Experimental Study on Flexural Properties of New Foamed Concrete Composite Wall Panels

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Abstract: Foam concrete composite wallboard has the advantages of lightweight, thermal insulation and other advantages, which is mainly used in the wall structure of buildings. This article conducts experimental research on the flexural performance of 12 steel truss composite panels (welded upper and lower chord steel bars and web bars). The research results show that the bending resistance of foam fine aggregate concrete composite slab is significantly improved with the increase of the steel bar diameter, but the bending resistance of the composite wallboard with the load bearing surface of fine aggregate concrete layer is weak, cracks appear earlier and the deflection is larger in the later stage of loading, so measures should be taken to control the development of cracks in the design. In addition, this paper uses the "Code for Design of Concrete Structures" to calculate the ultimate bending moment of composite wallboard and compare it with the measured value. It is found that the measured bending moment is much larger than the calculated bending moment, which indicates that the code design is too conservative and is not suitable for the bending moment calculation of foam fine aggregate concrete composite board, but the foam concrete board can meet the needs of the project and can be used as a light load-bearing component.

Keywords: Foamed Concrete; Superimposed Wallboard; Flexural Bearing Capacity; Measured Bending Moment

1. Introduction

With the promotion of energy-saving and environmental protection policies, the use of insulation and energy-saving building materials can effectively solve the problem of building energy consumption, and has good economic benefits and strategic significance [1-2]. Foam concrete is a porous lightweight concrete with the material characteristics of light weight, low elastic modulus, low thermal conductivity, etc. the prepared foam concrete wallboard has the advantages of lightweight, thermal insulation and other advantages. However, the study [3-5] found that foam concrete also has some shortcomings, such as large shrinkage, low strength and easy collapse of formwork, which restricts the application range of foam concrete wallboard. In order to improve the crack resistance and strength of foam concrete wallboard, it is combined with high-strength panels to form a composite wallboard, which can effectively improve the collapse phenomenon caused by the thicker foam concrete wallboard and the engineering failure caused by the shortcomings of low strength, poor crack resistance, etc. [6-9]. Luo Yunfeng [10] carried out various studies on the matching of core material foam concrete and face slab, and proposed a method to improve the stability of composite sandwich wallboard foam concrete slurry and prepare sandwich composite panels with intact integrity. Zhan Meng [11] studied the interface failure mechanism of foam concrete composite wallboard, obtained the interface bond slip constitutive equation of composite members under different foam concrete densities, and proposed the interface mechanics formula of concrete and foam concrete composite members. At present, the research of foam concrete wallboard mainly focuses on the interface treatment and mechanical properties of single material panel or composite sandwich panel (the other panel is usually metal or fiber material). In contrast, the research on wind load and horizontal load resistance of foam fine aggregate concrete composite wallboard is very limited. In view of this, 12 steel truss composite panels were poured in this article, and the bending performance test was conducted after considering factors such as the diameter of the steel bars and different loading surfaces. The research results can provide a reference for the related research and engineering application of foam-fine aggregate concrete composite wallboard.

2. Test Plan

2.1 Specimen Design

The foam fine aggregate concrete composite wall panel made in this paper consists of fine aggregate concrete and foam concrete. The cement used is Conch P · C 42.5, the foaming agent is hydroxypropyl methyl fiber, and the stacking form is artificial rough surface. The specific matching of foam fine aggregate concrete composite wallboard is shown in Table 1.

2.2 Test Piece Design

This test component is made of C30 fine aggregate concrete, M3.0 (measured M4.0) foam concrete, steel bars and steel truss connectors. The fabrication process of truss reinforced composite wallboard: bind and fix the steel bars and steel bar trusses with double-layer reinforcement mesh in the wood formwork. First, pour the fine aggregate concrete to the preset thickness and vibrate it tightly. After the strength of the fine aggregate concrete reaches 5MPa as required by the specification, continue to pour foam concrete and vibrate it tightly, until the component pouring is completed. The thickness of the composite plate is 200mm (80 mm for fine aggregate concrete and 120 mm for foam concrete), and the composite surface is artificial rough surface. The two sides of the long side of the wall panel are reinforced with HRB400 grade truss steel bars and equipped with double-layer bidirectional steel mesh. The diameters of the upper and lower chords of the three types of panels are 6mm (web reinforcement 4mm), 6mm (web reinforcement 6mm), and 8mm (web reinforcement 6mm), respectively. The specific reinforcement form is shown in Figure 1. The test piece number is A-B-C, A represents the loading surface (where W represents the foam concrete surface, S represents the fine aggregate concrete surface), B represents the diameter of the web bar reinforcement, C represents the number of the same group of test pieces, and the test piece parameters are shown in Table 2.

