

## A STUDY ON THE EFFECT OF TWO DIFFERENT FOAMING AGENTS ON FOAM CONCRETE PROPERTIES

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### ABSTRACT

Nowadays, foam concrete is widely used in construction. However, the structure and properties of foam concrete with a density  $< 1200 \text{ kg/m}^3$  are greatly affected by different foaming agents. In this study, the effects of Foaming agent 1 and 2 on the properties of foam concrete are presented such as compressive strength, flexural strength, shrinkage, water absorption, thermal insulation and microstructure. Research results show that Foaming agent 1 has better stability and durability than Foaming agent 2; compressive strength of foam concrete using Foaming agent 1 is higher from  $0.7 \div 1.1 \text{ MPa}$  and water absorption is lower than foam concrete using Foaming agent 2 from  $2.1 \div 6\%$ . In addition, the pore structure of the foam concrete was tested by electron microscopy (SEM). Foamed concrete using Foaming agent 1 showed a narrower pore size distribution in concrete than using Foaming agent 2. It can be proved that using Foaming agent 1 to produce foam concrete brings many practical meanings in the construction in Vietnam.

### KEYWORDS

Foaming, Foam concrete, Foam stabilization, Mechanical properties, Pore structure

### INTRODUCTION

In modern constructions, lightweight concrete with high thermal insulation is commonly used. Foamed concrete is lightweight concrete in which air voids are created by adding foam in a cement paste solution [1-3].

Foam concrete has excellent properties such as low heat conductivity, strong sound insulation, and low density (from  $320 \text{ kg/m}^3$  to  $1920 \text{ kg/m}^3$ ), which helps reduce the structure's self-weight. [1, 4]. Foam concrete widely used in insulating structures such as walls, roofs, etc. On the other hand, foam concrete has some disadvantages, such as low strength, strong dry shrinkage and water absorption, limiting its use in projects with high strength requirements [5, 6].

The properties of foam concrete vary depending on the foaming agent used, as each agent provides a different level of foam stability. Foam stability prevents the foam concrete mix from shrinking [7].

Currently, there have been many research works on foaming agents and foam concrete published. The compressive strength of foam concrete with a dry density of less than  $1200 \text{ kg/m}^3$  is strongly affected by the type of foaming agent, according to Falliano D. et al. [8]. This type of substance also causes a change in the compressive strength, heat resistance and heat absorption coefficient of foam concrete [9]. According to a study [10], foam stability improved when silica nanoparticles were added to the foaming agent. Ameer A et al. [11] have shown that foam concrete's pore structure can be greatly affected by foam performance

In the field of construction materials science, the investigation into the characteristics and performance of foam concrete has garnered significant attention. A pivotal study conducted by Kearsley E et al. [12] has established a critical relationship between the pore structure of foam concrete and several of its key properties, including dry shrinkage, water absorption rates, and mechanical strength. This study underscores the importance of understanding the microstructural aspects of foam concrete to optimize its performance for various applications.

Expanding upon this foundation, research conducted by Ailar H et al. [13] further delves into the influence of pore size distribution within foam concrete on its overall performance metrics. Their findings reveal that specimens characterized by a highly uniform pore distribution exhibit markedly enhanced strength characteristics. This observation points towards the critical role that the internal pore structure plays in defining the mechanical resilience of foam concrete, suggesting that a targeted manipulation of pore distribution could be a viable strategy for material optimization.

A significant factor influencing the pore structure within foam concrete is the type of foaming agent used in its production. The foaming agent is responsible for the creation of voids within the concrete matrix, thereby defining the eventual pore structure and distribution. It follows that the selection of the foaming agent can have profound implications on the uniformity of pore distribution, which, in turn, affects the concrete's strength and other performance characteristics. Despite the apparent importance of foaming agents in determining the quality of foam concrete, there exists a notable gap in the literature concerning the comparative analysis of different types of foaming agents and their respective impacts on the performance of foam concrete.

Given this context, it becomes apparent that further research is required to systematically explore the effects of various foaming agents on the microstructural and performance attributes of foam concrete. Such studies would not only contribute to a deeper understanding of the material science underlying foam concrete but also pave the way for the development of more effective and durable construction materials. By elucidating the relationship between foaming agents, pore structure, and concrete performance, researchers can unlock new potential in the optimization of foam concrete for a wide range of structural and non-structural applications.

