Düzce University
Journal of Science & Technology

Review Article

Foam Concrete And Surfactants

Nuri IŞILDAR [a,*]

[a] *Natural and Industrial Building Materials R&A Center,Suleyman Demirel University, Isparta, TURKEY*
* *Corresponding author's e-mail address: nuriisildar@sdu.edu.tr*

DOI: 10.29130/dubited.1513320

ABSTRACT

Lightweight concrete types have gained attention today due to their diverse range of applications. Cellular concretes such as aerated concrete and foam concrete hold a significant place in the construction sector due to their sustainability and recyclability. These materials stand out for their high efficiency, offering properties such as thermal insulation and fire resistance. In particular, pore size and distribution in foam concrete are among the most critical factors determining the mechanical strength and insulation performance of the material. In this context, understanding the chemical composition and properties of the foaming agent in detail is essential for achieving the desired performance. Surface-active agents, known as surfactants, are important components widely used in foam concrete production. The correct selection and application methods of surfactant types are crucial for ensuring that the concrete achieves its targeted properties. This study aims to examine the characteristics of various surfactants and contribute to meeting the desired performance criteria in foam concrete production.

Keywords: *Foam concrete, Foaming agent, Surfactant*

Köpük Beton ve Surfaktanlar

ÖZ

Hafif beton türleri, günümüzde çeşitli kullanım alanlarıyla dikkat çekmektedir. Gaz beton ve köpük beton gibi hücresel betonlar, sürdürülebilirlik ve geri dönüştürülebilirlik özellikleriyle yapı sektöründe önemli bir yere sahiptir. Bu malzemeler, ısı yalıtımı ve yanmazlık gibi yüksek verimlilik sunan özellikleriyle öne çıkmaktadır. Özellikle köpük betonda, gözenek boyutu ve dağılımı, betonun mekanik dayanımı ve yalıtım performansını belirleyen en kritik faktörler arasında yer almaktadır. Bu bağlamda, kullanılan köpük ajanının kimyasal yapısı ve özelliklerinin ayrıntılı olarak bilinmesi, istenilen performansın elde edilmesi için zorunludur. Yüzey aktif maddeler, diğer adıyla surfaktanlar, köpük beton üretiminde yaygın olarak kullanılan önemli bileşenlerdir. Surfaktan türlerinin doğru seçimi ve uygulama yöntemleri, betonun hedeflenen nitelikleri kazanması açısından büyük öneme sahiptir. Bu araştırmada, farklı surfaktanların özellikleri ele alınarak, köpük betonun arzu edilen performans kriterlerini sağlamasına yönelik katkılar sunulması hedeflenmiştir.

Anahtar Kelimeler: *Köpük beton, Köpük ajanı, Yüzey aktif madde*

Received: 09/07/2024, Revised: 16/11/2024, Accepted: 17/11/2024

I. INTRODUCTION

In the context of enhancing the insulation properties of lightweight concrete, the use of different components and methods is quite common. Minor differences in the components and curing methods can have significant effects on strength and insulation. One of the essential components of cellular concrete is foaming agents, primarily used to achieve porosity. Accordingly, there are numerous studies that involve the use of foaming agents with different origins and other specific properties [1], [2], [3], [4].

Comparative studies on the effects of foaming agents on foam concrete properties are extremely limited. In these studies, the foaming agents are mostly identified only by their commercial names, whether they are synthetic or natural, their usage amounts, and sometimes their densities. Therefore, there are challenges in comparing and evaluating the effectiveness of different foaming agents whose compositions and properties are not fully known. Sahu and Gandhi highlight that different foam formers lead to variations in the void structure of concrete, and they emphasize that there are fundamentally opposing results regarding the effects of natural and synthetic surfactants on foam stability, pore size, and compressive strength [5].

The primary materials used as foaming agents in foam concrete are surfactants, also known as surface-active agents. Therefore, recognizing surfactants and understanding their mechanisms of action on foam concrete properties are considered essential.

II. SURFACTANTS

Surfactants are surface-active agents composed of special types of molecules that reduce the surface tension (interfacial tension) between two liquids or between a liquid and a solid/gas, containing both lyophilic and lyophobic groups. Surfactants have a wide range of applications; they are used in products like shampoos, detergents, and other cleaning agents, as well as in cosmetic products such as creams, lotions, and perfumes. Additionally, they find use in lightweight concrete, paint, paper, ink, plastics, fibers, agricultural chemicals, food, and especially the oil industry, among other areas.

In conditions where the fluid is mostly water, the terms hydrophilic and hydrophobic are used instead of lyophilic and lyophobic for the polar head group and the tail parts of the molecule that prefer the non-polar environment, respectively. The primary classification of surfactants depends on the charge state of their hydrophilic groups and includes anionic, cationic, zwitterionic (amphoteric), and non-ionic surfactants [6]. Ionic surfactants with cationic (positively charged head group) characteristics often contain functional groups with nitrogen, such as amines and quaternary ammonium salts, while anionic (negatively charged head group) surfactants contain functional groups like carboxylate, sulfate, sulfonate, and phosphate. Zwitterionic surfactants, often referred to as amphoteric or ampholytic, typically have a positively charged ammonium or imidazolium group and a negatively charged carboxylate, sulfonate, sulfate, or phosphate group [7]. Non-ionic surfactants, which have little or no electrical interaction between the head groups, usually have hydrophilic groups made up of polyoxyethylene, glycerol, and sorbitol [8].

In aqueous solutions, surfactants can exist in monomolecular or supramolecular structures depending on their concentration [8]. The formation and shapes of supramolecular micelles are closely related to the type of surfactant, its concentration, and the chemical properties of the solution [10].

According to Porter, the chain length of hydrophobic groups is a determining factor for the solubility, adsorption, and surface-active efficiency of surfactants in water [11]. Surfactants with a chain length of 10-18 carbons exhibit low solubility and maximum surface-active properties, while those with a chain length of less than 8 carbons show increased solubility but weaker surface-active properties. In contrast, those with a chain length greater than 18 carbons demonstrate these properties at a minimum level [12].

Surfactants are classified as natural or synthetic based on their sources. According to Hayes and Smith, the main components of biologically derived surfactants include fatty acyl groups (derived from oilseeds, animal fats, and derivatives like fatty alcohols and amines), carbohydrates, proteins, extractive substances, and some biorefinery by-products [13]. The breakdown of proteins from animal sources (such as casein, blood, keratin, fish scales, and other animal carcass waste) into smaller hydrophobic molecules through peptide bond cleavage leads to decreased surface tension, interfacial formation, and the development of hydrogen bonds between molecular groups and air bubbles [14]. Boruah and Gogoi have listed common natural plant-based surfactant sources, including soapbark (Quillaja saponaria), chickpeas (Cicer arientinum), alfalfa (Medicago sativa), oats (Avena sativa), pepper (Piper nigrum), tea (Camellia assamica), spinach (Spinacia oleracea), and yucca (Yucca schidigera), attributing their surface-active properties to the presence of saponins [15].

