Study on Mechanical Properties of Green and Environment-Friendly Three-Mixture Concrete Self-Insulating Masonry

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Abstract. In recent years, the state has been actively promoting the concept of energy saving, green and sustainable development. In this paper, according to the characteristics of two kinds of industrial waste slag, silicon powder and fly ash, and the agricultural by-product of rice husk powder, the uniform design theory is used to design the test scheme, prepare green concrete hollow blocks, and assemble them into masonry. According to the test results, durability and economic requirements, the three materials of silicon powder, fly ash and rice husk powder are made of three-mixture concrete. The new block designed and made by ourselves is used, and the B1 grade EPS insulation board is used as the filling material to make the three-mixture concrete self-insulating masonry. This paper uses the method of control test to explore the mechanical properties of self-insulated masonry after design by studying the compressive strength, so that it is suitable for the construction industry, and also makes the straw resources in the building wall can be used in a variety of ways.

Keywords: Fly ash; Rice husk powder; Self-insulating block; Mechanical property

1 INTRODUCTION

With the development of industry and agriculture, a lot of by-products and waste have been produced, and the disposal of these by-products and waste needs to be solved urgently. According to statistics, China's annual output of straw is about 700 million tons. The plant fiber contained in the straw can be used as a green environmental protection material in the building concrete. Fly ash is the main solid waste discharged from coal-fired power plants.

As early as 1998, Wu Zhongwei studied the performance of green concrete [1]. In the subsequent research, he also proved that the performance of green concrete met the requirements [2]. Na Xigao also proposed the application of rice husk and rice husk ash in architecture in 1998 [3]. Zhang Ximing et al. showed in the experimental study of straw-fly ash concrete blocks that straw incorporation could obtain concrete blocks that could not only save energy but also meet C20 strength [3]. Wu Jianhua et al. proposed

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the concrete configuration technology with a large amount of fly ash [4], and Lei Rui et al. proposed that fly ash can play an important role in new building materials [5]. Jin Mingshan et al. studied the change of early compressive strength of concrete with large amount of fly ash [6], indicating the feasibility of adding fly ash to concrete. Zhang Ximing et al. showed in the experimental study of straw-fly ash concrete blocks that straw incorporation could obtain concrete blocks that could not only save energy but also meet C20 strength [7].For green concrete, our country has always been committed to studying the ways of its development.Xia Yuanying and others have already begun to study the green concrete pathway. The discussion was conducted in terms of recycled materials, waste materials, and durability.[8] Zhao Yu et al. also studied the production benefits of green concrete from the production method of green concrete.[9]For foreign countries, research on green concrete was already carried out in Denmark in 2000 by M. Glavind and C. Munch-Petersen.[10] In the last few years the modeling of compressive strength determination of concrete constructed with fly ash has also been studied.[11]

In this paper, fly ash, silicon powder and straw fiber are mixed into concrete to make a three-mixture concrete block, which is then laid into masonry. The influence of three kinds of materials on the mechanical properties of concrete masonry is studied, and the self-insulation masonry of three-mixture concrete is developed and utilized.

2 EXPERIMENTAL DESIGN SCHEME

This experiment mainly studies the mechanical properties of masonry. Masonry is a whole structure combined by masonry blocks and mortar. The main factors affecting the mechanical properties of masonry structure include: mortar strength grade M, block strength grade MU, mortar and block bonding performance, construction quality, loading method and speed, maintenance conditions, etc.

2.1 Blocking Making

2.1.1 Block Size Determination and Formwork Making.

Concrete blocks are mostly double-row and triple-row holes. Wang Jiani obtained the influence of holes on the thermal performance of self-insulating concrete hollow block in the analysis of hole performance [12]. The block designed in this paper is filled with polystyrene board insulation material in the cavity, which effectively isolates the heat flow propagation and weakens the heat transfer capacity of the wall. According to the size and shape of the block, you need to make your own template. To facilitate subsequent removal, the block uses a wood template with a bottom plate of 420mm x 240mm and the main dimension of the block is 390mm x 190mm. In the template, use glue to fix the Bl grade EPS board to the specified position in the mold. Remove the BL grade EPS board after the concrete has set.The shape of the mold is shown in Figure 1.

