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Experimental Study on Pore Structure and Mechanical Property of Chemical Foaming Foam Concrete

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In this paper, foam concrete (FC) was prepared by chemical foaming method. Besides, the effects of different density grades and fly ash content on the pore structure of FC and the mechanical response of FC under static and dynamic forces were discussed. At the same density grade, the FC strength shows the feature of first increasing and then decreasing with the increase of fly ash production. The pore diameter of FC prepared with protein foaming agent is between 60-800μm, with the uniform pore distribution. The higher the density grade, the smaller the proportion of irregular pores in the FC and the larger the proportion of round pores. When the fly ash content is relatively small, the pore diameter inside the concrete can be significantly reduced, and the pore shape develops more like a circle. When the external dynamic strain rate increases from 10^{-5}/s to 10^{-3}/s, the uniaxial compressive strength of the FC test sample increases by about 14.1%, and the triaxial compressive strength increases by about 61.9%. Therefore, FC exhibits typical ductile failure characteristics under dynamic stress, which can significantly delay the impact of dynamic loads such as earthquakes and explosions. This is of great significance for the engineering application of FC.

1. Introduction

Chemical foaming foam concrete is a new type of building material. It is a kind of chemical concrete made from foaming agents and other raw materials. It has good properties such as heat insulation, sound insulation, and shock absorption. Because of its light weight and good environmental protection, it has been widely promoted around the world now (Zhang et al., 2014; Nambiar and Ramamurthy, 2007; Hilal et al., 2015; Ramamurthy et al., 2009; Zhang et al., 2015; Mikulica and Hã¡Jkovã¡, 2016; Sun and Kim, 2015).

The pore structure of chemical foaming FC has an important influence on its mechanical properties. Researchers have improved the pore structure distribution of FC by adding fly ash, and chemical additives, etc. (Tiwari et al., 2017; Panesar, 2013; Mamun and Bindiganavile, 2010). However, there has been still a lack of systematic and comprehensive research on the density grade of FC and the effect of external additives on the internal pore structure of concrete (Nambiar and Ramamurthy, 2006; Al-Dulaimy, 2012).

In recent years, chemical foaming FC has been mainly used in the fields of building wall construction, roof insulation layer, military engineering, and road engineering etc. (Hajimohammadi et al., 2018; Amran et al., 2015; Xia, 2010). But, there have been relatively fewer literatures on the FC mechanical property under static and dynamic conditions. At present, the theoretical research of high-performance concrete has lagged far behind its engineering application (Just and Middendorf, 2009; Candappa, Sanjayan and Setunge, 2001; Namsone, Šahmenko and Korjakins, 2017).

On the basis of fully understanding the existing literature, this paper studies the pore structure, statics and dynamics characteristics of FC by chemical foaming method. The research results can provide a new idea and theoretical reference for the application of foam concrete.

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2. Test raw materials and test methods

Raw materials: P42.5 portland cement, protein foaming agent, foam stabilizer, polycarboxylate water reducer, distilled water, fly ash, and water-cement ratio 0.33:1.
Test methods and tests: Chemical foaming foam concrete was prepared using the method shown in Figure 1.
Compressive strength: concrete compressive strength tester;
Analysis of pore structure: use the multi-station automatic surface area and pore size test system, with nitrogen as the adsorption quality; analysis range of pore size distribution: 0.4-200nm.

