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Study on Interface Bonding Properties between Foamed Ceramics and Foamed Concrete

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Abstract: Foamed ceramic foam concrete composite wall was prepared by a direct casting method. Compressive and tensile tests were carried out on different densities of foamed ceramic boards. Changing rules of interface bonding properties of the composite wall under the influence of foamed concrete age, the surface treatment of foamed ceramic boards, and exposure to freeze–thaw cycles were studied; and the failure mechanism was analyzed and discussed. The results show that a foamed ceramic board with a density of 410 kg/m^3 is suitable for a panel of composite wallboard; when the age of the foam concrete increases from 3 to 7 days, and the interface bond strength of the composite wallboard increases, then the bonding strength of the composite wallboard gradually decreases with the increase in age; with the increase in freeze–thaw cycles, the interface bond strength of the composite wallboard decreases gradually. The interface agent was pre-painted on the foamed ceramic board, which can improve the interface bonding strength of the composite wallboard. The drying, shrinkage, and freezing and thawing cycles of the foam concrete have a great influence on the interface bond strength of the composite wallboard. The perforated long hole and rubber sleeve can be used to improve the safety of the composite wallboard.

Keywords: foamed ceramics; foamed concrete; composite wall panels; interfacial bond strength; freeze–thaw cycles

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1. Introduction

In recent years, with the vigorous promotion of construction industrialization in China, the development of prefabricated buildings has entered into the fast lane. The development of prefabricated buildings is inseparable from the development and application of new green wall materials and their application systems. In order to ensure the safety of use and living comfort of prefabricated buildings [1], performance requirements such as light weight and high strength, thermal insulation and energy-saving ability, moisture-proofness and waterproofness, sound insulation, and fire protection are proposed for envelope structure materials [2,3]. Foamed concrete can be used especially for prefabricated steel structure buildings and the corresponding lightweight composite wallboard. Even more, these application systems are urgently needed.

Foamed concrete has excellent properties, such as light weight, high strength, class A fire prevention, heat insulation, sound insulation, and sound absorption, but it also has problems, such as high water absorption and poor waterproofness [4,5]. As a lightweight thermal insulation board, foam concrete has been studied and applied in many aspects, such as exterior wall thermal insulation and floor and floor thermal insulation, but less research and application has been conducted in prefabricated buildings [6]. Foamed ceramic plate is a lightweight plate-shaped ceramic product with thermal insulation performance, which is made of industrial solid waste or other mineral raw materials as the main raw material, mixed with a small amount of admixtures and foaming agents, and baked and foamed at high temperatures. It has the properties of light weight, high strength, thermal insulation, sound insulation, fire resistance, and moisture resistance [7,8], but its high production cost limits its wide application in the construction field. Because foamed ceramics have the advantages of high fire resistance, low water absorption, and good stability, the foamed concrete has natural advantages in energy saving, heat preservation, heat insulation, light weight, fire resistance, and compounding with other materials [9]. Facing the special requirements of prefabricated buildings, the excellent properties of these two materials can be used to exert the synergistic effects of different materials. Additionally, the foamed concrete slurry can be poured between two foamed ceramic plates. Through the bonding properties of foamed concrete cementitious materials, panels are bonded into a whole to prepare non-load-bearing lightweight composite wall panels that can be used in prefabricated buildings. This preparation method does not require additional connection or reinforcement of tensioning parts, which avoids the thermal bridge caused by tension parts, but it also requires sufficient bonding strength between the two different materials to ensure the integrity of the wallboard [10,11]. In practical applications, foam concrete has some problems. For example, it has large shrinkage deformation and poor crack resistance. The interface bond has a high risk of failure, which affects the safety of the composite wallboard.

Regarding the bonding performance of the foamed concrete slurry itself to the board, different stress states will be formed due to different materials and different structural forms under various stress states. At present, no research can provide a suitable theoretical model. There is no unified standard in China, and there are few related research reports [12–14]. In this paper, the foamed ceramic board-foamed concrete composite wallboard was prepared by a direct casting method, and the influence of different factors on the interface bonding performance of the composite wallboard was discussed. This study provides a reference for further research on the direct composite of foamed concrete and the plate in the future, as well as some experimental bases, which can improve the performance of foam concrete composite wallboard.

