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Experimental Study on Water Absorption and Compressive Strength of Foamed Concrete Produced Using Eco-Foaming Agent

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Abstract

This paper presents the properties of foamed concrete using a plant based eco-foaming agent. Two series of foamed concrete, with target densities ranging from 1500 to 1800 kg/m3 were prepared using natural fine aggregates of varying particles sizes. Mix A (MA) incorporated aggregates passing a 2.36 mm sieve, while Mix B (MB) used aggregates passing a 1.18 mm sieve. The workability of fresh foamed concrete was assessed through spreadability tests. Hardened foamed concrete specimens were tested for compressive strength at 7, 14, and 28 days. Meanwhile, water absorption test was conducted at 28 days. The results revealed that MB exhibited higher compressive strength than MA at lower densities. Conversely, at higher densities, MA showed superior strength. MA also demonstrated slightly better spreadability, while MB had lower water absorption. These findings suggest that plant-based eco-foaming agents offer a sustainable and effective alternative for foamed concrete production.

Keywords: Foamed concrete, eco-foaming agent, size of fine aggregate, water absorption, compressive strength

1. Introduction

Nowadays, the construction industry has met increasing challenges of growing demand for building material, especially concrete. It has been reported that concrete demand per year for construction is almost 3 tons per person and this has led to negative impacts on the environment and human health (Elia et al., 2018). The concrete production process contributes to 81% of carbon emissions (Flower & Sanjayan, 2007). However, foamed concrete shows a much more sustainable pattern in minimizing impact towards the environment. This is because in the process of producing foamed concrete, less cement content is used and alternative materials are replaced to increase the strength of concrete, contributing to lesser carbon emissions (Nia & Chari, 2023).

Recent research highlights the potential of natural eco-foaming agents in improving the performance of foamed concrete. For example, Varghese et al. (2017) has demonstrated that foamed concrete made with natural foaming agents, such as soap nut extract, exhibited higher compressive strength compared to those made with synthetic agents., which demonstrated that the use of natural foaming agent is capable of high-quality foamed concrete. Similarly, studies utilizing other natural foaming agent, like hingot seed and sesame seed, reported compressive strengths ranging from 6 to 12 MPa, further validating that the eco-foaming agent can be used as a sustainable option in foamed concrete production (Selija & Gandhi, 2022).

This study aims to evaluate the properties of foamed concrete produced using a plant-based eco-foaming agent, focusing on workability, compressive strength, and water absorption. Additionally, it explores how density influences both strength and water absorption characteristics.

2. Methodology

2.1 Materials

The materials used to produce the foamed concrete included Ordinary Portland cement, fine aggregates, and preformed foam extracted from the plant-based eco-foaming agent (Figure 1).

Figure 1. Plant-based Eco-foaming agent

The cement added served as the binder, with water and natural fine aggregates of different sizes: Mix A (MA) utilized fine aggregate passing through 2.36 mm sieve, while Mix B (MB) used fine aggregate passing 1.18 mm sieve. Figure 2 shows the materials used in producing the foamed concrete.

Figure 2. Materials used in producing foamed concrete

2.2 Mix Design

For the mix design, the foamed concrete mix composition is divided into two series, MA and MB to evaluate the influence of aggregate size on the properties of the foamed concrete. MA had incorporated fine aggregate size passing 2.36 mm sieve, representing a coarser sand fraction. In contrast, MB utilized fine aggregate passing 1.18 mm sieve, representing a finer sand fraction. Table 1 shows the mix composition that was used in the study.

Table 1. Mix the composition of foamed concrete

Mix	Target density (kg/m^3)	Constituents			
		Cement (kg)	Sand (kg)	Water (kg)	Foam (liter) (Elia et al., 2018)
MA15	1500	1	2	0.55	1.1
MA16	1600	1	2	0.55	1.0
MA17	1700	1	2	0.55	0.8
MA18	1800	1	2	0.55	0.6
MB15	1500	1	2	0.55	1.1
MB16	1600	1	2	0.55	1.0
MB17	1700	1	2	0.55	0.8
MB18	1800	1	2	0.55	0.6