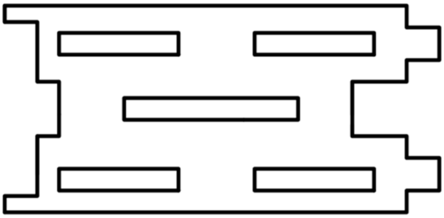


Fig. 1. Diagram of the shape of the block

2.1.2 Design of Strength and Mix Ratio of Concrete.

This experiment is based on the research of three-mixture concrete insulation block on the basis of the paper [13], and refers to the concrete mixing strength formula in the "Ordinary concrete Mix Design Regulations" (JGJ55-2011) (1) :

$$f_{cu.0} = f_{cu.k} + 1.645\sigma \quad (1)$$

$f_{cu.0}$ —— Concrete strength（N/mm^2）
$f_{cu.k}$ —— Standard compressive strength of concrete cube（N/mm^2）
σ —— Standard deviation of concrete strength（N/mm^2）

By calculation, the mix ratio of 1m3 ordinary concrete is 215.6:201.6:684.26:1272.73 (cement: water: sand: gravel). The material test of straw powder (rice husk powder), silicon powder and fly ash and other three-doped concrete is shown in the table 1.The solidified concrete blocks are shown in Figure 2.

Table 1. Test mix ratio of three doped concrete materials

cement/kg	water/kg	sand/kg	Natural crushed stone/kg	Silica pow-der/kg	rice husk pow-der/kg	Fly ash/kg
6.89	6.45	21.89	41	0.99	0.42	1.97

Fig. 2. Formed block

2.2 Masonry Making

According to the requirements of compressive strength test of masonry wall axis in Standard for Basic Mechanical Properties of Masonry , the height of masonry is the sum of the height of three layers of masonry blocks and two layers of mortar. The masonry size of this test is 590mm×190mm×600mm.

This test records the transverse and axial deformation of masonry in the loading process and the influence of load on the strength of mortar. According to the requirements of the code, it is suggested that the strength of mortar should be lower than the strength of block when laying masonry. According to the failure state of the bearing capacity, the masonry structure can achieve the best effect only when the masonry and mortar are destroyed at the same time. Because the strength characteristics of concrete mortar and block strength are different, the mortar strength designed in this test is M7.5, M10.0 and M15.0 according to the standard principles and existing problems. The mortar of each strength grade is taken as a group, with 3 test blocks and 3 auxiliary blocks in each group. The mix ratio of masonry mortar is shown in the following table 2.

The adaptive strength of masonry mortar is calculated according to the following formula. (2)

$$f_{m.0} = kf_2 \tag{2}$$

$f_{m.0}$ ——Test strength of mortar;(MPa)
f_2 ——Mortar strength grade value;(MPa)
k ——Coefficient of correlation. This article takes 1.20;

Table 2. Mix ratio of masonry mortar

Mortar grade	cement	sand	water
M7.5	220	1500	270~300
M10.0	250		
M15.0	280		

Masonry shall be laid according to the Standard of Test Methods for Basic Mechanical Properties of Masonry. Each masonry structure is made of three blocks, three auxiliary blocks and mortar in Figure 3 and Figure 4.At each layer of the masonry, we used the splices in Figure 5, where we filled the splices with mortar, and after making sure that the two blocks in each layer were tightly connected, we applied mortar to the top of each layer before placing the upper layer of the block assembly on top of it. This was repeated to obtain a three-layer masonry. The top of the member shall be levelled with mortar after the completion of masonry.The completed masonry is shown in Figure 6. The compressive strength of the masonry structure was tested after 28d maintenance.

