Research Article

Effect of Fibers on the Mechanical Properties and Mechanism of Cast-In-Situ Foamed Concrete

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The cast-in-situ foamed concrete is inherently susceptible to cracks due to its brittleness, which will limit the use [10–12].

Fiber is a conventional measure to improve the mechanical properties of concrete. Fiber is generally divided into high elastic modulus and low elastic modulus. As a high elastic modulus, alkali-resistant glass fiber is a reinforcing material with good mechanical properties, corrosion resistance, and fire resistance [13, 14]. The tensile strength of the cement matrix can be greatly improved by adding an appropriate amount of glass fiber into cement materials. The expansion of microcracks in the matrix can be greatly improved by adding an appropriate amount of glass fiber into cement materials. The expansion of microcracks in the matrix can be greatly improved by adding an appropriate amount of glass fiber into cement materials. The expansion of microcracks in the matrix can be greatly improved by adding an appropriate amount of glass fiber into cement materials.

1. Introduction

Cast-in-situ foamed concrete is a material developed in recent years. It is mainly composed of cement, an admixture, and water in specific proportions to form a slurry, which is then mixed with a specific proportion of small stable bubble group mix to form a fluid that eventually solidifies into a low-density filling material [1–3]. Its applications have expanded into roof insulation layers, floor heating insulation blankets, civil engineering, and industrial engineering applications [4–7]. According to the statistics of the China Concrete and Cement Products Association (CCPA), the annual total output of foamed concrete increased from 2010 to 2020 (Figure 1). Due to the growth of civil engineering construction projects, the applications of foamed concrete have also increased [8, 9]. The cast-in-situ foamed concrete is inherently susceptible to cracks due to its brittleness, which will limit the use [10–12].

Fiber is a conventional measure to improve the mechanical properties of concrete. Fiber is generally divided into high elastic modulus and low elastic modulus. As a high elastic modulus, alkali-resistant glass fiber is a reinforcing material with good mechanical properties, corrosion resistance, and fire resistance [13, 14]. The tensile strength of the cement matrix can be greatly improved by adding an appropriate amount of glass fiber into cement materials. The expansion of microcracks in the matrix can be prevented, and the generation of new cracks can be delayed. This provides an economical method to improve the deformation properties of the matrix, which improves the toughness and impact resistance of the matrix [15–17]. As a low elastic modulus, high-ductility fiber, polypropylene fiber has good
toughness and crack resistance, acid and alkali resistance, and low price. The tensile strength of the cement matrix can be economically improved by adding an appropriate amount of polypropylene fiber. The expansion of microcracks in the matrix can be prevented, and the generation of new cracks can be delayed, and the toughness and impact resistance of the matrix can be improved by improving the deformation properties of the matrix [18–20].

The main goal of this study was to investigate the influence of fibers on the mechanical properties of cast-in-situ foamed concrete using alkali-resistant glass fiber (high elastic modulus) and polypropylene fiber (low elastic modulus). First, the cast-in-situ foamed concrete with a dry density of 550 kg/m³ was designed. Compression tests were carried out using different fiber lengths and contents to determine the optimal fiber length, in which the fiber content was the mass ratio of the fiber to the designed dry density per unit volume. Then, compression tests and flexural tests were carried out to determine the optimal fiber content of each designed dry density by adding different contents of fibers with the optimal length to the foamed concrete with different design dry densities. Finally, failure mode analysis was carried out to explore the influence mechanism of fibers on the mechanical properties of foamed concrete.

2. Materials and Methods

2.1. Materials. The foamed concrete was mainly comprised of ordinary Portland cement, water, and bubbles. The cement was Type I Portland cement that conformed to GB 175–2007, and tap water was used. The bubbles were made from a synthetic foaming agent, with the density controlled at 35 ± 5 kg/m³ [21, 22]. The physical and mechanical properties of the fibers are shown in Table 1.

2.2. Mix Design Procedure. Table 2 shows the mixing proportions and major parameters of the foamed concrete. The designed dry density of pure cement foamed concrete was 1.211 times that of the unit cement content. When the fiber foamed concrete was included, the cement content was the same as that in the same designed dry density pure cement foamed concrete. A prefoaming method was used to produce the foamed concrete. For the standard curing condition, the samples were cured in a standard curing room after they were unmolded until tests. The humidity was constant at 100% [21, 22].

