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A Study on the Mechanical Properties of Glass-Fiber-Reinforced Defective Gypsum Boards

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Abstract: As a waste derivative, glass fiber has drawn a lot of interest from the engineering community. The purpose of this study was to use glass fiber to improve the performance of defective gypsum boards. Single compression experiments, repeated loading experiments, and scanning electron microscopy (SEM) testing were performed on defective gypsum boards. The results showed that the addition of glass fiber can improve the compressive strength of defective gypsum boards. When the fiber concentration is 1.5%, the strength of single-hole gypsum boards increases by 77.1%. Energy evolution and residual strain evaluation after repeated loading showed the significant reinforcement of the dual-hole gypsum board samples with the addition of glass fiber, improving the stress distribution and elasticity, which was confirmed using damage factor analysis. Glass fibers reduce stress concentrations, improve integrity, and prevent brittle failure, especially at high stress levels. The microstructural analysis showed that the addition of glass fiber improves adhesion and prevents microcracking while acting as a stress transfer bridge, enhancing the behavior of the specimen under cyclic loading. Based on the experimental results and cost, 1.5% glass fiber is the optimal concentration. The research results provide new ideas for the application of glass fiber in defective and brittle materials and contribute toward the sustainable development of the construction industry.

Keywords: waste-derived material; glass fibers; porous structures; repeat loading

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1. Introduction

Among the existing building materials, those that bear structural functions are generally wood, bamboo, stone, or concrete, all of which are brittle materials. Brittle materials have good performance in terms of compression resistance. However, due to the mutual exclusion problem of strength and toughness, materials with higher strength generally have poor toughness. Materials with higher strength are not easy to deform and cannot be effectively consumed through elastic–plastic deformation external load energy [1–3]. When faced with impact, bending, and stretching, microcracks can be easily produced, which can lead to the deterioration of the overall structure, bringing considerable hidden dangers to people's safety and property.

Studies have found that adding fibers can effectively improve the fracture toughness and cracking behavior after the bending of building materials [4–6]. The main principles are debonding, slipping, and pulling out between the fibers and the matrix, as well as the impact of the fracture of the fiber body on external energy. The loss replaces the initiation of cracks in the base material itself. Similarly, due to the bridging effect, the presence of fibers also reduces the width and number of cracks and their development speed, which greatly improves the material properties.

As a type of fiber material, glass fiber has received widespread attention in academia, and many domestic and foreign experts and scholars have invested in the research of glass

fiber [5,7–10]. As a high-performance, inorganic, non-metallic material, glass fiber has excellent properties such as strong corrosion resistance and high tensile strength [11–13]. When filamentous glass fibers are evenly distributed within the base material, they bond well and form an effective "fiber network" inside it, which improves the toughness of the material, prevents the expansion of cracks, and delays the occurrence of new cracks. At the same time, glass fiber is generally made from waste colored glass, colorless glass, and glass balls as raw materials through high-temperature melting, drawing, and other processes. The processing and reuse of waste glass is not only possible but also solves the problem of the disposal of waste glass. The use of glass fiber not only meets the requirements of resource-friendly and environmentally friendly development but also saves resources and protects the environment. It is highly consistent with the development requirements of energy conservation and emission reduction and has broad development potential in practical engineering applications.

A large number of studies conducted by scholars have confirmed that the addition of glass fiber can provide concrete materials with better crack resistance [14–17], impermeability [18,19], and durability [20–22], as well as improving compressive strength [23,24] and sustainability [15,25–27]. Ramadan investigated the mechanical properties, thermal stability, and radiation mitigation capabilities of composites containing glass waste [28–37]. M. Mastali [38] conducted a large number of experiments to explore the impact of glass fiber on the mechanical properties and impact resistance of self-compacting concrete. The test results showed that the incorporation of glass fiber improves the mechanical properties and impact resistance of concrete, among which the toughness of concrete is particularly improved. K. Katabira [39] explored contactless structural health monitoring using magnetostrictive materials in glass-fiber-reinforced composite material laminates. They developed magnetostrictive composites, correlated bending stress with magnetic flux density, and validated theoretical models with experiments. Engineering materials, including glass-fiber-reinforced composite materials, have historical significance and modern applications. K. V. S. Phani [40] explored glass-fiber-reinforced composite materials' structural properties and their enhancement through experiments, with comparisons being made to theoretical values and other composite materials. Notably, glass-fiber-reinforced composite materials exhibit improved mechanical characteristics. Faiz A. Mirza [41] conducted flexural tests on glass fiber concrete and found that as the amount of glass fiber increases, the number of shrinkage cracks on the concrete surface increases and the width decreases. The toughness and flexural strength of concrete increase with the increase in the amount of glass fiber. J. Blazy [42] highlighted how glass-fiber-reinforced concretes (GFRCs) excel in Smart City construction due to their enhanced properties, durability, and eco-friendliness, offering cost-effective, environmentally conscious solutions. Alireza Dehghan [43] analyzed the possibility of recycling glass fibers from waste glass fiber polymers through a large number of experiments. The test results showed that recycled glass fibers have no effect on the compressive strength and drying shrinkage properties of concrete. In most cases, the splitting tensile strength of concrete is improved. A. Tibebu [44] investigated the use of chopped alkali-free glass fibers to reinforce C-25-strength concrete with the goal of reducing cracks and improving durability. The results showed that a 0.10% glass fiber content increased the strength. As the glass fiber content increases, processability decreases. Concrete with more than 0.15% fiber exhibits poor performance. S. K. Sharma [45] explored the use of waste materials and glass fibers, especially recycled coarse aggregate, in M40-grade concrete and found that 30% replacement increases strength and flexibility without changing the ingredients. Glass fiber increases tensile and flexural strength, but reduces compressive strength, and is optimally added at 2% to achieve the target average strength.

