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Study on Quasi Static and Dynamic Mechanical Properties of Chemical Foaming Concrete

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Chemical foaming concrete is a kind of new building material. In this paper, the quasi-static conditions of foam concrete and dynamic mechanical properties under impact dynamic conditions are studied. This paper also analyzes in detail the damage mechanism, deformation characteristics and energy absorption characteristics of the foam concrete under compression and stretch conditions. The results indicate that, the lower the density is, the less the cells on the surface and the inside of the concrete material is, and the larger the diameter of the pores is. When the density increases, the number of cells increases as well, and the diameter of the pores decrease gradually. The whole process of uniaxial compression of foam concrete is divided into three stages, that is, the material's elasticity and plasticity stage, platform stage and material densification stage.
In the initial stage of stretch and compression, the stress-strain curve of foam concrete increases linearly basically. In platform stage, the foam concrete is mainly absorbing the energy, and there are both strain-softening and strain-hardening behaviors in this stage at the same time. The greater the density of the concrete, the earlier the densification stage occurs. The research on the impact dynamic properties of foam concrete shows that the dynamic strain rate is obviously positively correlated with the impact velocity, i.e., the greater the impact velocity, the greater the strain rate. The dynamic stress-strain curve of foam concrete is almost the same as that of static curve. It is also divided into three stages: linear elastic stage, material yield stage and material failure stage.

1. Introduction

Chemical foaming concrete is a kind of new building material, it was a chemical concrete made of foaming agent and other raw materials. It has good heat insulation, sound insulation and shock absorption performance (Tiwari et al., 2017; Panesar, 2013; Mamun and Bindiganavile, 2010; Zhang et al., 2014; Krämer et al., 2015). Because of its lightweight and environmental-friendly, it is now being promoted all over the world (Ranjani and Ramamurthy, 2012; Nambiar and Ramamurthy, 2007).
Chemical foaming concrete is mainly used in building wall construction, roof insulation, military engineering, road engineering, etc. (Just and Middendorf, 2009; Nambiar and Ramamurthy, 2007; Hilal et al., 2015). Most existing research papers are focus on the influence of fire resistance, thermal conductivity, thermal insulation, and cell diameter on the properties of concrete. Most research on mechanical properties are focus on static compression (Bing et al., 2012; Jiang et al., 2016). Meanwhile, research on the effect of different densities of foam concrete on its static mechanical properties and dynamic impact dynamic properties is not sufficient (Hilal et al., 2015; Hilal et al., 2016; Sayadi et al., 2016).
Based on the full comprehension of the existing references, this paper studies the quasi-static conditions and dynamic mechanical properties of chemical foaming concrete, analyzes in detail the damage mechanism, deformation characteristics and energy absorption characteristics of the material under compression and stretch. The research conclusion can provide theoretical guidance for the use of foam concrete.

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2. Static mechanical property analysis of foam concrete

2.1 Experimental materials and sample preparation methods

The main raw materials for chemical foaming concrete are foam-water solution, sand, cement, lime and other admixtures. It is a new type of porous concrete material with good heat insulation, sound insulation and shock absorption performance, it has low density, low elastic modulus, and high ductility (Ramamurthy et al., 2009; Al-Dulaimy, 2012; Nambiar and Ramamurthy, 2008). Figure 1 shows the preparation of chemical foaming concrete. Concrete pouring process should be strictly based on the implementation of standards to ensure that the foam is small, the foaming is evenly and not delaminated, otherwise it will compromise the mechanical properties of the foam concrete.