2. Raw Materials and Test Methods

2.1. Raw Materials

The raw materials used in the test include cement, fly ash, fine sand, water reducer, latex powder, foaming agent, cream interface agent, and foamed ceramic plate. The cement was PO 42.5 grade cement produced by Jidong Cement Plant (Tangshan, China). The fly ash was Class II, produced in Hebei, with a fineness (45 µm sieve residue) of 11% and a water requirement ratio 101%. The fine sand was natural river sand produced in Hebei with a particle size of less than 2 mm. The water-reducing agent was Sika polycarboxylate water-reducing agent in powder form; the water reducing rate was $\geq$30%. The latex powder was ELOTEX FX 2350. The foaming agent was YS-801 produced by Beijing Yashe Building Materials Technology Co., Ltd. (Beijing, China); the dilution ratio was 60 times, and the foam density was (50 $\pm$ 5) kg/m^3. The cream-like interface agent (BA–S01) was provided by Guangdong Longhu Sci &Tech Co., Ltd. (Shantou, China). The foamed ceramic panels were commercially available (Hebei Hengchuan Building Materials Co., Ltd. (Chengde, China), Shanxi Ansheng Technology Development Co., Ltd. (Jinzhong, China), Guangxi Tange Environmental Protection New Materials Co., Ltd. (Wuzhou, China)) with a density of 260 kg/m^3~430 kg/m^3. The error of each density grade was $\pm$10 kg/m^3.

2.2. Test Method

The composite wallboard took the foamed ceramic board as the protective surface layer and the steel mesh frame (mesh size was 50 mm to 100 mm) between the foamed ceramic boards as the reinforcement layer. The foamed concrete slurry was poured into the foamed ceramic board on both sides, and the non-load-bearing prefabricated outer wallboard made by hardening molding is shown in Figure 1. The system was synergistically stressed by foamed ceramic, foamed concrete, and steel mesh frame, relying on the steel mesh frame to lift the rigidity and flexural load bearing of the veneer to address the mechanical properties that should be satisfied as part of the wallboard.

Figure 1. Composite wallboard with foamed ceramic board and foamed concrete.

The foamed concrete was prepared by a physical foaming method [4], and the reference mix ratio of the foamed concrete is shown in Table 1. The test block was demolded after natural curing for 2 days. After standard curing to the specified age, it was taken out for performance testing. The compressive strength of the foamed concrete was tested according to 'Foamed Concrete' (JG/T 266-2011). The compressive strength test of the foamed ceramic board was carried out according to 'Light weight panels for partition wall used in building'(GB/T 23451-2009) [15], its size was 100 mm × 100 mm × 40 mm, and it took the arithmetic mean of the compressive strength of three specimens. The tensile strength test perpendicular to the direction of the board surface was carried out with reference to 'External thermal insulation composite systems based on expanded polystyrene' (GB/T 29906-2013) [16]. The interface bonding performance test of composite wallboard was carried out with reference to 'Products for external thermal insulation systems based on mineral binder and expanded polystyrene granule plaster' (JG/T 158-2013) [17]. The size of the freeze–thaw test specimen was 100 mm × 100 mm × 100 mm (the thickness of the foamed ceramic plate was 40 mm, and the thickness of the foamed concrete was 60 mm, 20 °C, and humidity above 90% for 16 h). The alternating cycle of such low temperature and normal temperature was simply referred to as a freeze–thaw cycle. The tensile bond strength test was carried out when the number of freeze–thaw cycles was 0, 4, 8, 12, and 16 times, respectively. The adhesives used in the adhesive performance test were all 914 epoxy adhesives. In the pull-out test and single-point loading test, the surface of the casing was coated with epoxy resin, which was tested after 24 h of installation according to 'Technical code for safety appraisal of engineering structural strengthening materials' (GB 50728-2011) [18].

Table 1. Basic mix proportion of foam concrete.

Cement/kg	Fly Ash/kg	Fine Sand/kg	Foam/m^3	Latex Powder/kg	Water Reducer	Water-Binder Ratio
800	200	120	0.7	1.0	Moderate	3.0~5.0

3. Test Results and Analysis

3.1. Selection of Density of Foamed Ceramic Board

At present, the compressive strength standard for non-load-bearing wall panels and prefabricated slats is not less than 3.5 MPa. Based on the building design to increase the redundancy factor and to meet the needs of anchor installation, the compressive strength of the composite wallboard should not be less than 5.0 MPa. As a closed-cell porous ceramic material, the mechanical properties of foamed ceramics such as compressive strength and tensile strength are related to the density. The six groups of foamed ceramic specimens of 260 kg/m^3, 300 kg/m^3, 340 kg/m^3, 380 kg/m^3, 410 kg/m^3, and 430 kg/m^3 were respectively subjected to compressive strength tests and tensile strength tests perpendicular to the direction of the board surface. The test results are shown in Table 2.

Table 2. Test results of compressive and tensile strength perpendicular to the plate surface of foamed ceramic specimens with different densities.