The above research was mainly based on a single compression experiment to explore the use of glass fiber in brittle concrete. In geotechnical structures, micropores are always distributed within the material. On the one hand, these holes reduce the effective bearing area of the structure and lower the macro-strength of the structure. On the other hand, the porous holes can effectively improve the stress concentration phenomenon, form structural

"defense holes", inhibit the expansion of cracks, and improve the stability and durability of the structure. However, there is a lack of research on the improvement in the mechanical properties of porous structures using glass fibers under cyclic loading. Therefore, it is of great engineering value to carry out cyclic loading and unloading tests of single and double holes with different glass fiber dosages to investigate the effects of glass fibers and defense holes on the improvement of structural stress distribution and damage evolution and on the stability evaluation and durability analysis of geotechnical engineering structures.

Gypsum and concrete are both brittle materials, and their low toughness makes it easy to observe cracks. Therefore, gypsum was used as a brittle matrix material in this study. Different numbers of holes were reserved during the pouring process of the gypsum samples, which caused a more obvious stress concentration during the repeated loading process to simulate the aging and deterioration of the brittle structure. The innovation of this study is the preparation of six types of defective gypsum boards with different glass fiber contents and conducting repeated loading experiments with different stress amplitudes to observe the failure mode and energy evolution of the specimens, which provides a theoretical basis for the sustainable utilization of glass fiber.

2. Materials and Methods

2.1. Specimen Preparation

The sample mold is made of an acrylic plate with dimensions of 100 × 130 × 20 mm. It has a hole radius of 5 mm, and for the two-hole gypsum board, the holes are spaced 15 mm apart. White high-strength gypsum was used in this test. The cementitious material standard complies with the high-strength gypsum technical specification JCT 2038-2010 [46]. The chemical composition of gypsum is shown in Table 1.

Table 1. Properties of gypsum.

Gypsum Properties	Gypsum
Compressive strength (MPa)	6.18–12.75
Flexural strength (MPa)	4.67–9.25
Loss on ignition	13–15%

The water-reducing agent is a liquid high-performance water-reducing agent from the Xi'an Building Materials Company of China, with a water-reducing rate of 30%, ensuring the fluidity and water retention of the cementitious material. The defoaming agent uses industrial-grade defoaming agent produced by Kelly Chemical to reduce the bubbles generated when the gypsum is mixed and injected into the mold, thereby reducing experimental errors. The glass fiber used in the experiment was produced by the Anjie Anti-Crack Company, and its parameters are shown in Table 2.

Table 2. Properties of glass fibers.

Fiber Properties	Glass Fiber
Specific gravity (g/cm^3)	3.63
Tensile strength (MPa)	4000
Diameter (μm)	10
Length(cm)	3
Modulus of elasticity (GPa)	105

The design water–gypsum ratio was 0.25, and the design compressive strength was 20 MPa. According to the different amounts of glass fiber, six different mix ratios were designed. The glass fibers in the gypsum were incorporated at 0%, 0.5%, 1.0%, 1.2%, 1.5%, and 2.0% by volume. The specimen preparation process is as follows. First, assemble the acrylic mold one hour in advance and use glue to adhere the molds. After the assembly is completed, fill the mold with water. If no water seeps out within half an hour, the mold

assembly is qualified. Wipe the mold and dry it for later use. Then, put the weighed gypsum, water-reducing agent, and defoaming agent into a horizontal mixer and stir for 1 min. The mixture's base proportions are shown in Table 3.

Table 3. Mixture base proportions.

Composition	Percentage (%)
Gypsum	77.8
Water	19.46
Water-reducing agent	1.95
Defoaming agent	0.79

Add the glass fiber to the mixer and stir for 2 min, and then slowly add water and continue stirring for 2 min. This is to ensure that all materials can fully contact each other and allow the gypsum specimen to be formed. Pour the stirred gypsum mixture into the mold and use a vibration table to vibrate at the same time. This process can make the bubbles attached to the reserved defective holes and the inner wall of the mold escape, ensuring the reliability of the experimental data. After curing for 24 h, disassemble the mold and take out the sample, place it in a curing room with a temperature of 20 ± 2 °C, and cure it for 28 days for testing. Each group of specimens must consist of six specimens for uniaxial compressive strength, constant stress lower limit cyclic loading and unloading, and variable stress lower limit cyclic loading and unloading tests. The preparation of these gypsum samples with different glass fiber concentrations is shown in Figure 1.

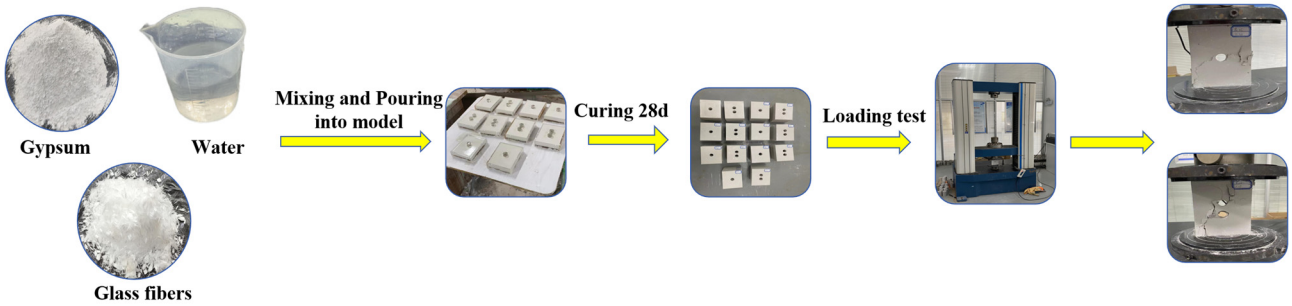


Figure 1. Schematic diagram of specimen preparation.