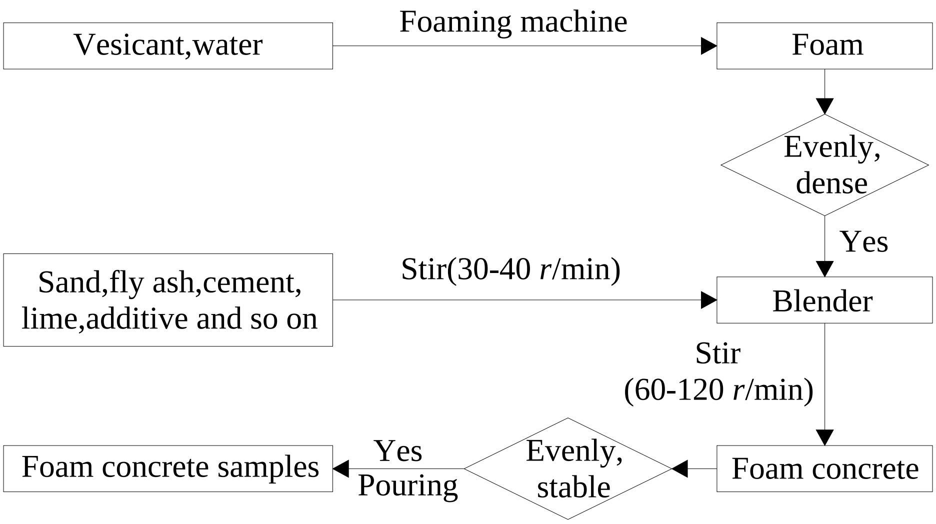

Figure 1: Chemical foaming concrete preparation process

Comparing the mechanical properties of chemical foaming concrete with different densities, concrete specimens with densities of p=360kg/m^3, p=570kg/m^3 and p=820kg/m^3 were fabricated respectively. Figure 2 shows foam concrete specimens with p=360kg/m^3 and p=820kg/m^3. As can be seen from the figure, the lower the density, the less the pores on the surface and the inside of the concrete material, and the larger the diameter of the pores; the larger the density, the more the cells and the smaller the diameter of the pores.

(a) p=360kg/m^3 (b) p=820kg/m^3

Figure 2: Sample structure of foam concrete with different densities

2.2 Comparison and analysis of mechanical properties of chemical foaming concrete with different densities

Figure 3 shows the nominal stress-strain curves of three kinds of foam concrete subjected to tensile stress. Nominal stress-strain refers to the stress and strain that are not taken into account for the geometric discontinuity of the material. It can be seen from the figure that in the initial stage of stretching, the stress-strain curve of three kinds of density concrete basically increases linearly. At this time, the foam concrete is mainly subjected to elastic strain and the tensile load is borne by the cell wall. With the tensile stress increases, oscillation appears on the nominal stress-strain curve. At this time, the concrete performance and internal foam cell wall appear partial failure, and micro-cracks appear on the material. When the tensile stress further increases, the micro-cracks gradually expand into macro-cracks and the concrete appears overall failure, then the stress-strain curve reaches a peak and straight down to 0, by then the material is plastic strain.

Figure 4 shows the nominal stress-strain curves of three kinds of foam concrete subjected to compressive stress. It can be seen from the figure that in the initial stage of material compression, the stress-strain curves of the three kinds of foam concrete show a linear and rapid growth trend, and the stress reaches its peak when the strain rate is still small. At this stage, micro-cracks already appear on the material, stress concentration begins to appear in local areas. When the local stress is greater than the breaking strength of the material, macro-cracks appear in the concrete and lead to brittle fracture. At this moment, the nominal stress-strain curve of the material suddenly drops, and when it drops to a certain extent, the nominal stress-strain curve gradually stabilizes, but doesn't reach 0. It indicates that there is no instantaneous failure when the pressure on the foam concrete exceeds its ultimate compressive strength, and there is still some bearing capacity, it also indicates that the foam concrete material shows good toughness.

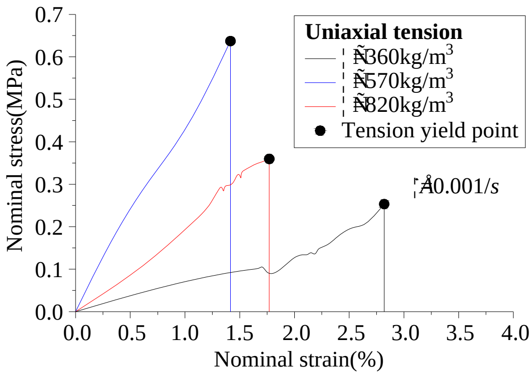

Figure 3: Nominal stress-strain curve of foam concrete with three kinds of densities under stretch

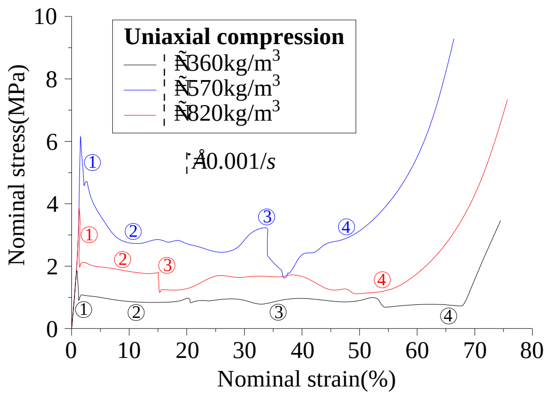

Figure 4: Nominal stress-strain curves of foam concrete with three kinds of densities under compression