A. SURFACTANTS AS FOAMING AGENTS

Foam is a structure in which bubbles of gas are separated by membranes in a liquid environment. Foam agents are additives that promote the formation of more foam bubbles by reducing surface tension [16]. The increase in surface viscosity due to the adsorption of the surfactant at the air-liquid interface weakens the drainage between the bubbles, contributing to the thinning of the bubble film and thus reducing bubble coalescence. In foam concrete studies, the most commonly used foam agents are synthetic and protein-based [17], [18], [19], [20], [21], [2], [22], [23], [24], although composite [25], [12], aluminum powder, hydrogen peroxide, detergents, adhesive resins, and saponins [26] have also been observed to be used (Table 1).

The evaluation of surfactants as potential foaming agents depends on their foam capacity, density, stability, dilution ratio, production pressure, and cost-effectiveness. For determining the required foam volume for the desired foam concrete density, it is necessary to know the foam capacity, which is the volumetric foam amount that can be produced per unit amount of surfactant, and the foam density. Foam stability is determined by the time it takes for the foam to revert to its original liquid and gas phases, or in other words, the drainage time [27]. Processes such as gravity-liquid flow, capillarity-liquid suction, gas-liquid interface shear stresses, and coalescence and expansion, which can occur simultaneously, affect foam drainage [28].

B. SURFACTANTS AND THEIR EFFECTS ON FOAM CONCRETE

It has been observed that certain properties such as CMC (Critical Micelle Concentration) and viscosity, which are highly influential on the properties of foam concrete, are provided very limitedly in Table 1 regarding foam agents.

Table 1. *Foaming Agents Used in Some Studies on Foam Concrete Production and Their Characteristics*

Foaming Agents	**Origins**	**Dilution Rate**	**Foam Density**	**Density**	**pH**	**Viscosity**	**CMC**	
AYDOS-LİGHTCON 25-28	Synthetic			+	+			[67]
FOAMCRETE 10K	Synthetic							[68]
İKSA FOAM–AD	Synthetic			+	+			[69]
MİLOFOAM	Plant							[70]
Biosaponeks	Saponin							[71]
NANO	Plant							[72]
ROGEN	Polymer							[73]
GENFİL	Organic		+	+				
GENOCELL	Organic			+				[74]
BETAFOAM CLC	Protein							
Dodecyl trimethyl ammonium bromide		+	+					[44]
Hexadecyl trimethyl ammonium bromide							+	[33]

Table 1 (cont). *Foaming Agents Used in Some Studies on Foam Concrete Production and Their Characteristics*

Trimethyl tetradecyl ammonium bromide							+	
Cetyl trimethyl ammonium bromide		+						[57]
Octylphenol ethoxylate		+						
Lauryl alcohol ethoxylate					+		+	[75]
Sodium Lauryl Sulfate	Synthetic	+						[17]
								[76], [27],[1]
		+			+			[48]
		+					+	[29]
Sodium Laureth Sulfate	Synthetic							[1], [55]
					+			[20]
		+	+	+	+			[77],[78]
		+			+			[48]
Sodium dodecyl sulphate	Synthetic	+	+					[18]
								[4],[20],[79]
					+		+	[75]
		+						[57]
		+					+	[31]
Sodium dodecyl benzene sulfanate	Synthetic							[80],[4],[81],[1]
Sodium alcohol ether sulphate		+			+			[48]
		+	+					[44]
Sodium alpha-olefin sulfanate	Synthetic				+			[54],[82],[16]
								[4]
				+			+	[20]
								[21]
		+			+			[48]
							+	[33]
BENOTEH PB-C	Synthetic							[2],[83]
PİONEER PG	Synthetic							[2]
PENTA SURFACTANT 430A	Synthetic						+	[36]
PENOSTROM	Synthetic			+	+		+	
H_2O_2								[84],[81],[85], [86]
MİCROAİR	PEG Faty acid							[80]
								[4]
PB-LUKS	Synthetic			+	+			[87]
FOAMTEK	Synthetic	+	+	+	+			[77],[78]
	Synthetic	+	+					[88]
SY-F30 (Plant + Animal-Based)	Composite	+						[3]
LASTON	Protein							[2]
FOAMSEM	Protein			+	+	+		[23]
PİONEER BIO	Protein							[2]
FOAMİN	Protein	+	+	+	+			[77], [78]
NORAITE PA-1	Protein	+	+					[89],[90],[91], [92],[93]
TEGO Betain F 50)	Organic Coconut Oil							[94]
Vinsol Resin	Organic Pine Tree							[80]
Kokodietanolamid	Coconut Oil							[1]
Cocoamidopromil betaine		+						[44]
FA-1		+		+	+			[95]

Table 1 (cont). *Foaming Agents Used in Some Studies on Foam Concrete Production and Their Characteristics*

Micro Air 210 (Alkyl Ether Sulphate)								[76]
Nonyl Phenol Ethoxylate		+						[17]
Alkyl Ethoxy Sulphate					+			[16], [82]
Rosin Malate					+			[54]
BİOPORE							+	[36]
Pb-2000							+	
Oleic Acid								[76]
EABASSOC		+	+	+	+			[96],[97]
		+	+					[98]
AREKOM							+	[36]
Polyurethane			+					[99]
	Protein		+					[22]
	Protein	+						[57]
	Protein							[100]
	Protein	+	+					[101]
	Protein		+					[102]
	Protein Hemoglobin							[103]
	Protein Enzymatic							[104]
	Protein Collagen				+			[51]
	Protein Antibacterial Enzyme			+				[24]
	Protein	+	+	+	+	+		[19]
	Protein	+	+					[105]
	Organic	+	+					[106]
	Organic	+	+					[107]
	Synthetic		+					[56]
	Synthetic							[108]
				+	+			[45]
	Detergent							[95]
	Plant Soap			+	+			[16], [82]
	Fe-protein			+	+			[54],[16],[82]
		+						[109]
	Natural							[108]
	Plant		+					[56]
	Animal-Based		+					
	Synthetic	+	+	+	+			[19]

B.1. Critical Micelle Concentration (CMC)

The critical micelle concentration (CMC) of a surfactant corresponds to the concentration above which there is insufficient space for adsorption due to monomolecular adsorption being completed, leading to the formation of multiple micelles. If surfactants are above their CMC in solution, they may enter the dispersed phase in limited quantities or migrate to the water-air interface, and excess surfactant molecules will form micelles [29].

Surfactant effectiveness, which is a function of the interface concentration causing a decrease in surface tension, is influenced by factors such as the chemical structure of the surfactant, solution ionic strength and ion types, particles, the ratio of CMC to C20 (the concentration required to reduce the surface tension of the solution by 20 mN/m), pH, temperature, and others. Generally, an increase in surfactant concentration improves foaming until reaching CMC, beyond which further increases do not contribute to foam production. Furthermore, an increase in surfactant hydrophobicity enhances adsorption at the interface, thereby improving foaming, but excessively high hydrophobicity can lead to a surfactant film that is too rigid or insoluble, thereby reducing foaming [30]. Indeed, Johnson et al. reported that sodium dodecyl sulfate with the same CMC as a commercial dishwashing surfactant required 10 times the CMC for optimal foam formation, and further increases resulted in a decrease in foam mass [31].

