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Impact of foaming agent: water ratio on foam stability of lightweight concrete

Abhilasha Prajapati [a,b,1], Rajesh Kumar [b,c,2,*], Soumitra Maiti [b,d,3], Rajni Lakhani [b,e,4], Amit Yadav [e,5]

[a] Ph. D. Scholar 1CSIR- Central Building Research Institute, Roorkee, Uttarakhand, 247 667, India
[b] Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, 201 002, India
[c] Senior Scientist, ACSC division, CSIR-CBRI Roorkee, India
[d] Principal Scientist, BMES division, CSIR- Central Building Research Institute, Roorkee, Uttarakhand, 247 667, India
[e] CSIR- Central Building Research Institute, Roorkee, Uttarakhand, 247 667, India
[1] abhilashaprajapati115@gmail.com; [2] rajeshkumar@cbri.res.in; [3] soumitramaiti@gmail.com; [4] rlakhani_cbri@rediffmail.com;
[5] ay5692813@gmail.com
* corresponding author

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ABSTRACT

Foamed concrete, renowned for its lightweight nature and thermal insulating properties, has gained substantial interest in the construction industry. The stability of foamed concrete is directly related to the stability of preformed foam used for making foamed concrete. Foam stability is the prime factor which influences the overall performance and properties of the foamed concrete. Foam stability refers to the ability of the foam to maintain its structure and volume over time. The stability of foamed concrete is greatly impacted by the selection of the foaming agent and the ratio of foaming agent to water (FA/W). Protein based foaming agent (as per ASTM C796/C796M-19) has been used for this study. An excess of water can weaken the foam structure, leading to instability, while inadequate water can lead to issues such as reduced workability and uneven distribution of foam within the mixture. This paper investigates the effect of FA:W ratio on the stability of foam concrete. Three different FA:W ratio i.e. 1:10, 1:20 and 1:30 has been used for this study. Respective slumps to these ratios have also been investigated at different time intervals to check their consistencies. The main aim of this study is to optimize the FA/W ratios on the properties of foamed concrete. Three mix proportions were used to produce foam concrete of 1000kg/m3 density. Impact of aforementioned FA/W ratios on the properties of foamed concrete (As per; IS 2185 part-4) were discussed in this article.

1. Introduction

Foamed Concrete a type of light weight concrete (LWC) has emerged as a promising material in the construction industry due to its reduced weight, improved thermal properties, and enhanced fire resistance. It is produced by adding stable foam bubbles to a cementitious slurry, which yields a material that is much less dense than conventional concrete [1]–[3]. Foamed concrete has good thermal insulation qualities because of the air spaces the foam bubbles create. This makes it appropriate for uses where thermal efficiency is crucial, like insulation panels or building envelopes [4], [5]. Foam stability is the prime factor which influences the overall performance and properties of the foamed concrete. Foam stability refers to the ability of the foam to maintain its structure and volume over time [6], [7]. The stability of foam significantly influences the performance and characteristics of foamed concrete [8].

However, the foam stability of foamed concrete remains a critical aspect to be investigated. The stability of foamed concrete is greatly influenced by the selection of the foaming agent and the ratio of foaming agent to water (FA/W) [9]–[12]. Foaming agents, available in various types, such as synthetic surfactants, bio-based alternatives [13], or protein-based agents [14], are critical players in foam concrete production. Their primary function is to generate stable foam bubbles, introducing air voids into the cementitious matrix. An appropriate foaming agent ensures desired foam quality and long-term stability. Numerous factors affect the characteristics of foam concrete. Various studies have been done on different aspects of foamed concrete [15]. The strength and hardened properties of foam concrete are directly influenced by various factors, including the type of foam, cement, aggregate, mineral additives, and air voids characteristics etc. Previous researches have also investigated the variables affecting foam stability in foamed concrete, such as the kind and amount of foaming agents, the ratio of water to cement, and the mixing techniques. Many studies have looked into adding different materials to foamed concrete. For example, a study on the addition of waste polyurethane foam to cementitious mixtures discovered that the waste increased the concrete's compressive strength [16]. According to another study, adding minerals like fly ash and silica fume improved the foamed concrete's strength properties [17]. The physico-mechanical characteristics of foamed concrete with low-graded industrial waste materials have been the subject of several investigations. Compaction strength, density, workability, thermal conductivity, and water absorption are among the mechanical and physical properties that have been examined [18]–[22]. It has been noted that these characteristics can be considerably changed by the addition of these waste materials. In one study, the addition of granite and palm kernel shell to concrete improved its compressive strength [19], [20]. This study focused on the development of LWC using industrial waste materials. Another study looked into the engineering properties of structural LWC composed of clay and expanded shale combined with large amounts of class F and class C fly ash [21]. To achieve desired properties and foam stability, mix proportions must be optimised [18]. Likewise, researchers have studied the impact of various curing strategies understanding how appropriate curing strategies support the best possible development of strength [16]. Furthermore, research on the addition of fibres to foamed concrete has shown that they may improve crack resistance and tensile strength [23]. Additionally, studies on pore size have provided insight into how it relates to the physico-mechanical properties of foamed concrete [24], [25]. Research has been done on replacing cement with fly ash and other additional materials. One study revealed their effects on the durability and strength characteristics of foamed concrete [26]. By means of these comprehensive investigations, a deeper understanding of the variables impacting the foamed concrete strength parameters has been attained, opening up the opportunity to enhanced mix-design and implementation in diverse construction conditions. Thus, in order to determine how different foaming agent to water (FA/W) ratios affect foam stability over time, this study looks at the factors such as- bubble size distribution, drainage characteristics, and performance factor. As fresh state attributes: bubble size distribution, drainage characteristics were determined using image analysis and slump loss, respectively. While, performance factor was determined after 28 days using the ratio of compressive strength and oven dry density (OD).