2.3 Experimental Tests

To obtain the density of the foamed concrete, equation 1 is used where "M" refers to the mass (kg) and "V" is the volume (m^3) of the specimen where the load is applied. The unit for density, "P" is kg/m^3.

$$P = \frac{M}{V} \tag{1}$$

The workability of each fresh foamed concrete mix was measured based on the flow diameter through the spreadability test by using a cylinder of 75 mm diameter x 150 mm height (Figure 3). The diameter of the flow is the average of the horizontal and longitudinal flow diameters of each mix. 50 mm cubes were used to evaluate the compressive strength and water absorption of foamed concrete. A total of 88 cubes samples were cast for experimental purposes where 72 cubes were tested for compressive strength test. All cubes were subjected to air curing. Compressive strength test was conducted in accordance with ASTM C109 (ASTM, 2008) on 7, 14, and 28 days by using the universal compressive machine (Figure 4). Besides, water absorption test was carried out at 28 days in accordance with ASTM C1403. Two cubes for each mix were used to evaluate the water absorption. The cubes were oven-dried for 24 hours under a temperature of 105ºC before submerging in the water for another 24 hours. The water absorption of the hardened foamed concrete cubes was calculated based on equation 2 where W_{sat} is the saturated weight and W_{dry} is the oven-dried weight of the cubes.

$$Water\ Absorbtion = \frac{Wsat - Wdry}{Wdry} \text{ x } 100\% \qquad (2)$$

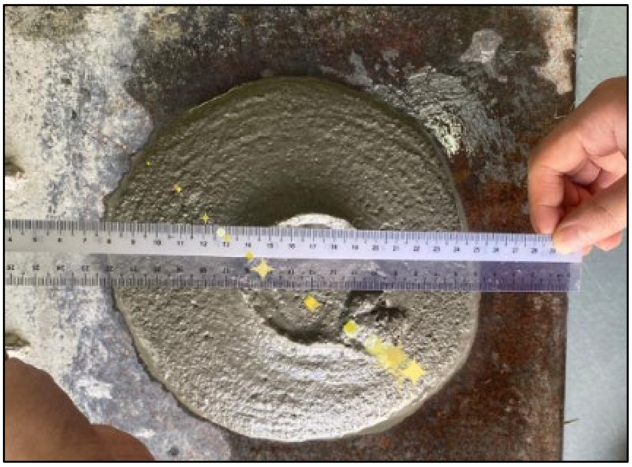

Figure 3. Spreadability testing offresh foamed concrete

Figure 4. Compressive strength test

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3. Results and Discussions

3.1 Workability

The workability of foamed concrete paste produced using eco-foaming agent: MA (using aggregate size 2.36 mm) and MB (using aggregate size 1.18 mm) was evaluated using spreadability testing. The result of this test is summarized in Table 2.

Table 2. Spreadability of foamed concrete

Density (kg/m^3)	Spreadability (mm)	
	MA	MB
1500	212	208
1600	207	189
1700	189	179
1800	182	176

The data obtained were analysed and translated into graph as shown in Figure 5. The test depicted in Figure 5 demonstrate a clear relationship between the density of concrete and spread diameter of slump for both mixes. Specifically, both mixes have shown that as the density of foamed concrete increase, the spread diameter of slump decreases. Mix MB, which had used the 1.18 mm sand size, representing a finer size of fine aggregate, exhibited slump diameter in range of 176 mm at higher densities to 208 mm at lower densities. Meanwhile, for MA, which utilized sand passing 2.36 mm sieve, representing a coarser size of sand, demonstrate a spread diameter of 182 mm to 212 mm, which was higher than MB. These results can be due to finer size aggregate which was used on MB mix contributes to a denser and more cohesive paste which is able to resist flow, resulting in lower spread diameter in comparison with MA. In terms of workability and flowability, MB provides better packing and reduction of voids within the matrix, which may improve the mechanical properties of foamed concrete, particularly compressive strength.