Feneuil et al. noted that higher yield stress values in cement paste increase foam stabilization; in the context of the adsorption of most surfactants on cement particles and their concentration-dependent effects on the yield stress of cement paste, an increase in interparticle hydrophobic attractive forces increases yield stress, which rapidly weakens beyond the threshold concentration, leading to a significant decrease in yield stress [32]. CMC is generally indicated as an appropriate concentration for foam stability [33]. However, Kuzielová et al. mentioned that surfactant concentration is also among the factors affecting foam stability, with different opinions on whether it should be lower or higher than the critical micelle concentration (CMC) for optimal concentration [34]. In a study where they used a protein-based surfactant at normal and low (1.4% and 0.7% w/w, respectively) concentrations, they evaluated that the low concentration surfactant increased foam stability and accelerated hydration without significant differences compared to normal concentration, which was much higher than CMC.

Tran et al. emphasize that selecting a concentration equal to or below the CMC value is crucial for foam stability [35]. In a study where concentrations of 300, 600, 1000, and 2000 ppm of sodium dodecyl sulfate were used below the CMC value (~2500 ppm), it was shown that at higher concentrations of surfactant (2000 ppm), the increased coalescence and agglomeration were due to the hardening of cell walls resisting drainage and increasing the curvature of intermediate films with smaller bubble sizes. On the other hand, in another study where different foam agents were used at mass ratios of 0.5-5% (Biopore, PB-2000, Arekom, Penta Surfactant 430A, and Penostrom), it was noted that Penta Surfactant 430A and Penostrom caused a greater decrease in surface tension compared to others, thereby improving micelle formation conditions. Additionally, considering foam concrete strength, Penta Surfactant 430A at 2.6% of CMC was deemed appropriate [36].

B.2. Viscosity

Viscosity resulting from the collision of particles flowing at different velocities within a liquid increases as the particle count increases [37]. The addition of high viscosity achieved through the inclusion of surfactants used in foam creation or certain additives reduces system drainage, leading to higher internal pressure in bubbles and thus formation of smaller, stable bubbles [12], [5], [38]. This enhances the performance of foam concrete [39]. Recent studies frequently encounter materials such as nano-silica and hydroxypropyl methylcellulose [40], nano-alumina [41], starch [42], carboxymethyl cellulose [43], nano-silica and nano-calcium carbonate [44], and xanthan gum [45], [46], used as foam stabilizers, each with varying mechanisms of action.

In a study optimizing the extraction process of surfactants from two different natural sources (protein-based sesame seeds and saponin-based hingot fruit), research focused on fundamental properties such as initial foam density, foam stability, bubble size, and surfactant viscosity. Increasing the heating temperature from 50°C to 100°C and extending the duration from 3 hours to 10 hours resulted in increases of 45% and 29%, respectively, in surfactant viscosity, while causing decreases in initial foam density, foam drainage, and bubble size. It was noted that the concentration of NaOH used for protein hydrolysis in sesame seeds had little effect on the examined properties [47].

In another study investigating the effects of xanthan gum on the properties and stability of different surfactants (Hingot- natural saponin-based and Nonylphenol ethoxylate- nonionic synthetic) and the resulting changes in foam concrete's setting behavior, compressive strength, and thermal conductivity [46], it was found that xanthan gum caused a tenfold increase in viscosity for both surfactants but did not lead to significant changes in surface tension. The increase in viscosity was evaluated to decrease bubble size and increase lamellar thickness, indicating the effectiveness of the xanthan gum-Hingot combination, which resulted in a 51% increase in compressive strength. Decreases in thermal conductivity were attributed to reductions in pore size caused by xanthan gum.

A study on nano-silica and nano-calcium carbonate, with an average particle size of 50 nm, investigated their effects on foam properties and stabilization mechanisms with anionic (sodium alcohol ether sulfate), cationic (dodecyl trimethyl ammonium bromide), and amphoteric (liquid cocoamidopropyl betaine) surfactants, as well as their impacts on foam concrete properties. The study concluded that increasing nanoparticle content led to increased foam density for all surfactants, while reducing foam formation times and water release amounts. Positively charged nanoparticles could bind to anionic and amphoteric molecules at the gas-liquid interface, reducing gas-liquid contact area and internal gas flow, thereby stabilizing foams. Nano-calcium carbonate was found more effective in reducing fluidity and increasing foam concrete viscosity, thereby enhancing foam concrete strength. It was also observed that nanoparticles dispersed in the foam liquid film altered the Ca and Si content of foam concrete pore wall surfaces, affecting hydration product formation and surface microstructure.

This research highlights the diverse effects of different additives and surfactants on foam properties and the performance of foam concrete.

B.3. pH

The type and charge of surfactants, as well as the pH of the foam solution, play a crucial role in foam stability. It is known that the attachment of positively or negatively charged ionic surfactants to the surface of air bubbles increases foam stability due to electrostatic repulsion [29]. It has been reported that zwitterionic surfactants exhibit optimal foaming properties at alkaline pH levels [12], while in another study using anionic surfactants (sodium lauryl sulfate, alpha olefin sulfonate, sodium lauryl ether sulfate, and sodium alcohol ether sulfate) with pH values of 6.7, 6.6, 6.7, and 6.8 respectively, alpha olefin sulfonate provided better gains in mechanical, transport, and microstructural properties of anionic lightweight concrete. Additionally, it was noted that the scope of the study was not sufficient for evaluations related to potential effects of non-ionic or mixed surfactants [48].

Composite protein surfactants have been found to be more effective than other used rosins, dodecyl, and lauric acids in reducing surface tension or increasing bubble film strength, thereby achieving more stable bubbles. For pH values of 7.9, 8.2, 8.0, and 8.1, composite protein, resin, dodecyl, and lauric acid exhibited foaming rates of 22.1%, 29.6%, 33.3%, and 42.5%, bubble film resistances of 682.5, 340.8, 321.6, and 305.4 Pa, and minimum stable bubble radii of 0.17, 0.21, 0.21, and 0.27 mm, respectively [49]. On the other hand, in a study examining foam stability by adjusting the pH of composite foam-forming agents (sodium α-alkenyl sulfonate, sodium dodecyl sulfate, coconut oil, liquid resin with foam stabilizers hydroxypropyl methylcellulose ether, xanthan gum, and sucrose) to a range of 11-14 using diluted NaOH solution, a foaming coefficient of 41, settlement distance of 1 hour, and zero bleeding rate were determined, with the foam maintaining stability for 2 hours but beginning to deteriorate once the pH exceeded 12.4 [39]. Another study compared nano-alumina modified surfactants and $Ca(OH)_2$ as foam stabilizers adjusted to pH 9, 11, and 12.5 with deionized water applications. For deionized water and the mentioned pH levels, viscosities were determined as 0.248, 0.263, 0.235, and 0.200 PaS, and bubble wall thicknesses were 39.25, 49.52, 33.30, and 26.05 μm, respectively. It was noted that the reaction of alumina-$Ca(OH)_2$ on the surface delayed bubble disproportionation and fusion, thereby preventing drainage and enhancing foam stability, ultimately achieving a finer and more homogeneous pore structure for improved performance of foam concrete [50].