2.3. Testing Method

2.3.1. Compression Tests. For the tests, three identical samples (100 mm long × 100 mm wide × 100 mm high) were cast for each mix proportion. The samples were tested using a compressive machine at rates of 2.00 kN/s according to GBT 11969–2008 [21].

2.3.2. Tensile Strength Tests. Tensile strength is one of the basic properties of foamed concrete, but there are few studies on the tensile strength of foamed concrete. There are mainly three kinds of test and measurement methods of concrete: splitting test, bending test, and direct tensile test.

(1) Splitting Tests. The 100 mm × 100 mm × 100 mm cube sample was used with reference to GB/T11969-2008. A cushion bar was placed between the steel cushion bar and the sample to form a strip load above and below the specimen, which caused the specimen to crack and damage along the center of the cube. The axial tensile strength of foamed concrete can be obtained from the splitting force, which can be calculated according to the following formula:

\[ f_{ts} = \frac{2P}{\pi A} \]  \hspace{1cm} (1)

where \( f_{ts} \) is the splitting tensile strength; \( P \) is the ultimate failure load of the specimen; and \( A \) is the area of the splitting surface of the specimen.

(2) Bending Test. The flexural strength of foamed concrete was obtained by three-point bending tests and was used as the main index to test the toughness of the materials. The sample size was 40 mm × 40 mm × 160 mm, and the pouring method was similar to the compression test. The flexural strength was calculated as follows:

\[ f_f = \frac{1.5PL}{bh^2} \]  \hspace{1cm} (2)

\( P \) is the ultimate failure load of the specimen; \( L \) is the distance between supports; \( B \) is the width of the specimen; and \( H \) is the height of the specimen.

(3) Direct Tensile Test. Direct tensile tests can reflect the tensile strength of materials, but the implementation of these tests is difficult due to strict requirements for the production of specimens and test alignment. Any deviations will cause improper tensile failure, which affects the test results.
Direct tensile tests are carried out on a cylinder (Ø100mm x 500mm) with embedded steel bars at both ends with an embedded depth of reinforcement of 150mm. The results were relatively discrete, and the fixture used in the existing testing machine is shown in Figure 2(a). Through upper rotation, the lower fixture moved up and down with the reinforcement clamp. When the fixture and reinforcement contacted, rotation and moving up and down formed vertical and tangential stresses in the sample. For the sample with a low dry density, this caused reinforcement pull-out.

To solve the above problems, the improved fixture was adopted, as shown in Figure 2(b). The knobs on both sides were rotated to ensure that the chuck was in close contact with the vertical steel bar of the sample, and no vertical or tangential stresses were generated, which satisfied the requirement that no damage was caused to the specimen in the process of fixing the steel bar.

### 3. Results and Discussion

#### 3.1. Effects of Density on Mechanical Properties

It can be seen from Figure 1 that the stress-strain curves all show a stage where the stress increases linearly with the strain and then reaches a peak. When the designed dry density was low, the stress fluctuated upon increasing the strain, but it did not exceed the peak value. When the designed dry density was high, the stress suddenly decreased and then decreased slowly with the strain.

The stress-strain curve characteristics of cast-in-situ foamed concrete with different design dry densities were summarized, and an invalid curve caused by defects in the sample itself was removed. The compression curve model of cast-in-situ foamed concrete was obtained as shown in Figure 3, which is divided into three main stages:

1. The elastic stage (OA section): For this stage, the stress increased linearly upon increasing the strain, and the stress increased sharply.

2. The brittle stage (AB section): This stage was accompanied by the beginning of the expansion of microcracks in the specimen and the emergence of new cracks. The stress increased slowly upon increasing the strain. Compared with the elastic stage, the elastic modulus at this stage decreased.