2.3 test method

The loading situation of the test piece is shown in Figure 2. The experiment refers to the "Standard for Test Methods of Concrete Structures" (GB 50152-2010) [12], and uses a hydraulic jack to load the wall panel step by step with 5kN per level until the test wall panel fails. In this experiment, a micrometer was used to measure the deflection of the wall panel, and a crack observer was used to measure the crack width. Strain gauges were attached to the surface of the wall panel (2.5cm from the top and bottom of the panel and 2.5cm above and below the joint surface) and the steel truss to obtain the strain of the concrete and steel bars.

3. Analysis of Test Results

3.1 Experimental Phenomenon

During the experimental loading process, the bonding condition of the composite wall panels was good, and there was no relative slip observed. This phenomenon indicates that the composite wall panels have good integrity, and effective stress transfer can occur between the interfaces. However, different loading surfaces will directly affect the failure state of the composite wall panels.

Table 1. Concrete Mix Proportion

Concrete Type	water-cement ratio	cement (kg/m^3)	water (kg/m^3)	Gravel (kg/m^3)	sand (kg/m^3)	Foaming agent (kg/m^3)	Polystyrene particles (kg/L)
C30 fine aggregate concrete	0.5	400	200	1100	720	--	--
M4.0 foam concrete	0.42	592	248.5	--	--	2.96	888

Table 2. Specimen Parameters

Specimen number	load surface	Specimen Specifications	Truss bar diameter (mm)	Longitudinal bar area (mm^2)
W-4-1	Foam coagulation	3000×900×200	6	175.84
W-6-1			6	197.82

W-8-1			8	351.68
S-4-1	fine stone concrete		6	157.00
S-6-1			6	169.56
S-8-1			8	301.44

