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Mechanical and thermal tests of an innovative environment-friendly hollow block as self-insulation wall materials

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HIGHLIGHTS

- Energy and resource consumption is quite large in China.
- Shale and waste could be used to produce fired hollow blocks.
- Mechanical performances of the fired hollow block walls were studied.
- Thermal properties of the fired hollow block wall were tested using hot box method.
- The block is a green self-insulation wall material to bear pressure and preserve heat.

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ABSTRACT

Nowadays, energy dissipation of buildings has caused serious problems to the environment for leading to overuse of resources in China. To reduce energy consumption and protect the environment, shale that widely distributed in China and the waste, including both building waste and industrial waste are used as raw materials to manufacture fired hollow blocks with 29-row holes which ensure the insulation properties and reduction of weight. As samples, 365 mm × 248 mm × 249 mm rectangular fire hollow blocks with density of 850 kg/m^3 were produced to study the mechanical and thermal properties of this wall material. The results satisfied the relevant Chinese Standard, and the block has a high compressive strength and reliable insulation performance comparing with fired common brick or other hollow blocks. Because of the excellent self-insulation characteristics, the blocks could be used directly as wall materials without requiring the usage of special insulation measures in masonry structures, which mean that this new-type material could reduce the cost of housing construction and had broad application prospect in masonry structures. Therefore, using this block could not only cut down the consumption of energy, but also could ease the pressure applied on the environment.

1. Introduction

Hollow blocks or bricks are becoming more and more popular because of its environmentally friendly characteristics of low heat dissipation and less raw material usage for the exists of cavities, which are especially significant to developing countries for huge amount of resources are needed to make the buildings erected and keep the indoor temperature livable. As the biggest developing country and the second economic entity in the world, China has become the second largest global energy consumer and carbon dioxide emitter [1]. The area of new buildings reach two billion square meters every year in China, resulting in extensive use of concrete and steel, so China has established relevant building energy efficiency standards for new buildings which has been proved effective through the engineering practice. Take the year 2009 for an example, about one billion square meters of energy-saving buildings were built which brought in the energy conservation of nine million tons of standard coal and an emission reduction of 18 million tons of carbon dioxide [2]. Therefore, energy-saving buildings should be promoted so as to realize the sustainable development of China.

To achieve the target of energy saving effect, materials of external walls of buildings should be paid more attention because exterior walls are the separation of indoor and outdoor environment, and large amount of energy dissipates through walls, so the

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insulation effect would be better if the walls themselves are made of thermal materials. The blocks/bricks of exterior walls that most buildings select could be divided into organic materials and inorganic materials according to the raw materials used to manufacture them.

The application of organic materials, which mainly means the usage of crop residues or part of fruit shells, are emerging research area in recent years, and the substance people choose from these materials are actually vegetable fibers which could be used singly or mixed with other binders. Chikhi et al. [3] investigated the mechanical and thermal properties of new composite materials made of date palm fibers. Binici et al. [4] introduced a material from sunflower stalk, textile waste and stubble fibers in Turkey, which would ward off the problems when these waste are burned or directly discharged to the nature. Zhou et al. [5] manufactured a lightweight mixture, composed of cotton stalk fibers, which possesses good thermal conductivity. Panyakaew et al. [6] described the production of boards made from coconut husk and bagasse to save energy as insulation material.

Organic materials make full use of the waste from crops or fruits in order to reduce the bad influence they would cause on the nature, such as destroying the atmosphere after burning or taking up a lot of space if nothing is did to them. Still a problem, which exists in this kind of material, is that the fire resistance should not be neglected before being proved effective. If the blocks made of vegetable fibers are combustible or nonflammable, the whole building will be in a dangerous situation once fires break out, because the wall materials may accelerate the development of the fire and the collapse of the whole buildings. But as traditional materials, inorganic materials will represent advantages in this condition for their incombustible characteristics and durability. Besides the mechanical properties, people also pay attention to the thermal performance, Wongkeo et al. [7] used bottom ash from power plant as raw materials to produce concrete block which would improve the compressive strength and thermal conductivity. Sousa et al. [8] studied a new-type concrete units with appropriate compressive strength and good thermal insulation. Bories et al. [9] considered the effect of different pore-forming agents on the physical, mechanical and thermal properties of clay bricks.

