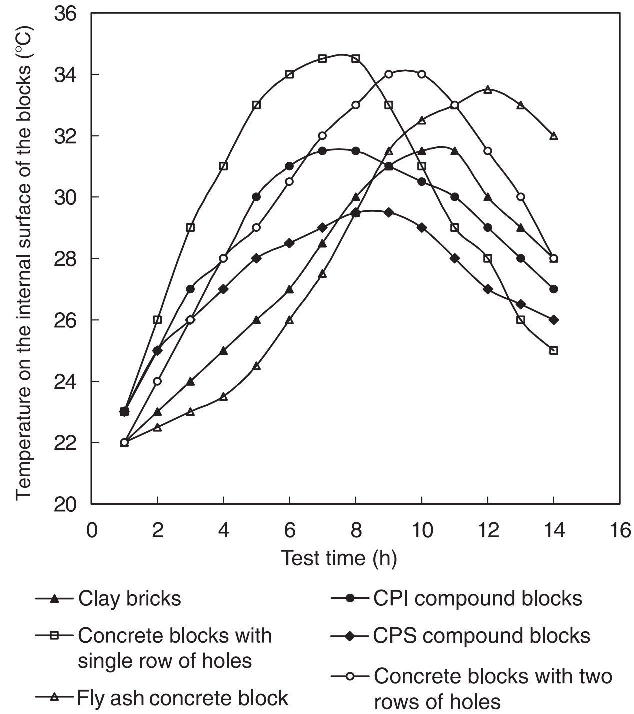

Fig. 1. Relations between the temperature on the internal surface of the test block walls and the test time.

Table 3
Calculated and test results in thermal insulation properties for walls made of various blocks

Index of heat physical property		Highest temperature in the internal surface (°C)	
		Calculated results	Test results
Rows of holes in the concrete hollow blocks	One	39.84	34.5
	Two	38.64	34.0
	Three	37.63	32.5
Lightweight aggregate concrete hollow blocks	Cinder concrete	39.10	33.8
	Fly ash concrete	39.10	33.5
	Shale ceramic aggregate concrete	38.89	33.1
Blocks with single rows of holes, covered with 30-mm heat insulation board	Polystyrene board	37.05	31.2
	Mineral wool board	37.21	31.5
240-mm clay brick walls		37.24	31.5
New compound blocks	CPI	37.5	31.2
	CPS	36.0	29.5

The highest temperature outside the walls (in a hot room) during the test was 55.5 °C, which occurred after 3.5 h of heating and testing and kept for 2 h before dropping down slowly.
The calculation is based on the heat physical parameters provided for the Nanjing District of China by GB50176-93.
All the walls are internally and externally plastered with a thickness of 20 mm.
The apparent density of the lightweight aggregate concrete is 1500 kg/m^3 for cinder concrete or fly ash concrete, and 1300 kg/m^3 for shale ceramic aggregate concrete.

3. Conclusions

1. The thermal insulation and heat preservation effects of the concrete hollow blocks with a single row of holes are poorer than that of clay bricks. Application of multirow holes, lightweight aggregates, or outside wrappings may provide a significant enhancement on heat preservation effects but little improvement on thermal insulation effects. Furthermore, under natural ventilation cooling, the dropping of room temperature is slowed down.
2. The heat preservation effect of the compound concrete hollow blocks is better than that of clay bricks. For thermal insulation effect, the CPI blocks are as good as the clay bricks and the CPS blocks are better than the clay bricks.

3. With compact face layer, the compound concrete blocks can effectively prevent the leakage of water, and also can be made with required decorative results.

Acknowledgements

The authors would like to thank the National Natural Science Foundation of China for the support. This research is a part of key project no. 59938170.

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