The specimens were polished to ensure a smooth, even surface and consistent thickness. They were then categorized into two series based on defect type: SH (single hole) and DH (double hole). Depending on the fiber concentration, twelve distinct groups were established: SH-00, SH-05, SH-10, SH-12, SH-15, SH-20, DH-00, DH-05, DH-10, DH-12, DH-15, and DH-20. SH-05 represents a single-hole gypsum board specimen with a glass fiber content of 0.5%, and DH-05 represents a double-hole gypsum board specimen with a glass fiber content of 0.5%. SH-00 and DH-00 represent gypsum boards without fibers for single-hole and double-hole specimens, respectively.

2.2. Cyclic Loading and Unloading Test Program

To investigate how upper and lower stress limits affect specimen damage under intermittent loading, cyclic experiments were conducted following two load paths, as shown in Figure 2.

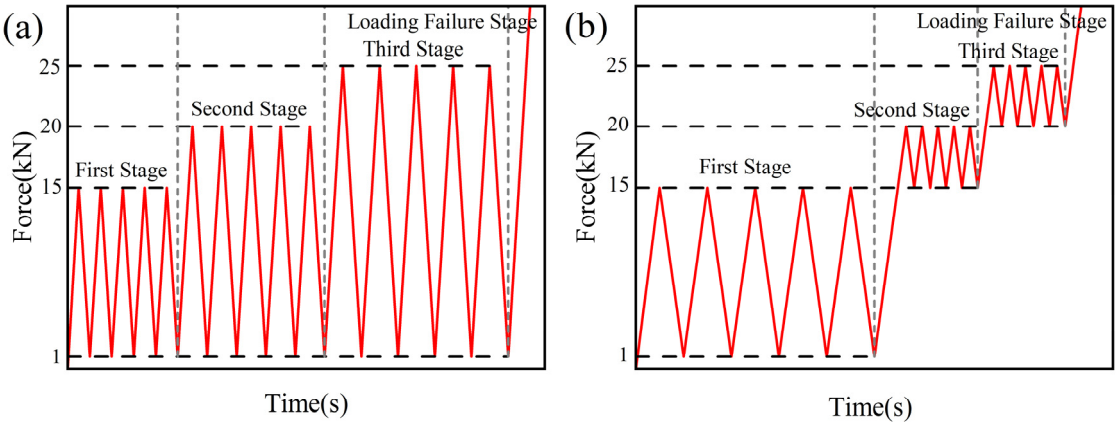


Figure 2. Cyclic load and unload paths. (**a**) Scheme 1. (**b**) Scheme 2.

Scheme 1: Constant Stress Lower Limit Repeated Loading Experiment (CSRLE).

This experiment evaluates the impact of the upper stress limit on the cyclic damage of the gypsum board. The upper cyclic stress limits were set to 10 kN, 15 kN, and 20 kN. For each stage, the lower cyclic stress limit remained constant at 1 kN, ensuring sufficient contact between the specimens and the press. Each stress stage was cycled five times.

Scheme 2: Variable Stress Lower Limit Repeated Loading Experiment (VSRLE).

This experiment mainly investigates the effect of the lower limit of stress on the cyclic damage of the gypsum board. Similar to the upper limit of Scheme 1, the upper stress limit was set to 10 kN, 15 kN, and 20 kN, and the lower stress cycle limits were set to 1 kN, 10 kN, and 15 kN for each stage. Each stage was cycled five times.

3. Results and Discussion

3.1. Uniaxial Compression Experiments

The loading rate was controlled at 500 N/s, and the obtained uniaxial compressive strength of the specimen is shown in Table 4. The uniaxial compression tests showed that the strength of the two-hole gypsum board was lower than that of the single-hole gypsum board. This can be attributed to the reduction in the effective load-bearing area of the double-hole gypsum boards. Therefore, under the same stress load, the double-hole gypsum board reached the cracking strain first, resulting in a decrease in the overall strength. For specimens with different fiber contents, the strength of the specimens improved to varying degrees. This shows that with the addition of glass fibers, the micropores and microcracks within the gypsum board are filled, thereby increasing its strength.

Table 4. Uniaxial strength of the specimens.

Specimens	SH-00	SH-05	SH-10	SH-12	SH-15	SH-20
Uniaxial compression/(MPa)	12.99	19.19	17.92	22.42	23.01	23.06
Specimens	DH-00	DH-05	DH-10	DH-12	DH-15	DH-20
Uniaxial compression/(MPa)	11.38	18.31	15.66	18.67	20.43	21.30

The ultimate strength of the gypsum board increases with increasing fiberglass content. When a gypsum board with a circular hole defect is subjected to compressive loading, tensile stress concentrations will occur above and below the hole. The addition of glass fiber can enhance the tensile strength, thereby continuously improving the strength of the sample. The increase in ultimate strength is not significant when comparing SH-15 and SH-20 samples. This suggests that while glass fibers can increase the stiffness of a sample, their effectiveness diminishes once a certain stiffness threshold is reached. Therefore, in real engineering scenarios, a balance must be struck between cost-effectiveness and safety performance.

3.2. Repeat Loading Experiments

The results of the Constant Stress Lower Limit Repeated Loading Experiment (CSRLE) are provided in Table 5. In the CSRLE, the strength of the SH and DH series specimens was significantly improved after adding glass fiber. When the glass fiber content of the SH series was 1.5%, the maximum strength improvement was 48.9%. Similarly, the DH series exhibited the largest strength improvement when the glass fiber content was 1.5%, with a value of 136.9%. This proves that the addition of glass fiber can effectively improve the ability of brittle materials to resist repeated loading. At the same time, more holes mean a smaller effective bearing area and a more obvious reinforcement effect of the glass fiber.

Table 5. Repeated loading peak strength of specimens.