In the present study, an in-depth examination of foam concrete characterized by varying wet densities of  $700$ ,  $900$ , and  $1100 \text{ kg/m}^3$  is undertaken. The investigation focuses on the comparative analysis of two distinct types of foaming agents: Foaming agent 1 and 2, which are hypothesized to significantly influence the foam concrete's overall quality and performance, particularly given its low-density composition. The structural characteristics of these foaming agents were meticulously analyzed using Fourier Transform Infrared Spectroscopy (FTIR), aiming to elucidate their impact on the stability and strength of the produced foam. This research extends its scope to assess critical properties of foam concrete such as water absorption capacity, compressive strength, and the extent of dry shrinkage, which are pivotal in determining the material's suitability for construction applications. Furthermore, the study employs Scanning Electron Microscopy (SEM) techniques to scrutinize the pore structure within the foam concrete. This detailed analysis is intended to shed light on how variations in the pore structure, attributed to the differing properties of the utilized foaming agents, contribute to the observed disparities in the performance of foam concrete. Through this comprehensive approach, the research aims to provide valuable insights into the optimization of foam concrete formulations for enhanced performance in construction contexts.

**MATERIALS AND METHODS**

**Materials**

But Son Cemnet PC40 (C) in accordance with TCVN 2682-2019,  $\rho = 3.10 \text{ g/m}^3$ . The chemical composition of cement is presented in Table 1.

River sand Da Bac (SA) was used as fine aggregate with fineness modulus  $M_k = 3.1$ ,  $\rho = 2.65 \text{ g/m}^3$ , relative density =  $1620 \text{ kg/m}^3$  and bulk density =  $1450 \text{ kg/m}^3$ .

Silica fume SF90, from Vietnam, has a density of  $2.15 \text{ g/m}^3$ . Figure 1 illustrates the particle size distribution of Silica fume and cement.

Tab. 1 - Chemical composition of Portland cement and silica fume

Materials	Composition (%)							
	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	Na <sub>2</sub> O	LOI	Other
Portland cement	22.56	5.29	3.47	63.37	2.01	0.15	2.55	0.60
Silica fume	90.76	2.24	2.48	0.52	-	0.56	2.57	0.87