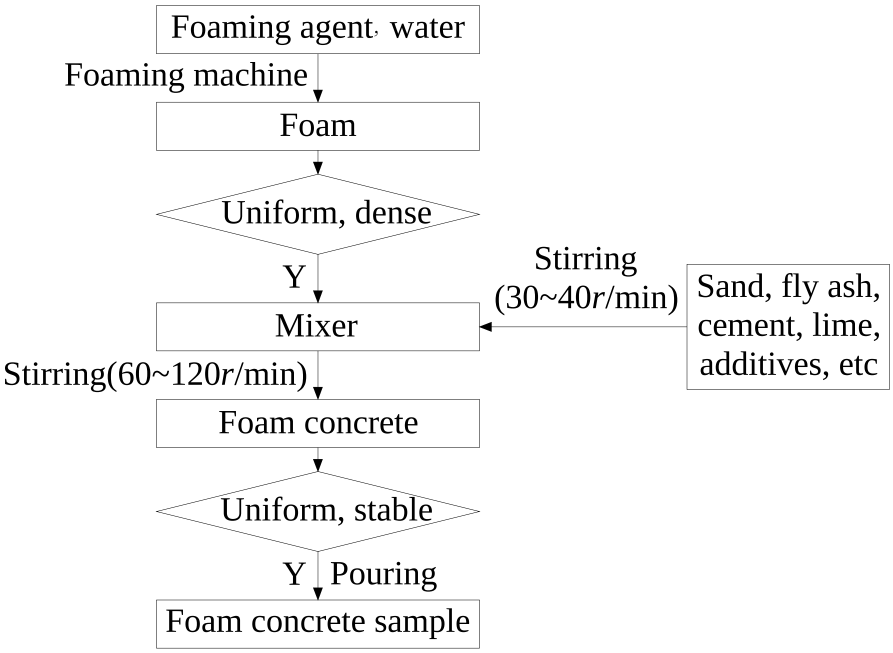


Figure 1: Chemical foaming foam concrete preparation process

3. Test results and analysis

3.1 Pore structure analysis of foam concrete

The water reducing agent was set to be 0.4% of the cement mass. Table 1 lists the the basic physical parameters and compressive strength of the FC mixed with different fly ash.

Table 1: Physical parameters and compressive strength of different types of foam concrete

Specimen No.	Cement/kg	Fly ash/kg	Density level	Compressive strength/MPa
1	380	120	630	5.5
2	845	0		15.8
3	670	182	1000	18.9
4	490	355		20.7
5	355	490		15.6
6	956	228	1400	35.5

It can be seen from the table that at the same density grade, the FC strength appears to increase first and then decrease as the fly ash yield increases. When the fly ash yield is 40%, the compressive strength of concrete reaches a maximum of 21.1 MPa.

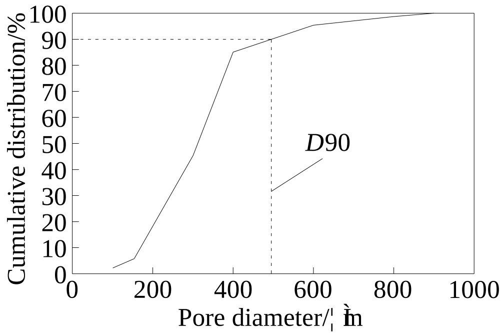


Figure 2: The cumulative pore size distribution of chemical foaming foam concrete

Figure 2 shows the cumulative distribution of FC pore size. It can be seen from the figure that the pore sizes of the FC prepared with the protein foaming agent are all between 60-800 μm, and the proportion of the pores with the pore diameter of 150-400 μm is 80%. As a whole, the pore diameter of the prepared FC is relatively uniform.
Figure 3 shows the pore size distribution of FC at three density grades. It can be seen from the figure that the FC pore diameters at the three density grades are normally distributed. At the concrete density grade of 600, the correlation coefficient of the fitting curve reaches 0.94; when the density grade increases to 1400, the fitting curve decreases to 0.89. When foam is introduced into plain concrete, the foam volume gradually decreases and the volume gradually increases under the effect of defoamer, so that the pore size of the concrete with the higher density grade is obviously larger than that of the concrete with lower density grade.