(3) The yield stage: This stage was divided into concussion yield (BC section) and point yield. For the concussion yield, an individual wall of holes on the surface of the specimen began to be overwhelmed after reaching the stress peak, and it produced stress concentration in the rest of the holes on the surface of the wall. Finally, the hole wall on the surface was crushed, and the stress decreased slightly. When the crushed layer was compacted, the stress rose slightly upon increasing the strain, but it did not exceed the peak value. Then, the pores in another layer were crushed and compacted, and a similar phenomenon occurred (Figure 4(a)). The point yield was divided into a sudden descending segment (BD section) and a slow descending segment (DE section). When the stress of the cast-in-situ foamed concrete exceeded the fracture bearing capacity of the specimen, a penetrating crack appeared 45° along the vertical axis. The specimen suffered sudden brittle fracture, and the stress suddenly decreased with the strain. When the main crack was generated, the load was shared by the upper and lower parts. Upon increasing the vertical displacement, the specimen was staggered, secondary cracks formed, and the specimen was further damaged. The stress decreased upon increasing the strain (Figure 4(b)).

Compression tests and tensile strength tests (splitting test, bending test, and direct tensile test) were carried out on five groups of cast-in-situ foamed concretes with a designed dry density. The results in Table 3 show that all parameters increased upon increasing the designed dry density. When the designed dry density increased from 300kg/m³ to 800kg/m³, the unconfined compressive strength increased from 0.654MPa to 5.357MPa, and the elastic modulus increased from 655.2MPa to 619.1MPa. The splitting tensile strength increased from 0.093MPa to 0.808MPa, the flexural strength increased from 0.181MPa to 1.518MPa, and the degree of direct tension increased from 0.108MPa to 0.933MPa.
Figures 3–8 show the relationship between the elastic modulus and the unconfined compressive strength. The elastic modulus was about 110.0 times higher than the unconfined compressive strength through linear fitting, which showed a high degree of fit.

Figure 7 shows the variation curve of the ratio of the three types of tensile strength to the unconfined compressive strength as a function of the designed dry density. According to the comparative analysis, the ratio of flexural strength to unconfined compressive strength was the largest (0.272–0.283 times). When the designed dry density was different, the ratio was discrete, but the discreteness was small.

The ratio of the direct tensile strength to the unconfined compressive strength was investigated next (0.154–0.174 times). The results had a large dispersion, even though the fixture of the direct tensile equipment was improved. The ratio of splitting tensile strength to unconfined compressive strength was the smallest (0.094–0.151 times), and this ratio increased upon increasing the designed dry density.

Figure 8 shows the splitting failure diagram of cast-in-situ foamed concrete. The cushion strip appears to have been embedded in the sample, and this phenomenon gradually decreased upon increasing the designed dry density. Combined with the vertical lateral stress distribution of the split specimen in the splitting test (Figure 9) and assuming that the size of the sample remained unchanged, the stress generated compressive stress about 1/8$d$ from the end and a relatively uniform tensile stress in the middle 3/4$d$ section.

Combined with the schematic diagram of the transverse stress distribution on the vertical plane of the split sample in the 11 split tests in Figures 3–11 and assuming that the sample size remained unchanged, it was deduced that compressive stress was generated when the stress was about 1/8$d$ away from the end. In section 3/4$d$ from the middle, a more uniform tensile stress was generated.
inside. For the cast-in-situ porous foamed concrete material, the cushion strip was embedded in the sample, and splitting occurred after a shear band was formed, which changed the force distribution. The cast-in-situ foamed concrete material was subjected to a splitting test, but there were some problems. For the porous cast-in-situ foamed concrete material, the cushion strip was inserted into the sample to form a shear band before splitting, which changed the force distribution; thus, there were still some problems when the splitting test was applied to the foamed concrete.

In the direct tensile test samples, both ends of the reinforcement were not convenient to fix and easily produced nonvertical phenomena. To ensure that the tensile position of the foamed concrete material was not affected by the action of reinforcement, a part of the foamed concrete layer

| Designed dry density (kg/m³) | Unconfined compressive strength (MPa) | Elastic modulus (MPa) | Splitting tensile strength (MPa) | Flexural strength (MPa) | Direct tensile strength (MPa) |
|------------------------------|--------------------------------------|----------------------|---------------------------------|------------------------|-----------------------------|
| 300                          | 0.654                                | 55.39                | 0.093                           | 0.181                  | 0.108                       |
| 425                          | 1.138                                | 107.43               | 0.163                           | 0.310                  | 0.175                       |
| 550                          | 2.359                                | 280.78               | 0.347                           | 0.660                  | 0.391                       |
| 675                          | 3.913                                | 468.94               | 0.569                           | 1.084                  | 0.608                       |
| 800                          | 5.357                                | 557.05               | 0.808                           | 1.518                  | 0.933                       |

Figure 5: Stress-strain curve of cast-in-situ foamed concrete with different design dry densities.