Specimens	**SH-00**	**SH-05**	**SH-10**	**SH-12**	**SH-15**	**SH-20**
CSRLE/(MPa)	14.79	21.45	18.04	18.84	22.03	19.91
VSRLE/(MPa)	13.25	20.18	14.65	17.80	23.21	20.57
Specimens	DH-00	DH-05	DH-10	DH-12	DH-15	DH-20
CSRLE/(MPa)	9.55	18.61	17.44	22.31	22.62	22.51
VSRLE/(MPa)	7.23	16.21	14.84	22.58	23.07	22.38

The results of the Variable Stress Lower Limit Repeated Loading Experiment (VSRLE) are also provided in Table 5. In the VSRLE, the addition of glass fiber also improved the ability of the gypsum specimen to resist repeated loading. When the glass fiber concentration was 1.5%, the failure stress of both the SH sample and the DH sample was the largest. Compared with the baseline group without fibers, the strength increased by 75.1% and 219.1%, respectively.

Comparing the two repeated loading experiments, the addition of glass fiber had positive significance in improving the gypsum specimens' ability to withstand cyclic loads. In both loading modes, the strength of the specimen was maximized when the glass fiber concentration was 1.5%, which proves that this glass fiber concentration comprehensively improves the fatigue resistance of the specimen. At the same time, the strength improvement of the VSRLE gypsum specimens was better than that of CSRLE, which benefits from the increase in loading frequency caused by the shortening of the loading path. The stress–strain relationship of the sample in CSRLE is shown in Figure 3, while the stress–strain relationship of the sample in VSRLE is shown in Figure 4.

3.3. Energy Evolution

During cyclic loading, the loading and unloading curves diverge, creating a hysteresis loop. On the stress–strain graph, the area under the loading curve represents the mechanical energy density, while that under the unloading curve indicates the elastic energy density. The discrepancy between these two areas signifies the energy dissipated. Refer to Figure 5 for the energy diagram.

The formula for calculating the energy density is shown below.

$$U = U^e + U^d \tag{1}$$

U is the total mechanical energy density, MJ/m^3; U^e is the elastic energy density, MJ/m^3; and U^d is the dissipative energy density, MJ/m^3.

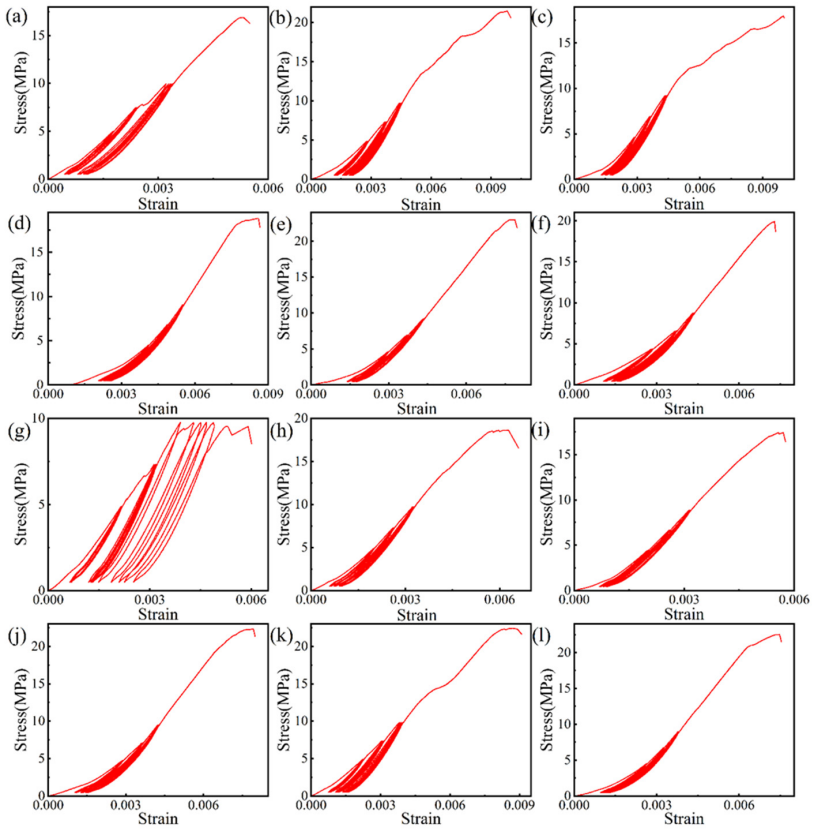


Figure 3. CSRLE cyclic stress–strain curves. (**a**) SH-00; (**b**) SH-05; (**c**) SH-10; (**d**) SH-12; (**e**) SH-15; (**f**) SH-20; (**g**) DH-00; (**h**) DH-05; (**i**) DH-10; (**j**) DH-12; (**k**) DH-15; (**l**) DH-20.