The relationship between foam yield and pH in protein-based surfactants is quite specific. The highest foam yield is typically obtained near the isoelectric point pH, varying across a wide pH range for different surfactants. Generally, an increase in pH enhances foaming [51]. However, under very high alkaline conditions, the reduced solubility of protein particles in water makes them less suitable for foaming [52]. In cementitious mixtures, the foaming behaviors of 13 proteins were examined in deionized water and a synthetic pore solution (0.1062 M KOH, 0.0489 M Na_2SO_4, 0.037 M K_2SO_4, and 0.0212 M $Ca(OH)_2$ - pH ~13.6). It was evaluated that the high pH of the pore solution increased foaming, bubble film roughness, and thickness, indicating improved foam stability [53].

B.4. Foam Shape and Size Distribution

In foamed concrete, pore sizes are generally classified into three size ranges based on different standards and methods: gel pores (<10 nm), capillary pores (10-10,000 nm), and macro pores (10,000-100,000 nm, including entrained and entrapped air pores). The foam bubbles obtained with foaming agents are mostly spherical, and the pores of the foamed concrete used exhibit spherical or nearly spherical, ellipsoidal, or irregular structures. The high concentration of foaming agent increases the number and distribution of bubbles. Additionally, the properties of the liquid film separating the bubbles vary depending on the type of surfactant. Bubble size is related to bubble stability and shape.

Spherical, small-diameter bubbles with good distribution enhance foam stability. Due to the inverse proportionality of the pressure difference between the inside and outside of the bubble to the bubble radius and direct proportionality to surface tension, smaller bubbles have a higher curvature radius than larger bubbles [54]. Differences in curvature radius between adjacent air bubbles lead to pressure differences, which disrupt bubbles if they exceed the surface tension of the cement paste [55].

Studies on the effects of different types of surfactants on foam bubble size and foam concrete porosity are actively ongoing. Microstructure analysis using X-CT and bubble analysis apparatus has shown that synthetic surfactants lead to smaller pore sizes, a narrower range of pore sizes, and smaller pore connections [56]. In a study using sodium dodecyl sulfate (anionic), cetyltrimethyl ammonium bromide (cationic), octyl phenol ethoxylate (nonionic), and protein-based (amphoteric) surfactants, it was found that the size distribution of bubbles in foams larger than 300 µm undergoes a complex change over time, initially increasing and then decreasing. It was also reported that the type of charge of the surfactant affects adsorption and stabilizes the foam due to decreased gas transfer, and as particles harden, the process of pore formation occurs [57].

Some studies also observe the use of composite surfactants or certain additives. A combination of anionic and non-ionic (neutral) surfactants was found to reduce the maximum pore diameter from 1.84 mm to 1.49 mm and increase strength by 25%, compared to using only anionic surfactants. It was evaluated that most anionic surfactants are adsorbed onto positively charged areas of cement particles, leading to excessive migration from the air-liquid interface and compromising foam stability [58]. In another study evaluating the performance of foam produced using sodium lauryl sulfate and nonylphenol ethoxylate surfactants with the additive sodium carboxymethyl cellulose, it was noted that increasing surfactant and additive concentrations led to the formation of smaller foam bubbles, resulting in a 24-44% decrease in average air void diameter and a 29-37% increase in compressive strength of concrete [5]. Xiong et al. used nano-Al_2O_3 to adjust viscosity for stabilizing foam and methyl cellulose to enhance foam stability for a synthetic surfactant containing CH_3 as a hydrophobic group and -COOH as a hydrophilic group [59]. In another study, foam concrete with different densities (398, 460, 580, and 759 kg/m^3) was produced using a polymer composite foam agent, and pore sizes and distributions from nanometer to micron levels were determined using nuclear magnetic resonance. It was evaluated that increasing density reduced micro-pore sizes and increased compressive strength and thermal conductivity [60].

B.5. Density

Foam density plays a critical role in calculating the necessary foam volume required to achieve the desired density of foam concrete [27]. According to ASTM C796/C796M standard, the recommended unit volume mass for foam concrete ranges from 30 to 65 kg/m^3 [61]. This range can be adjusted based on recommendations from manufacturers depending on the foaming agent used, chemical additives, and foam generator. Additionally, it is emphasized that foam density depends on various factors such as the type of surfactant [62], surfactant concentration [27], additives [17], lamellar thickness [63], foam production pressure [1], and viscosity of the foam solution.

The bubbles within the foam are surrounded by a liquid layer called lamellae. The thickness of these lamellae and the properties of the liquid within them significantly influence the overall properties of the foam [12]. Generally, high-density foams have thicker lamellar layers compared to low-density foams. Therefore, as the thickness of the lamellar film around the bubbles increases, the stability of the foam also increases. Researchers argue that synthetic foaming agents tend to expand more compared to protein-based foaming agents, resulting in lower density [64].

Therefore, when using low-density foams in foam concrete production, it is recommended to add foam thickening agents to increase foam density. Researchers have added various additives such as carboxymethyl cellulose [17], sodium hydroxide, sodium carbonate, and sodium chloride to increase the viscosity of the foam solution and thereby improve foam density and concrete properties [12].

It has been found that starch nanoparticles modified with hydrophobicity through citric acid, in combination with synthetic surfactants containing hydrophilic and hydrophobic groups, increased foam density from 21 kg/m^3 to 69 kg/m^3 and viscosity from 0.135 to 0.189 PaS. Additionally, the compressive strength after 28 days of curing increased from 2.35 MPa to 2.77 MPa. These changes were attributed to the uniform adsorption of hydrophobic starch nanoparticles on foam surfaces and their use in filling inter-pore spaces between foam-cement matrix [42]. A similar approach was demonstrated by Xiong et al., aiming to prepare ultra-stable foam using thionyl chloride ($SOCl_2$) treatment and nano-alumina (NA) modification, utilizing vegetable (PS) and animal protein (AS) based and synthetic surfactants (SS) with similar functional groups [41]. Indeed, the addition of nano-alumina increased foam densities for vegetable, animal, and synthetic surfactants from 18, 21, and 19 kg/m^3 to 22, 24, and 76 kg/m^3 respectively. The differences in drainage reductions of 4%, 5%, and 11% respectively in 5 minutes were attributed to the homogeneous and discrete distribution of nano-alumina, where homogeneous distribution increased interfacial resistance and consequently delayed drainage further. On the other hand, the hydration product of $Ca(OH)_2$ - nano-alumina pozzolanic reaction was evaluated to fill cell wall pores, thereby enhancing the performance (mechanical strength, drying shrinkage, and homogeneity) of foam concrete.

