PREPARATION OF HIGH-EFFICIENCY FOAMING AGENT AND ITS APPLICATION IN FOAMED CONCRETE

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Abstract. In this paper, the foaming properties of a foaming agent were studied. The foaming agent was prepared with rosin as the basic material. The effects of alkali addition, reaction temperature and reaction time on the foaming properties of foaming agent were studied. By adding sodium dodecyl benzene sulfonate and gelatine, the performance of the foaming agent was improved. The foaming ratio and bleeding rate were investigated. The foamed concrete was prepared using the high-efficiency foaming agent. When water to cement ratio (w/c) is 0.42-0.46, the dry density and compressive strength are 400-500 $kg \cdot m^{-3}$ and 1.25-1.5 MPa, respectively.

Keywords: foamed concrete; density; compressive strength; foaming agent.

Introduction

With the development of economy and society, the energy problem has increasingly become a constraint to economic development. Excessive energy consumption has brought considerable pressure on resources and the environment [1-3]. Therefore, the development of lightweight energy-saving building materials is of great significance for reducing the energy consumption.

When foam is added to the cement paste through mixing, the bubbles become pores hardening of the cement paste, so foamed concrete has porous characteristics. The foam is made of a foaming agent and water through high-speed mixing, and the pore wall forming strength is formed by hydration of cement paste [4-6].

The density of foamed concrete is generally 300-1200 $kg \cdot m^{-3}$, which can be used as filling, partition, ceiling, floor and other non-structural components, and has a broad application prospect. When the density of foamed concrete is lower, the proportion of its reduced dead weight is larger, and the thermal insulation properties are better. When the density and strength are appropriate, it can even replace the organic insulation material as the wall insulation layer, solving the problems that the organic thermal insulation material cannot solve. Therefore, the research on lightweight foamed concrete has gradually become a research hotspot. Light foamed concrete has gradually become the focus of research due to its low density, low water absorption, good thermal insulation performance and other advantages. But at the same time, when the density drops to 300 $kg \cdot m^{-3}$, the porosity will reach more than 85%, making the strength of foamed concrete generally about 0.02 MPa [7-9]. Therefore, strengthening foamed concrete at low density has become a key technical bottleneck that restricts the application of foamed concrete in wall materials. For example, foamed concrete is easy to be damaged due to low strength during transportation and stacking.

After the addition of air entraining agent, a large number of bubbles are generated. When the dosage is small, the distance between the bubbles is appropriate. As the dosage increases, some bubbles begin to merge, and adjacent bubbles tend to aggregate into large bubbles and produce large pores with uniform pore sizes [10].

Because of the large porosity of foamed concrete, its pore structure has a greater impact on strength and other properties. Therefore, the amount of the foaming agent has a decisive impact on the performance of foamed concrete. In addition, the properties of cement paste have a great impact on the performance of foamed concrete. If the water cement ratio is too small, the cement paste will be too thick, which will cause foam to burst when mixing with cement paste, increasing the density. If the water cement ratio is too large, and the cement paste is too thin, the foam will not be stable enough to exist, which will also cause the foam to burst, which will also increase the density.

Foaming agent for foamed concrete is an additive, which can reduce the surface tension of the liquid after being dissolved in water and produce a large number of uniform and stable foams through physical methods. The foam stability of the foaming agent plays a major role for preparing foamed concrete. The foamed concrete prepared with better stability has better performances. Foaming agents can be divided into a liquid foaming agent and a powder foaming agent in terms of the material form [11]. The performance of different foaming agents is different, and the stability of foam prepared is also different, which affects the basic performance of foamed concrete.

Materials and methods

Raw materials

The foaming agent is a surfactant substance formed by the reaction of rosin and alkali. The main component of rosin is resin acid, accounting for about 90%. The molecular formula is $C_{19}H_{29}COOH$, and the molecular weight is 302.46. Rosin is a light yellow or brown transparent glassy brittle substance with a special smell. Analytical pure sodium hydroxide is used as base, and gelatine and sodium dodecyl benzene sulfonate are used as modifiers. The content of protein in gelatine accounts for 82%, which can be decomposed to form a surfactant under alkaline conditions. Sodium dodecyl benzene sulfonate is the analytical reagent.