Fig. 3. Front view and top view of auxiliary block 1

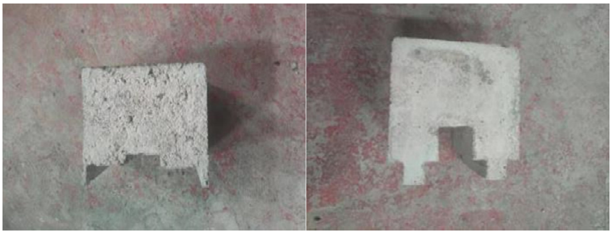


Fig. 4. Front view and top view of auxiliary lock 2

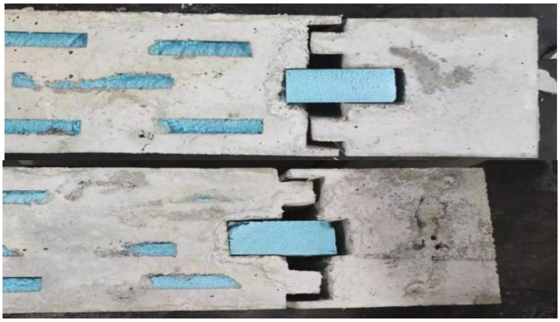


Fig. 5. Masonry masonry combination

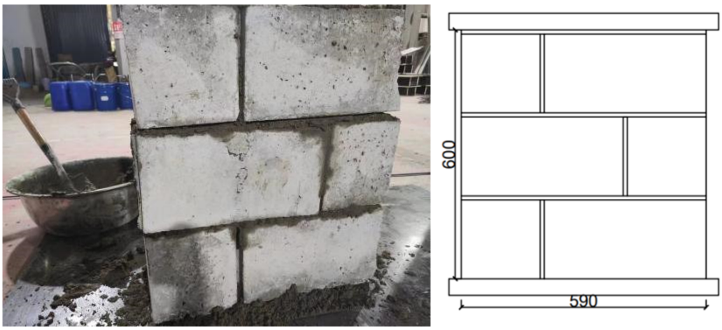


Fig. 6. Masonry specimen size and schematic diagram

3 TEST PROCESS AND RESULT ANALYSIS

3.1 Test Process

This test was conducted with reference to the compressive strength determination method of Tuo Zijie et al.[14]The compressive strength test of masonry is loaded with a 500t test press in the test room. The loading process is carried out according to the standard in progress method.

The failure load of the masonry structure is preliminarily estimated according to the design value of the block and mortar strength, and then the masonry structure is prepressed according to the requirements of the code. The prepressed load value is 5%-10% of the estimated load, and the prepressed three times. After the preloading of the structure, the masonry is loaded step by step. The load value of each stage is about 10% of the failure load, the load control of each stage is 100KN, the loading speed is 200N/s, and the load holding time after loading is 1min-1.5min. After the loading is stable, the corresponding displacements of loads at all levels are recorded, the morphological changes of masonry structures are observed, the failure mechanism and the time position and load value of the first crack are analyzed, the development direction of cracks are observed, and the ultimate load value is recorded until the specimen fails and loses its bearing capacity.

3.2 Failure Pattern

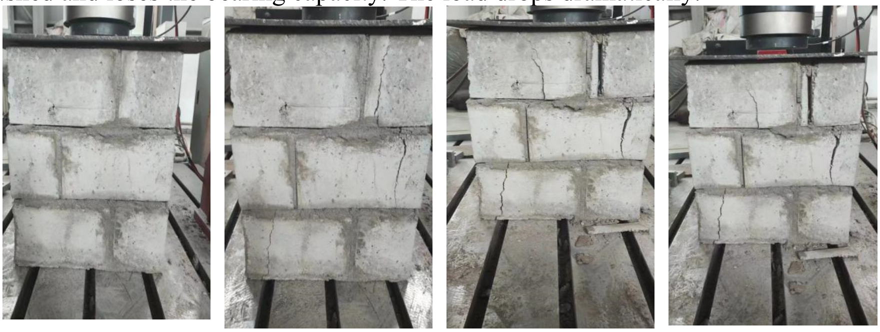
Under the action of uniform distribution load, the three-mixture concrete self-insulation masonry mainly experiences four stages of change.The failure modes of each stage are shown in Figure 7:

1) Initial stage: According to the requirements of the code, the masonry is prepressed first, and the appearance of the masonry at this stage has not changed significantly. The masonry will have a small sound during the loading process, and the masonry has no cracks at this stage. At this stage, the load increases faster.