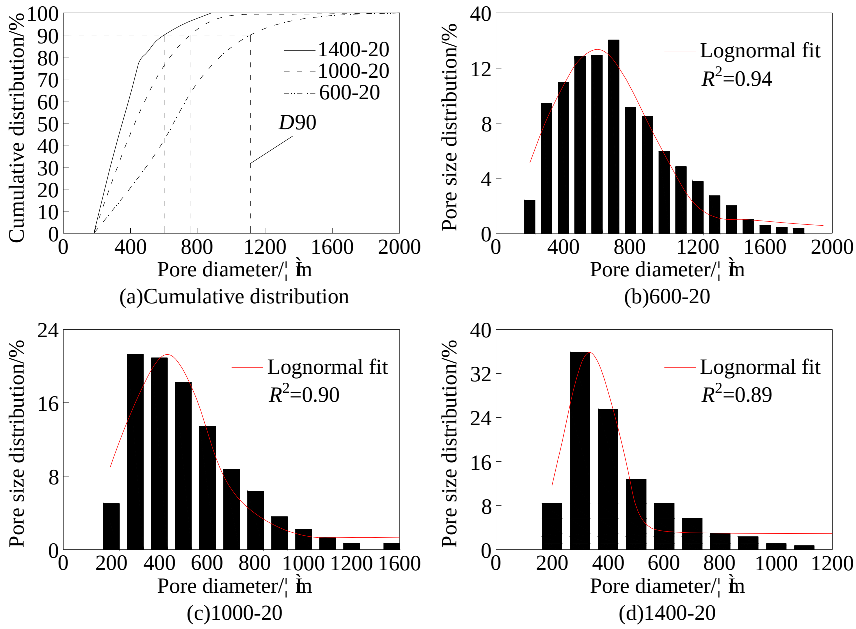
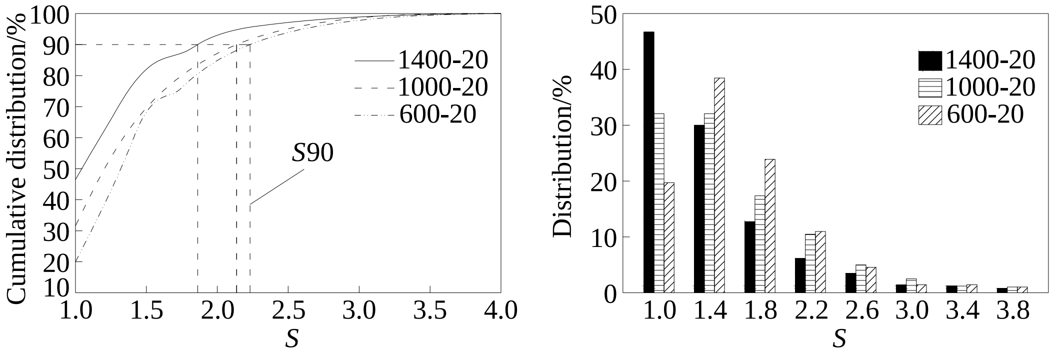


Figure 3: Pore size distribution of chemical foamed Foam concrete with three density grades

The shape factor S of FC pore can be expressed as:

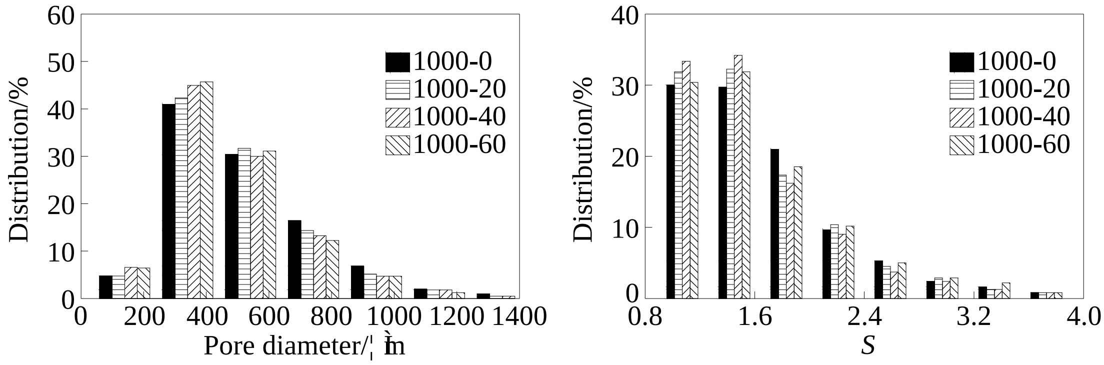
$$S = \frac{P^2}{4\pi A} \tag{1}$$

where, P and A are the perimeter and area of the pore, respectively. The larger the S value, the closer the pore shape is to the ellipse. The distribution of FC shape factors with three density grades is shown in Figure 4. It can be seen from the figure that the S value of the FC with density grade of 600, 1000, and 1400 are 2.21, 2.07, and 1.83, respectively, where the pore shape is cumulatively distributed at 90%. That is, the greater the density grade is, the less the irregular pores in the concrete account for, and the larger the proportion of round pores. This indicates that when the coagulation and the inner foam gradually increase, the mutual elimination of different foams also causes the shape factor of the pores to gradually increase.



(a)Cumulative distribution (b)Distribution

Figure 4: Shape factor for chemical foaming foam concrete at Three Density grades



(a)Pore diameter distribution (b)Shape factor distribution

Figure 5: Effect of fly ash content on the pore size of concrete

Figure 5 depicts the effect of fly ash content on the pore size distribution and pore shape of FC. It can be seen from the figure that when the fly ash content is relatively small, the size and shape of the pores inside the concrete can be significantly reduced, so that the volume of the pores gradually decreases, and the shape of the pores develops more like a circle, because a small amount of fly ash can effectively fill the cracks and pores inside the concrete. However, when the fly ash content is gradually increased, the pore size and shape factor of the pores begin to increase. This may be because excessive fly ash affects the hydration process of the cement, deteriorating the stability of the cement gel.

3.2 Mechanical property of foam concrete under static and dynamic conditions

Fig.6 shows the mechanical property after uniaxial compression. During engineering applications, FC elastic modulus and strength are required to be moderate, for too high elasticity and strength shall result in high brittleness, and too low shall tend to cause large deformations. It can be seen from Figure 6 that the strength and elastic modulus of the foamed concrete prepared in this paper are all lower than those of the common concrete. At the same time, the FC does not undergo obvious brittle failure during the compression process and exhibits excellent ductility.

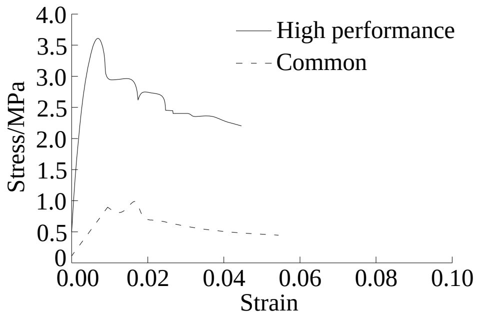


Figure 6: Uniaxial compression mechanical property of foam concrete

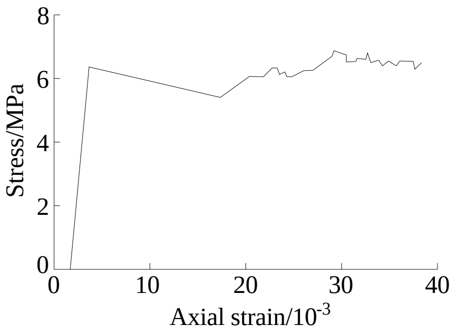


Figure 7: Axial mechanical properties of foamed concrete under hydrostatic pressure

Figure 7 shows the axial mechanical property of foamed concrete under hydrostatic pressure. It can be seen from the figure that in this case the ultimate yield strength of FC is 5.9 MPa, and the stress-strain curve of the material after yielding does not drop rapidly, but keeps vibrating constantly on a high level, indicating that the FC at this time is in a kind of ideal elastoplastic state. Because the FC contains a large number of pores, the concrete volume shrinks significantly under the hydrostatic pressure, but still maintains its integrity during this shrinkage process. It again shows that the FC has strong property of deformation and ductility.