![Figure 5: Stress-strain curve of cast-in-situ foamed concrete with different design dry densities.](image)

![Figure 6: The relationship between elastic modulus and unconfined compressive strength.](image)

![Figure 6: The relationship between elastic modulus and unconfined compressive strength.](image)

Table 3: The results of mechanical tests.

Figure 6: The relationship between elastic modulus and unconfined compressive strength.
separated in the middle. The stress analysis showed that the crack surface was a weak surface with defects, but the test showed that the crack surface was not a plane. The direct tensile test was not suitable for measuring the tensile strength test of foamed concrete materials because of high dispersion due to many factors.

Figure 7: The ratio of tensile strength to compressive strength with dry density.

Figure 8: Splitting failure diagram of cast-in-situ foamed concrete.

Figure 9: Schematic diagram of vertical lateral stress distribution of the split specimen.
Comprehensive comparative analysis showed that flexural tests can be used to measure the tensile strength of foamed concrete materials. This provides a simple method to make a sample and also produces a small operating error and small results dispersion; therefore, the flexural test was used to test the tensile strength of foamed concrete materials in the following experiments.

3.2. Research on the Influence of Fibers on the Mechanical Properties

3.2.1. Optimal Fiber Length Determination. Figure 10 shows the relationship curves between the unconfined compressive strength and glass fiber content in the foamed concrete with four groups of glass fiber lengths. The unconfined compressive strength increased first and then decreased for the four groups of fiber lengths foamed concrete. When the fiber length was 3 mm, 6 mm, 9 mm, and 12 mm, the maximum unconfined compressive strength was 3.19 MPa, 3.41 MPa, 3.13 MPa, and 3.12 MPa, respectively, and the corresponding fiber contents were 1.0%, 0.4%, 0.2%, and 0.2%, respectively. Upon increasing the fiber length, the optimal content decreased. For the four groups of fiber lengths, the maximum unconfined compressive strength increased by 40.8%, 50.5%, 36.1%, and 38.2%, respectively, compared with the reference value (fiber content = 0%).

Figure 11 shows the relationship between the unconfined compressive strength and polypropylene fiber content of the foamed concrete with four groups of glass fiber lengths.
When the fiber length was 3 mm, 6 mm, 9 mm, and 12 mm, the unconfined compressive strength of foamed concrete increased first and then decreased upon increasing the fiber content, and the maximum values were 2.848 MPa, 3.022 MPa, 2.850 MPa, and 2.729 MPa, respectively. The corresponding fiber contents were 0.4%, 0.6%, 0.6%, and 0.8%, which increased by 25.6%, 33.3%, 25.7%, and 20.4%, respectively, compared with the base value. When the fiber lengths were 3 mm, 6 mm, 9 mm, and 12 mm, the optimal content of polypropylene fiber increased upon increasing the fiber length. When the fiber length was 6 mm, and the fiber content was 0.6%, the unconfined compressive strength of foamed concrete reached the maximum.

Comparing Figures 10 and 11, when the optimal fiber content was not reached, the unconfined compressive strength of glass fiber increased upon increasing the fiber length at the same fiber content, while the unconfined compressive strength of the polypropylene fiber decreased upon increasing the fiber length. The main reason is that the glass fiber has a high elastic modulus and a large diameter, while the polypropylene fiber has a low elastic modulus and small diameter. Glass fiber remained linear in the foamed concrete slurry, which formed a good three-dimensional network structure, while the polypropylene fiber easily bent in the foamed concrete, resulting in an effective length reduction. For the same fiber, the maximum unconfined compressive strength first increased and then decreased upon increasing the fiber length. The main reason is that the bridging effect was more obvious and the dosage was small when the fiber was longer, but this easily caused fiber agglomeration. The foamed concrete could not reach its maximum performance when the fiber length was short, the bridging effect was weak, and the dosage was high (Figure 12).

For the foamed concrete mixed with fibers, when the fiber length exceeded 6 mm during mixing, they easily agglomerated, as shown in Figure 13. At the same time, during forming and scraping of the specimen, the fibers clumped, and drops often occurred, indicating that it was difficult to stir evenly when the fiber length was longer (Figure 14). Combined with the relationship curves of unconfined compressive strength with fiber content at different fiber lengths and the problems during stirring, the optimal fiber length of 6 mm was selected.