2) Elastic stage: continue to increase the load, the load growth rate is relatively gentle and tends to be stable. Cracks begin to appear at this point, and cracks first appear in the top mortar layer of the block, passing from top to bottom. Cracks appear on both the front and side of masonry, and the cracks of masonry are small. Masonry cracks develop slowly. At this time, the load value is about 65%-75% of the ultimate load.

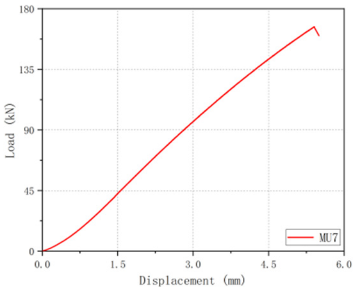
3) Plastic stage: The crack development of masonry structure is very obvious, especially the end crack, forming a longitudinal through crack, and the front crack development through the upper and lower. The load growth rate begins to decrease. The surface of masonry structure began to fall off, and the sound of concrete being crushed gradually increased. With the increase of load, the area of masonry structure falling off became larger and larger. At this stage, the masonry structure has not lost its bearing capacity, the load continues to gr-ow, and the masonry has not been completely crushed. The load value is about 90% of the ultimate load.

4)Failure stage: at this stage, the cracks of masonry structure develop rapidly, the side cracks develop rapidly, and the cracks are rapidly connected in the longitudinal direction. At the same time, the front cracks develop rapidly, the upper and lower through, and finally the masonry structure reaches the ultimate bearing capacity, is crushed and loses the bearing capacity. The load drops dramatically.

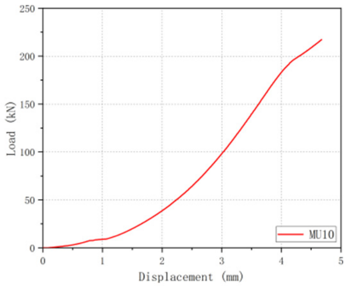


a.Initial stage b.elastic stage c.plastic stage d.Masonry failure stage

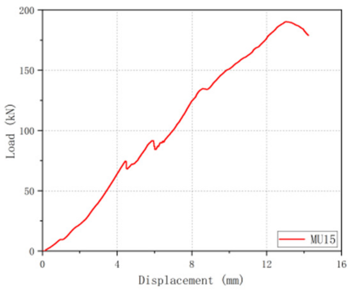
Fig. 7. Masonry failure



M7.5 mortar



M10.0 mortar



M15.0 moratr

Fig. 8. Force-displacement diagram

To measure the axial compressive strength of masonry, according to the calculation standards in literature [15], the calculation formula is as follows.(3)

$$f_c = N/A \tag{3}$$

f_c ——Compressive strength of masonry structure(MPa);
N ——Failure load of masonry structure(N);
A ——The cross-sectional area of masonry structure（mm²）;

According to the requirements of the compressive strength of hollow concrete blocks in the code, the experimental and theoretical values of the compressive strength of the masonry axis are compared as shown in the following table. According to the calculation formula of compressive strength and the measured compressive strength of mortar in Figure 8, the axial compressive strength value of masonry concrete mortar with strength grade M15.0 can be obtained. The calculation formula is as follows.(4)

$$f_{m,1} = k_1 f_1^{\propto}(1 + 0.07 f_2) k_2 \tag{4}$$

$f_{m,1}$ ——Average compressive strength of masonry axis(MPa);
$k_1, \propto$——Different factors of masonry influence coefficient.$k_1 = 0.46, \propto = 0.9$;
f_1 ——Block strength grade（MPa）;
f_2 ——Mean mortar strength;
k_2 ——The influence coefficient of mortar strength is 1;

Table 3. Comparison of experimental values and theoretical values of masonry axial compressive strength

Mortar grade	Mean mortar strength (MPa)	Area of section (mm²)	Measured resistance to pressure and strong enemy (MPa)	Theoretical compressive strength (MPa)	Measured value/theoretical value
M7.5	10.2		12.03	11.68	1.03
M10.0	13.5	590×190	13.92	13.26	1.05
M15.0	17.2		16.22	15.02	1.08

It can be seen from the table 3 that the strength grade of mortar is related to the compressive strength performance of masonry structure, and the change of the strength grade of mortar will affect the strength directly to the masonry. It can also be seen from the table that the difference between the test value and the theoretical value of the axial compressive strength of the masonry structure is small, and its coefficient of variation is about 1.08.