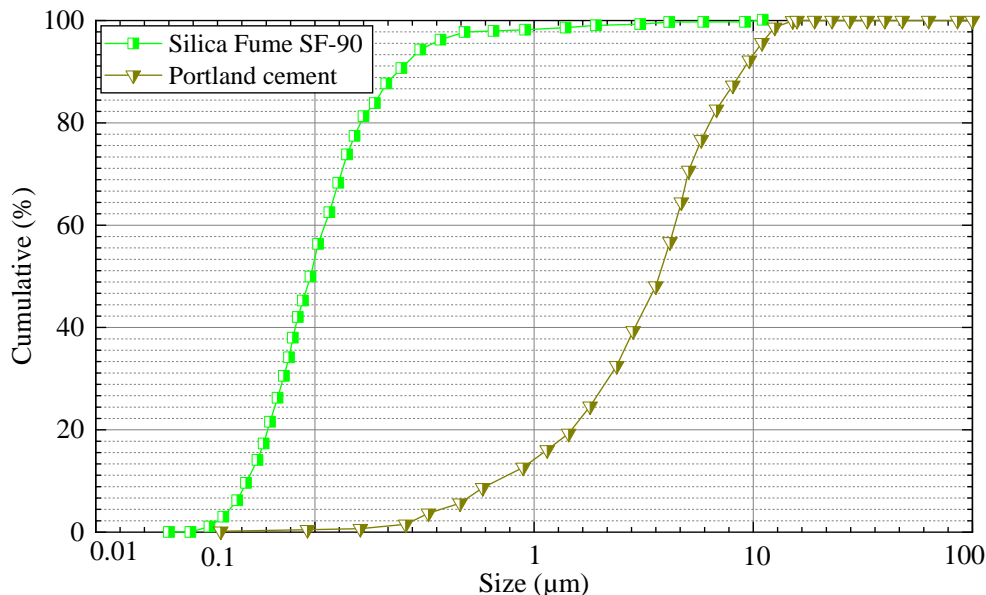


Fig. 1 – Particle size distribution of Silica fume and Portland cement

For the production of foam concrete, 'Foaming agent 1', supplied by a UK-based manufacturer, with a specific weight of  $1.02 \text{ g/cm}^3$ , to be administered at a rate of 0.5 liters per cubic meter. Conversely, 'Foaming agent 2', produced by a chemical company in China, with a specific weight of  $0.54 \text{ g/cm}^3$  and a dosage rate of 3.5 liters per cubic meter, as a relatively new foaming agent for foam concrete production that remains underutilized when compared to the popularity of 'Foaming agent 1' counterpart. There is no extant research on 'Foaming agent 2' within Vietnam. Figure 2 presents the FTIR spectrum of the foaming agent, displaying nearly identical peaks of -OH- and -CH- at  $3300 \text{ cm}^{-1}$  and  $2700 \text{ cm}^{-1}$ , respectively, but with the notable exception of -C=C- only apparent in 'Foaming agent 1'.

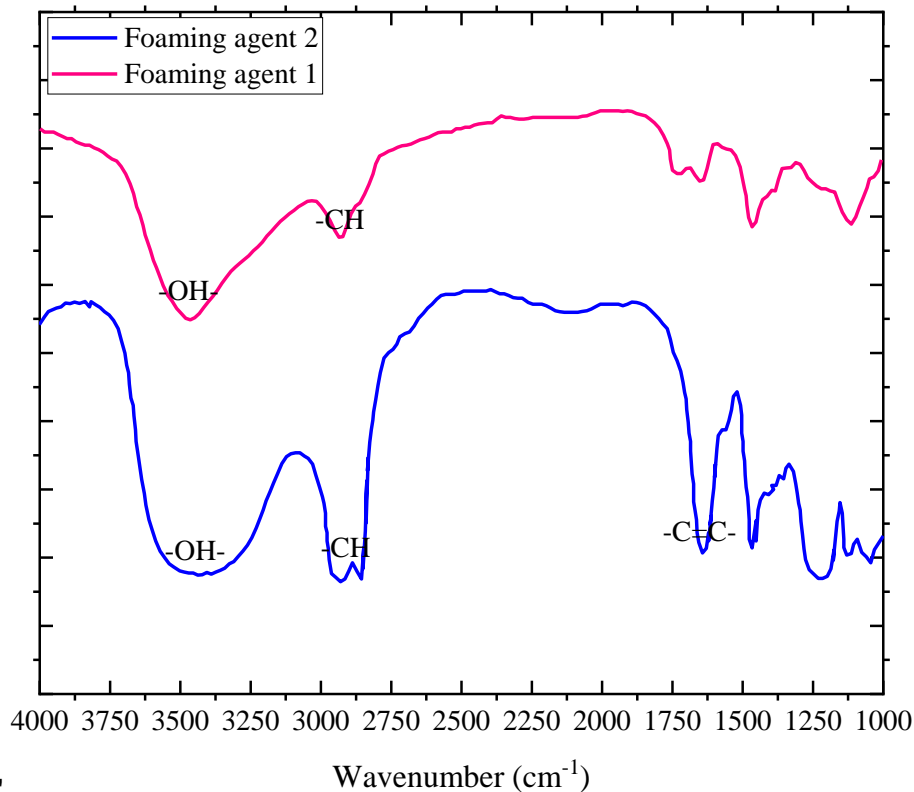


Fig. 2 – FTIR spectra of Foaming agent 1 and 2

Mixing water (W) in accordance with GOST 23732-2011 and TCVN 4506:2012 standards

**Methods**

- The particle size distribution of Portland cement and Silica fume was determined using the BRUKER laser particle analyzer.
- The composition of the foam concrete mixture was determined using the absolute volume method.
- Mechanical properties of foam concrete were assessed in accordance with the Russian standard GOST 10180-2012. Meanwhile, the GB/T 11969-2008 standard was used to gauge the dry shrinkage of foam concrete.
- Water absorption of foam concrete is tested according to TCVN 9030:2017.

**Mixture ratio and sample preparation**

In this study, the mixing ratio of foam concrete is given in Table 2. According to study [14], the Portland cement content  $C=350 \text{ kg/m}^3$ . In addition, the author used Silica fume to increase the strength of foam concrete  $SF90/C= 0.1$  [15].