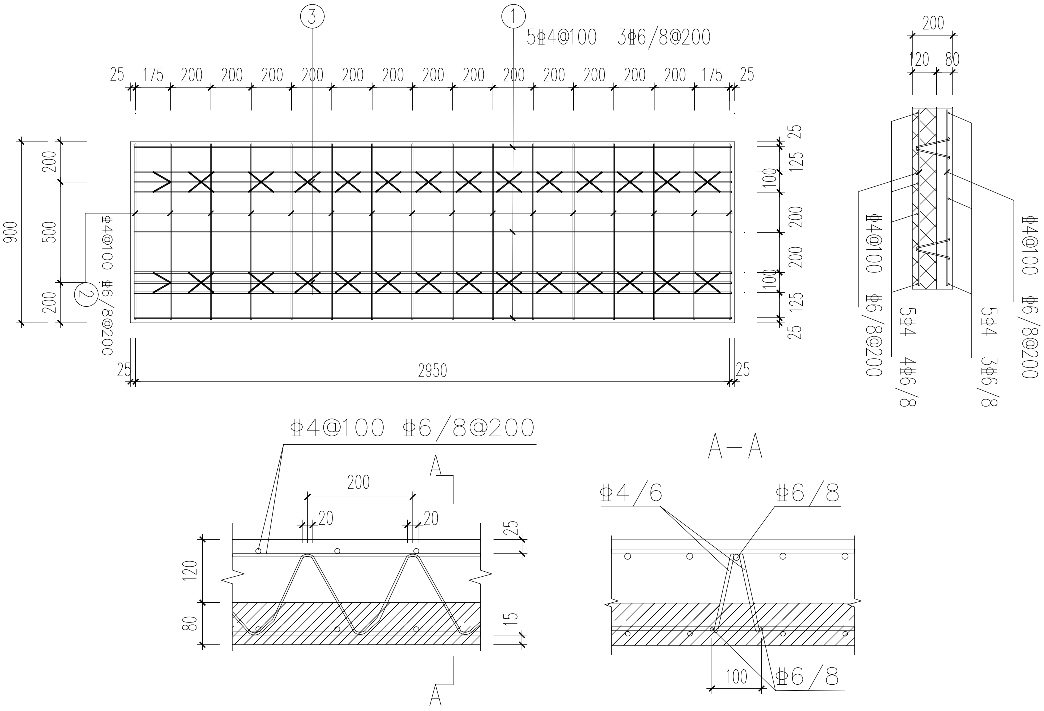


Figure 1. Reinforcement Form of Test Piece

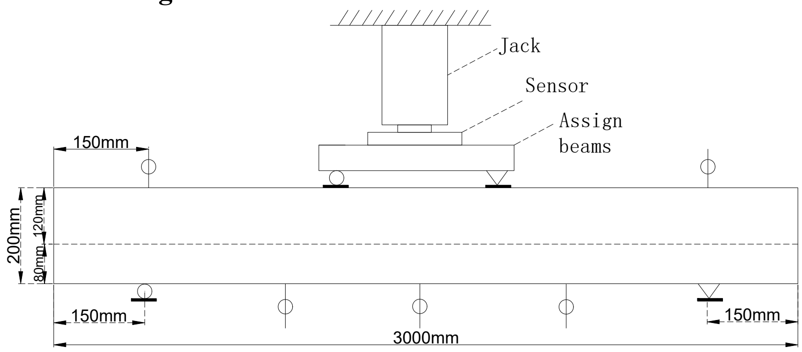


Figure 2. Schematic Diagram of Loading Device

When the load bearing surface is foam concrete layer, the crack distribution is shown in Figure 3. When loaded to around 5kN, the concrete reaches its ultimate tensile strength, and 1-3 cracks appear at the mid span position on the side of the slab. The cracks gradually develop with the increase of load. When loaded to around 60% Pu (Pu is the ultimate bearing capacity), the crack width reaches 0.5mm. Most of the cracks stop developing at the composite surface, and only a few main cracks cross the composite surface and rapidly develop at around 80% Pu. Continuing to load, the deflection and crack width develop rapidly, and the main crack penetrates the entire section. The load reaches the limit value, and the failure is declared as the inability to continue loading. The ultimate bearing capacities of the three types of plates are 45.0kN, 48.4kN, and 75.0kN, respectively.

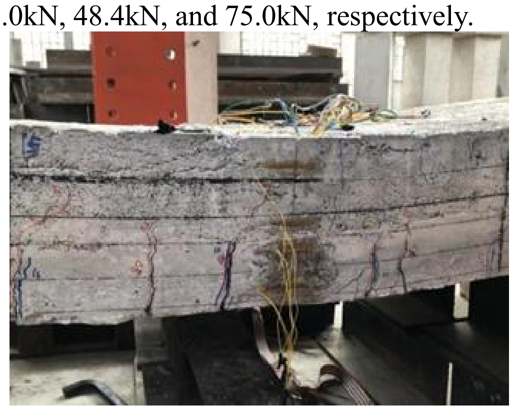


Figure 3. Wallboard with Load Bearing Surface of Foam Concrete

When the load-bearing surface is a fine aggregate concrete layer, the crack distribution is shown in Figure 4. As the load increases to around 4.5kN, there are many small cracks appearing in the mid span of the slab bottom. As the load increases, when loaded to around 55% Pu, the crack width reaches 0.5mm and no new cracks appear. The initial crack develops rapidly and forms the main crack. When loaded to around 75% Pu, the main cracks begin to rapidly propagate along the thickness direction beyond the overlapping surface. Continuing to load, the deflection and crack width rapidly developed, and the main crack penetrated the entire section and could not continue to be pressurized. The test ended. The ultimate bearing capacities of the three types of plates are 28.1kN, 45.4kN, and 64.7kN, respectively. Except for the laminated wall panel with a belly reinforcement diameter of 4mm, which exhibits some brittleness due to a slightly lower reinforcement ratio, all other wall panels show bending failure characteristics and exhibit good bending performance within the designed load.