The main raw material for preparing foamed concrete is P▪O 42.5 cement and fly ash. The solid content of polycarboxylate superplasticizer as additive is 10%.

Sample preparation

Powdered NaOH was added into a three necked flask with dehydrator, thermometer and agitator, the temperature was raised to 80-100 ºC, then rosin was added into the reactor in batches, and the foaming agent was obtained after the reactants were filtered.

Cement, fly ash and water were mixed in a fixed proportion at a rate of 120 rpm for 2 min slowly and then for 2 min quickly. The foam was prepared while mixing the cement slurry. The foaming agent and water were mixed at a fixed ratio at a high speed of 800 rpm to obtain the foam. The foam was weighed and mixed with the cement slurry. The cement slurry and foam were slowly mixed at a rate of 120 rpm, and the foamed concrete can be obtained by standing and molding.

Test methods

According to the Chinese industrial standard JC/T 2199-2013 (Foaming Agent for Foamed Concrete) the foam expansion ratio and 1h bleeding rate were determined. The measured samples were dried at 105 ºC to a constant weight. The compressive strength and dry density data were collected in three samples. The size of the formed specimen is 100 mm × 100 mm × 100 mm. The reported data are the averages of all corresponding measurements.

Results and discussion

Orthogonal test of the foaming agent

Factors and levels of orthogonal tests are shown in Table 1. The orthogonal results of 9 foaming agents are shown in Table 2. The analysis of orthogonal test results of foam volume and foam stability shows that the optimization conditions for foaming ability are A2B2C2, and the optimization conditions for foam stability are A2B1C2. It can be seen from the analysis of the results of the above orthogonal test that the best scheme of the two is not consistent, but the influence of the amount of alkali added and the heating time of the two is more consistent, that is, the best rosin: NaOH = 6:1, the heating time 2.5 hours. B2 is selected as the optimal reaction time, i.e. 85 ºC.

Table 1

Factor and level of orthogonal test

Level	Factor		
	Rosin: NaOH	**Temperature, ºC**	**Time, h**
1	5:1	75	1.5
2	6:1	85	2.5
3	7:1	95	3.5

Table 2

Orthogonal test results

Orthogonal Test				Results	
No.	**Rosin: NaOH**	**Temperature, °C**	**Time, h**	**Foam expansion ratio**	**Defoaming time, min**
1	1	1	1	19.71	70
2	1	2	2	20.64	92
3	1	3	3	20.3	70
4	2	1	3	24.23	87
5	2	2	1	22.54	80
6	2	3	2	20.45	100
7	3	1	2	21.53	130
8	3	2	3	22.45	120
9	3	3	1	20.91	110
k1	k1A = 20.2	k1B = 21.8	k1C = 20.8	Analysis and optimization of foam expansion ratio	
k2	k2A = 22.4	k2B = 21.8	k2C = 21.9		
k3	k3A = 21.6	k3B = 20.5	k3C = 21.4		
Optimality	A2	B2	C2		
k1	k1A = 95.6	k1B = 96.6	k1C = 86.6	Analysis and optimization of defoaming time	
k2	k2A = 97.3	k2B = 96.3	k2C = 107.3		
k3	k3A = 93.3	k3B = 93.3	k3C = 20.6		
Optimality	A2	B1	C2		

Modification test of the foaming agent

1. Effects of gelatine on properties of the foaming agent

The amount of gelatine is 0%, 5%, 10% of the rosin mass. It can be seen from Fig. 1 that when the amount of gelatine added reaches 10%, the foaming multiple increases significantly, 53.4% higher than that of the control group. After adding 10% gelatine, the bleeding rate of foaming agent was significantly reduced, which was 30.4% lower than that of the control group in 20 min. The above results show that gelatine can significantly improve the foaming performance and foam stability.

