

Research Progress on Thermal Properties of Aerated Concrete, Sintered Shale Brick and Composite Materials

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Abstract. Currently, construction energy saving has been paid more and more attention in our country. Enclosure materials such as walls are important industries within the scope of energy saving of constructions, which makes the rational utilization of enclosure materials like walls particularly important. The energy consumption of construction industry is too high, and the thermal insulation performance of the wall still cannot alleviate the actual contradiction of energy saving of the current wall materials. To improve the thermal performance of wall thermal insulation, the thermal performance of sintered shale brick and aerated concrete are introduced in this paper. The research progress of aerated concrete and shale porous brick are sorted out, and the role of thermal performance of new wall materials on construction energy saving is comprehensively described through the analysis of their thermal performance data and the experiments of other scholars. Finally, the future development trend is predicted.

Keywords: Aerated concrete, sintered shale brick, thermal performance, energy saving of buildings.

1. Introduction

The total energy consumption of the whole construction process in the construction industry accounts for a large proportion of the energy consumption of China. At present, China has made solemn commitments in the international world and issued the “opinions on fully, accurately and comprehensively implementing the new development concept to do a good job in carbon peaking and carbon neutralization”. The above activities are to ensure that carbon peaking and carbon neutralization can be achieved on schedule. Therefore, enterprises engaged in the construction should combine their business activities with the goals of carbon peaking and carbon neutralization at the national level. With the gradual improvement of building energy efficiency requirements and the introduction of mandatory national standards, building energy efficiency has become a hot research topic, which has attracted great attention in the society.

There is a strong energy saving potential in the construction field, and the external wall has a great impact on the energy saving of buildings. Therefore, improving the thermal performance of building exterior wall is of vital importance to achieve building energy saving and seeking green development. In recent years, many new insulation wall materials have appeared, such as aerated concrete and sintered shale brick. These new wall materials have attracted wide attention from scholars at home and abroad, and their thermal performance has been studied in detail.

Under such circumstance, the thermal performance of aerated concrete and sintered shale brick by studying the thermal performance of these two materials, as well as the relevant indicators and the latest research results are explored in this paper. Meanwhile, the roles of different new wall materials in building energy saving are comprehensively analyzed, and finally, the future development trend is predicted.

2. Literature Review

New wall materials can make up for the deficiency of traditional wall materials. Organic materials can be combined with inorganic materials to achieve thermal insulation, sound insulation, etc., so as

to maximize the utilization of resources. Compared with traditional wall materials, they have higher construction technology and level. Its production cost is relatively low, and simultaneously, it has a high technical content. Furthermore, the effect is more remarkable in practical application. There are many kinds of new wall materials. Here, the basic properties, development history, as well as the development status of sintered shale brick and aerated concrete are introduced.

Currently, the self-insulation wall materials used in buildings in hot summer and cold winter areas in China mainly consists of sintering type, autoclaved type and composite type according to the manufacturing process. Sintered self-insulation materials mainly consists of sludge sintering, shale sintering and coal gangue sintering according to different raw materials [1].

As a new building energy-saving wall material, sintered shale brick can not only be used for building load-bearing walls. It has good thermal performance and is consistent with the construction building modulus, which can reduce the loss in the construction process and improve the work efficiency. When the hole rate reaches more than 40%, it can reduce the weight of the wall and save the cost of foundation works. Compared with ordinary sintered porous brick, it has the characteristics of heat preservation, heat insulation, light weight, high strength, as well as high construction efficiency.

Taking shale as the raw material, the production process of high vacuum extrusion molding of brick machine and one-time code burning is adopted. At present, considering the recent sales of sintered shale bricks in the domestic socialist economic market environment, shale sintered bricks are expected to be a representative product for the production of Chinese building raw materials. It can be exported to some capitalist countries in Europe, America, Australia etc. with high economic development level [2].

Autoclaved wall materials are mainly autoclaved aerated concrete with advantages of light weight, high thermal insulation performance, as well as stable strength. It is one of the most promising new wall materials in building walls, becoming the earliest and most widely used wall materials in China.

Furthermore, it is a light porous silicate product made of siliceous materials including sand, fly ash and silicon containing tailings and calcareous materials such as lime and cement through multiple processes. It is also called aerated concrete because there will be a large number of small and uniform pores in the aerated concrete. In the 1960s, China introduced the aerated concrete production line from abroad, and the technology has been nearly mature. Aerated concrete has many excellent properties and great engineering potential for application, becoming a very ideal building structure insulation material.

Many universities and institutions at home and abroad have carried out a lot of research on the properties of sintered shale brick and aerated concrete masonry. For instance, the drying shrinkage law, anti-seismic energy consumption, etc. are studied and successfully simulated and analyzed by computer software, which has also been well applied in practical projects [3].