3.2.2. Optimal Fiber Content Determination. For the cast-in-situ foamed concrete with a designed dry density of 300–800 kg/m³ (gradient 125 kg/m³), the fiber content was 0.2–1% (gradient 0.2%). The unconfined compressive strength and elastic modulus were obtained by sorting out the compression test data of the cast-in-situ foamed concrete with glass fibers, which are shown in Tables 4 and 5, respectively.

The compressive strengths were normalized, in which the reference value was the compressive strength of cast-in-situ foamed concrete with a fiber content of 0%. The curves of unconfined compressive strength versus fiber content were analyzed for different design dry densities, as shown in Figure 15. Analysis showed that the compressive strength of foamed concrete first increased and then decreased upon increasing the glass fiber content. When the designed dry densities were 300 kg/m³, 425 kg/m³, 550 kg/m³, 675 kg/m³, and 800 kg/m³, respectively, the maximum unconfined compressive strengths were 0.883 MPa, 1.608 MPa, 3.548 MPa, 5.564 MPa, and 8.109 MPa, respectively, and the corresponding fiber contents were 0.2%, 0.4%, 0.4%, 0.6%, and 0.6% respectively. There is an optimal fiber content for each designed dry density, and the optimal fiber content increased upon increasing the designed dry density.

The flexural strength results were obtained by sorting out the bending test data, which are shown in Table 6. The flexural strength results were normalized, as shown in Figure 16. The results show that the flexural strength increased first and then decreased upon increasing the fiber content.

Compression tests and bending tests were carried out for the foamed concrete with polypropylene, and the data were collated to obtain the unconfined compressive strength, elastic modulus, and flexural strength (Tables 6–8). Results analysis showed that the unconfined compressive strength, elastic modulus, and flexural strength of the foamed concrete mixed with polypropylene fiber had similar trends to the corresponding mechanical parameters of the foamed concrete with glass fiber. Upon increasing the fiber content, they all increased first and then decreased. Compared with the same designed dry density foamed concrete with glass fibers, the polypropylene fiber content increased, but the maximum value of each parameter was lower.

3.2.3. Destruction Mode. As can be seen from Figures 17(a) and 17(b), both specimens with and without fiber exhibited shear failure. For the foamed concrete specimens without fiber, there was block shedding near the fracture surface when it was damaged, while the shear face of the specimen with fiber mainly displayed the shedding of small particles. When the crack expanded, many fibers appeared in the crack, accompanied by fiber pull-out and breaking.

It can be seen from Figures 17(a) and 17(b) that all the foamed concrete specimens with and without fibers showed shear failure. When the foamed concrete specimen was damaged, mass fell off near the rupture surface; however, after the addition of fiber, the main manifestation of the shear face was the shedding of microparticles. When the crack expanded, many fibers could be seen in the crack, accompanied by fiber pull-out and breaking.

Figure 18 shows that the stress-strain curves of foamed concrete with and without fibers immediately dropped to a certain value after the stresses reached the peak values, and the material showed obvious brittleness. When the stress of foamed concrete with fiber fell behind, the stress increased slightly upon increasing the strain due to the effect of the fibers. The foamed concrete with fibers displayed a plastic stage in the stress-strain curve before it reached the stress peak due to fiber pull-out, and tensile breaking occurred between cement hardening products. From the microscopic
analysis, this stage involved the fracture of the hydrate crystal lattice and displayed pseudoplasticity due to the slip of the crystal lattice [23].

![Figure 12: Schematic diagram of fiber distribution in cast-in-situ foamed concrete slurry. (a) Glass fiber. (b) Polypropylene fiber.](image)

![Figure 13: Fiber clusters appearing during stirring.](image)

![Figure 14: Uneven fiber clusters fall when the sample was scraped.](image)

| Fiber content (%) | 300   | 425   | 550   | 675   | 800   |
|-------------------|-------|-------|-------|-------|-------|
| 0                 | 0.654 | 1.138 | 2.339 | 3.913 | 5.357 |
| 0.2               | 0.883 | 1.524 | 3.058 | 4.973 | 6.623 |
| 0.4               | 0.823 | 1.608 | 3.548 | 5.588 | 7.464 |
| 0.6               | 0.770 | 1.510 | 3.277 | 5.364 | 8.109 |
| 0.8               | 0.737 | 1.407 | 3.120 | 5.067 | 7.344 |
| 1                 | 0.696 | 1.275 | 3.022 | 4.743 | 6.993 |