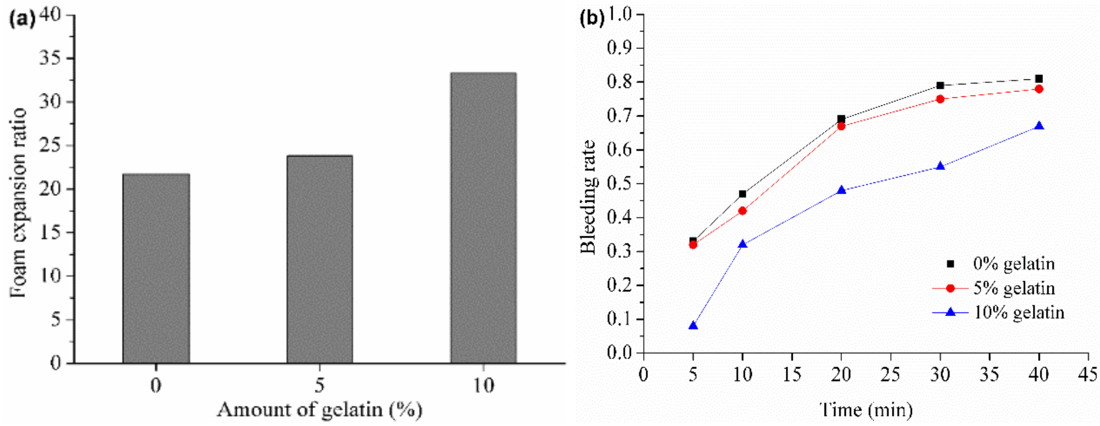


Fig. 1. **Effect of gelatine on the properties of the foaming agent**

2. Effects of sodium dodecyl benzene sulfonate on properties of the foaming agent

It can be seen from Fig. 2 that the addition of sodium dodecyl benzene sulfonate enhances the foaming ability. When the amount of sodium dodecyl benzene sulfonate is between 0 and 1.5%, the foaming ratio increases with the increasing amount of sodium dodecyl benzene sulfonate, and the foaming ratio at the amount of 1.5% is more than 30% higher than that without the addition, indicating that sodium dodecyl benzene sulfonate can effectively improve the foaming ability, as sodium dodecyl benzene sulfonate is a surfactant with the function of air entrainment. However, when the content of sodium dodecyl benzene sulfonate is more than 1.5%, the foaming ratio will decrease. It is mainly because the liquid density in the foam increases with the increasing content, so the gravity effect is obvious, and the liquid film gradually becomes thin, which will lead to the foam rupture when it is thin to a certain extent [4].

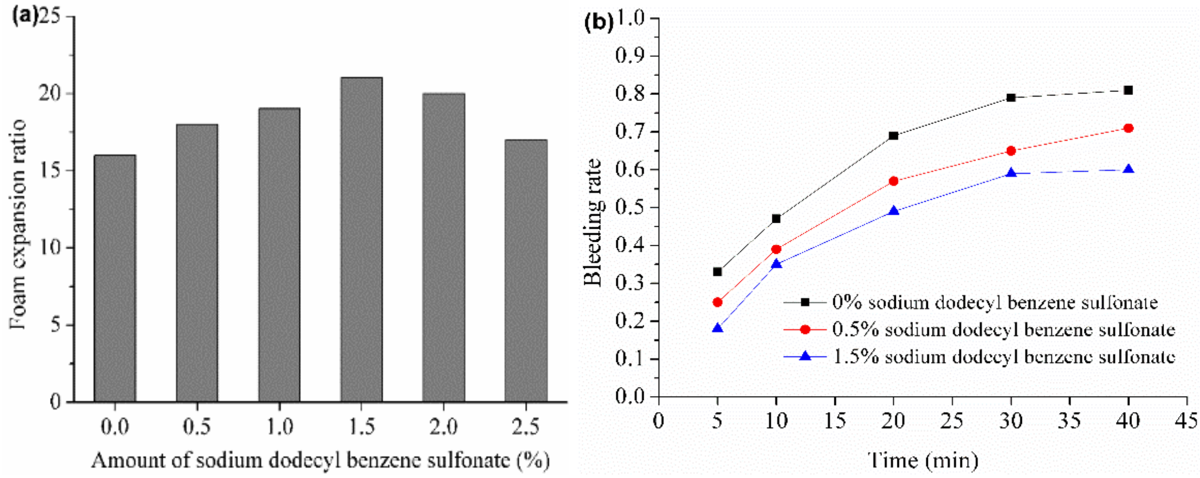


Fig. 2. **Effect of sodium dodecyl benzene sulfonate on the properties of the foaming agent**

Effects of foam content on properties of foamed concrete

The weight of cement, fly ash and water is 500 g, 1000 g and 270 g for each sample, and the amount of foam is changed from 1000 mL to 1400 mL. It can be seen from Fig. 3 that the greater the foam content, the smaller the dry density of the test. The number of pores in concrete is proportional to the foam content, so the larger the foam content, the lower the density. In addition, the compressive strength decreases with the increase of the foam content, which is consistent with the change of density.