Tab. 2 - Mix proportions of foam concrete

No	Foaming agent	SF90/C	Dry density (kg/m <sup>3</sup> )	Wet density (kg/m <sup>3</sup> )	C (kg/m <sup>3</sup> )	SA (kg/m <sup>3</sup> )	SF90 (kg/m <sup>3</sup> )	W (kg/m <sup>3</sup> )	Foam (L/m <sup>3</sup> )
1	SERIES I (Foaming agent 1)	0.1	663	700	350	123	35	192.5	633.9
2		0.1	852	900	350	323	35	192.5	558.4
3		0.1	1046	1100	350	523	35	192.5	482.9
1	SERIES II (Foaming agent 2)	0.1	661	700	350	123	35	192.5	633.9
2		0.1	850	900	350	323	35	192.5	558.4
3		0.1	1045	1100	350	523	35	192.5	482.9

The "MasterMix" mixer was used to blend dry Portland cement, sand, and silica fume at 50 rpm, for 1 to 3 minutes, at a temperature of 20°C, based on the mix composition outlined in Table 2. Subsequently, water was added and stirred for 2 minutes to produce a wet binder mixture. Simultaneously, the foam from the foam generator was introduced into the foam concrete mixer and mixed for 1 minute. The resulting foam concrete was immediately poured into a mold and left stationary for 24 hours, according to the specification. The foam concrete samples were cured in the laboratory for 24 hours, as illustrated in Figure 3b.



(a) Prepare foam concrete



(b) Sample curing

Fig. 3 – Foam concrete preparation process

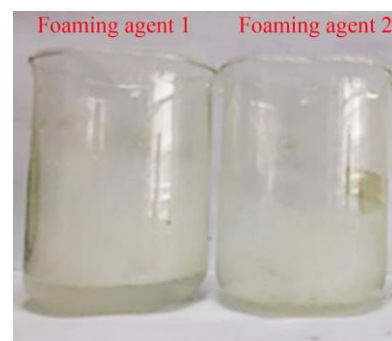
## RESULTS AND DISCUSSION

### Foam stability

In Figure 4, the air stability of 'Foaming agent 1' and 'Foaming agent 2' is displayed, with the average disappearance rate for 'Foaming agent 1' and 'Foaming agent 2' being 0.25 percent per minute and 0.5 percent per minute, respectively. 'Foaming agent 1' exhibits superior stability compared to 'Foaming agent 2' due to the correct proportioning of functional groups in the "Foaming agent 1". This allows organic chains to bond strongly through hydrogen bonding or even chemical bonding on the surface, leading to bubble formation in the aqueous medium [16]. Furthermore, 'Foaming agent 1' boasts unique stabilizers, including nanoparticles, which can agglomerate at the bubble-bubble interface to prevent collapse. Maintaining the foam structure in the cement paste can promote foam stability, according to research [17].



Initial state



After 100 minutes

Fig. 4 - Foam stability over time

**Compressive strength and water absorption**

Figure 5 depicts the speed at which the foam concrete's compressive strength develops and the relationship between compressive strength and curing age for the samples studied.