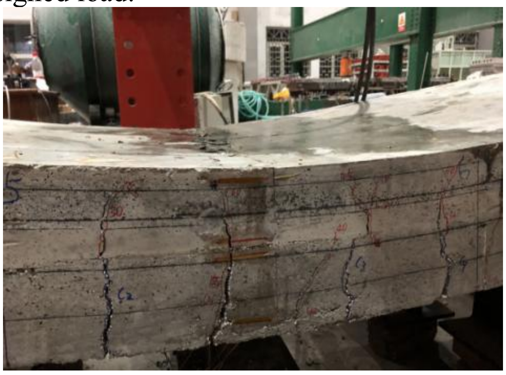


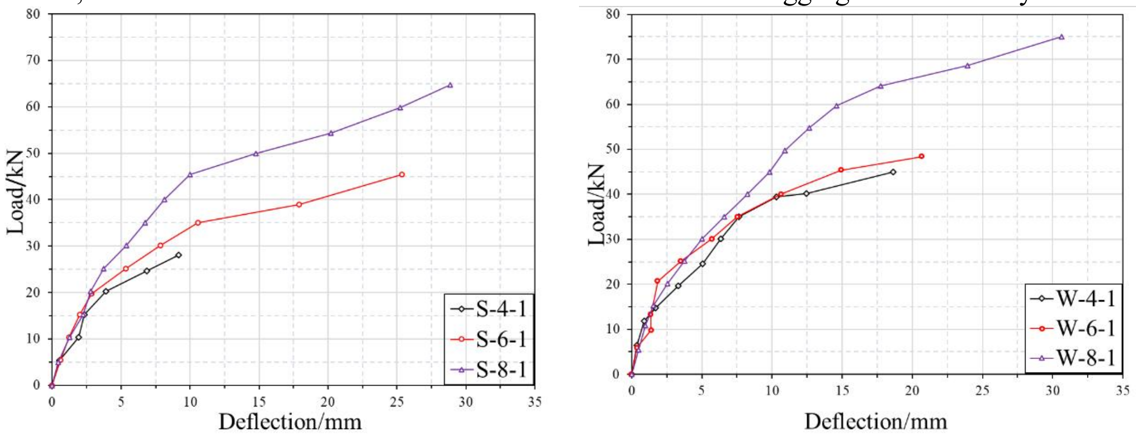
Figure 4. Wall Panel with Fine Aggregate Concrete as the Load-Bearing Surface

3.2 Load-Deflection Curve

The load deflection curve of foam concrete composite wallboard is roughly the same as that of ordinary concrete slab, which can be divided into three stages. Firstly, before the cracks appear, the micro cracks inside the wall panel are in a stable stage, and the deflection increases linearly with the load. After concrete cracking, internal forces are redistributed, and the wall panel is in the elastic-plastic stage, with the slope of the load deflection curve becoming flatter. Finally, in the later stage of loading, the steel bars bear all tensile forces, and the rate of deflection change further increases.

For wall panels, the wind pressure perpendicular to the surface is an important design indicator. In order to determine whether the wind pressure of stacked wall panels meets the basic requirements of construction, this article equivalently considers it as a uniformly distributed load and calculates it according to the provisions of the "Code for Load of Building Structures" (GB50009-2012) [13]. The results show that when the load is 0.842kN, the wind pressure that meets the requirements of the code is not less than 0.3kN/m2. According to the experimental data, the minimum load corresponding to the occurrence of cracks in the laminated wall panel is 2.5kN, and the wind pressure at this time is 0.89kN/m2, which is approximately three times the required value in the specifications. The deflection is about 0.13mm, which is only 0.0043% of the board height. From this, it can be seen that the bending resistance of the specimens tested in this article is good and meets the construction requirements. In addition, the fine aggregate concrete slab in the foam fine aggregate concrete composite wall slab mainly plays the role of protection and construction load, and its thickness does not need to be too large.

From Figures 5, it can be seen that under the same experimental conditions, the failure load of test panels with different loading surfaces increases with the increase of reinforcement ratio of the composite wall panel, and the slope of the load deflection curve also increases accordingly. The length of the elastic-plastic section of the composite wall panel shows a gradually increasing trend. This indicates that increasing the diameter of steel bars within the appropriate reinforcement range can effectively enhance the sectional stiffness of laminated wall panels and improve their bending performance. It is worth noting that when the load bearing surface is foam concrete layer, the diameter has no obvious influence on the growth trend and growth rate of the load deflection curve of the composite wallboard before the deflection is about 7 mm, as shown in Figure 5(a). As shown in Figure 5(b), when the load-bearing surface is a fine aggregate concrete layer, the load deflection curve of the composite wall panel shows differences earlier. The reason for this phenomenon is that the strength of fine aggregate concrete is higher and the elastic modulus is larger than that of foam concrete, so the cracking load of fine aggregate concrete is higher than that of foam concrete. At the initial stage of loading, the foam concrete in the middle of the bottom span of the slab cracked early and quit the load bearing work prematurely, and the load was gradually borne by the steel bars. Therefore, the diameter of the steel bars had a more obvious effect on the load deflection curve of the composite wallboard with the load bearing surface of fine aggregate concrete layer.