No.	Density (kg/m^3)	Compressive Strength (MPa)	Tensile Strength Perpendicular to the Board Surface (MPa)
1	260	1.6	0.2
2	300	2.5	0.3
3	340	3.4	0.4
4	380	4.5	0.6
5	410	5.4	0.8
6	430	6.6	0.9

In Table 2, when the density increases, the compressive strength of the foamed ceramic board and the tensile strength perpendicular to the board surface increased. The compressive strength of the foamed ceramic board with a density of 410 kg/m^3 was greater than 5.0 MPa. It was satisfactory with the requirements of the average bonding strength. Each group of samples of prefabricated components with facing bricks should not be less than 0.6 MPa and should meet the requirements of the paste surface, according to the 'Standards for Bonding Strength of Facing Bricks in Construction Engineering' (JGJ/T 110-2017) [19]. Therefore, in order to reduce the weight of the foamed ceramic board as much as possible and to facilitate construction under the premise of satisfying the mechanical safety, the foamed ceramic board with a density of 410 kg/m^3 should be selected as the plate for the composite wallboard.

3.2. Influence of Foam Concrete Age on Interface Bonding Strength

Figure 2 shows the effect of age on the interface bonding strength and the compressive strength of the foam concrete. As can be seen in Figure 2, the compressive strength of the foamed concrete increased with age, and the increase rate is rapid within 28 days. However, after 28 days, it increased slightly and tended to be stable gradually. The reason is that the strength of the foamed concrete is formed mainly due to the hydration of cement, and higher compressive strength can be obtained with an increase in age. The interfacial tensile bonding strength first increased, then decreased, and then tended to decrease slowly. This can be attributed to fact that the interface bonding strength is the bonding ability of foam concrete for composite wallboard, but the bonding interface is a weak link, and the shrinkage of foam concrete is 10 times that of ordinary concrete [20]. Wan [21] believed that the drying shrinkage of foamed concrete is divided into three stages, the first stage of which, water loss, is not obvious. In the second stage, the foamed concrete begins to shrink, but the water loss is less. Finally, the third stage basically stops the shrinking. After curing, the foamed concrete will slowly lose water in the natural environment in a saturated state. Before 7 days, the strength of the foamed concrete is dominant, the interface bonding strength increases, and the bonding strength increases. The huge difference in dry shrinkage will generate shrinkage stress, leading first to micro-cracks and damage inside the interface [22]. Then, this destroys the bonding effect of the interface and the uniform distribution of stress on the interface. The dry shrinkage value gradually increases, resulting in the continuous expansion of micro-cracks and accumulation. This damage leads to a decrease in interface tensile bond strength.

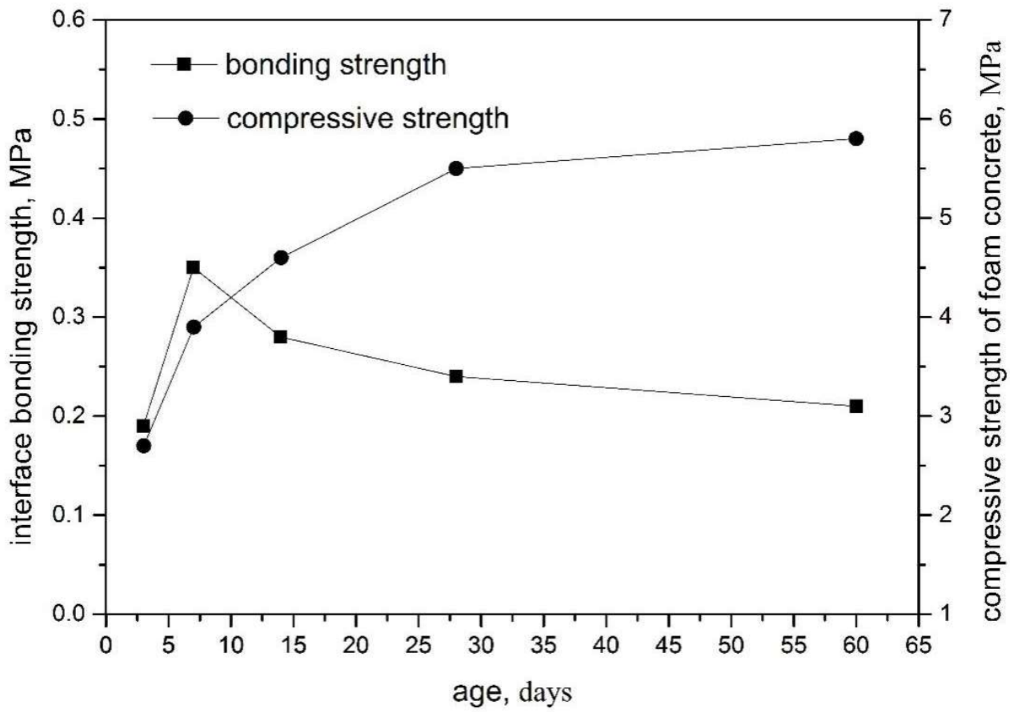


Figure 2. Effect of foam concrete age on the interface bonding strength of composite wallboard and the compressive strength of foam concrete.