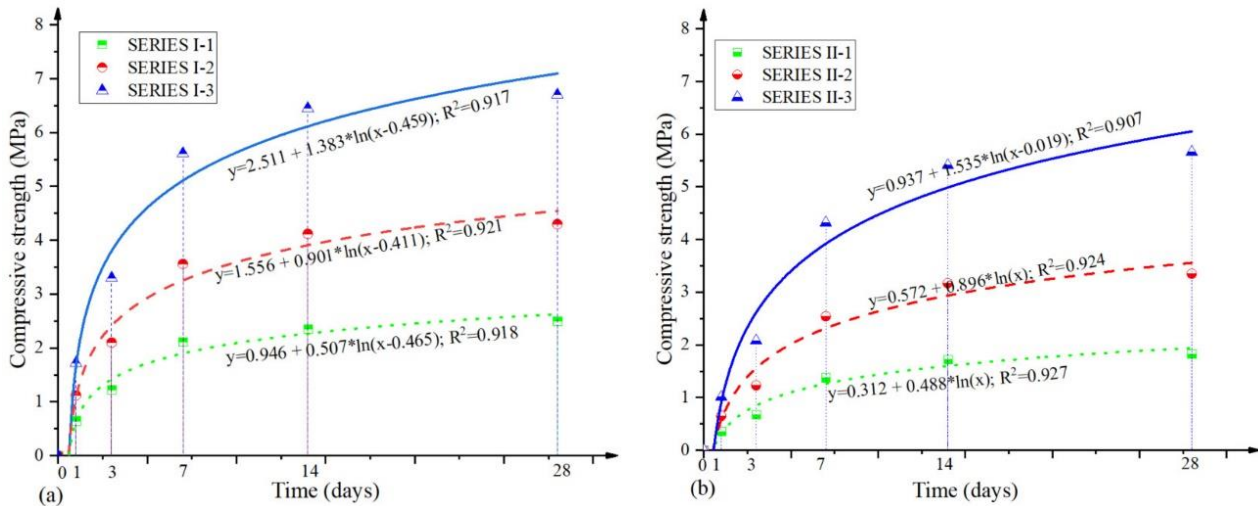


Fig. 5 - Compressive strength versus time for foam concrete: (a) foam concrete with 'Foaming agent 1'; (b) foamed concrete with 'Foaming agent 2'

The relation between compressive strength and curing age, as shown in previous studies [1], could have the following shape for foam concrete:

- + For SERIES I-1:  $y = 0.946 + 0.507 \cdot \ln(x - 0.465)$  with  $R^2 = 0.918$  (1)
- + For SERIES I-2:  $y = 1.556 + 0.901 \cdot \ln(x - 0.411)$  with  $R^2 = 0.921$  (2)
- + For SERIES I-3:  $y = 2.511 + 1.383 \cdot \ln(x - 0.459)$  with  $R^2 = 0.917$  (3)
- + For SERIES II-1:  $y = 0.312 + 0.488 \cdot \ln(x)$  with  $R^2 = 0.924$  (4)
- + For SERIES II-2:  $y = 0.572 + 0.896 \cdot \ln(x)$  with  $R^2 = 0.924$  (5)
- + For SERIES II-3:  $y = 0.937 + 1.535 \cdot \ln(x - 0.019)$  with  $R^2 = 0.907$  (6)

The impact of different foaming agents on the compressive strength of hardened foam concrete is depicted in Figure 5. The compressive strength of foam concrete using 'Foaming agent 1' is consistently higher than that produced using 'Foaming agent 2' at all ages. This can be attributed to the superior foam stability of 'Foaming agent 1' as compared to 'Foaming agent 2'.