2. Method

2.1. Materials

OPC-43 grade used a binder in the production of foamed concrete, was obtained from J.K. Cement from local supplier as per IS 8112: 2013 [27]. River sand, which complies with IS 383:2016 [28], and grading zone IV, was used in this study as a filler. Protein based foaming agent (As per; ASTM C796/C796M-19 :2019) [29], has been used for this study. Show as Fig. 1.

(a) (b) (c)

Fig. 1. (a) OPC-43 Cement, (b) Foaming agent, and (c) River Sand

2.2. Production of Foam

In the first step solution of foaming agent was prepared by diluting the foaming agent in water. Foam generator was used to combine foaming agent, water, and air to create foam. Using a air compressor, air was injected into the foam generator. Foaming agent solution was added to the foam generator from a tank containing the foaming agent solution, which was prepared in the first step. Inside the foam generator, foam is produced as a result of the mixture of air, water, and foaming agent. A container is used to collect the foam that is expelled from the foam generator through an outlet port. To make sure the foam fulfils the specifications for its intended application, the density, stability, and quality of the foam are continuously monitored and changed during the foam generation process. Fig. 2 shows the methodology of preperation of foam.

(a) (b) (c)

Fig. 2. (a) Dilution of foaming agent, (b) Set up of foam generator, and (c) Collection of foam

2.3. Stability of Foam

Three different ratios of foaming agent to water (FA/W) have been used for making foam to achieve desired density as per; ASTM C796/C796M-19 :2019 [29]. Three different FA/W ratio i.e. 1:10, 1:20 and 1:30 has been used for this study. Respective slumps to these ratios have observed at different time intervals to check their consistencies. Fig. 3 represents the slump in different ratios after 90 minutes.

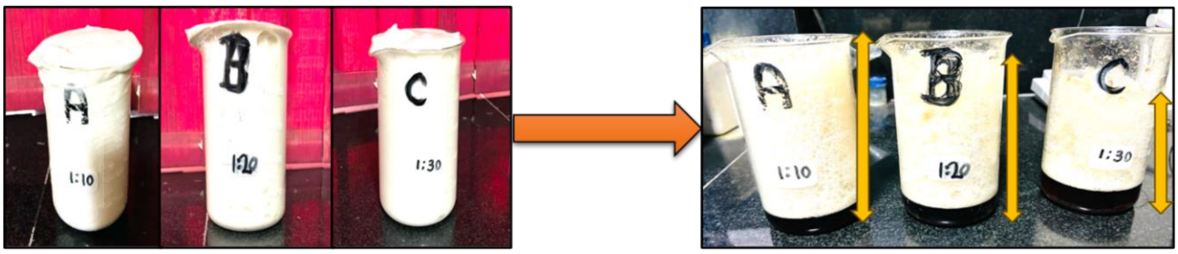

Fig. 3. Collapse in preformed foam after 90 mins

2.4. Test set up for Image analyser

Pore size analysis was conducted using an image analysis system that included an inverted microscope, a high-resolution digital camera, and sophisticated yet user-friendly image analysis software. Using an inverted microscope and a digital camera on a computer interface, images were taken, and Metavis image analyzer user interactive software was used for processing and analysis. It is able to identify, count, and compute the distance between objects in addition to many other functions including calculating the entrained air pores, radius, area, perimeter, roundness, and aspect ratio of foamed concrete. Fig. 4 shows the experimental set up of image analyser.