3.3. Influence of the Treatment Method of the Foamed Ceramic Plate on the Interface Bonding Strength

Literature [12] reports a method of pre-painting tile adhesive on the surface of calcium silicate board, pouring foam concrete to improve the interface bonding strength of composite wallboard. It also points out that the pre-painted bonding mortar with a cohesive strength is higher than the tensile strength of the foamed ceramic. The foamed ceramic board may be cracked at the edge of the board because of large shrinkage stress, or even torn as shown in Figure 3. This is because the foamed ceramic material is a brittle material with low strength and poor deformability.

Therefore, we should select a cream-like interface agent with good permeability. It can infiltrate the surface of the foamed ceramic material to be painted on the surface of the foamed ceramic plate. Additionally, it also increases the adhesion between the foamed concrete and the foamed ceramic plate and buffers the two stresses due to the shrinkage of the foam concrete.

It can be seen in Figure 4 that after the surface was coated with the interface agent, the interface bonding strength under the age of 28 days increased first and then tended to be stable, and it decreased slightly after 28 days. However, its tensile bonding strength at each age was higher than the interface bonding strength when the foamed ceramic board was combined with the foamed concrete. This shows that the coating of the foamed ceramic material with the interface agent can improve the interface bonding strength. After the interface agent was painted, an elastic and good bonding strength isolation layer formed between the foamed ceramic plate and the foamed concrete. It could partially absorb the stress generated by the curing process of the foamed concrete, and the interface agent could be well sealed. The pores on the surface of the foamed ceramic material increased the effective contact area between the foamed concrete and the plate.

Figure 3. Foamed ceramic board is torn by shrinkage stress of bonding mortar.

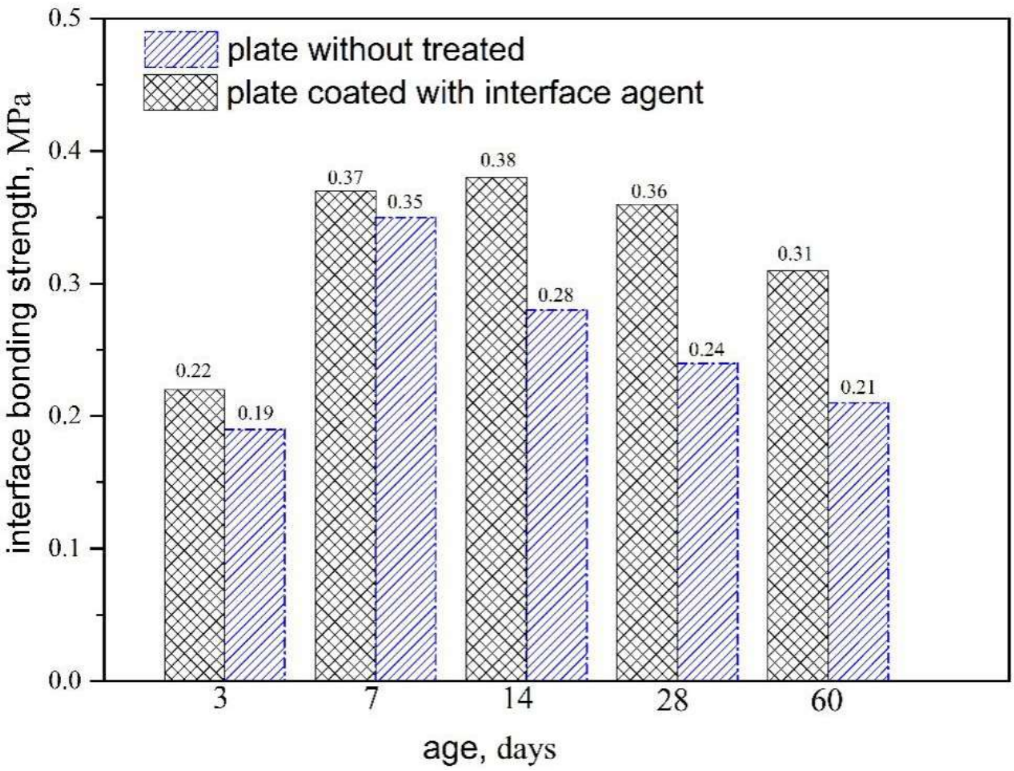


Figure 4. Effect of treatment of the foamed ceramic board on bonding strength of the composite wallboard with different ages.

3.4. *Effect of Freeze–Thaw Cycles on the Interface Bonding Strength*

The study found that the test value of the linear thermal expansion coefficient of the foamed ceramic material was $4.7 \times 10^{-6}/°C$, and deformation under the action of the environment and other factors was relatively small. According to reports from the literature [5,23], the test value of the linear thermal expansion coefficient of cement mortar is $10.2 \sim 20.0 \times 10^{-6}/°C$. As foamed concrete is a heterogeneous brittle material with a porous structure, it has the disadvantages of large brittleness, large shrinkage deformation, poor crack resistance, and low tensile bond strength. The application of composite wallboard should consider quality problems such as cracks, hollowing, and shedding, that are caused by environmental changes such as cold and heat exchange, wind, and rain.