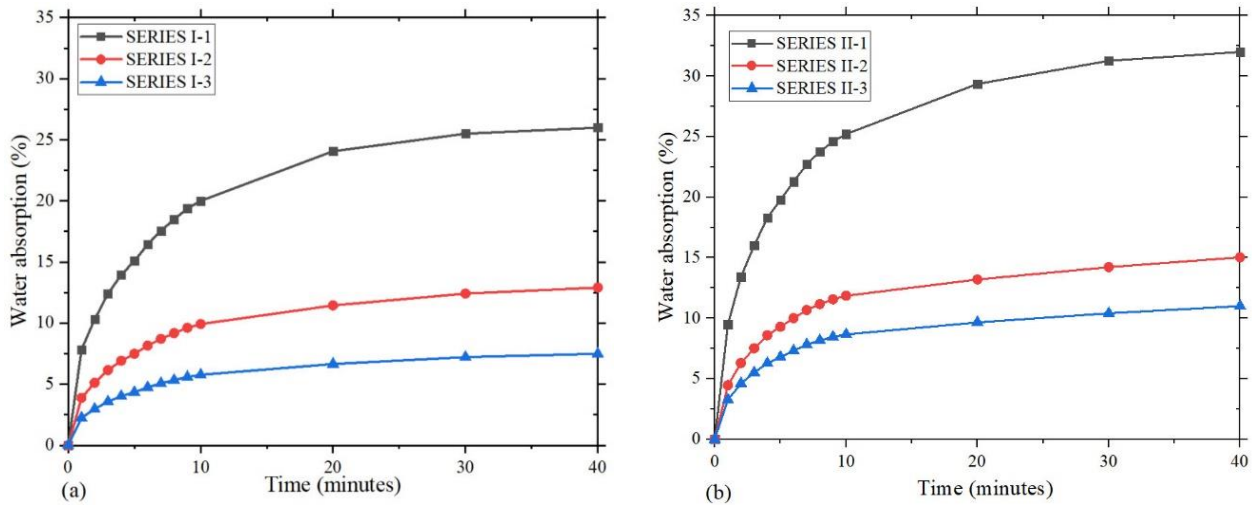


Fig. 6 - Foam concrete water absorption at different times. (a) foam concrete with 'Foaming agent 1'; (b) foamed concrete with 'Foaming agent 2'

The water absorption rate of 28-day curing foam concrete is shown in Figure 6. Figure 6 shows that the water absorption of foam concrete using 'Foaming agent 1' is lower than that of foam concrete using 'Foaming agent 2'. In addition, both forms of foam concrete exhibit quick water absorption in the first 10 minutes, after which the water absorption slows down. This observation is in agreement with the results reported by Ma C et al [18]. The finding suggests a close link between foam concrete's compressive strength and its water absorption, which can be attributed to the better foam stability of 'Foaming agent 1' compared to 'Foaming agent 2'. Consequently, the pore structure of foam concrete using 'Foaming agent 1' is more uniform, explaining its lower water absorption.

### Dry shrinkage

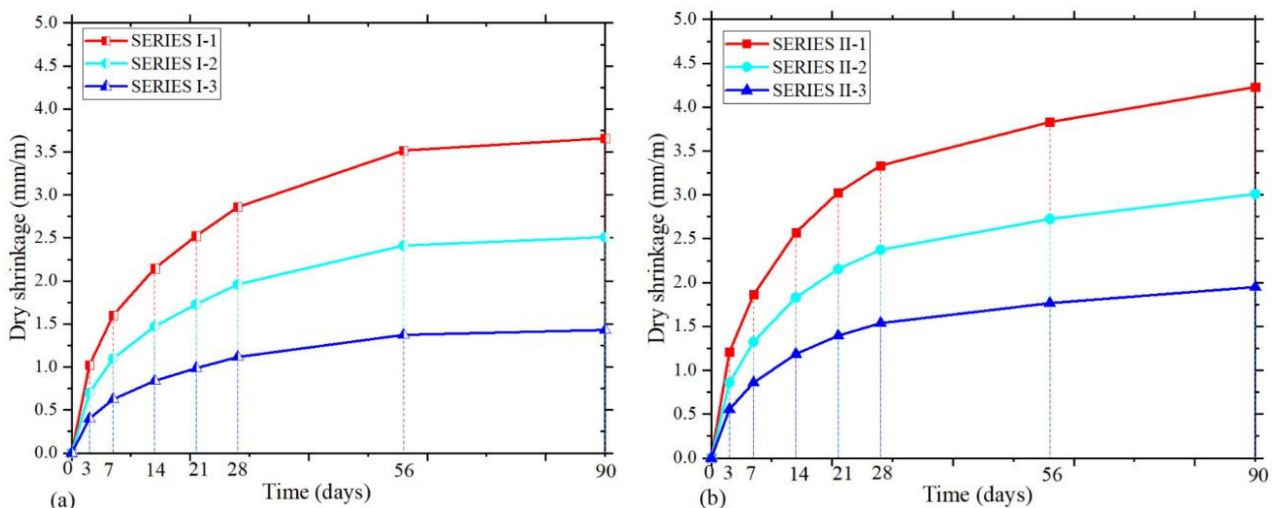


Fig. 7- Dry shrinkage of foam concrete at different times. (a) foam concrete with 'Foaming agent 1'; (b) foamed concrete with 'Foaming agent 2'

Figure 7 depicts the shrinkage of foamed concrete as it dries with various foaming agents. In the first 14 days, the dry shrinkage of foam concrete is significant. The dry shrinkage of foam concrete using 'Foaming agent 1' is lower than that using 'Foaming agent 2' by 2.1-6%. The difference in dry shrinkage of foam concrete with different foaming agents may be related to the pore

structure of the foam concrete, and decreased pore connectivity may help to reduce the dry shrinkage of foam concrete.