III. CONCLUSION

In studies on foam concrete, the limited provision of foam agent characteristics such as only commercial names, whether they are synthetic or natural, their usage amounts, and densities makes it difficult to evaluate the findings obtained [65]. Furthermore, even when the same foam agent is used, variations in dilution ratio, shaping process, air pressure, addition to mortar, and mixing process can lead to changes in the properties of foam concrete. Therefore, this situation underscores the key role of foam quality in foam concrete properties.

Natural surfactants are reported to be 60-70% cheaper than synthetic surfactants, and their high medical values, along with antimicrobial and antibacterial properties against microorganisms, have made them an indispensable part of human life [15]. Yang et al., evaluated a foam agent (SJ-2) derived from fruits of certain natural plants such as Chinese soapberry, whose main chemical component is triterpenoid saponin. They examined its effects on the workability, permeability, air bubbles, strength, freeze/thaw resistance, etc., of fresh and hardened concrete, comparing it with Vinsol resin and abietic soap concrete. The agent was considered a high-quality air-entraining agent based on these evaluations [66].

In related studies, it is suggested that instead of synthetic surfactants, whose exact contents are often undisclosed and widely used, there would be benefit in exploring the comparative use of natural surfactants as part of sustainability efforts.

IV. REFERENCES

[1] Ranjani, I. S., Ramamurthy, K.. “Relative assessment of density and stability of foam produced with four synthetic surfactants,” *Materials and structures*, 4310, 1317-1325, 2010.

[2] Prishepa, I.A. Shangin, S.N. KurmangalievIn, R.M. “Vliyaniye Modifitsiruyushchikh Dobavok Na Svoystva Penoobrazovateley Tsementnykh Kompozitsiy”, *Ix Mezhdunarodnaya Konferentsiya Studentov I Molodykh Uchenykh*, Perspektivy Razvitiya Fundamental'nykh Nauk. 2012

[3] Xingjun, L., Mingli, C., Yan, L., Xin, L., Qian, L., Rong, T., Yuping, D., “A new absorbing foam concrete: preparation and microwave absorbing properties,” *Advances in concrete construction*, vol. 3, no. 2, pp. 103-111, 2015.

[4] Gao, L., “Experimental study of the effect of chemical additives on mechanical properties of foamed concrete,” *Functional materials*, vol. 26, no. 4, pp. 802-806, 2019.

[5] Sahu, S. S., and Gandhi, I. S. R., “Studies on influence of characteristics of surfactant and foam on foam concrete behaviour,” *Journal of Building Engineering*, vol. 40, pp. 1-16, 2021.

[6] Kronberg, B., Holmberg, K., and Lindman, B., “Types of surfactants, their synthesis, and applications,” *Surface Chemistry of Surfactants and Polymers*, pp. 1-47, 2014.

[7] Gerola, A. P., Costa, P. F., Quina, F. H., Fiedler, H. D., and Nome, F., “Zwitterionic surfactants in ion binding and catalysis,” *Current opinion in colloid & interface science*, vol. 32, pp. 39-47, 2017.

[8] Nakama, Y., *Cosmetic Science and Technology Theoretical Principles and Applications*. Kanagawa, Japan, Elsevier, 2017, Chapter 15 - Surfactants, pp. 231-244.

[9] Mokaya, R. (Robert A. Meyers (Ed)), *Encyclopedia of Physical Science and Technology*, Third Edition, California, U.S., Academic Press Inc., 2003, Mesoporous Materials Synthesis and Properties, pp. 369-381.

[10] Middleton, J. M., Siefert, R. L., Markie'Sha, H. J., Schrand, A. M., and Kolel-Veetil, M. K., “Micelle formation, structures, and metrology of functional metal nanoparticle compositions,” *AIMS Materials Science*, vol. 8, no. 4, pp. 560-586, 2021.

[11] Porter, M.R., *Handbook of Surfactants*. Cardiff, UK, Springer, 2013, pp. IX-227.

[12] Sahu, S. S., Gandhi, I. S. R., Khwairakpam, S., “State-of-the-art review on the characteristics of surfactants and foam from foam concrete perspective,” *Journal of The Institution of Engineers* India: Series A, vol. 99, pp. 391-405, 2018.

[13] Hayes, D. G., and Smith, G. A.. *Biobased surfactants*, Champaign, USA, Aocs Press, 2019, ch. 1, pp. 3-38.

[14] Panesar, D. K., “Cellular concrete properties and the effect of synthetic and protein foaming agents”, *Construction and building materials*, vol. 44, pp. 575-584, 2013.

[15] Bulbul Boruah, B. B., and Minti Gogoi, M. G., “Plant based natural surfactants”. *Asian Journal of Home Science*, vol. 8, no. 2, pp. 759-762, 2013.

[16] Kim, J. M., Jeong, J. Y., “Influence of foaming agents on the properties of foamed concretes having various densities,” *한국건축시공학회지*, vol.12, no. 1, pp. 22-30, 2012.

[17] Colak, A., “Density and strength characteristics of foamed gypsum,” *Cement and Concrete Composites*, vol.22, no. 3, pp.193-200, 2000.

[18] Hajimohammadi, A., Ngo, T., Mendis, P., Kashani, A., and van Deventer, J. S., “Alkali activated slag foams: the effect of the alkali reaction on foam characteristics,” *Journal Of Cleaner Production*, vol. 147, pp. 330-339, 2017.

[19] Ghorbani, S., Sharifi, S., de Brito, J., Ghorbani, S., Jalayer, M. A., and Tavakkolizadeh, M., “Using statistical analysis and laboratory testing to evaluate the effect of magnetized water on the stability of foaming agents and foam concrete,” *Construction and Building Materials*, vol. 207, pp. 28-40, 2019.

[20] He, J., Gao, Q., Song, X., Bu, X., He, J. “Effect of foaming agent on physical and mechanical properties of alkali-activated slag foamed concrete,” *Construction and Building Materials*, vol. 226, pp. 280-287, 2019.

[21] Senff, L., Novais, R. M., Carvalheiras, J., Labrincha, J. A., “Eco-friendly approach to enhance the mechanical performance of geopolymer foams: Using glass fibre waste coming from wind blade production,”*Construction and Building Materials*, vol. 239, pp. 1-11, 2020.

[22] Davraz, M., Kilinçarslan, Ş., Koru, M., Tuzlak, F., “Investigation of relationships between ultrasonic pulse velocity and thermal conductivity coefficient in foam concretes,” *Acta Physica Polonica* A, vol. 130 no. 1, pp. 469-470, 2016.