(a) (b)

Figure 5. Wall Panel Load-Deflection Curve

From Figure 6, it can be seen that the load deflection curves of the two types of load-bearing wall panels have roughly the same growth trend. The difference is that under the same load, the slope of the load deflection curve of the composite wallboard with the load bearing surface of foam concrete layer is always greater than that of the composite wallboard with the load bearing surface of fine aggregate concrete layer, and the gap between the two gradually increases with the increase of the load. This is because when the loading surface is fine aggregate concrete, the cracking load of the foam concrete layer in the pure bending section is small, the failure load is low, and the crack develops rapidly and has a large width. This phenomenon indicates that the section stiffness of composite wall panels with fine aggregate concrete as the compression surface is low and the bending performance is poor.

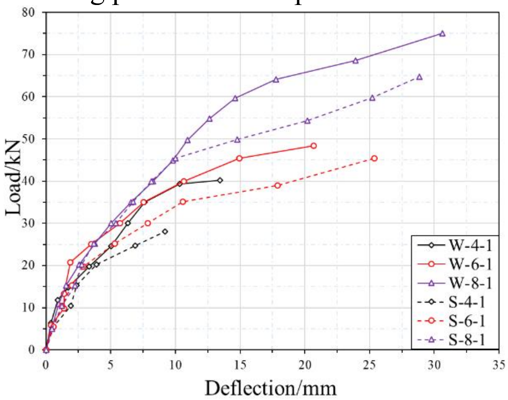


Figure 6. Wall Panel Load-Deflection Curve

3.3 Load-Strain Curve

Analyze the strain at the mid span position of the longitudinal stressed steel bars on the lower chord of the laminated panel truss (the lower chord is the lower chord when loaded), as shown in Figure 7 for load strain relationship. Comparing the strain development of steel bars with the same diameter on different loading surfaces and steel bars with different diameters on the same loading surface, it can be seen that the strain development law of the steel bars in the test plate is basically the same. Before concrete cracking, the tensile force is mainly borne by the concrete at the bottom of the slab, and the strain of the steel bars increases linearly with the load, with a small curvature. Subsequently, the concrete cracked, causing a redistribution of internal forces and an increase in the tensile force borne by the steel bars. The strain growth rate increased compared to before the cracking. In the later stage of loading, the steel bars bear all tensile forces, and the strain growth rate increases significantly, with a clear curve in the load strain graph. Compared with the test plate with the foam concrete layer as the loading surface, the strain growth rate of the reinforcement is faster when the fine aggregate concrete is used as the loading surface. The main reasons are as follows: 1) At the initial stage of loading, the foam concrete layer on the opposite side mainly bears the bending moment, the cracking load of foam concrete is low, and the foam concrete in the middle of the span exits the load bearing work prematurely; 2) When the load-bearing surface is fine aggregate concrete, there are fewer lower chord steel bars, and the tension borne by the bars is greater, resulting in faster strain growth.