In Figure 5, no matter whether the surface of the foamed ceramic board was coated with interface agent or not, the interface bonding strength increased with an increase in the number of freeze–thaw cycles (0, 4, 8, 12 and 16 times). Further, it showed a slow drop in the initial stage and a steep drop after a certain number of freeze–thaw cycles. It can be noted that with the increase in the number of freeze–thaw cycles, the influence on the interfacial bond strength increased. Under the action of freeze–thaw cycles, micro-cracks occurred between the cement stone and the aggregate cement stone bonding surface in the foamed concrete. This resulted in a decrease in the adhesive force and mechanical occlusal force on the bonding surface, accompanied by the generation and development of tiny cracks that directly led to a deterioration of the performance of the bonding interface. Meanwhile, during the hardening process of the foamed concrete, the volume shrinkage was limited by the foamed ceramics, resulting in a corresponding shrinkage stress. The alternating tensile and compressive stress produced by the temperature change and the tensile and compressive stress produced by the shrinkage were superimposed. When the bonding strength of the surface was exceeded, the bonding surface cracked, and the bonding strength decreased. During the melting process, water vapor will enter these cracked gaps and turn into tiny ice grains in the next cooling process. When the water vapor freezes again, the cracked surface will further expand due to the further expansion of the frozen volume. A new and greater tensile stress is generated, and the bonding surface is further damaged. Repeated many times, this eventually led to the generation of macroscopic cracks and caused instability and expansion, resulting in freeze–thaw failure (Figure 6a).

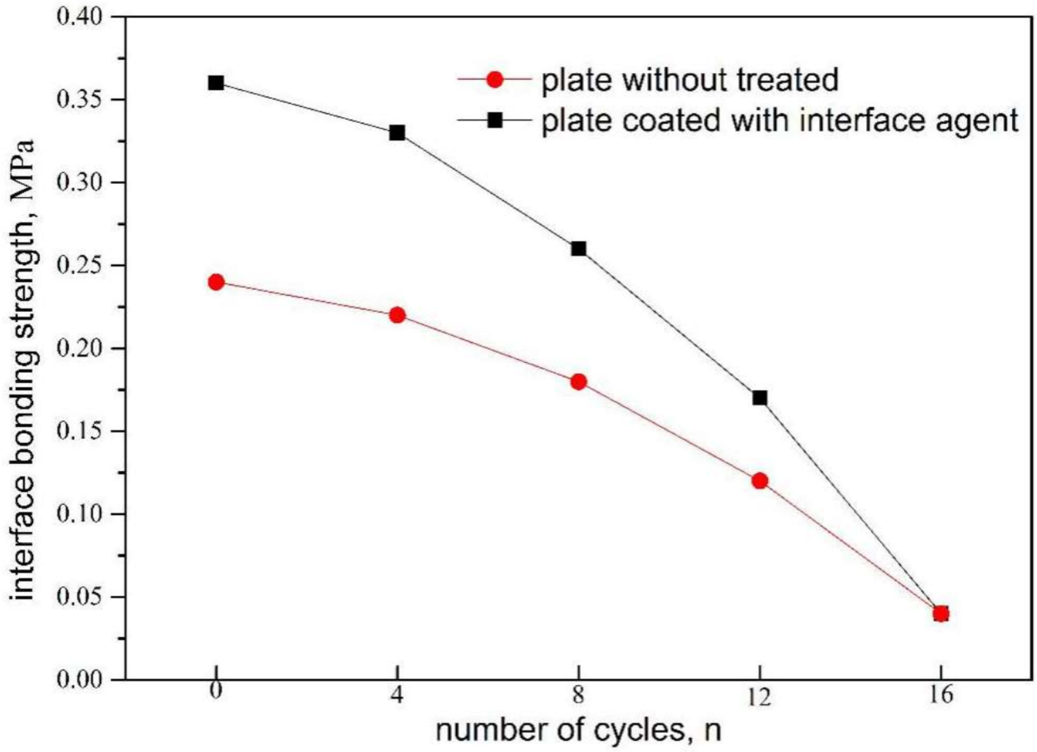


Figure 5. Effect of freeze–thaw cycles on interface bonding strength.