In China, with the usage of inorganic materials, fired clay bricks have been developed for more than 2000 years and are known for "Qin Brick and Han Tile" [10] because of their outstanding insulation performance and durability compared to timber houses or adobe buildings. As a price of convenience to people, lots of arable land had to be destroyed to obtain clay just to fire the bricks (Fig. 1), so the prohibition of fired clay bricks has been carried out from 1999 in some big cities and new sintering materials are promoted to replace them. At the same time, to meet the requirement of the National Standard GB 50189-2005 [11] which formulates the thermal transmittance (U-value, W/m^2 K), cavities are set in the blocks to reduce the U-value because the heat transfer efficient of air is much lower than common materials. Among the substitutions of clay, shale is becoming more of a concern for its environmentally pollution-free and huge reserves. That is the background why this kind of thermal insulation block is generated, not only the high carrying capacity, but also the insulation requirements is satisfied. The heat-retaining performance, in particular, is very good due to the high void ratio, which could realize the aim of the insulation through the wall itself, and that is self-insulation. Without the usage of special insulation measures, the construction process will be easier and the cost will be lower.

The aim of this paper is to discuss the raw materials that constitute the block, and study the carrying capacity and thermal performance of walls built with this new blocks.

Fig. 1. The destruction of arable land.

2. Materials and block shape

Shale, fly ash, bricks from the building rubbish and waste paper pulp are the main raw materials used to produce the fired shale hollow blocks, as shown in Fig. 2.

2.1. Shale

As conventional sintered materials, the clay would be exploited by destroying lots of cultivated land to manufacture fired common bricks, and loss of soil could take place easily without the protection of vegetation and topsoil when raining heavily. But there will be no similar problems if we use shale as the raw material to produce fired hollow blocks. Shale is a kind of sedimentary rocks, which is formed by long-term silt deposition. In China, more than 75% of land surface are covered by sedimentary rocks, among which the shale possess a proportion of 77.5% [12]. The resources are so abundant and easily mined that the exploitation of the shale would have little impact on the environment. Though the chemical composition are different in different regions, some adjustments could be made to the mixture to produce qualified blocks.

2.2. Fly ash

Fly ash is a waste which is collected from the smoke after the burning of the coal. Thermal power generation is still the major method to produce electricity till now in China, and as the chief solid waste of coal-fired power plant, fly ash is one of the largest emission of industrial residue. When this material is used as raw material of blocks, lots of fuel would be saved as a result of the high residual heat, and also the density would be lighter after burning. In [13], the fired bricks made of high volume ratio of fly ash were of reliable compressive strength, low water absorption, etc.

2.3. Waste paper

Reusing the waste paper would bring in pollution to the environment, but the waste paper could be made into paper pulp so as to be added into the mixture. Microporosities would be produced after the firing procedure because of cellulose fibers containing in the paper pulp. And the pore in the blocks could improve the thermal performances and reduce the deadweight [14].

2.4. Crushed bricks

More than one billion tons of construction waste are produced every year in China, and the utilization rate is still at a low level of about 5%, which means that most of these waste are discharged to the environment directly without effective treatment and occupy lots of land. At present, the utilized parts of the building waste are mainly abandoned concrete which could be used as coarse aggregate in the recycled aggregate concrete, while other building waste such as the waste bricks are cast aside and lack of special research. A new method to solve the problem is to grind the bricks and used as raw material to produce sintered materials, which have little influence on shrinkage and compressive strength of the fired blocks if appropriate proportion is chosen [15].

2.5. The blocks

The chemical compositions of the shale, fly ash and crushed bricks used in this study are given in Table 1.