[23] Mestnikov, A., Semenov, S., Strokova, V., Nelubova, V., “Autoclave Foam Concrete: Structure and Properties,” *In Aıp Conference Proceedings*, vol. 1698, no. 1, pp. 1-6, 2016.

[24] Oren, O. H., Gholampour, A., Gencel, O., Ozbakkaloglu, T., “Physical and mechanical properties of foam concretes containing granulated blast furnace slag as fine aggregate,” *Construction and Building Materials*, vol. 238, pp. 1-9, 2020.

[25] Ai, L., “Construction method of the new thermal insulation material foam concrete,” 6th *International Conference on Management, Education, Information and Control*, 2016, pp. 408-412.

[26] Chica, L., Alzate, A., “Cellular concrete review: New trends for application in construction,” *Construction and Building Materials*, vol. 200, pp. 637-647, 2019.

[27] Ranjani, G., Ramamurthy, K.,“Analysis of the foam generated using surfactant sodium lauryl sulfate,” *International Journal of Concrete Structures and Materials*, vol. 4, no.1, pp. 55-62, 2010.

[28] Lioumbas, J. S., Georgiou, E., Kostoglou, M., and Karapantsios, T. D., “Foam free drainage and bubbles size for surfactant concentrations below the CMC,” *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, vol. 487, pp. 92-103, 2015.

[29] Souza, M. T., Maykot, C. K., Araújo, A. C. Z., Raupp-Pereira, F., and de Oliveira, A. N., “Electrolytes’ influence on foamability and foam stability of cement suspensions,” *Construction and Building Materials*, vol 157, pp. 363-371, 2017.

[30] Tunstall, L. E., Ley, M. T., and Scherer, G. W., “Air entraining admixtures: Mechanisms, evaluations, and interactions,” *Cement and Concrete Research*, vol. 150, pp. 1-25, 2021.

[31] Johnson, P., Vaccaro, M., Starov, V., and Trybala, A., “Foam formation and interaction with porous media,” *Coatings*, vol. 10, pp. 1-16, 2020.

[32] Feneuil, B., Pitois, O., and Roussel, N., “Effect of surfactants on the yield stress of cement paste,” *Cement and Concrete Research*, vol. 100, pp. 32-39, 2017.

[33] Mortada, N., Phelipot-Mardele, A., & Lanos, C. “Effects of surfactants on aqueous foams properties: a step towards mineral foams”. *European Journal of Environmental and Civil Engineering*, vol. 26, no. 14, pp. 7307-7318, 2022.

[34] Kuzielová, E., Pach, L., and Palou, M., “Effect of activated foaming agent on the foam concrete properties,” *Construction and Building Materials*, vol. 125, pp. 998-1004, 2016.

[35] Tran, N. P., Nguyen, T. N., Ngo, T. D., Le, P. K., and Le, T. A., “Strategic progress in foam stabilisation towards high-performance foam concrete for building sustainability: A state-of-the-art review,” *Journal of Cleaner Production*, vol. 375, pp. 1-27. 2022.

[36] Gorbach, P., Shcherbin, S., and Savenkov, A., “The method of selecting a foaming agent and its concentration in the production of non-autoclaved hard cellular concrete”, In *MATEC Web of Conferences*, vol. 212, no. 01004, pp. 1-5, 2018.

[37] Boddepalli, U., Gandhi, I. S. R., and Panda, B., “Stability of three-dimensional printable foam concrete as function of surfactant characteristics,” *Frontiers of Structural and Civil Engineering*, vol. 17, no. 6, pp. 935-947, 2023.

[38] Falliano, D., Restuccia, L., and Gugliandolo, E., “A simple optimized foam generator and a study on peculiar aspects concerning foams and foamed concrete”. *Construction and Building Materials*, vol. 268, pp.1-16, 2021.

[39] He, J., Liu, G., Sang, G., He, J., and Wu, Y., “Investigation on foam stability of multi-component composite foaming agent,” *Construction and Building Materials*, vol. 391, pp. 1-15, 2023.

[40] She, W., Du, Y., Miao, C., Liu, J., Zhao, G., Jiang, J., and Zhang, Y., “Application of organic- and nanoparticle-modified foams in foamed concrete: Reinforcement and stabilization mechanisms,” *Cement and Concrete Research*, vol. 106, pp. 12-22, 2018.

[41] Xiong, Y., Zhu, Y., Chen, C., and Zhang, Y., “Effect of nano-alumina modified foaming agents on properties of foamed concrete,” *Construction and Building Materials*, vol. 267, pp. 1-13, 2021.

[42] Song, N., Li, Z., Yi, W., and Wang, S., “Properties of foam concrete with hydrophobic starch nanoparticles as foam stabilizer,” *Journal of Building Engineering*, vol. 56, pp. 1-12, 2022.

[43] Sahu, S. S., Ranjani Gandhi, I. S., Kumar, A., and Garg, S., “Evaluation of suitability of carboxymethyl cellulose in performance improvement of sodium lauryl sulfate foam and compressive strength of foam concrete,” *Advances in Civil Engineering Materials*, vol. 10, no. 1, pp. 74-92, 2021.

[44] Jiang, L., Wang, Z., Gao, X., Cui, M., Yang, Q., and Qin, J., “Effect of nanoparticles and surfactants on properties and microstructures of foam and foamed concrete,” *Construction and Building Materials*, vol. 411, pp.1-12, 2024.

[45] Zhu, H., Chen, L., Xu, J., and Han, Q., “Experimental study on performance improvement of anionic surfactant foaming agent by xanthan gum,” *Construction and Building Materials*, vol. 230, pp. 1-8, 2020.

[46] Wagh, C. D., and Gandhi, I. S. R., “Investigations on the performance of xanthan gum as a foam stabilizer and assessment of economic and environmental impacts of foam concrete production,” *Journal of Building Engineering*, vol. 82, pp. 1-23, 2024.

[47] Khwairakpam, S., Gandhi, I. S. R., and Wagh, C., “Investigations on Optimization of Extraction Process of Surfactant from Hingot Fruit (Balanites aegyptiaca) and Sesame Seed (Sesamum indicum) and Its Suitability in Foam Concrete Production,” *Arabian Journal for Science and Engineering*, vol. 48, no. 10, pp. 14119-14152, 2023.

[48] Maglad, A. M., Mydin, M. A. O., Datta, S. D., Abbood, I. S., and Tayeh, B. A., “Impact of anionic surfactant-based foaming agents on the properties of lightweight foamed concrete,” *Construction and Building Materials*, vol. 438, pp. 1-16, 2024.

[49] Xiao, M., Li, F., Yang, P., Li, B., Wei, J., and Yu, Q. “Influence of slurry characteristics on the bubble stability in foamed concrete,” *Journal of Building Engineering*, vol. 71, pp. 1-12, 2023.

[50] Yuanliang, X., Baoliang, L., Chun, C., and Yamei, Z., “Properties of foamed concrete with Ca (OH)2 as foam stabilizer”. *Cement and Concrete Composites*, vol. 118, pp. 1-11, 2021.