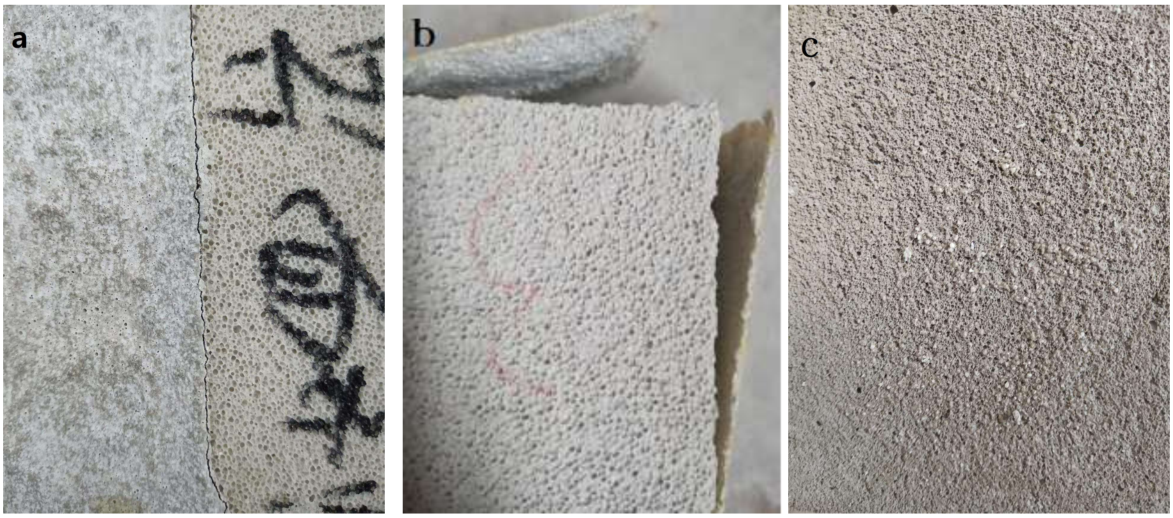


Figure 6. Damage characteristics of the interface of the specimens caused by freeze–thaw cycles: (**a**) surface damage characteristics of the composite wallboard coated with the interface agent on the surface of the foamed ceramics; (**b**) damage characteristics of the foamed ceramic specimens coated with the polyurethane adhesive on the surface; (**c**) interface damage characteristics of the composite wallboard coated with the interface agent on the surface of the foamed ceramics. The interfacial agent layer that suffered from freeze–thaw destruction was visible on the surface of foamed concrete.

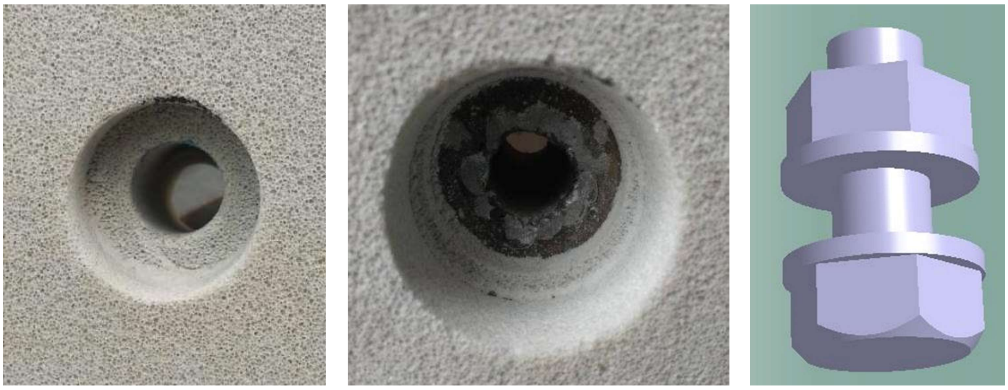
Similarly, a polyurethane adhesive with a cohesive strength much greater than the tensile strength of the foamed ceramic was used to coat the foamed ceramic specimen with a density of 330 kg/m^3 for four weeks. Then, the freeze–thaw cycle test was carried out. It was found that after more than 40 freeze–thaw cycles, the alternating tensile and compressive stress generated by the temperature change and the tensile and compressive stress generated by the shrinkage superimposed more stress than the bonding strength of the surface. The bonding surface of the foamed ceramic and the polyurethane adhesive gradually cracked (Figure 6b). This indicates that the damage to the bonding surface by the freeze–thaw cycle is much more serious than that to the material itself.

For the composite wallboard coated with interfacial agent on the surface, the interface bonding strength after 16 freeze–thaw cycles was 88.9% lower than the unfrozen tensile bond strength. In contrast, the interface bonding strength after 16 freeze–thaw cycles of the composite wallboard without interface agent coating on the surface was reduced by 83.3% when compared with the unfrozen tensile bond strength. This shows that the coating of the interface agent on the surface did not improve its freeze–thaw resistance. This is because the foamed ceramic board is a closed-cell ceramic material with high porosity that does not absorb water in the body and will not expand and deform, whereas the foamed concrete absorbs water and freezes and expands. As a result, the internal structure at the interface was damaged (Figure 6c), and its performance gradually deteriorated. There were some tiny cracks in the interface layer, causing more water vapor to enter. However, this type of cream-like interface agent has poor water resistance. When the water vapor in the tiny cracks condensed into ice at low temperatures, it generated expansion stress on the interface bond. Those tiny cracks expanded and could not be recovered after the ice melted. Repeated freeze–thaw cycles accumulated damage and led to the continuous expansion and connection of micro-cracks. The adhesive force dropped rapidly.