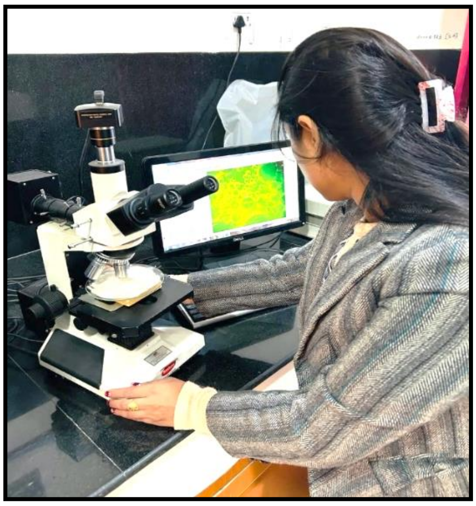

Fig. 4. Image analyser to study pore structure of foam

2.5. Test set up for Performance factor

Using a 1000 kN Shimadzu universal testing machine, foamed concrete cube specimens were cast and tested for Compressive strength in accordance with IS 2185: Part IV (Concrete masonry units: Preformed foam cellular concrete blocks) [30]. Since compressive strength is dependent on the OD, it is meaningless in the case of foamed concrete. Performance factor (PF) in the context of foamed concrete interpreted as a ratio of average Compressive strength and OD at 28 days. Set up for Compressive strength test is shown in Fig. 5.

Fig. 5. Set up for testing compressive strength of foamed concrete after 28 days

3. Results and Discussion

3.1. Shump Loss

Slump is the term used to describe this decrease in foam height when discussing foam stability. Monitoring the change in foam height at regular intervals post foam generation is a common method of measuring slump in foam stability. Better foam stability is indicated by a slower rate of collapse and a higher final foam height because the foam keeps its volume and structure over time. Observed slump values are given in Table 1, which clearly shows that in the case of 1:10 ratio, slump is least after 70 min. which provides best consistency to the foam. In case of FA/W ratio 1:10, total slump after 70 min. was found 5.0 mm only, which is 220% and 668% lower than 1:20 and 1:30 ratio respectively.

Table 1. Cumulative slump in pre-foamed foam after certain time

S.No.	Foaming Agent: Water	Foam Density (kg/m3)	Slump (mm)			
			20 min.	*30 min.*	*50 min.*	*70 min.*
1	01:10	77	0	0	4.1	5
2	01:20	125	0	2.3	8.5	16
3	01:30	130	0.8	3.3	21.1	38.4

Fig. 6 presents the graphical representation of cumulative slump. A higher FA/W ratio causes thinner and weaker bubble walls in the foam. As a result of these weaker bubble walls, foam becomes less resistance to gravity and other destabilizing forces, so foam is more likely to drain.