In addition to these aspects, their thermal performance is also of great application value in building materials. With the implementation of the design standard that building energy saving should reach 75% or higher, there is very limited self-insulation application of sintered bricks. Therefore, it is necessary to vigorously develop sintered porous bricks, hollow bricks and blocks beneficial for composite insulation materials, so as to realize composite insulation [4]. The thermal insulation performance of these two meets the requirements of energy saving of constructions and plays a significant role in promoting sustainable development.

3. Aerated Concrete

3.1. Preparation and characteristics of aerated concrete

Aerated concrete is mostly made of four kinds of raw materials, namely, cementitious materials, aerating materials, regulating materials, as well as structural strengthening materials. Cementitious materials mainly refer to siliceous materials and calcareous materials. After grinding and processing the cementitious materials, the aerating materials, regulating materials and stabilizers will be added

in a certain proportion to make aerated concrete through mixing, pouring, pre-curing, cutting, autoclaving and curing. Aluminum powder is usually used as the aerating agent. However, since the aerating process is easily affected by various materials and environmental factors, it is necessary to adjust the rate of the aerating process, so as to avoid the poor production effect of aerated concrete resulted from unsatisfactory aerating process [5, 6].

Excellent aerated concrete materials generally have the following characteristics:

(1) Being porous and light; (2) Possessing high strength utilization coefficient; (3) Having large elastic coefficient under short-term load, and small creep deformation under long-term load; (4) Being provided with the capability of slow water absorption and moisture conduction; (5) Performing better in thermal insulation performance than most building materials; (6) Acquitting itself well in heat resistance and fire resistance; (7) Being provided with the capability of sound absorption; (8) Presenting stable long-term performance and having a good durability [7].

3.2. Thermal performance of aerated concrete

Aerated concrete has excellent thermal insulation performance and is the only material in the wall materials that can meet the energy saving requirements [8]. The thermal performance specification of autoclaved aerated concrete blocks of the current national standard is shown in Table 1 [9]. The lower the density of the block, the smaller the thermal conductivity, and the better the thermal insulation performance.

When the humidity correction coefficient of mortar joint of 1.25 is taken into consideration, the average heat transfer coefficient of aerated concrete self-insulation blocks with different specifications can be calculated. When the wall thickness is 250mm, the aerated concrete of the B04 grade can fully meet the energy-saving requirements of public buildings in ordinary areas and the energy-saving standards of public buildings in most of cold regions [10].

Table 1. Specification of the thermal performance of autoclaved aerated concrete [9]

Level of the dry density			B03	B04	B05	B06	B07	B08
Drying shrinkage value*	Standard method		≤0.5 (mm/m)					
	Quick method		≤0.8 (mm/m)					
	Weight loss		≤5.0%					
Resistance to coldness	Strength after freezing	Superior products (A) MPa≥	0.8	1.6	2.8	4.0	6.0	8.0
		Superior products (B) MPa≥			2.0	2.8	4.0	6.0
Thermal conductivity (dry state) [W/(M·K)]≤			0.10	0.12	0.14	0.16	0.18	0.20

*Note: According to the stipulation, the standard method and rapid method shall be adopted to determine the dry value of the block. If the measurement results are inconsistent and cannot be determined, the results determined by the standard method shall be adopted.

3.3. Composite materials of aerated concrete

(1) Phase change microcapsule / aerated concrete composite

When preparing aerated concrete, phase change microcapsules (MPCMS) with RT25 paraffin can be added to obtain phase change microcapsules / aerated concrete composites as phase change material. Phase change composite building materials are the combination of phase change materials and building materials, and the high phase change latent heat of phase change materials can be used to improve the heat storage capacity of building materials. This material can effectively reduce the fluctuation of indoor temperature, thereby reducing the use of heating system and achieving the purpose of reducing building energy consumption [11].

(2) Autoclaved aerated concrete and extruded polystyrene board composite block

Polystyrene foam extruded board is a kind of building insulation material adopted in Wuhan, etc. The heat transfer coefficient of the composite block made of this material and aerated concrete is

much lower than that of the autoclaved aerated concrete block under the same conditions, which shows that the thermal insulation performance of this composite material is much better than that of ordinary autoclaved aerated concrete. This composite block is an integrated structural material, which simplifies the construction process, reduces the thermal bridge at the interface, and effectively improves the thermal insulation performance [12].