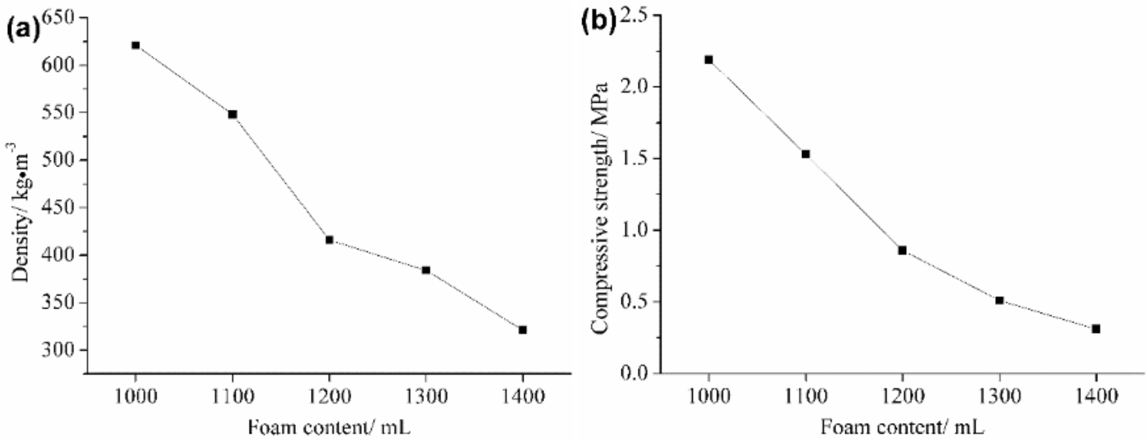
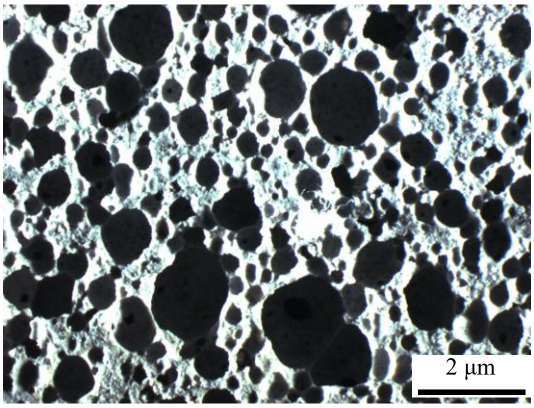
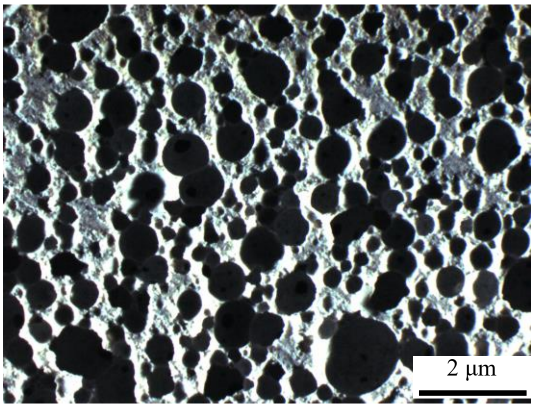


Fig. 3. **Effects of foam content on the properties of foamed concrete**

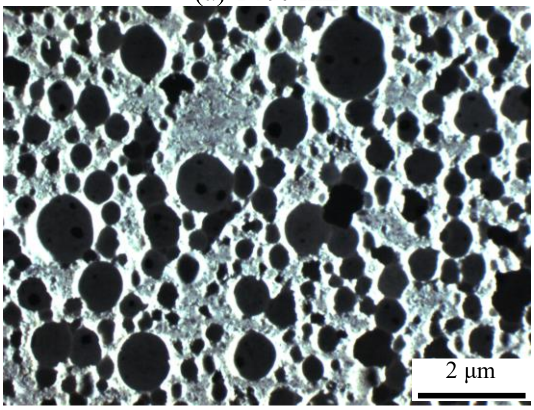
Fig. 4 shows that with the increase of the foam content, the porosity and average pore diameter increase significantly. It can be seen that the content of foam is the most important factor to control the pore structure. With the increase of the foam content, the pore size increases continuously, and the pores tend to overlap, individual large pores appear, and the uniformity of pore size distribution decreases. When the amount of foam is small, the distance between foam is appropriate. With the increase of the amount of foam, some of the pore distribution areas begin to overlap, and adjacent pores are easy to converge into large pores. In this case, pores can be merged evenly and produce large pores with uniform pore size. With the increase of the dosage, the overlapping degree of the pore increases, and some larger pores appear.