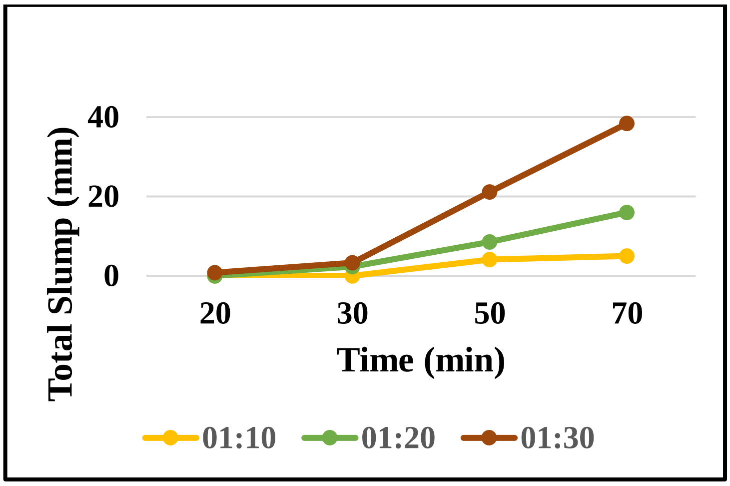

Fig. 6. Deviation of Slump with time

3.2. Bubble Size Distribution

Bubble size distribution in the foam is measured by using an inverted microscope. Foamed concrete's characteristics, such as density, strength, thermal conductivity, and durability, can be greatly impacted by the distribution of bubble sizes in the material. Because foam is mixed into the mixture, foamed concrete usually has a large amount of air spaces in it. To manage different properties of the material, the size distribution of these air bubbles is essential. Table 2, represents Bubble size range at different time interval, Aspect ratio and Roundness. From which we can conclude that in the ratio 1:10 roundness is nearly one, which is the criteria of sphericity. Typically, foaming agents are composed of surface-active chemicals or surfactants, which lower water's surface tension. The foaming agent promotes the development of more homogeneous, smaller, spherically-shaped bubbles by lowering surface tension. In case of higher FA/W ratio, water amount is high which caused higher surface tension results non spherical bubbles. Fig. 7 represents the bubbles shapes which presents in different ratios.

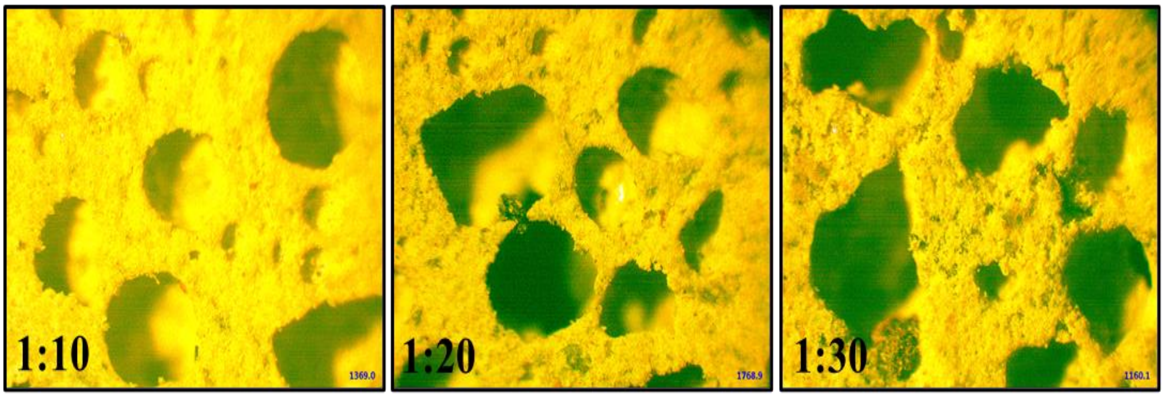

Fig. 7. Findings of aspect ratio of hardened foamed concrete after 28 days

3.3. Thermal Conductivity

The ability of foamed concrete to conduct heat is known as its thermal conductivity. It measures how well thermal energy is transferred through the structure of foamed concrete. Better insulation qualities, or the ability of the foamed concrete to stop heat transmission, are indicated by a lower thermal conductivity. Thermal conductivity for foamed concrete with different foaming agent and water ratio has been determined by C- Therm analyser and given in Table 2. Thermal conductivity for 1:10 ratio was found to be 0.201 W/m*K, which is 5.97% and 26.37% lower than 1:20 and 1:30 ratio respectively. This happened due to the formation of stable and spherical pores in case of 1:10 ratio. Finer the pores better the insulation.

Table 2. Bubble Size Range, k- Value, Aspect ratio and Roundness for different FA:W ratio

S. No.	Foaming Agent: Water	Bubble Size range (µm) after	k- Value (W/m*K)	Aspect ratio	Roundness	S. No.	Foaming Agent: Water
		0 min.	*30 min.*	*60 min.*			
1.	1:10	0.56- 40.02	1.05- 60.4	1.15-140.7	0.201	0.94- 1.01	0.998
2.	1:20	0.89- 50.63	2.48- 110.61	2.79-145.79	0.213	1.10- 1.40	0.942
3.	1:30	1.2-75.98	3.82-160.32	4.89- 180.94	0.254	0.773- 2.68	0.764

3.4. Performance Factor after 28 days

In case of foamed concrete strength has no significance, because strength depends on the OD. Performance factor (PF) in the context of foamed concrete interpreted as a ratio of average Compressive strength and OD at 28 days. Values of P.F for different ratios are given in Table 3, which indicates that for ratio 1:10 value of P.F is higher than rest two ratios.