3.4. Advantage of aerated concrete series materials in energy saving in constructions

Aerated concrete materials can effectively reduce energy consumption in construction after the standard preparation and curing process, and the thermal performance of its composite materials is also superior. Facing the new energy-saving goal of China, aerated concrete series materials can achieve the following points: (1) Lower heat transfer coefficient than ordinary materials, fewer thermal bridges at the interface, as well as lasting insulation. (2) When it is also used as wall materials, it can save resources, reduce wall thickness, reduce cost and have higher efficiency. (3) The material is stable, not easy to generate cracks, good water retention, and can be used for a long time. (4) Light weight, relatively simple process, low energy consumption in the manufacturing process. (5) The new low-energy enclosure structure that can match the complete set is relatively complete, and the energy loss is greatly reduced in use.

4. Sintered Shale Bricks

4.1. Preparation and characteristics of sintered shale bricks

Sintered shale brick/block is a kind of wall material which is produced with shale as the main raw material, using the process of high vacuum extrusion molding and one baking by brick machine. It can be used for a variety of walls such as masonry load-bearing walls. It has good thermal performance and low loss during construction. According to the difference of hollow rate, Sintered shale bricks/blocks can be divided into solid bricks, porous bricks, porous blocks, hollow bricks, hollow blocks [13]. The research focuses on sintered shale porous bricks with hollow blocks.

The presence of many air holes inside the sintered shale porous brick makes the heat transfer process more complicated. It includes the thermal conductivity of the porous brick solid and air inside the hole, convective heat exchange between air and wall, and radiation heat exchange between hole walls. This undoubtedly increases the difficulty of theoretical calculations and experimental methods for its thermal performance. The thermal performance of the single self-insulated sintered shale porous brick currently produced in China is still poor [13].

Sintered shale porous bricks are strongly supported by governments at home and abroad because of their own advantages of soil saving and energy saving. China is the birthplace of sintered brick and tile in the world, and masonry wall structures have a long history in China, with 6000 years of history by now, and these sintered bricks and tiles have good durability [14].

4.2. The thermal performance of sintered shale bricks influencing factors

For the investigation of its thermal performance, it is found that the heat transfer of sintered shale porous brick walls is not a thermal conductivity process of a wall composed of a single material. This process includes the thermal conductivity of the solid part of the porous brick and the air of the hole, the convection inside the hole of the porous brick and the radiation between the walls of the hole. Therefore, sintered porous brick wall heat transfer in the solid heat conduction at the same time, but also accompanied by the conductive heat transfer of the air in the hole, the convective heat transfer between the air in the hole and the wall and the radiation heat transfer process between the hole walls occur. This is also the reason for the poor thermal performance of the sintered shale bricks themselves.

The factors that affect the heat transfer of sintered porous bricks, in addition to the porous brick material itself, are also associated with parameters such as the aspect ratio of the momentary holes of the sintered porous brick, the porosity, the arrangement of the holes, the number of arrangements of the holes, and the thickness of the outer wall and the ribs [13].

To improve the thermal performance of sintered shale porous brick, it can be solved by optimizing the ratio of hole size, increasing the hole rate, reducing the thickness of the hole wall, filling the holes with thermal insulation material and changing the thermal conductivity of the material.

4.3. Experimental study of the thermal performance of sintered shale bricks

Many scholars have tested the heat transfer coefficient, thermal conductivity by different methods. And proposed the influencing factors and optimization solutions.

4.3.1 Steady-state protective thermal chamber method to measure the thermal performance of sintered shale bricks

Liu [15] used the steady-state protective hotbox method to measure, and the results showed that the heat transfer coefficient of sintered porous bricks commonly used in Jiangxi province is $1.99\sim 2.43$ W/(m²·K) (190 Wall). The heat transfer coefficient of sintered hollow bricks is $1.81\sim 2.18$ W/(m²·K) (190 Wall). The heat transfer coefficient of sintered insulated bricks/blocks is $1.20\sim 1.58$ W/(m²·K) (240 Wall). The transient hot wire method was used to test the conductivity of the sintered product substrates. Under other conditions fixed, the difference in thermal conductivity of the substrate has some influence on the thermal performance of the masonry, and the moisture content condition of the wall also has a great influence on the heat transfer coefficient.

4.3.2 Optimization scheme of thermal performance of sintered shale bricks

The optimization scheme has more studies on hole filling and the enhancement of hole type on thermal performance. Mao [16] tested the thermal performance of sintered shale hollow blocks and their five optimized solutions. The energy consumption of buildings with different blocks was simulated using PKPM software, and it was concluded that sintered shale hollow blocks have good thermal performance. It can realize the self-insulation or auxiliary insulation of the wall, which can meet the requirement of 50% energy saving of the building, and has been successfully applied in engineering practice. They optimize the sintered shale hollow blocks, i.e., fill their holes with EPS, which can effectively improve their thermal performance, and as the filling ratio increases, the insulation performance will continue to improve.