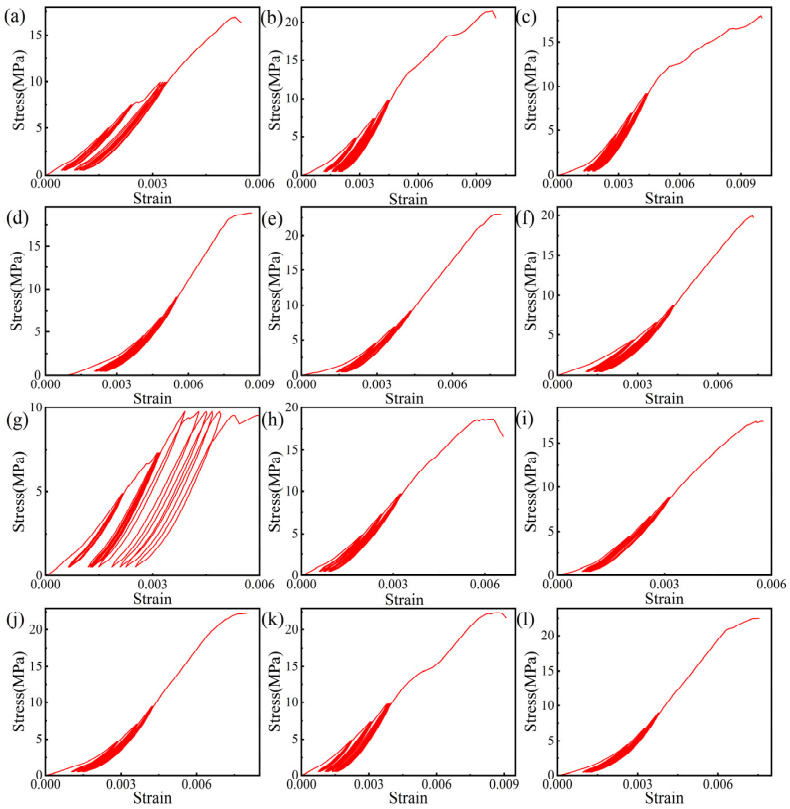


Figure 4. VSRLE cyclic stress–strain curves. (**a**) SH-00; (**b**) SH-05; (**c**) SH-10; (**d**) SH-12; (**e**) SH-15; (**f**) SH-20; (**g**) DH-00; (**h**) DH-05; (**i**) DH-10; (**j**) DH-12; (**k**) DH-15; (**l**) DH-20.

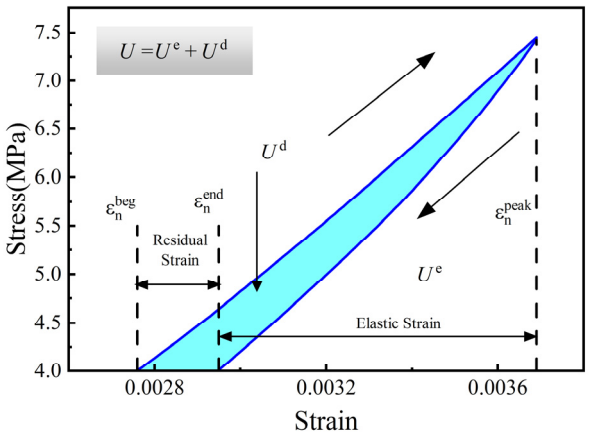


Figure 5. Schematic diagram of energy partitioning.

The dissipated energy density curve of the specimen was obtained as shown in Figure 6. In the CSRLE, when the glass fiber content was 0.5%, 1.0%, and 2.0%, the energy dissipation of the SH specimen was higher than that of the DH specimen. However, in the VSRLE, the energy dissipation of the SH samples was lower than that of the DH samples at fiber contents of 0%, 0.5%, and 1.0%. It is worth noting that when the fiber content is low, the energy dissipation also jumps significantly in the mutation stage of the upper stress limit. But as the fiber content increases, the transition becomes smoother, indicating that a higher fiber content can suppress sudden energy fluctuations and reduce the probability of sudden failure of the specimen. The evolution law of energy dissipation is not completely consistent with the intensity law of cyclic experiments, which proves that there is also a certain amount of energy released during the crushing and damage stage of the specimen.

3.4. Residual Strain

Residual strain is an important indicator used to measure the strain recovery ability of the structure and appropriately reflects the anti-interference ability of the structure. The smaller the residual strain, the stronger the recovery ability of the specimen. Graphs showcasing the variations in the residual strain across different glass fiber doping levels during the 15th cycle are depicted in Figure 7. The residual strain of the SH specimen exhibits minimal fluctuations, suggesting that glass fiber has a marginal impact on its strain recovery capacity. In contrast, the DH specimen displays a markedly different fluctuation pattern. After adding glass fiber, the residual strain of the double-hole gypsum board was significantly reduced. This trend was demonstrated in the VSRLE. The residual strain was reduced from 43×10^{-4} to 22×10^{-4}, with a decrease of 43.84%. This indicates that adding glass fiber can effectively reduce the stress concentration within the sample and enhance the anti-interference ability and strain recovery ability of the specimen.

3.5. Damage Factor

To investigate more deeply the damage characteristics of gypsum boards with different defect types and glass fiber content, the damage factor was calculated for each cycle, which was derived from the dissipated energy and is shown in Figure 8. The damage factor was calculated using the following formula:

$$D_i = \sum_{i=1}^{n} \frac{U_i^d}{U^d} \tag{2}$$

where D_i is the damage factor of the ith cycle, and U_i^d is the dissipated energy density of the ith cycle, MJ/m^3.

