

Compressive Strength and Block-Mortar Bond of a New-Type of Insulation Hollow Block

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Abstract. This paper mainly studies the mechanical properties of hollow block made from shale, coal gangue and sawdust. In China, shale is gradually used as substitute material for clay in the manufacture of sintered masonry materials. The research goal was to provide basis for the generalization and application of the fired shale hollow block through uniaxial compressive test and failure mode under biaxial stress state. Results showed that the hollow block had reliable compressive strength and bond strength with lower density and good thermal insulation performance, meaning the feasibility of application in practical engineering.

1. Introduction

Masonry blocks, being used in China for thousands of years, are becoming a research hotspot recently along with the emphasis on environmental protection and energy saving. Shale, instead of clay, is used to manufacture fired hollow blocks which could not only reduce the damage to cultivated land but also improve energy saving effect of the buildings. The mechanical properties of masonry blocks should be studied so as to promote practical application in engineering.

The compressive strength of masonry prisms, bond strength of block and mortar are commonly used to study the mechanical properties of the masonry blocks, which could ensure the application safety. A variety of experimental research and theoretical analysis have been done to study the compressive and shearing behavior of masonry block made from different raw materials.

Lima [1] studied the compressive strength of masonry column and absorption of building blocks made from sugarcane bagasse ash. They reported that the SBA could be incorporated into the CEBs and masonry without damage to the mechanical properties. Sherwood [2] used a simple and accurate empirical formula to predict the compressive strength of ungrouted hollow concrete block masonry. The study showed that the proposed formula gave the most accurate prediction of compressive strength with the least variation. Zhou [3] proposed the use of artificial neural networks and adaptive neuro-fuzzy inference systems for estimating the compressive strength of hollow concrete block masonry prisms which had excellent prediction ability with insignificant error rates. Zhu [4] used numerical analysis to investigate the masonry wallette compressive strength and some parameters were also ranked in order of importance.

Beneditti [5] introduced an analytical response curve to predict the shear displacement relationship which could reproduce the observed experimental behavior. Establishment of theory was based on assuming a no tension elastic perfectly plastic materials for the masonry. Thamboo [6] carried out the investigations of flexural and shear bond characteristics of thin mortars which was only 1mm~4mm



thick. Comparing with the conventional masonry, the bond strength of concrete masonry using thin mortar was improved. Dehghan [7] assessed the effects of sand grading on the properties of mortar as well as masonry through comprehensive experimental study.

Rahman [8] investigated the shear load-displacement behavior of horizontal joints in unreinforced brick masonry subjected to constant compression. They built FEM models, using cohesion and internal friction angle from test results, to predict the bed joint behavior, and the simulation results were reliable. The relationship between bond strength and compressive strength of masonry were studied by Sarangapani [9]. Through the tests, using local bricks and mortars, it could be concluded that the compressive strength of the masonry increased as the bond strength increased. Bortolotti [10] proposed an elliptical curve for masonry and concrete in compression biaxial state, and limit surface in the principal stress space in triaxial compression stress state.

Current studies have shown that (1) compression and shear test is the basic method to study the mechanical properties of block; and (2) the shear strength of masonry prisms would change with the increasing of axial compressive stress.

This paper mainly examines the strength grade of thermal insulation block and mortar, compressive and shear strength of masonry prisms, and the failure pattern of specimen under biaxial stress state. The studies could provide theoretical support for the subsequent research through the basic mechanical properties test of block.

2. Materials used in experimental program

2.1. Shale fired thermal insulation block

In China, sintered clay bricks, with the characteristics of durability and heat preservation, have been used as traditional wall materials for more than 2000 years (Li [11]). A lot of clay is excavated to satisfy the need for sintered clay products, which would destroy the farmland seriously, so it's necessary to seek for a new type raw material to reduce the usage of clay.

In these circumstances, shale has gradually attracted the attention of researchers, for more than 75% of land area are covered by sedimentary rocks in China, in which shale accounts for 77.5% (Yu [12]). In addition, coal gangue and sawdust are also used as raw materials; these two materials could burn during the firing process of blocks, which would reduce the amount of fuel and make micropores after burning. Besides the micropores, relatively high void ratio (46%) could also improve the insulation performance of block, so the block is designed as shown in Figure 1, and the size of which is 240mm × 240mm × 190mm (length × width × height). The compressive strength of the block is established as 5.90MPa through compression test of 10 blocks (Figure 2), and according to National Standard GB/T 13545-2014 (Code of China [13]), the strength grade of block is MU5.0.



Figure 1. Shale fired thermal insulation block



Figure 2. Failure form of the block

2.2. Mortar

On the basis of Industry Standard JGJ/T 98-2010 (Code of China [14]) and JGJ/T 70-2009 (Code of China [15]), the mix proportion of mortar is determined as shown in Table 1. The cube specimen, whose size is 70.7mm × 70.7mm × 70.7mm (length width height), is used to obtain the strength grade of

mortar through compression test. The average compressive strength of 6 cube is 5.39MPa, so the strength grade of mortar is M5.0.