Cui [17] filled sintered shale bricks with polystyrene panels and numerically simulated. The results show that: The use of polystyrene board to fill or reduce the size of the hole is conducive to improving the insulation performance of the insulation block. Zhao [18] also concluded by a similar treatment that the pore type has a great influence on the insulation performance of porous bricks, with rectangular pore bricks having the best insulation performance. Holes filled with insulation materials can significantly improve the insulation performance of porous brick. With the reduction of thermal conductivity of porous brick matrix material, its thermal resistance value gradually increases, and the insulation performance gradually becomes superior.

4.4. Composite material of sintered shale bricks

Sintered shale brick composites combine other green materials with shale bricks. Various aspects of the porous brick were analyzed by finite element analysis software to improve the insulation properties, porosity and pore structure. Ultra-lightweight foam concrete and sintered shale brick composite

It uses ordinary silicate cement as cementitious material, mixed with fly ash, silica fume and admixtures, and applies chemical foaming method to prepare an ultra-lightweight foam concrete, and fills it into the matching optimized design of sintered shale hollow blocks to develop high-performance sintered shale composite insulation blocks. Compared with 240mm thick conventional sintered shale hollow blocks, its thermal insulation performance was improved by 42.5%. This high-performance composite insulating block can provide new options for the selection of self-insulating wall materials in hot-summer and cold-winter regions [19].

(1) Plant fiber self-insulating shale sintered microporous brick

It uses plant fibers and self-insulating shale sintered bricks to make composite materials, and starts from five pore structures including pore aspect ratio, pore rate and inter-pore rib width. The new plant fiber self-insulating shale sintered microporous brick with 28% porosity was analyzed with ANSYS Workbench 17.0 finite element analysis software, which can effectively provide thermal insulation [20].

(2) Coal gangue shale sintered brick composites

The gangue and shale are mixed according to the mass ratio of 9:1, and the analysis shows that under the condition that the sintering temperature and the heat preservation time after reaching the sintering temperature are certain, extending its heat preservation time at the peak temperature of gangue heat release can improve the performance of gangue shale brick, improve its microscopic pore structure, and meet the building energy-saving standards when practical [21].

4.5. Sintered shale brick series materials building energy-saving applications and prospects

The energy consumption simulation related to building 5 of Sinosteel-Century Garden in Taizhou City, Zhejiang Province was carried out as an example [16]. Reduced building energy consumption and increased energy efficiency when the optimized solution using sintered shale bricks is used in real buildings. In the case of Dingqiao housing construction [1], 240mm thick sintered shale porous bricks were applied to the main exterior wall, which proved to have good thermal insulation effect and could fully meet the requirements of energy-saving design standards in hot summer and cold winter areas.

Sintered shale bricks and their composites as an alternative material to traditional clay bricks. It retains the characteristics of sintered wall materials, but also has the advantages of heat preservation and energy saving, high cavity rate, convenient construction, and not easy to crack. It has very good promotion prospects.

The wall self-insulation system has good technical performance and comprehensive economy, and is a new technology of energy saving for external walls. In this field, sintered shale brick has obvious comprehensive advantages and is one of the leading products of new wall materials, so it is of great practical significance to carry out research and application of sintered shale brick wall self-insulation system to support the development of building energy saving.

5. Conclusion

This paper collates the research on aerated concrete and porous bricks and draws the following conclusions.

(1) When making aerated concrete must standardize the process and carry out proper maintenance work. The focus should be on the gassing process, which will directly affect the density of the masonry material and make the thermal conductivity is not standard, which in turn affects the thermal performance of the material. This material, if produced in accordance with the specifications, the finished product can be used independently and meet the building energy-saving standards.

(2) Aerated concrete synthetic materials are mostly compounded with other new materials, which can combine the strengths of both to be used for building energy efficiency. Because of its own superior thermal performance, and less short board and easy to make synthetic materials, making it a composite material in the field of building energy saving development prospects are very good.

(3) Reducing the size of the hole is conducive to improving the thermal insulation performance, of which rectangular hole brick has the best thermal insulation performance. Holes filled with insulation materials can significantly improve the insulation performance of porous brick such as polystyrene board filling. Porous brick matrix material thermal conductivity is reduced, thermal resistance value increases, thermal insulation performance is enhanced.

(4) Domestic production of a single self-insulating sintered shale porous brick thermal performance is not high enough, the composite material retains the characteristics of sintered class

wall materials, but also has the advantages of heat preservation and energy saving, high porosity, convenient construction, not easy to crack, and has been used in a large number of practical cases.

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