![Table 4: Unconfined compressive strength results of cast-in-situ foamed concrete with glass fiber (unit: MPa).](table)

![Table 5: Elastic modulus results of cast-in-situ foamed concrete with glass fiber (unit: MPa).](table)

![Table 5](table)

| Fiber content (%) | Designed dry density (kg/m³) |
|-------------------|-----------------------------|
| 300               | 55.39 107.43 280.78 468.94 557.05 |
| 425               | 93.74 180.30 351.86 447.55 862.66 |
| 550               | 80.40 174.31 417.88 579.17 890.69 |
| 675               | 58.36 127.57 377.83 578.42 754.09 |
| 800               | 58.75 124.97 367.02 562.48 718.27 |

![Table 5](table)

![Figure 15: The change of unconfined compressive strength with fiber content.](image)

The influence of fiber content on the compressive strength, elastic modulus, and failure mode of foamed concrete was analyzed. When the fiber content was small, they could be evenly distributed in the foamed concrete slurry to form a three-dimensional disordered supporting network structure, which prevented the base material from hardening early to form drying shrinkage cracks. At the same time, the fibers formed a bridge structure
between the hardening products, which increased the adsorption forces between the hardening products of foamed concrete, thus increasing the compressive strength of foamed concrete (Figure 19). When the elastic modulus of the fiber was higher than that of the cement substrate, the deformation of the fiber was less than that of the cement substrate under a vertical load. Before the cement substrate cracked, the fiber restricted the substrate, constrained the lateral deformation of the specimen (tightening action), and improved the elastic modulus. Before the cement substrate cracked, the fiber constrained the lateral deformation of the specimen and improved its elastic modulus. The elastic modulus of the fiber with a low elastic modulus was similar to that of the cement substrate. Under a vertical load, the fiber and cement substrate acted together to reduce the lateral deformation and increase the elastic modulus, but the increase rate was lower than that of the fiber with a high elastic modulus. When the fiber content was high, fiber agglomeration occurred, which produced internal defects in the foamed concrete specimen, leading to a decrease in the compressive strength and elastic modulus of foamed concrete.

Combined with the bending load and displacement curves in Figure 20 and the destroyed flexural test specimen in Figure 21, it can be seen that the load for the foamed concrete specimens without fiber fell rapidly to 0 after reaching the peak value. The failure of the specimen showed that the crack expanded instantly after it was produced, and the specimen was destroyed; however, for foamed concrete specimens with fiber, extended cracks formed, and the stress rapidly dropped to a certain value when the load reached the peak. When the crack expanded, fiber bonding and fiber pull-out and breaking occurred, which can be seen in Figure 22.

Combining with the flexural strength results in Tables 6 and 9, for the foamed concrete with a designed dry density of 300–800 kg/m³, the corresponding optimal glass fiber content range was 0.2–0.6%, and the flexural strength increased by 48.1–85.2% compared with the reference value (fiber content = 0%). The corresponding optimal polypropylene fiber content range was 0.4–0.8%, and the flexural strength was increased by 39.8–55.3%. Combined with the influence of fiber from the load-displacement curves and the failure mode of foamed concrete, it can be seen that the addition of fiber significantly increased the toughness of foamed concrete. When a vertical load acted on the specimen, the fiber and the cement substrate bear the load together. Due to the

| Fiber content (%) | Designed dry density (kg/m³) | Flexural strength/Reference value |
|-------------------|-----------------------------|----------------------------------|
|                   | 300 | 425 | 550 | 675 | 800 |
| 0                 | 0.181| 0.330| 0.660| 1.166| 1.518|
| 0.2               | 0.268| 0.469| 0.922| 1.586| 2.016|
| 0.4               | 0.248| 0.555| 1.222| 2.006| 2.384|
| 0.6               | 0.237| 0.475| 1.164| 1.959| 2.709|
| 0.8               | 0.223| 0.455| 1.135| 1.895| 2.471|
| 1                 | 0.221| 0.416| 1.083| 1.743| 2.401|