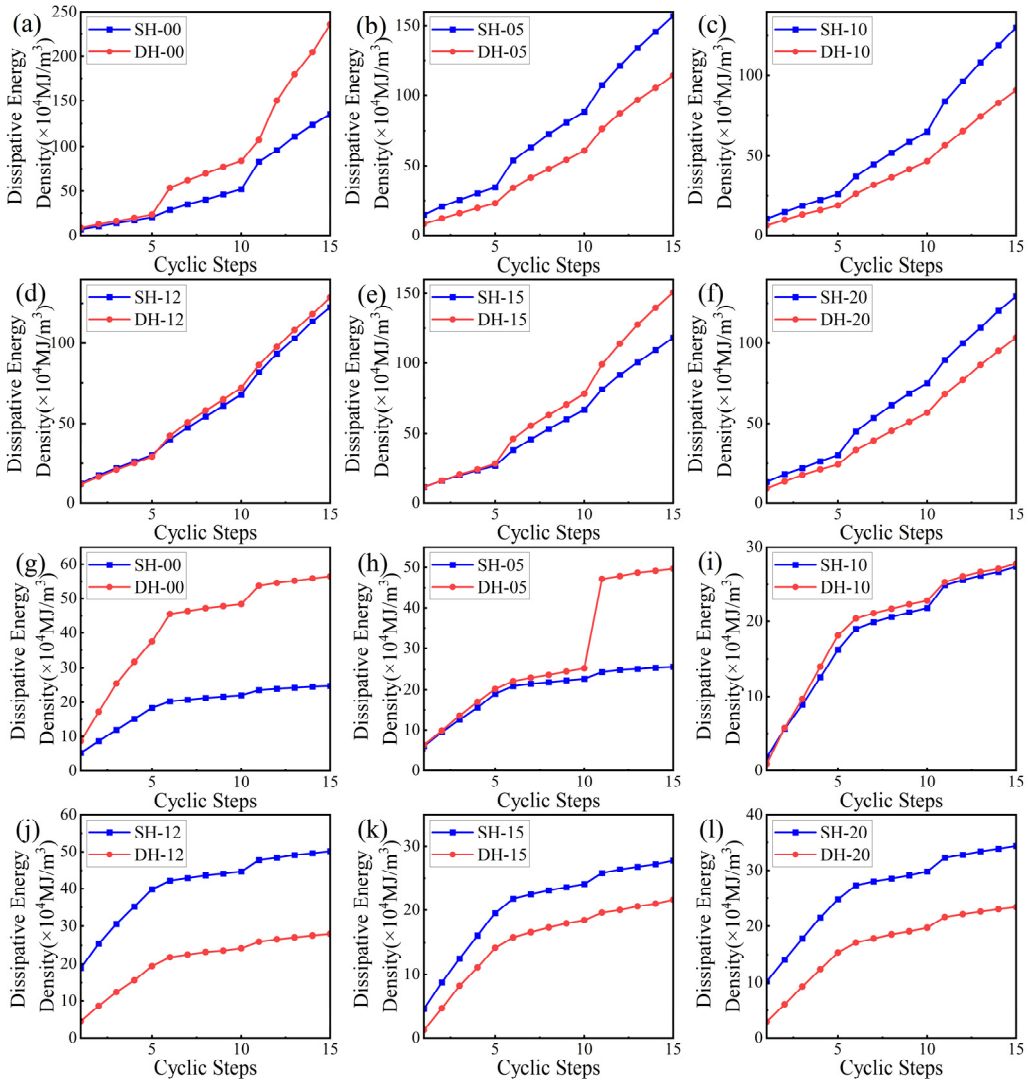


Figure 6. Dissipative energy density curves. (**a**) CSRLE-00; (**b**) CSRLE-05; (**c**) CSRLE-10; (**d**) CSRLE-12; (**e**) CSRLE-15; (**f**) CSRLE-20; (**g**) VSRLE-00; (**h**) VSRLE-05; (**i**) VSRLE-10; (**j**) VSRLE-12; (**k**) VSRLE-15; (**l**) VSRLE-20.

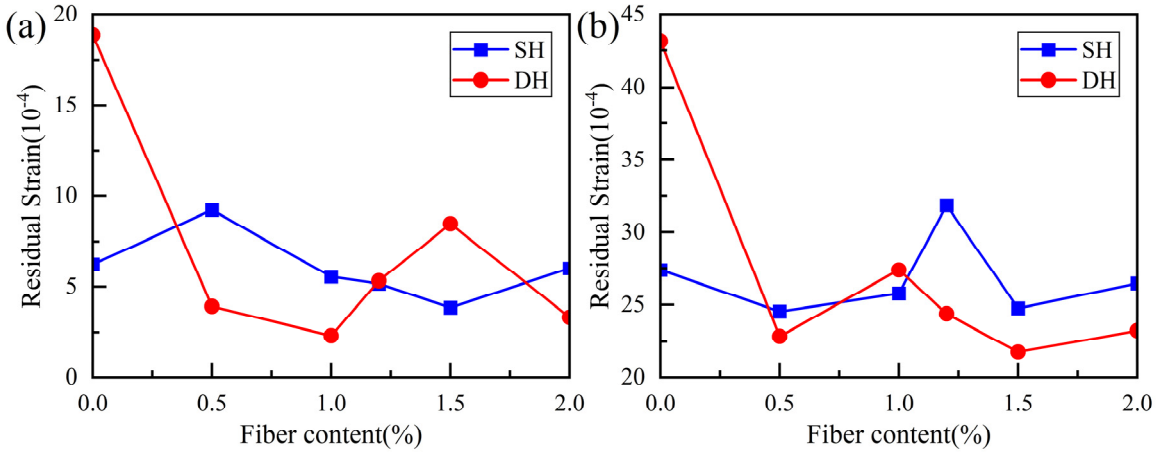


Figure 7. Residual strain curves ((**a**) VSRLE; (**b**) CSRLE).