Figure 5 shows the stress-strain curve of the whole process of uniaxial compression of chemical foaming concrete of three kinds of densities, the curve is divided into three stages: the elastic and plastic stage (Figure 1), the platform stage (Figure 2 and 3), and the material densification stage (Figure 4). The stress-strain changes in the elastic-plastic stage are the same as those explained above. The stage of the platform is the stage where the main energy is absorbed by the foam concrete. The stress decreases significantly at this stage, and then the stress continuously oscillates at a low level, indicating that there are both strain-softening and strain-hardening behaviors in this stage. At the same time, the appearance of macro-cracks also makes the concrete surface spalling. During the late stage of the platform stage, most of the cells in the concrete are destroyed, the cell walls touch and rub with each other, and the external load is mainly borne by the compressive deformation of the concrete. The stress-strain curve shows a clear rebound, and this is the densification stage of the concrete. The greater the density of the concrete, the earlier the densification stage occurs.

3. Impact dynamic performance analysis of chemical foaming concrete

Further study the impact dynamic properties of the foam concrete, the preparation of foam concrete is the same as previous, density p=260kg/m^3, and use Split Hopkinson Pressure Bar (SHPB) to hit the foam concrete. Because of the relatively low density and wave impedance of the foam concrete, the stress inside the foam concrete is more difficult to maintain during the test. Therefore, improve the SHPB pressure bar, use semi-conductive strain gauge to collect the impinging transmission signals, and pre-process incident waves using waveform shaping technology, the processing results are shown in Figure 6. As can be seen from the figure, after shaping, the rising front of the waveform significantly broadened, rising section is about 140μs, the overall incident wave duration increases from 310μs to 400μs.

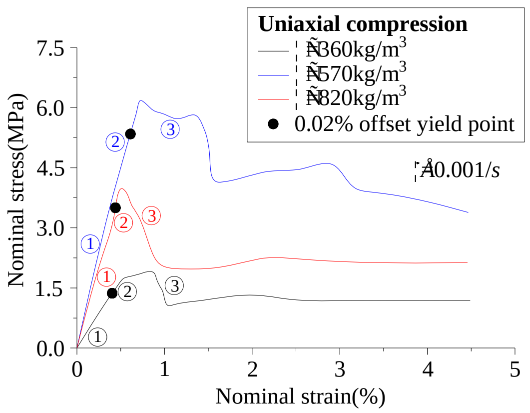

Figure 5: Stress-strain curve of the whole process of uniaxial compression of foam concrete with three kinds of densities

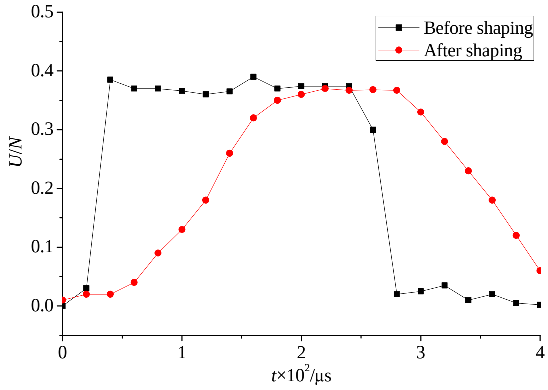

Figure 6: The incident wave contrast curves before and after shaping

Improve the traditional three-wave method to get the following formula:

$$\dot{\varepsilon}_s(t) = C_0 / l_s \left[\varepsilon_i(t) - \varepsilon_r(t) - \varepsilon_t(t) \right] \tag{1}$$

$$\varepsilon_s(t) = \frac{C_0}{l_s} \int_0^t \left[\varepsilon_i(\tau) - \varepsilon_r(\tau) - \varepsilon_t(\tau) \right] d\tau \tag{2}$$

$$\sigma_s(t) = \frac{EA}{A_s} \varepsilon_t(t) \tag{3}$$

Figure 7 shows the dynamic stress-strain curves of foam concrete at different impact velocities. Figure 8 shows the foam concrete strain rate curve. As can be seen from Figure 7, the dynamic strength of foam concrete is quite small, only about 0.4-0.6MPa. As can be seen from Figure 8, the concrete strain rate and impact velocity showed a significant positive correlation, that is, the greater the impact velocity, the greater the strain rate.