The mechanical properties of the foam concrete prepared under dynamic conditions were further analysed. The test equipment was high-pressure dynamic triaxial apparatus. The dynamic strain rate was 10^{-3}, and the ambient confining pressure of the test sample was set to be 1MPa.

Figure 8 depicts the uniaxial mechanical properties of foam concrete under dynamic conditions and Fig.9 depicts the triaxial mechanical properties of foam concrete under dynamic conditions. From Figs. 8 and 9, it can be seen that the prepared FC does not show obvious failure points under dynamic stress, but exhibits typical ductile failure characteristics, whereas traditional rock and concrete materials will undergo brittle failure under the dynamic stress. Thus, FC can significantly delay the impact of earthquakes, explosions and other dynamic loads, which is of great significance for the application of foam concrete.

Comparing Fig. 6 to Fig. 9, it can be seen that when the external dynamic strain rate increases from 10^{-5}/s (regarded as static effect) to 10^{-3}/s, the uniaxial compressive strength of the FC sample increases by about 14.1%, while the triaxial compressive strength increases by approximately 61.9%.

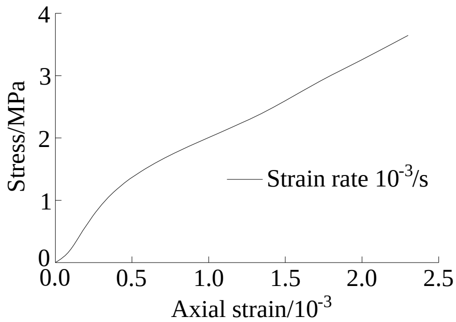


Figure 8: Uniaxial mechanical properties of foam concrete under dynamic conditions

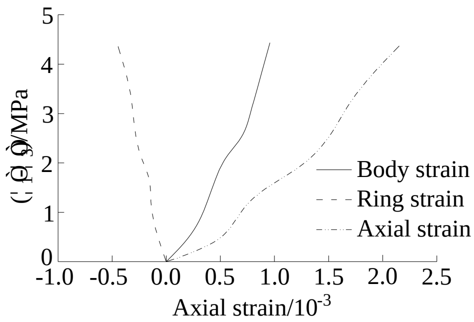


Figure 9: Triaxial mechanical properties of foam concrete under dynamic conditions

4. Conclusions

In this paper, the foam concrete was prepared by the chemical foaming method, and then the effect of different density grades and fly ash content on the foamed concrete pore structure, and the mechanical response of the foamed concrete under static and dynamic forces were discussed. The findings are as follows:

(1) At the same density grade, the FC strength appears to increase first and then decrease as the fly ash production increases. The pore ize of FC prepared with protein foaming agent are all between 60-800 μm, the proportion of the foam with 150-400 μm pore size is 80%, and the pore distribution is more uniform.

(2) The greater the density grade, the smaller proportion the irregular pores in foam concrete and the larger proportion of round pores. When the fly ash content is relatively small, the pore diameter inside the concrete can be significantly reduced, and the pore shape develops more like a circle; however, excessive fly ash affects the hydration process of the cement and deteriorates the stability of cement gel.
(3) When the external dynamic strain rate increases from 10^{-5}/s to 10^{-3}/s, the uniaxial compressive strength of the foam concrete sample increases by about 14.1%, and the triaxial compressive strength increases by about 61.9%. Foam concrete exhibits typical ductile failure characteristics under dynamic stress, which can significantly delay the impact of dynamic loads such as earthquakes and explosions. This is of great significance for the application of foam concrete.

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