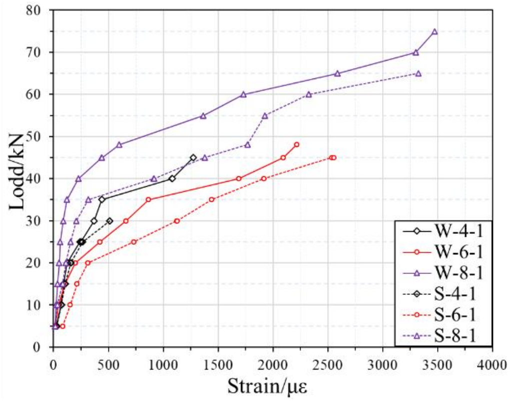


Figure 7. Longitudinal Reinforcement Load-Strain Curve

4. Calculation and Analysis of Bending Capacity

It can be seen from the failure form of the test piece that the bond between foam concrete and ordinary concrete is good, and there is no slip and separation phenomenon. Therefore, the normal section bearing capacity of the composite slab is calculated by referring to the bearing capacity formula of ordinary concrete slab. The calculation of the bending capacity of the normal section follows the basic assumptions of the "Code for Design of Concrete Structures" (GB 50010-2010) [14]. Among them, when the upper compression zone is foam foam concrete, the stress-strain relationship curve refers to the research results of Liu Dianzhong et al. [15]; α 1 and β 1 are selected according to the "Technical Standard for Application of Lightweight Aggregate Concrete" (JGJ/T 12-2019) [16].

Based on the above basic assumptions, it has been calculated that the neutral axis in the wall panel is located above the overlapping surface, and the height of the compression zone x>as'. Therefore, it can be obtained from static equilibrium:

$$\alpha_1 f_c b x = f_y A_s \tag{1}$$

$$M_u = f_y A_s (h_0 - \frac{x}{2}) \tag{2}$$

In the formula, the meanings of each parameter are detailed in GB50010-2010.

Calculate the bearing capacity according to the following formula:

$$M_u' = \frac{ql^2}{8} + \frac{pa}{2} \tag{3}$$

In the formula: a-the distance from the concentrated force to the support, taken as 900mm; q-Equivalent uniformly distributed load (calculated from the self weight of the slab), taken as 2.56kN/m; l- Calculate the span, taking 2.7m; p-ultimate load (sensor display value); M_u'-measured ultimate bending moment value.

The calculated bending moment and measured bending moment of the test plate are shown in Table 3 below:

Table 3. Calculation Results

Specimen number	P_{cr} (kN)	p (kN)	M_{cr}' (kN.m)	M_u (kN.m)	M_u' (kN.m)	M_{cr}'/M_u' (%)	$(M_u'-M_u)/M_u'$ (%)
W-4-1	5.3	45.0	4.7	15.6	22.6	21	31
W-4-2	5.0	44.1	4.6	15.6	22.2	21	30
W-6-1	5.1	48.4	4.6	17.3	24.1	19	28
W-6-2	4.9	49.0	4.5	17.3	24.4	18	29
W-8-1	5.4	75.0	4.8	27.7	36.1	13	23
W-8-2	5.3	74.5	4.7	27.7	35.9	13	23
S-4-1	4.6	28.1	4.4	13.3	15.0	29	11
S-4-2	4.5	24.7	4.4	13.3	13.5	33	1
S-6-1	4.9	45.4	4.5	14.2	22.8	20	38
S-6-2	4.7	45.0	4.4	14.2	22.6	19	37
S-8-1	4.9	64.7	4.5	22.9	31.5	14	27
S-8-2	5.0	64.2	4.6	22.9	31.2	15	27

From the data in the table, it can be found that the difference between the measured bending moment and the calculated bending moment gradually decreases with the increase of the reinforcement ratio, indicating that the contribution of the web reinforcement to the flexural bearing capacity of the laminated plate decreases with the increase of the reinforcement ratio, while the The wall panel with fine stone concrete as the load-bearing surface and the diameter of the web reinforcement is 4mm, because the longitudinal reinforcement is less, the web reinforcement will be damaged before it can function.

5. Conclusion

(1) The interface bonding performance of foam concrete and fine aggregate concrete composite

wallboard with artificial rough surface is good, and there is no obvious relative slip in the loading process, which indicates that the foam fine aggregate concrete composite wallboard has good integrity;

(2) The reinforcement ratio is an important factor affecting the flexural capacity of slabs. When other test conditions are the same, the flexural performance of foam fine aggregate concrete composite wallboard is significantly improved with the increase of reinforcement diameter;

(3) The measured bending moment of the composite panel wall is much larger than the calculated bending moment, indicating that the code design is too conservative, but the foam concrete slab can basically meet the needs of the project and can be used as a light load-bearing component. It also indirectly indicates that the calculation formula of flexural bearing capacity in the Code for Design of Concrete Structures is not applicable to the bending moment calculation of foam fine aggregate concrete composite slabs.

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