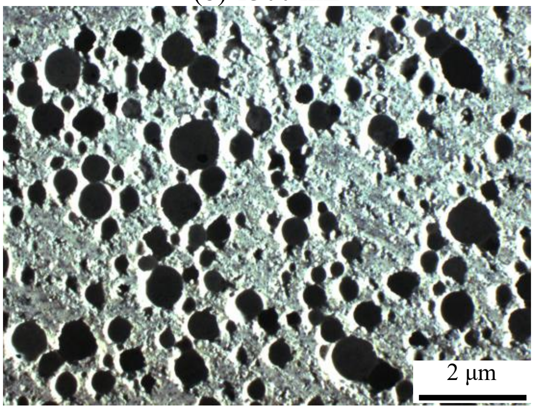
(a) 1400 mL



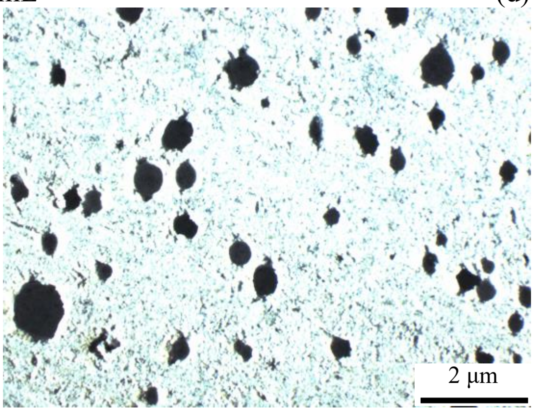
(b) 1300 mL



(c) 1200 mL



(d) 1100 mL



(e) 1000 mL

Fig. 4. **Effects of water consumption (w/c) on the properties of foamed concrete**

Effects of water consumption on properties of foamed concrete

The weight of cement and fly ash is 500 g and 1000 g, and the amount of foam is 1200 mL for each sample, the weight of water is changed from 240 g to 300 g. Water consumption is the ratio of water to fly ash and cement mass (w/c).

It can be seen from Fig. 5 that the dry density and compressive strength are related to w/c. When w/c fluctuates in the range of 0.4-0.46, the dry density decreases with the increase of w/c, but the compressive strength shows an increasing trend.

When w/c changes between 0.46 and 0.5, the dry density continues to decrease, and the compressive strength also decreases. On the one hand, the resistance of the bubbles is small, and the bubbles are easier to float. Small bubbles merge into large bubbles, resulting in a large pore. On the other hand, too large w/c is not conducive to the thickening and hardening of the slurry, resulting in poor uniformity and large strength loss of the specimen. In conclusion, the optimal range of w/c in the test is 0.42-0.46. When the w/c is adopted, the foamed concrete prepared has not only low dry density, but also relatively high strength value. Thus, w/c mainly affects the rheological and thickening properties of slurry. If w/c is too small and slurry is too thick, the shear stress will inevitably be too high, making it difficult for bubbles to grow and push the slurry to expand, hindering the gas generation process, resulting in fewer pores and smaller pore sizes. When w/c is too high, the shear stress and viscosity of the slurry are relatively small, and bubbles are prone to float and merge into large bubbles, resulting in an increase in the average pore size [12].