[51] Montayev, S. A., Shakeshev, B. T., Ryskaliyev, M. Z., Adilova, N. B., Narikov, K. A., “Collagen agent technology for foam concrete production,” *ARPN J. Eng. Appl. Sci*, vol. 12, no. 5, pp. 1674-1678, 2017.

[52] Cai, J., Zhang, G., Xie, Z., Zhu, Y. “Preparation of foaming agent from photosynthetic bacteria liquid by direct thermal alkaline treatment,” *Construction and Building Materials*, vol. 238, pp. 1-8, 2020.

[53] Masoule, M. S. T., Baffoe, E., and Ghahremaninezhad, A., “On the physicochemical properties and foaming characteristics of proteins in cement environment,” *Construction and Building Materials*, vol. 366, pp. 1-17, 2023.

[54] Kim, J. M., Kwak, E. G., Oh, K. C., Kang, C.,“Properties of bubble according to types and concentrations of concrete foaming agent,” *Journal of the Korea concrete institute*, vol. 232, pp. 151-158, 2011.

[55] Sang, G., Zhu, Y., Yang, G., Zhang, H., “Preparation and characterization of high porosity cement-based foam materia,” *Construction and Building Materials*, vol. 91, pp. 133-137, 2015.

[56] Sun, C., Zhu, Y., Guo, J., Zhang, Y., Sun, G., “Effects of foaming agent type on the workability, drying shrinkage, frost resistance and pore distribution of foamed concrete,” *Construction and Building Materials,* vol. 186, pp. 833-839, 2018.

[57] Zhang, M., Li, J., Bian, P., Gao, P., Guo, B., Zhan, B., and Yu, Q., “Investigation of the evolutionary behavior and stabilization mechanism of foams with different properties in cement paste,” *Construction and Building Materials*, vol. 426, pp. 1-13, 2024.

[58] Kashani, A., Ngo, T. D., Nguyen, T. N., Hajimohammadi, A., Sinaie, S., and Mendis, P., “The effects of surfactants on properties of lightweight concrete foam,” *Magazine of concrete research*, vol. 72, no. 4, pp.163-172, 2020.

[59] Xiong, Y., Hu, Z., Jia, Z., Liu, C., Ma, L., and Liu, Z., “Effect of formic acid as an accelerator on foam-stability, compressive strength, and pore size distribution of foam concrete,” *Journal of Building Engineering,* vol. 66, pp. 1-11, 2023.

[60] Bie, Y., Ba, S., and Chen, S., “Studies on foamed concrete micropores and their effects on stress distribution and heat conduction,” *Journal of Building Engineering,* vol. 87, pp. 1-11, 2024.

[61] Standard Test Method for Foaming Agents for Use in Producing Cellular Concrete Using Preformed Foam, ASTM C796/C796M, 2019.

[62] Hamad, A. J., “Materials, production, properties and application of aerated lightweight concrete,” *International journal of materials science and engineering*, vol.2, no. 2, pp. 152-157, 2014.

[63] M. Krzan, “Rheology of the wet surfactant foams and biofoams-a review,” *Tech. Trans. Chem*. 1-Ch, pp. 9–27, 2013.

[64] Amran, Y., Farzadnia, N., Ali, A., “Properties and applications of foamed concrete; a review,” *Constr. Build. Mater*. vol. 101, pp. 990–1005, 2015.

[65] Brady, K. C., Watts, G. R. A., and Jones, M. R., “Specification for foamed concrete,” Crowthorne, UK: TRL Limited, 2001, pp. 1-78.

[66] Yang, Q., Zhu, P., Wu, X., Huang, S., “Properties of concrete with a new type of saponin air-entraining agent,” *Cement and Concrete Research*, vol. 308, pp. 1313-1317, 2000.

[67] Aydos Chemical Industry and Trade Inc. (Jul. 10, 2023), *Köpük Ajanı* [Online]. Available: https://www.aydos.com.tr/tr/urunler/kopuk-ajani.

[68] Draco. (Jul. 10, 2023). *Foam Concrete*, [Online]. Available: https://www.draco.com.tr/FOAMCRETE-i354.

[69] Iksa Constructıon Addıtıves Industry and Trade Inc. (2022). Accessed: Oct. 03, 2022 [Online]. Available: http://www.iksa.com.tr/pdf/bkk1.pdf.

[70] Milonga Inc. (2022) Accessed: Oct. 03, 2022 [Online]. Available: https://milohafifbeton.com/?gclid=EAIaIQobChMIvMnpzN7gIVESwYCh3glQjeEAAYASAAEgKhdvD_BwE.

[71] Biosaponeks. (Jun. 10, 2024), *Uygulamalar*. [Online]. Available: https://biosaponeks.com.tr /tr/ uygulamalar.html.

[72] Nanohb. (Mar. 05, 2024) *Köpük Ajanı.* [Online].https://www.nanohbt.com/kopuk-ajani.html.

[73] Artra Construction. Landscape Plastic Inc. (Oct. 10, 2022) [Online]. Available: http://www.artrainsaat.com.

[74] Fatsa Chemical Industry and Trade Inc. (Oct. 10, 2022). *Hafif Köpük Beton Ajanı* [Online]. Available: https://www.fatsakimya.com/kategori/hafif-kopuk-beton-ajani/

[75] Emami, H., Ayatizadeh Tanha, A., Khaksar Manshad, A., and Mohammadi, A. H., “Experimental investigation of foam flooding using anionic and nonionic surfactants: A screening scenario to assess the effects of salinity and ph on foam stability and foam height,” *ACS omega*, vol. 7, no. 17, pp. 14832-14847, 2022.

[76] Esmaily, H., Nuranian, H., “Non-autoclaved high strength cellular concrete from alkali activated slag,” *Construction and Building Materials*, vol. 26, no. 1, pp. 200-206, 2012.

[77] Falliano, D., De Domenico, D., Ricciardi, G., Gugliandolo, E., “Key factors affecting the compressive strength of foamed concrete,” In *IOP Conference Series: Materials Science and Engineering*, vol. 431, no. 6, pp. 1-8, 2018.

[78] Falliano, D., De Domenico, D., Ricciardi, G., Gugliandolo, E., “Experimental investigation on the compressive strength of foamed concrete: Effect of curing conditions, cement type, foaming agent and dry density,” *Construction and Building Materials*, vol. 165, pp. 735-749, 2018.

[79] Wang, X., Huang, J., Dai, S., Ma, B., Jiang, Q., “Investigation of silica fume as foam cell stabilizer for foamed concrete,” *Construction and Building Materials*, vol. 237, pp. 1-12, 2020.

[80] Stencel, J. M., Song, H., Cangialosi, F., “Automated foam index test: Quantifying air entraining agent addition and interactions with fly ash–cement admixtures,” *Cement and Concrete Research*, vol. 39, no. 4, pp. 362-370, 2009.