Table 1. Mix ratio of masonry mortar

Material	Cement	Sand	Water
Proportions by weight (kg/m ³)	224	1450	300

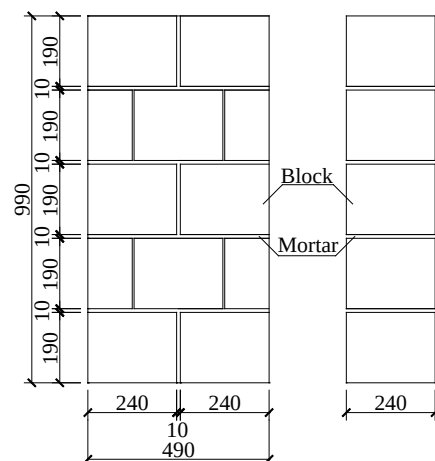
According to National Standard GB 50003-2011 (Code of China [16]), the strength grade of the mortar should not be lower than the strength grade of the block, so the materials used in this paper could satisfy the requirements of specification.

3. Experimental plan

The relevant provisions of compression and shear test of specimen are given by National Standard (Code of China [17]): the height of the compressive specimen should be 1.2~2.0 times the thickness, while the shear specimen is designed as double shear form.

3.1. Test of compressive strength

The size of specimen could be seen in Figure 3(a), and the construction process was completed by a medium skilled worker [Figure 3(b)]. In order to obtain the stress-strain curve through the longitudinal and lateral deformation, four dial gauges were arranged on the front and back of the specimen (Figure 4).



(a) Specimen size



(b) Construction process

Figure 3. Compressive specimen



Figure 4. Layout of dial gauge

3.2. Test of bond strength of block and mortar

Shear strength of masonry plays an important role in the mechanical behavior of masonry structure, so double shear specimen was designed to get the shear performance of prisms [Figure 5(a)]. In order to study the effect of axial compressive stress on bond strength of block and mortar, a new loading device was designed driven by hoisting jack [Figure 5(b)].

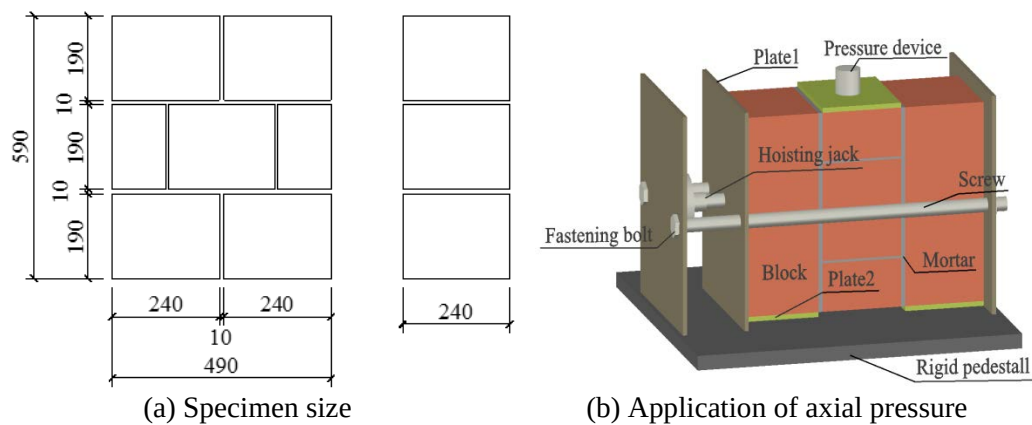


Figure 5. Shear specimen



Figure 6. Failure modes of prisms

4. Results and discussion

4.1. Failure modes and compressive strength

The first crack appeared at the corner of the specimen edge when the load value was about 50% of the failure load, and the specimen was in elastic loading stage at this time. Cracks occurred in the middle of the upper part of the specimen with the increasing of load, developed and extended vertically while the growth rate of dial indicator readings gradually increased. At the same time, local area of the block surface appeared spalling phenomenon which would reduce the effective area of masonry pressure bearing surface and accelerated the failure of the specimen (this process was identified as an elastic-plastic stage). At the final stage of loading (plastic stage), the development of the original cracks was sufficient while there were almost no new cracks appeared (Figure 6). The peak load which was recorded by the test machine was failure load when the damages of the specimen occurred.

The average value of compressive strength of 10 specimens was 3.47MPa, and basing on the National Standard (Code of China [16]), the standard values and design values of compressive strength were determined as 2.57MPa and 1.60MPa, respectively.

4.2. Compressive stress-strain curve

Stress-strain relationship is an important index to reflect the mechanical properties of masonry. At the initial stage of loading, the specimen was in elastic stage, meaning that the stress-strain curve was linear. With the increasing of load values, the change range of strain was larger than stress because of the appearance and development of cracks, and the relationship between stress and strain became nonlinear.