4 FINITE ELEMENT ANALYSIS OF SELF-INSULATING MASONRY WITH THREE-MIXTURE CONCRETE

In this paper, isotropic method is adopted to simplify the treatment. First, the masonry model diagram is constructed, which is shown in Figure 7, and then the stress-strain relationship of masonry is simulated by the method of graded loading, and the stress characteristics of masonry are analyzed.As a result, finite element analysis diagrams for various perspectives in Figure 9, Figure 10, Figure 11, Figure 12, and Figure 13 were obtained.

From the finite element analysis, it can be seen that the maximum value of stress in the figure is 12.2684MPa distributed at the edges and corners of the masonry. Compared with other parts, the stress value in the middle cavity of the masonry is smaller. At the joint of auxiliary block 2 and upper and lower layers, the stress value is the smallest, and the minimum value is 1.603MPa, which has a greater influence on the strength of masonry.

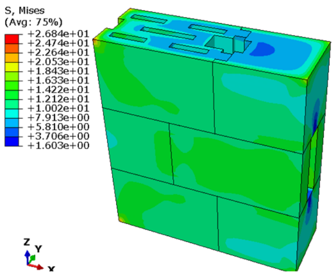


Fig. 9. General stress distribution diagram

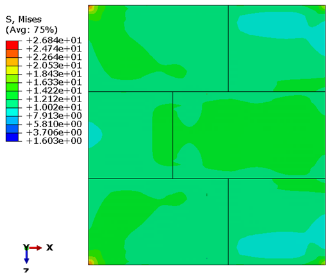


Fig. 10. Stress distribution elevation

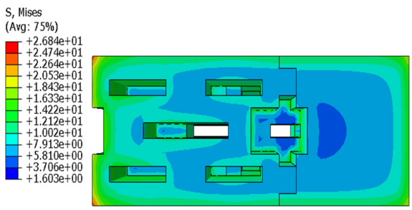


Fig. 11. Top view of stress distribution

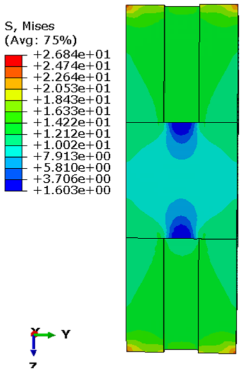


Fig. 12. Stress distribution diagram on the left

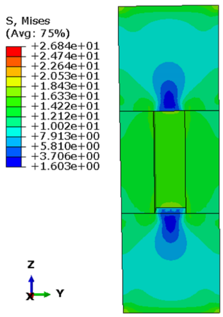


Fig. 13. Stress distribution diagram on the right

5 CONCLUSION AND RROSPECT

Based on the mix ratio designed in the paper [13], this paper prepared three-mixture concrete self-insulating blocks (rice husk powder, silicon powder, fly ash), and then made masonry and continued to study the mechanical properties of masonry, through which the following conclusions were drawn.

In this paper, the compressive strength of masonry under different mortar strengths is obtained after the test. Through the test, it is concluded that when the mortar grade is M15, the compressive strength of masonry obtained is the highest, the theoretical strength is 8.32MPa, and the actual strength is 9.85MPa.

Therefore, it is concluded that the strength of the three-mixture concrete self-insulating block masonry meets the standard, but the material used in it has low cost and high economic benefit, and can also deal with agricultural and industrial by-products (straw and fly ash). It can be seen that the application prospect of the masonry is broad.

In this experiment, the mechanical compressive properties of masonry were investigated, and the compressive properties were found to meet the standard of strength. In the future research, the thermal properties of masonry can be studied. Replacing fine aggregates with more environmentally friendly materials; The strength of masonry under different mix ratio is studied.

Utilizing the by-products of the production of waste materials to form concrete with strength that meets the requirements through various technologies is a very important method of producing green concrete, which can protect the environment and save resources. Although the current technology is still limited and immature, but in the future, with the concept of sustainable development continues to deepen, the continuous optimization of technical methods, green concrete will certainly usher in a bright future of development.

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