### Pore structure

"In Figure 8, the microstructure of foam concrete (with a density of  $900 \text{ kg/m}^3$ ) obtained through scanning electron microscopy (SEM) is displayed. It is evident that the pores in the foam concrete produced with 'Foaming agent 1' are smaller than those in the foam concrete produced with 'Foaming agent 2'. The difference in pore structure between foam concrete made with 'Foaming agent 1' and 'Foaming agent 2' is primarily attributed to the variation in average pore size and pore size distribution, rather than pore shape. Thus, these factors are the most critical microstructural properties that affect the strength of foamed concrete [19-21].

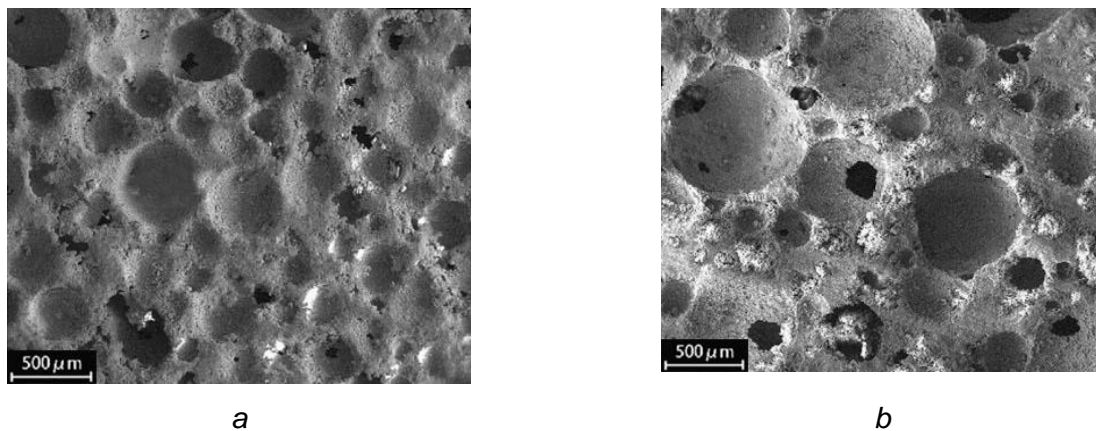


Fig. 8 - SEM image of foam concrete (a, SEM of foam concrete using 'Foaming agent 1'; b, SEM of foam concrete using 'Foaming agent 2')

### CONCLUSIONS

The research findings suggest the following conclusions:

The Fourier Transform Infrared Spectroscopy (FTIR) analyses revealed that 'Foaming agent 1' and 'Foaming agent 2' possess analogous functional groups within their molecular structures. Nevertheless, the foam produced using 'Foaming agent 1' demonstrated superior stability and mechanical strength compared to that generated with 'Foaming agent 2', which can be attributed to the former's enhanced density and viscosity properties. Quantitative assessments indicated that the compressive strength of foam concrete with 'Foaming agent 1' was significantly higher, ranging from 16.4% to 28%, compared to foam concrete with 'Foaming agent 2'.

Further investigations into the hygrothermal performance of the materials revealed that foam concrete with 'Foaming agent 1' had a notably reduced water absorption rate, registering between 2.1% and 6%, relative to the foam concrete synthesized using 'Foaming agent 2'. In terms of dimensional stability, foam concrete with 'Foaming agent 1' exhibited a lower extent of drying shrinkage, measured at 1.43 to 3.66 mm/m, compared to the foam concrete with 'Foaming agent 2', which displayed values ranging from 1.95 to 4.23 mm/m.

The pore architecture of the foamed concretes was examined through Scanning Electron Microscopy (SEM), revealing that foam concrete with 'Foaming agent 1' was characterized by a more uniform pore size distribution and a reduced incidence of interconnected porosity compared to its 'Foaming agent 2' counterpart. These microstructural attributes were posited to significantly contribute to the observed disparities in mechanical and physical properties, particularly the enhanced strength and diminished water absorption capacities of the foam concrete with 'Foaming agent 1'. Such findings underscored the pivotal role of the foaming agent's physicochemical

properties in dictating the performance characteristics of foam concrete, thus providing crucial insights for the formulation and optimization of high-performance foam concrete composites.

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