4. Research on Connection Structure of Composite Wallboard with Foamed Ceramics and Foamed Concrete

In general, the foamed concrete has poor adhesion and adsorption ability to the foamed ceramic board. It easily causes the board surface to peel off from the core material, affecting the overall integrity of the composite wallboard. Therefore, such plates can be used for non-load-bearing internal partition walls. When used for external walls with large environmental changes, technical measures should be taken to improve the overall integrity of the composite wallboard. This paper provides an idea for adopting a constructive way to fix the material's defects.

The test found that, after drilling holes and implanting diameters of 14 mm on 100 mm-thick foamed ceramic plates and foamed concrete, the pull-out force of the viscose casing with a buried depth of 50 mm could reach 2.0 kN and 1.9 kN, respectively. Additionally, the larger the pipe diameter and the greater the burial depth, the greater the pull-out force test value. Therefore, a structural connection scheme of pre-embedding sleeves to prepare composite wallboard was designed. Specifically, a penetrating circular hole with a diameter of 22 mm was drilled on the board, and a counterbore with a diameter of 40 mm and a depth of 20 mm was drilled on one side of the board surface (as shown in Figure 7a). A sleeve was built in (as shown in Figure 7b) and the connecting bolts were put into the casing (as shown in Figure 7c). The bolts not only pre-tightened the composite wall panels, but also connected with the main steel structure.



(**a**) (**b**) (**c**)

Figure 7. Connection structure of composite wallboard with foamed ceramic and foamed concrete: (**a**) penetrating round hole; (**b**) sleeve placed in long hole; (**c**) connecting bolt locking sleeve.

Considering the tensile and compressive stress of the foamed ceramic board due to temperature change and foam concrete shrinkage, the foamed ceramic board with a thickness of 100 mm was used as the base material to test the foamed ceramic board under the action of the vertical board surface force by means of jack pressure. The single-point anti-failure load of the long-hole casing with glue and without glue was studied. The test loading device is shown in Figure 8a. The test found that if the casing was directly put into the long hole, the casing disc compressed the foamed ceramic plate when it was squeezed. When the load was about 800 N, the foamed ceramic under the disc began to be crushed, causing the casing to sink, and the casing was pushed out. The maximum load was greater than 4 kN. However, the foamed ceramic plate was not damaged, but only partially compressed (Figure 8b). If the reinforced plastic was used to bond the casing to the long hole, when the load was above 7 kN, the plate was damaged and the casing was still bonded in the long hole (Figure 8c). Therefore, the connection structure of the composite wallboard for the exterior wall should adopt the scheme of penetrating long holes and rubber sleeves.

(**a**) (**b**) (**c**)

Figure 8. Schematic diagram of single-point loading and failure characteristics of foamed ceramic plates: (**a**) single-point loading diagram; (**b**) failure characteristics of non-adhesive sleeve placed in long hole; (**c**) failure of plastic sleeve placed in long hole feature.

5. Conclusions

Based on the presented results and discussion, several conclusions can be summarized as follows:

1. With the increase in their densities, the compressive strength of the foamed ceramic plate and the tensile strength that is perpendicular to the direction of the board surface increase. The foamed ceramic board with a density of 410 kg/m^3 meets the technical requirements of compressive strength of non-load-bearing prefabricated wallboard and the need for sticking surfaces.
2. As the age of the foam concrete increases, the interface bonding strength at first increases, and then decreases. This is because the drying shrinkage of the foam concrete produces shrinkage stress and leads to interface damage. This seriously affects the interface bonding strength. The interface agent is pre-painted on the foamed ceramic board to improve the interface bonding strength of the composite wallboard.
3. With the increase in the number of freeze–thaw cycles, the interface bonding strength decreases gradually, and the damage to the bonding surface by the freeze–thaw cycle is much more serious than the damage to the material body. The coating of the interface agent does not improve the composite wallboard. Brushing the interface agent did not improve the freeze–thaw resistance of the interface of the composite wallboard.
4. The single-point anti-damage load test shows that the solution with penetrating long holes and a glue-type sleeve can pre-tighten the composite wallboard. This can be achieved even if the board is damaged; the node is not damaged, thereby enhancing the safety of the composite wallboard.