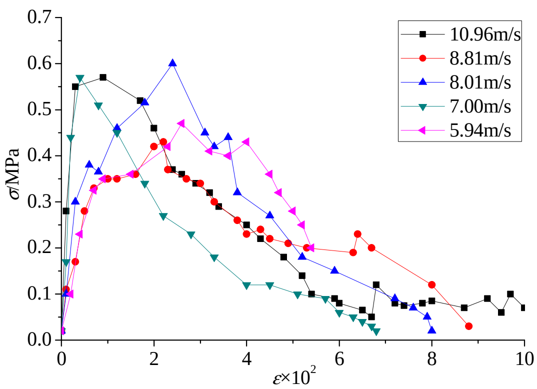

Figure 7: Dynamic stress-strain curves of foam concrete at different impact velocities

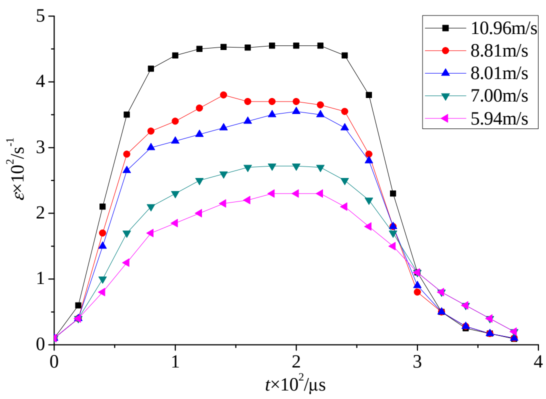

Figure 8: Strain rate curves of foam concrete at different impact velocities

The dynamic stress-strain curve of foam concrete is generally the same as the static curve, and is also divided into linear elastic stage, material yield stage and material failure stage. In the elastic stage, the material itself has the bearing capacity, the material in the yield stage is damaged to some extent, but there is still some bearing capacity, and the material will no longer bear the load when the final foam concrete is damaged.
Fitting the impact velocity and specimen evaluation strain rate, the fitting curve is shown in Figure 9.
As can be seen from the figure, the two are basically linear.

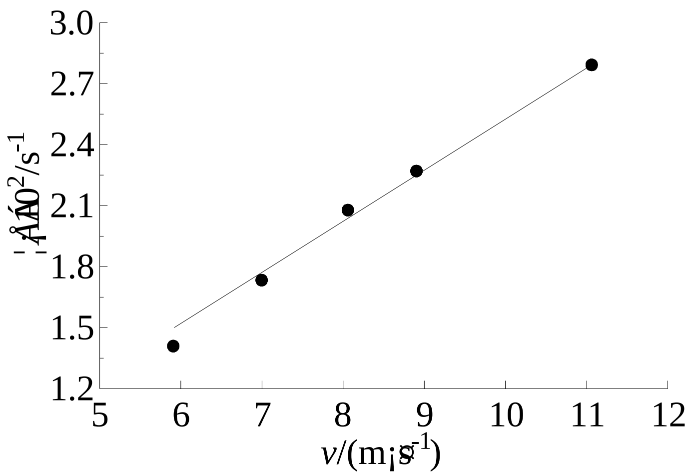

Figure 9: Foam concrete average strain rate - fitting curve of the impact velocity

4. Conclusion

Chemical foaming concrete is a new type of building material. In this paper, the quasi-static conditions of foam concrete and dynamic mechanical properties under impact dynamic conditions are studied. The damage mechanism, deformation characteristics and energy absorption characteristics of the foam concrete under compression and stretch conditions are analyzed in detail. The conclusions are as follows:
(1) The lower the density, the less the pores on the surface and the interior of the concrete material, the larger the pore diameter is; as the density increases, the number of cells increases and the pore diameter decreases. The whole process of uniaxial compression of foam concrete is divided into three stages, namely the material's elastic and plastic stage, the platform stage, and the material densification stage. In the initial stage of stretch and compression, the stress-strain curve of foam concrete increases linearly basically. The stage of the platform is the stage where the main energy is absorbed by the foam concrete. At this stage, there are both strain-softening and strain-hardening behaviors. The greater the density of the concrete, the earlier the densification stage occurs.
(2) The impact dynamic performance analysis of chemical foaming concrete shows that there is a clear positive correlation between the dynamic strain rate and the impact velocity, that is, the greater the impact velocity, the greater the strain rate. The dynamic stress-strain curve of foam concrete is almost the same as the static curve, and is also divided into linear elastic stage, material yield stage and material failure stage.