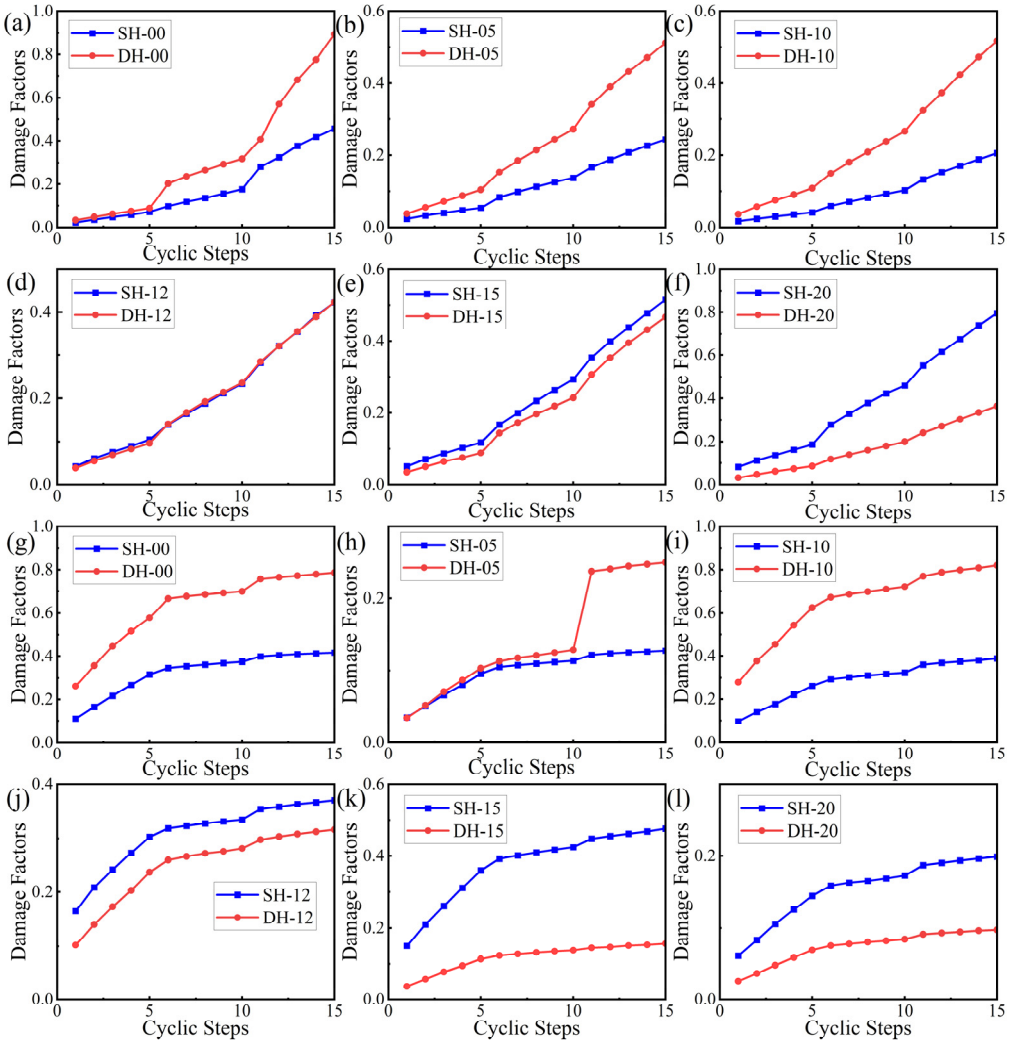


Figure 8. Damage factor curves. (**a**) CSRLE-00; (**b**) CSRLE-05; (**c**) CSRLE-10; (**d**) CSRLE-12; (**e**) CSRLE-15; (**f**) CSRLE-20; (**g**) VSRLE-00; (**h**) VSRLE-05; (**i**) VSRLE-10; (**j**) VSRLE-12; (**k**) VSRLE-15; (**l**) VSRLE-20.

The damage factor curve shows that in the CSRLE and VSRLE, as the glass fiber content increased, the damage to the SH sample was gradually higher than that of the DH sample. This is consistent with the conclusion in the strength analysis, further verifying that the porous structure can effectively improve the stress concentration problem.

In the CSRLE, the damage factor of the DH sample continued to decrease with the gradual increase in fiber content. The damage factor of the DH-00 specimen was as high as 0.9 when cycled 15 times, while the damage factor of the DH-20 specimen dropped to 0.36 when cycled 15 times, a decrease of 60%. This shows that adding glass fiber can effectively reduce the damage degree of double-hole gypsum board.

In the VSRLE, the damage factor of the DH specimen decreased with the increase in the glass fiber content. This shows that glass fiber can also reduce the damage to the specimen in the variable cyclic stress lower limit experiment. Comparing CSRLE and VSRLE, the damage factor in CSRLE is greater than VSRLE, which proves that glass fibers play different roles in damage at different stress amplitudes. In practical applications, when the structure is disturbed, adding glass fiber can effectively improve the stability and durability of the structure.

3.6. Destruction Characteristics

Figure 9 shows a photo of the specimen after damage. Due to the existence of the round hole, the specimen shows tensile stress concentrations at the upper and lower ends

of the round hole and compressive stress concentrations at its left and right ends. Therefore, tensile cracks initiate and propagate at the upper and lower ends, while shear cracks initiate and propagate at the left and right ends. As the glass fiber content increases, the surface and distal cracks of the sample are significantly reduced, and the integrity of the specimen is improved. This proves that glass fiber strengthens the bond between gypsum crystals and improves the specimen's ability to resist cyclic loading. When glass fiber is not added to the DH specimen, the sample shows greater brittleness and lower integrity, and the area between the double holes is destroyed due to the stress concentration. With the addition of glass fiber, the integrity of the specimen is significantly improved, and the inter-pore area is preserved, which indicates that the addition of glass fiber effectively alleviates the problem of pore stress concentration.

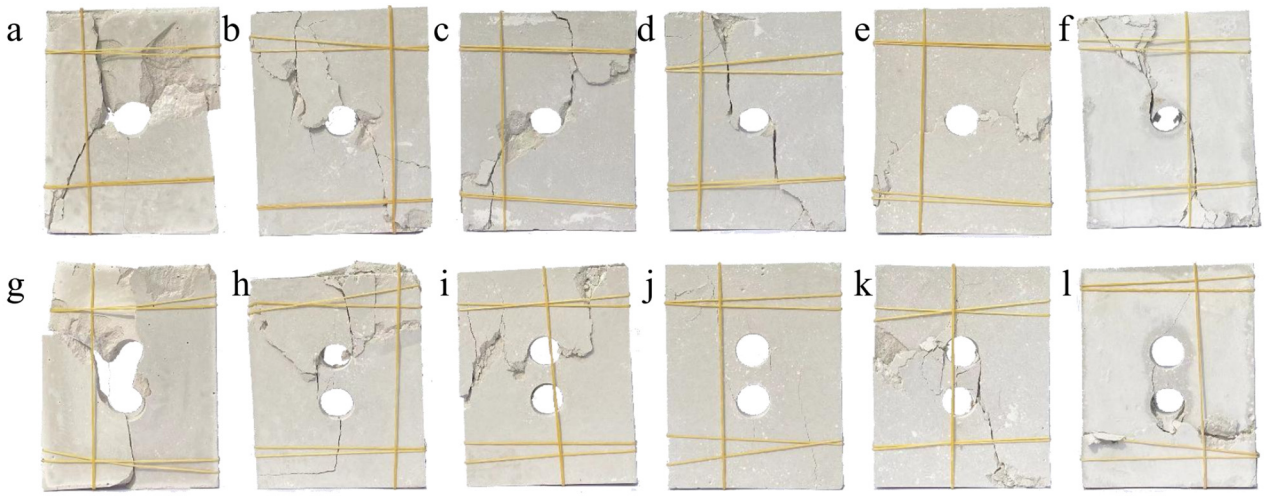


Figure 9. Damage pattern of the specimens. (**a**) SH-00; (**b**) SH-05; (**c**) SH-10; (**d**) SH-12; (**e**) SH-15; (**f**) SH-20; (**g**) DH-00; (**h**) DH-05; (**i**) DH-10; (**j**) DH-12; (**k**) DH-15; (**l**) DH-20.