[81] Pan, Z., Li, H., Liu, W., “Preparation and characterization of super low density foamed concrete from Portland cement and admixtures,” *Construction and Building Materials*, vol. 72, pp. 256-261, 2014.

[82] Kim, J. M., Jeong, J. Y., Hwang, E. H., Shin, S. C., “Properties of foamed concrete according to types and concentrations of foam agent,” *Journal of the Korea concrete institute*, vol. 24, no. 1, pp. 61-70, 2012.

[83] Kudyakov, A. I., Kopanitsa, N. O., Sarkisov, J. S., Kasatkina, A. V., Prischepa, I. A., “Foam concrete of increased strength with the thermomodified peat additives,” In *IOP Conference Series: Materials Science and Engineering*, vol. 71, no. 1, pp. 1-7, 2015.

[84] Liu, R., Ouyang, P., Yang, Y., Qi, W., “Relationship Between FreezeThaw Resistance and AirVoid Characteristics of Foam Concrete with Hydrogen Peroxide as Foaming Agent,” *Journal of The Chinese Ceramic Society*, vol. 428, no. 8, pp. 1055-1063, 2014.

[85] Łach, M., Korniejenko, K., Mikuła, J., “Thermal insulation and thermally resistant materials made of geopolymer foams,” *Procedia Eng*, vol. 151, pp. 410-416, 2016.

[86] Samson, G., Cyr, M., “Porous structure optimisation of flash-calcined metakaolin/fly ash geopolymer foam concrete,” *European Journal of Environmental and Civil Engineering*, vol. 22, no. 12, pp.1482-1498, 2018.

[87] Steshenko, A., Kudyakov, A., Konusheva, V., Syrkin, O., “Structure formation control of foam concrete,” In *AIP Conference Proceedings* vol. 1800, no. 1, pp. 1-8, 2017.

[88] Batool, F., Bindiganavile, V., “Fresh properties of fiber reinforced cement-based foam with Pozzolans,” *Iranian Journal of Science and Technology*, Transactions of Civil Engineering, vol. 44, pp 253-264, 2020.

[89] Othuman, M. A., Wang, Y. C., “Elevated-temperature thermal properties of lightweight foamed concrete,” *Construction and Building Materials*, vol. 25, no. 2, pp. 705-716, 2011.

[90] Awang, H., Mydin, M. A. O., Roslan, A. F., “Effect of additives on mechanical and thermal properties of lightweight foamed concrete,” *Advances in applied science research*, vol. 3, no. 5, pp. 3326-3338, 2012.

[91] Awang, H., Mydin, M. A. O., Roslan, A. F., ”Mıcrostructural ınvestıgatıon of lıghtweıght foamed concrete ıncorporatıng varıous addıtıves,” *International Journal of Academic Research*, vol. 4, no. 2, pp. 196-200, 2012.

[92] Mydin, M. A. O., Wang, Y. C., “Mechanical properties of foamed concrete exposed to high temperatures,” *Construction and Building Materials*, vol. 26, no. 1, pp. 638-654, 2012.

[93] Roslan, A. F., Awang, H., Mydin, M. A. O., ” Effects of various additives on drying shrinkage, compressive and flexural strength of lightweight foamed concrete LFC,” *In Advanced Materials Research*, vol. 626, pp. 594-604. 2013.

[94] Krämer, C., Schauerte, M., Kowald, T. L., Trettin, R. H., "Three-phase-foams for foam concrete application," *Materials Characterization*, vol. 102, pp. 173-179, 2015.

[95] Waheed, A., Arshid, M. U., Mehboob, S., Ahmed, A., Sultan, T., "Preparation of Low-Cost Foam Concrete Using Detergent," *Technical Journal*, vol. 24, no. 4, pp. 1-7, 2019.

[96] Hilal, A. A., Thom, N. H., Dawson, A. R., "On void structure and strength of foamed concrete made without/with additives," *Construction and Building Materials*, vol. 85, pp. 157-164, 2015.

[97] Hilal, A. A., Thom, N. H., Dawson, A. R., "On entrained pore size distribution of foamed concrete," *Construction and Building Materials*, vol. 75, pp. 227-233, 2015.

[98] Van, L. T., Kim, D. V., Xuan, H. N., Tho, V. D., Bulgakov, B. I., Alexandrova, O. V., "Modelling of the effect of the water-cement ratios on properties foam concrete," *In Journal of Physics: Conference Series* Vol. 1425, No. 1, pp. 1-9, 2019.

[99] Harith, I. K., " Study on polyurethane foamed concrete for use in structural applications," *Case studies in construction materials*, vol. 8, pp. 79-86, 2018.

[100] Long, W. W., Wang, J. S., "Study on compressive strength and moisture content of different grades density of foam concrete," In *2015 International Conference on Material Science and Applications (ICMSA-15)*, 2014, pp. 167-172 .

[101] Bing, C., Zhen, W., Ning, L., "Experimental research on properties of high-strength foamed concrete," *Journal of materials in civil engineering*, vol. 24, no. 1, pp. 113-118, 2012.

[102] Wei, S., Yiqiang, C., Yunsheng, Z., Jones, M. R., "Characterization and simulation of microstructure and thermal properties of foamed concrete," *Construction and building materials*, vol. 47, pp. 1278-1291, 2013.

[103] Remadnia, A., Dheilly, R. M., Laidoudi, B., Quéneudec, M., "Use of animal proteins as foaming agent in cementitious concrete composites manufactured with recycled PET aggregates," *Construction and Building Materials*, vol. 23, no. 10, pp. 3118-3123, 2009.

[104] Yang, K. H., Lee, K. H., Song, J. K., Gong, M. H., "Properties and sustainability of alkali-activated slag foamed concrete," *Journal of Cleaner Production*, vol. 68, pp. 226-233, 2014.

[105] Kilincarslan, Ş., Davraz, M., Akça, M., "The effect of pumice as aggregate on the mechanical and thermal properties of foam concrete", *Arabian Journal of Geosciences*, vol. 11, no. 289, 2018.

[106] Nambiar, E. K., Ramamurthy, K., "Shrinkage behavior of foam concrete," *Journal of materials in civil engineering*, vol. 21, no. 11, pp. 631-636. 2009.

[107] Dayalan, J., "Experimental Study on Properties of Light Weight Foam Concrete," *International Research Journal of Engineering and Technology IRJET*, vol.06, no. 5, 2019.

[108] Varghese, S., Ashok, A. M., Joseph, A. K., Emmanuel, S., Swathylekshmi, O. V., "A study on properties of foamed concrete with natural and synthetic foaming agent,"*International Research Journal of Engineering and Technology*, vol. 4, no. 3, pp. 2009-2011, 2017.

[109] Akthar, F. K., Evans, J. R. G., " High porosity (> 90%) cementitious foams", *Cement and Concrete Research*, vol. 40, no. 2, pp. 352-358, 2010.