Table 3. Performance Factors for foamed concrete with different FA:W ratio

S. No.	FA /Water	w/c ratio	Designed Parameters	Calculated from formula	OD Density at 28 days (kg/ m3)	Average Compressive strength at 28 days (MPa)	Performance factor (Pa/(N/m3))
1	01:10	0.63	Total water (kg/m3)	252	1127.3	4.61	408.15
			Volume of air required (Va) (m3)	0.397			
			Volume of foam (Vf) (m3)	0.417			
			Weight of foam (kg/m3)	32.1			
			Water in mortar base mix (Wmbm) (kg/m3)	219.9			
2	01:20	0.63	Total water (kg/m3)	252	1082.5	4.25	392.26
			Volume of air required (Va) (m3)	0.397			
			Volume of foam (Vf) (m3)	0.417			
			Weight of foam (kg/m3)	52.1			
			Water in mortar base mix (Wmbm) (kg/m3)	199.9			
3	01:30	0.63	Total water (kg/m3)	252	1197.3	4.57	382.52
			Volume of air required (Va) (m3)	0.397			
			Volume of foam (Vf) (m3)	0.417			
			Weight of foam (kg/m3)	54.2			
			Water in mortar base mix (Wmbm) (kg/m3)	197.8			

Fig. 8 presents the graphical representation of P.F. Here OD varies from 1127- 1197 kg/m3 for all the ratio. So, performance factor for Compressive strength at 28 days was calculated for each ratio and it found to be 408.15 Pa/(N/m3) in case of 1:10 ratio mix. Which is 4.05 % and 6.07% higher than 1:20 and 1:30 ratio mix. This is because higher water content causes the weak bubble boundaries and hence collapse of bubbles, consequently low performance factor in higher FA/W ratios.

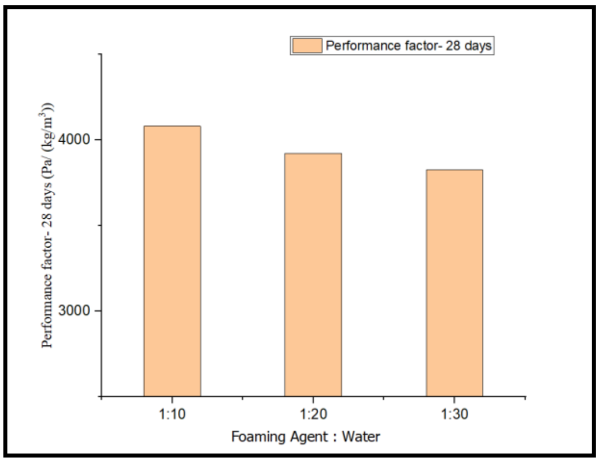

Fig. 8. Performance factor for foamed concrete with different ratios after 28 days

4. Conclusion

Foaming agent and water ratio have a major effect on foamed concrete, influencing various important properties. The proportion of water to foaming agent can affect the strength of foamed concrete. A balance between density and strength can be achieved with optimum ratios. Increased porosity from higher foaming agent concentrations may weaken the foamed concrete strength. The findings from the above study are listed: 1) For 1:10, foaming agent: water ratio achieved density ratio varies from 0.926-1.255; 2) A higher FA/W ratio causes thinner and weaker bubble walls in the foam. As a result of these weaker bubble walls, foam becomes less resistance to gravity and other destabilizing forces, so foam is more likely to drain; 3) Aspect ratio for 1:10 ratio, is nearly 1.00 and desirable for circle, as well as Roundness for this ratio also confirms the circularity in shape. This is because foaming agent promotes the development of more homogeneous, smaller, spherically-shaped bubbles by lowering surface tension. In case of higher FA/W ratio, water amount is high which caused higher surface tension results non spherical bubbles; 4) Thermal conductivity for 1:10 ratio was found to be lower than the other two ratio, this happened due to the formation of stable and spherical pores in case of 1:10 ratio. Finer the pores better the insulation; 5) Lower performance factor was observed in case of 1:20 and 1:30 ratio, because higher water content causes the weak bubble boundaries and hence collapse of bubbles, consequently low performance factor in higher FA/W ratios. In conclusion, the proportion of foaming agent to water ratio is a critical factor in defining the characteristics and functionality of foamed concrete. It's important to remember that the ideal ratio of foaming agent to water can change based on a number of variables, including the intended use, the availability of local resources, project restrictions, and the individual application. As a result, figuring out the best ratio for a given circumstance may require much thought and testing. There is great potential to enhance the performance of the material and promote sustainability by investigating the effects of the ratio of foaming agent to water on foam stability in lightweight concrete. Future research may result in improvements to construction techniques, a deeper comprehension of material behavior, and mix design advances, all of which would strengthen infrastructure resilience.

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Declarations

Author contribution. All authors contributed equally to the main contributor to this paper. All authors read and approved the final paper.

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