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References

1. Marzena, K.; Beata, G.; Adam, K. Cost analysis of prefabricated elements of the ordinary and lightweight concrete walls in residential construction. *Materials* **2019**, *12*, 3629. [CrossRef] [PubMed]
2. Kilincarslan, S.; Davraz, M.; Akca, M. The effect of pumice as aggregate on the mechanical and thermal properties of foam concrete. *Arab. J. Geosci.* **2018**, *11*, 289. [CrossRef]
3. Vojtech, V.; Tomas, D.; Vojtech, D.; Daxner, J.; Št'astný, M. Polyurethane foam as aggregate for thermal insulating mortars and lightweight concrete. *Teh. Vjesn. Tech. Gazette* **2012**, *19*, 665–672.
4. Lili, H.; Wuping, Y.; Liqiang, C.; Peizhuang, Z. Preparation and properties of high strength high thermal resistance foam concrete. *Concrete* **2021**, *153–155*, 160.
5. Yang, J.; Fu, W.; Hu, X.; Liu, C.; Qixin, Y.J.; Woody, J. Experimental study on the long-term behaviors of spray-applied acrylate waterproofing membrane for tunnels exposed to aggressive ions. *Constr. Build. Mater.* **2020**, *258*, 119603. [CrossRef]
6. Dongyi, L.; Liping, G.; Jiaping, L.; Changwen, M.; Wei, S. Research and application of foam concrete. *Funct. Mater.* **2017**, *48*, 11037–11042, 11053.
7. Christina, K.; Matthias, S.; Kowald Torsten, L.; Trettin, R.H.F. Three-phase-foams for foam concrete application. *Mater. Charact.* **2015**, *102*, 173–179. [CrossRef]
8. Kumar, A.S.; Zymantas, R.; Danute, V. Development of flowable ultra-lightweight concrete using expanded glass aggregate, silica aerogel, and prefabricated plastic bubbles. *J. Build. Eng.* **2020**, *31*, 101399. [CrossRef]
9. Pasupathy, K.; Ramakrishnan, S.; Sanjayan, J. Formulating eco-friendly geopolymer foam concrete by alkali-activation of ground brick waste. *J. Clean. Prod.* **2021**, *325*, 129180. [CrossRef]
10. Rybakov, V.A.; Kozinetc, K.G.; Vatin, N.I. Lightweight steel concrete structures technology with foam fiber-cement sheets. *Mag. Civ. Eng.* **2018**, *82*, 103–111. [CrossRef]
11. Liu, C.; Fang, D.; Zhao, L. Reflection on earthquake damage of buildings in 2015 Nepal earthquake and seismic measures for post-earthquake reconstruction. *Structures* **2021**, *30*, 647–658. [CrossRef]
12. Yunfeng, L.; Zhenshan, C.; Qijun, Y.; Jiangxiong, W.; Fangxian, L.; Jie, H.; Dong, L. Study on interfacel bonding properties of silicon calcium foam concrete. *Funct. Mater.* **2015**, *46*, 22049–22053.
13. Ni, X.Y.; Cao, S.Y. Shear lag and effective flange width of T-shaped short-leg shear walls. *J. Eng. Res.* **2018**, *6*, 31–52.
14. Sun, X.D.; Tao, X.X.; Duan, S.S.; Liu, C. Kappa (k) derived from accelerograms recorded in the 2008 Wenchuan mainshock, Sichuan, China. *J. Asian Earth Sci.* **2013**, *73*, 306–316. [CrossRef]
15. *GB/T 23451-2009*; National Standard of the People's Republic of China, Light Weight Panels for Partition Wall Used in Buildings. Standards Press of China: Beijing, China, 2009. (In Chinese)
16. *GB/T 29906-2013*; National Standard of the People's Republic of China, External Thermal Insulation Composite Systems Based on Expanded Polystyrene. Standards Press of China: Beijing, China, 2013. (In Chinese)
17. *JG/T 158-2013*; Industry Standard of the People's Republic of China, Products for External Thermal Insulation Systems Based on Mineral Bindef and Expanded Polystyrene Granule Plaster. Standards Press of China: Beijing, China, 2013. (In Chinese)
18. *GB 50728-2011*; National Standard of the People's Republic of China, Technical Code for Safety Appraisal of Engineering Structural Strengthening Materials. China Architecture & Building Press: Beijing, China, 2011. (In Chinese)
19. *JGJ/T 110-2017*; Industry Standard of the People's Republic of China, Standards for Bonding Strength of Facing Bricks in Construction Engineering. China Architecture & Building Press: Beijing, China, 2011. (In Chinese)
20. Nambiare, K.; Ramamurthy, K. Sorption characteristics of foam concrete. *Cem. Concr. Res.* **2007**, *37*, 1341–1347. [CrossRef]
21. Wan, K.; Li, C.; Wang, S.; Pang, C. 3D full field study of drying shrink-age of foam concrete. *Cem. Concr. Compos.* **2017**, *82*, 217–226. [CrossRef]
22. Liu, C.; Ni, X.Y.; Wu, H.D.; Be, H. Calculation Theory and Test Verification for Skeleton Curve of T-shaped Shear Walls. *Struct. Eng. Int.* **2017**, *27*, 281–291. [CrossRef]
23. Shen, D.; Shen, J.; Huang, J.; Cao, J. Study on thermal expansion coefficient of cement-based materials at early age and hardening stage. *J. Hydraul. Eng.* **2012**, *43*, 153–160.