In the study of this paper, only the ascending section of the stress-strain curve could be obtained by the conventional testing machine because that the destruction of masonry prisms occurred rapidly when reaching the failure load. According to the existing research results and test data of this paper, the stress-strain relationship is given by Equation (1).

$$\frac{\sigma}{\sigma_0} = 1.56 \left(\frac{\varepsilon}{\varepsilon_0} \right) - 0.58 \left(\frac{\varepsilon}{\varepsilon_0} \right)^2 \quad (1)$$

In this equation, σ_0 and ε_0 separately represent the peak pressure and peak strain, σ and ε represent the stress and strain during the test, respectively. The stress-strain curve which is calculated by the Eq. (1) is in good agreement with experimental data (Figure 7).

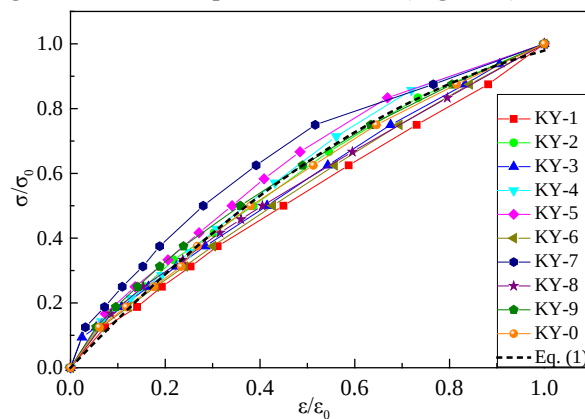


Figure 7. Stress-Strain Curve

4.3. Shear bond strength

Shear failure is the common form of destruction mainly caused by lateral load due to horizontal seismic effects. Horizontal load is the main reason for the formation of diagonal cracking failures, and the bond strength of block and mortar play an important role in the failure process. Masonry members, with or without effective restrictions of constructional column and ring beam, are under vertical compression from self-weight and other building structural loads. The compressive stress has an obvious effect on bond strength which would change the mechanical properties of masonry structure.

In the experimental study of this paper, the range of axial compressive stress was 0~0.6MPa, and amplitude of variation was 0.1MPa. The failure modes of specimen under Shear-compression Loading could be divided into 3 types: shear friction failure, shear compression failure and local compressing failure.

1. Shear friction failure

Shear friction failure meant that the bond strength between mortar and masonry could not satisfy the shear strength which would lead to the occurrence of shear slip. The failure mode mainly occurred when the axial pressure was small [Figure 8(a)].

2. Shear compression failure

Spalling occurred on the surface of block in this failure mode, and the crack on one side of the specimen was penetrated through the joint [Figure 8(b)].

3. Local compressing failure

Local compressing failure occurred when the axial pressure continued to increase. The ends of the specimen were crushed before shear failure occurred [Figure 8(c)].



(a) Shear friction failure



(b) Shear compression failure



(c) Local compressing failure

Figure 8. Failure mode under biaxial stress state

Shear strength and damage shape under different axial pressures could be seen in Table 2. The failure mode of the specimen was mainly shear failure when the axial pressure was small (0MPa,

0.10MPa and 0.20MPa). With the increasing of axial compressive stress, the destruction of the specimen exhibited the characteristics of compressive failure (0.25MPa, 0.30MPa and 0.35MPa). The specimen was crushed before the cracks appeared in the joint when the axial compressive stress increased to a certain range (0.35MPa and 0.40MPa).

Table 2. Shear failure under different axial pressures

Specimen number	Number of tests	Axial pressure (MPa)	Shear strength(MPa)	Failure types	Number of failure types
JY-0	6	0.00	0.220	Shear friction failure	6
JY-1	6	0.10	0.241	Shear friction failure	6
JY-2	6	0.20	0.286	Shear friction failure	6
JY-3	6	0.25	0.291	Shear friction failure	2
				Shear compression failure	4
JY-4	6	0.30	0.295	Shear compression failure	6
JY-5	6	0.35	0.298	Shear compression failure	3
				Local compressing failure	3
JY-6	6	0.40	0.301	Local compressing failure	6

5. Conclusions

In this study, compressive strength of block, mortar and block prisms, and shear strength of the prisms with or without axial compressive stress were investigated. Based on the experimental results, the following conclusions could be drawn:

1. The compressive strength of the block and mortar are 5.90MPa and 5.39MPa, respectively. The strength grade could be established as MU 5.0, while the strength grade of mortar is M 5.0, meaning that the hollow block and mortar could be used in practical engineering.
2. The damage characteristics of new block masonry prisms, obtained through compression test, is similar to traditional blocks. During the process of damage, there are obvious peeling phenomenon, showing the brittle characteristics.
3. With the increasing of axial compressive stress, the failure form of the specimen gradually changes from shear friction failure to shear compression failure and local compressing failure, meaning that the axial pressure has a significant effect on the shear resistance of masonry.
4. Related tests have proved that the block made of shale and coal gangue has good mechanical properties, ensuring the application prospects, and deserve further study.

6. Acknowledgments

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