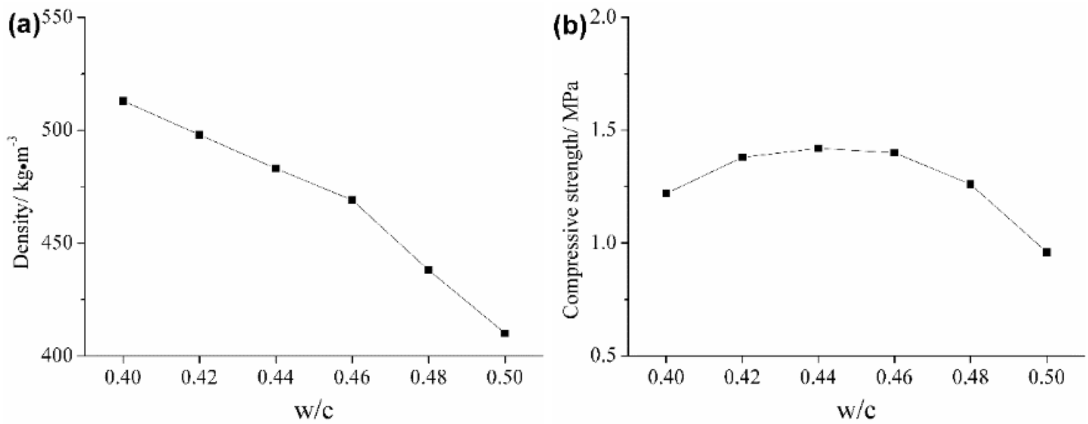


Fig. 5. **Effects of water consumption (w/c) on the properties of foamed concrete**

Conclusions

The foaming ability of a single rosin foaming agent is relatively poor, and the foam is extremely unstable; the foaming performance is affected by the reaction time, reaction temperature and alkali addition. Through a group of orthogonal experiments, the optimum reaction time was 2.5 hours, reaction temperature was 80 ℃, and the amount of alkali was 0.2. Adding 1.5% sodium dodecyl basic sulfonate can enhance the stability of the foam. When gelatine is added, the foaming agent prepared has good performance. When w/c is 0.42-0.46, the foamed concrete prepared with the prepared foaming agent has not only low dry density, but also a relatively high strength value. The dry density and compressive strength of foamed concrete are 410-515 kg·m^{-3} and 0.95-1.35 MPa, respectively.

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Author contributions

Conceptualization and writing, Xiaoling Qu; funding acquisition, Zhiguang Zhao; writing – review and editing, Chaocheng Yu; data curation, Sanyin Zhao. All authors have read and agreed to the published version of the manuscript.

References

[1] Amran Y.H.M., Farzadnia N., Ali A.A.A., Properties and applications of foamed concrete; a review, Constr. Build. Mater., 101, 2015, pp. 990-1005.

[2] Kearsley E.P., Wainwright P.J. The effect of high fly ash content on the compressive strength of foamed concrete, Cem. Concr. Res., 31 (1), 2001, pp. 105-112.

[3] Ranjani I.S., Ramamurthy K. Relative assessment of density and stability of foam produced with four synthetic surfactants, Mater. Struct. Constr., 43, 2010, pp. 1317-1325.

[4] Siva M., Ramamurthy K., Dhamodharan R. Development of a green foaming agent and its performance evaluation, Cem. Concr. Compos., 80, 2017, pp. 245-257.

[5] Ngo H.T., Mendis P. Enhancing the strength of pre-made foams for foam concrete applications, Cem. Concr. Compos., 1 (87), 2018, pp. 164-171.

[6] Jones M.R., Ozlutas K., Zheng L. Stability and instability of foamed concrete, Mag. Concr. Res., 68, 2016, pp. 542-549.
[7] Cong M., Bing C. Properties of a foamed concrete with soil as filler, Constr. Build. Mater., 76, 2015, pp. 61-69.
[8] Ma C., Chen B. Properties of foamed concrete containing water repellents, Constr. Build. Mater., 123, 2016, pp. 106-114.
[9] Kearsley E., Wainwright P. Porosity and permeability of foamed concrete, Cem. Concr. Res., 31, 2001, pp. 805-812.
[10] Tran N.P., Nguyen T.N., Ngo T.D. et al., Strategic progress in foam stabilisation towards high-performance foam concrete for building sustainability: A state-of-the-art review, J. Clean. Prod., 375, 2022, 133939.
[11] Namsone E., Šahmenko G., Korjakins A. Durability properties of high performance foamed concrete, Proc. Eng., 172, 2017, pp. 760-767.
[12] Xiao M.,.Li F.X, Yang P. F. et al., Influence of slurry characteristics on the bubble stability in foamed concrete, J, Build, Eng., 71, 2023, 106500.