3.7. Microscopic Electron Microscope Analysis

In order to study the interaction between gypsum crystals and glass fibers on a microscopic scale, scanning electron microscopy was performed on the fragments at the circular hole of the specimen, and the images are shown in Figure 10. In the absence of glass fibers, there are obvious cracks between the gypsum crystals (such as in Figure 10a,b). When the glass fiber content is low, the binding force between the fiber and gypsum is weak, causing the fiber to slip and pull out (such as Figure 10c,d), and there are obvious small cracks between the gypsum crystals. When the glass fiber content increases, the bonding force between the fibers and gypsum crystals is stronger (such as in Figure 10e,f), inhibiting the generation of microcracks. At the same time, the fibers exhibit a bridging effect, and the fiber connections transmit stress at both ends of the gypsum crystal, thus avoiding stress concentration.

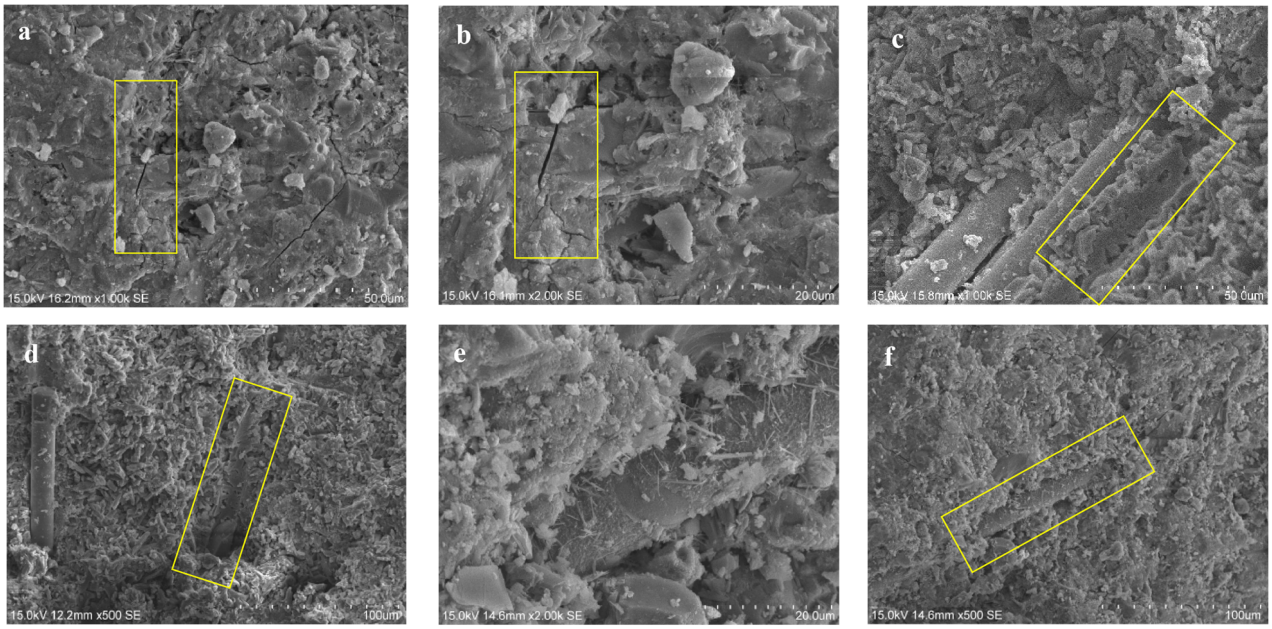


Figure 10. Scanning electron microscope images. ((**a**,**b**) Micro cracks in cement matrix; (**c**,**d**) Glass fiber slip marks; (**e**,**f**) Tightly wrapped glass fiber).

4. Conclusions

(1) Uniaxial tests show that two-hole gypsum boards have weaker strength due to the reduced effective bearing area, leading to early cracking. Adding fiberglass can increase strength, but the effect diminishes beyond a 1.5% threshold. Balancing cost and safety is critical in engineering.

(2) Glass fibers exert influence on the recuperation of strain in gypsum boards. While their impact is negligible in single-hole (SH) samples, a substantial decrease in strain is observed in dual-hole (DH) samples. The addition of fibers leads to the enhanced distribution of stress and elasticity. An analysis of damage factors affirms this enhancement, particularly fortifying structural stability and longevity.

(3) Glass fibers mitigate stress concentrations and fortify sample integrity. Their absence leads to brittleness and stress concentrations between double pores. A low glass fiber content weakens bonding, causing slippage; a higher content inhibits microcracking, and the fibers act as stress-transferring bridges, enhancing cyclic loading behavior.

(4) This study provides a new idea for the application of glass fiber as a waste derivative in brittle materials, which is helpful for the sustainable development of the construction industry.

5. Research Shortcomings and Future Work

(1) In this study, the specimen was in a uniaxial compression state, and the inhibitory effects of lateral stress and intermediate principal stress on cracks were ignored.

(2) In underground engineering, joints seriously affect the stability of structures. Therefore, it is necessary to explore the coupling effect between cracks and holes in future work.

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