Reference

Al-Dulaimy A.A., 2012, The use of additives to enhance properties of pre-formed foamed concrete, 7(4), 286-293. DOI: 10.7763/ijet.2015.v7.806

Bing C., Zhen W., Ning L., 2012, Experimental research on properties of high-strength foamed concrete, Journal of Materials in Civil Engineering, 24(1), 113-118, DOI: 10.1061/(asce)mt.1943-5533.0000353

Hilal A.A., Thom N.H., Dawson A.R., 2015, On entrained pore size distribution of foamed concrete, Construction & Building Materials, 75, 227-233, DOI: 10.1016/j.conbuildmat.2014.09.117

Hilal A.A., Thom N.H., Dawson A.R., 2015, On void structure and strength of foamed concrete made without/with additives, Construction & Building Materials, 85, 157-164, DOI: 10.1016/j.conbuildmat.2015.03.093

Hilal A.A., Thom N.H., Dawson A.R., 2016, Failure mechanism of foamed concrete made with/without additives and lightweight aggregate, Journal of Advanced Concrete Technology, 14(9), 511-520， DOI: 10.3151/jact.14.511

Jiang J., Lu Z., Niu Y., Li J., Zhang Y., (2016), Study on the preparation and properties of high-porosity foamed concretes based on ordinary portland cement, Materials & Design, 92, 949-959, DOI: 10.1016/j.matdes.2015.12.068

Just A., Middendorf B., 2009, Microstructure of high-strength foam concrete. Materials Characterization, 60(7), 741-74811, DOI: 10.1016/j.matchar.2008.12.011

Krämer C., Schauerte M., Kowald T.L., Trettin R.H.F., 2015, Three-phase-foams for foam concrete application, Materials Characterization, 102, 173-179, DOI: 10.1016/j.matchar.2015.03.004

Mamun M., Bindiganavile V., 2010, Drop-weight impact response of fibre reinforced cement based foams, International Journal of Protective Structures, 1(3), 409-424, DOI: 10.1260/2041-4196.1.3.409

Nambiar E.K.K., Ramamurthy k., 2007, Air‐void characterisation of foam concrete, Cement & Concrete Research, 37(2), 221-230, DOI: 10.1016/j.cemconres.2006.10.009

Nambiar E.K.K., Ramamurthy K., 2007, Sorption characteristics of foam concrete, Cement & Concrete Research, 37(9), 1341-1347, DOI: 10.1016/j.cemconres.2007.05.010

Nambiar E.K.K., Ramamurthy K., 2008, Models for strength prediction of foam concrete, Materials & Structures, 41(2), 247-254, DOI: 10.1617/s11527-007-9234-0

Panesar D.K., 2013, Cellular concrete properties and the effect of synthetic and protein foaming agents, Construction & Building Materials, 44(7), 575-584, DOI: 10.1016/j.conbuildmat.2013.03.024

Ramamurthy K., Nambiar E.K.K., Ranjani G.I.S., 2009, A classification of studies on properties of foam concrete, Cement & Concrete Composites, 31(6), 388-396, DOI: 10.1016/j.cemconcomp.2009.04.006

Ranjani G.I.S., Ramamurthy K., 2012, Behaviour of foam concrete under sulphate environments, Cement & Concrete Composites, 34(7), 825-834, DOI: 10.1016/j.cemconcomp.2012.03.007

Sayadi A.A., Tapia J. V., Neitzert T.R., Clifton G.C., 2016, Effects of expanded polystyrene (eps) particles on fire resistance, thermal conductivity and compressive strength of foamed concrete, Construction & Building Materials, 112, 716-724, DOI: 10.1016/j.conbuildmat.2016.02.218

Tiwari B., Ajmera B., Maw R., Cole R., Villegas D., Palmerson P., 2017, Mechanical properties of lightweight cellular concrete for geotechnical applications, Journal of Materials in Civil Engineering, 29(7), 06017007. DOI: 10.1061/(asce)mt.1943-5533.0001885

Zhang Z., Provis J.L., Reid A., Wang H., 2014, Geopolymer foam concrete: an emerging material for sustainable construction, Construction & Building Materials, 56(3), 113-127, DOI: 10.1016/j.conbuildmat.2014.01.081