**Figure 16:** The change of flexural strength with fiber content.

| Fiber content (%) | Designed dry density (kg/m³) | Flexural strength/Reference value |
|-------------------|-----------------------------|----------------------------------|
|                   | 300 | 425 | 550 | 675 | 800 |
| 0                 | 0.654| 1.138| 2.359| 3.913| 5.357|
| 0.2               | 0.827| 1.393| 2.515| 4.332| 5.839|
| 0.4               | 0.829| 1.457| 2.743| 4.680| 6.503|
| 0.6               | 0.791| 1.426| 3.145| 5.028| 6.750|
| 0.8               | 0.751| 1.371| 2.700| 5.001| 6.782|
| 1                 | 0.675| 1.255| 2.619| 4.246| 5.834|

**Table 7:** Unconfined compressive strength results of polypropylene fiber cast-in-situ foamed concrete (unit: MPa).

| Fiber content (%) | Designed dry density (kg/m³) | Flexural strength/Reference value |
|-------------------|-----------------------------|----------------------------------|
|                   | 300 | 425 | 550 | 675 | 800 |
| 0                 | 55.39| 107.43| 280.78| 468.94| 557.05|
| 0.2               | 72.94| 137.00| 292.47| 524.01| 632.19|
| 0.4               | 72.63| 142.31| 309.79| 550.06| 699.41|
| 0.6               | 71.73| 144.07| 349.35| 561.23| 750.73|
| 0.8               | 52.08| 105.93| 306.24| 560.35| 576.71|
| 1                 | 49.09| 101.77| 275.96| 536.13| 520.67|

**Table 8:** Elastic modulus results of polypropylene fiber cast-in-situ foamed concrete (unit: MPa).
addition of fiber, the load and the corresponding load-displacement increased when the specimen reached the initial crack. Secondly, the elongation of the fiber was greater than that of the cement material. After the specimen was cracked, the fiber bridged the two sides of the crack to prevent the crack from expanding.

Figure 17: The failure mode of the specimen (compression test). (a) Blended with fiber. (b) Without adding fiber.

Figure 18: The stress-strain curves of the test pieces.

Figure 19: The SEM images of foamed concrete structures. (a) Glass fiber. (b) Polypropylene fiber.
Table 9: Flexural strength results of polypropylene fiber cast-in-situ foamed concrete (unit: MPa).

| Fiber content (%) | 300  | 425  | 550  | 675  | 800  |
|-------------------|------|------|------|------|------|
| 0                 | 0.181| 0.330| 0.660| 1.166| 1.518|
| 0.2               | 0.252| 0.450| 0.844| 1.490| 1.899|
| 0.4               | 0.253| 0.490| 0.953| 1.706| 2.174|
| 0.6               | 0.246| 0.488| 1.025| 1.754| 2.272|
| 0.8               | 0.236| 0.460| 0.929| 1.660| 2.275|
| 1                 | 0.234| 0.442| 0.870| 1.604| 2.200|
4. Conclusion

The following conclusions can be drawn based on the experimental and comparative results:

1. The compression curve model of cast-in-situ foamed concrete was divided into three main stages: the elastic stage, the brittle stage, and the yield stage. There are still some problems in the application of direct tensile test and splitting test to foamed concrete materials, and only the bending test was suitable for measuring the tensile strength of foamed concrete materials.

2. For foamed concrete with a designed dry density of 300–800 kg/m³, the compressive strength, elastic modulus, and tensile strength of foamed concrete increased upon increasing the casting density, and the compression failure type changed from shock yield to point yield.

3. Upon increasing the fiber content, the compressive strength, elastic modulus, and flexural strength of foamed concrete first increased and then decreased. The optimal fiber length was 6 mm, the optimal glass fiber content range was 0.2–0.6%, and the optimal polypropylene fiber content range was 0.4–0.8%. The optimal fiber content increased upon increasing the designed dry density.

4. The fibers formed a bridge structure between the hardened products, which increased the adsorption force between the hardened products of foamed concrete, thus increasing the compressive strength and the flexural strength of foamed concrete.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Supplementary Materials

The values of the plots of the graphs shown in Figures 1, 3, 6, 7, 10, 11, 15, 16, 18, and 20 are displayed in tables. (Supplementary Materials)

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