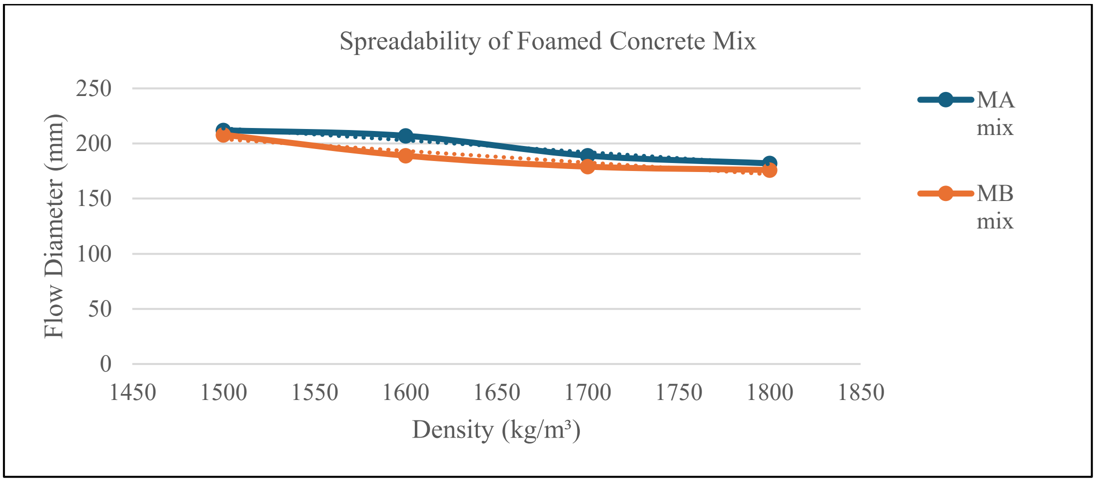

Figure 5. Workability of foamed concrete

The observations obtained in the study are supported by previous research conducted by Al-Baghdadi et al (2021), stating that finer aggregates contribute to denser microstructure. Additionally, another study by Alhozaimy and Alnuamni in 2015 shows that finer size aggregates contributed to much better self-compacting properties making the concrete paste much denser in comparison to coarser size aggregates.

3.2 Compressive strength

As for compressive strength for a period of 7, 14 and 28 days, the data for both MA and MB were also recorded and illustrated in Figure 6 and Figure 7. The results show a clear pattern of the compressive strength development of foamed concrete until 28 days, in which compressive strength for both MA and MB demonstrated an increment value with curing time, aligning with the theory of hydration in concrete, where the strength develops gradually over time (Neville, 2012).

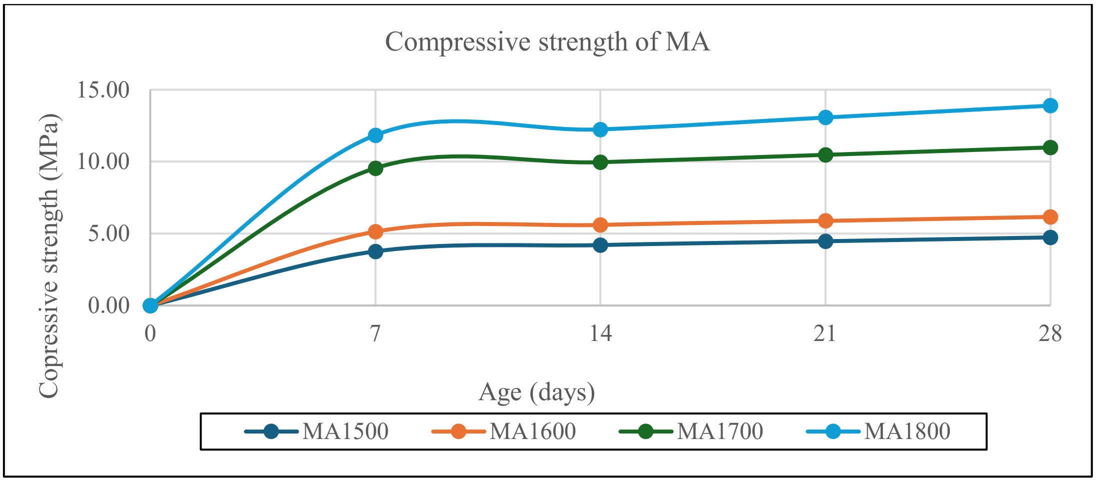

Figure 6. Compressive strength development of MA

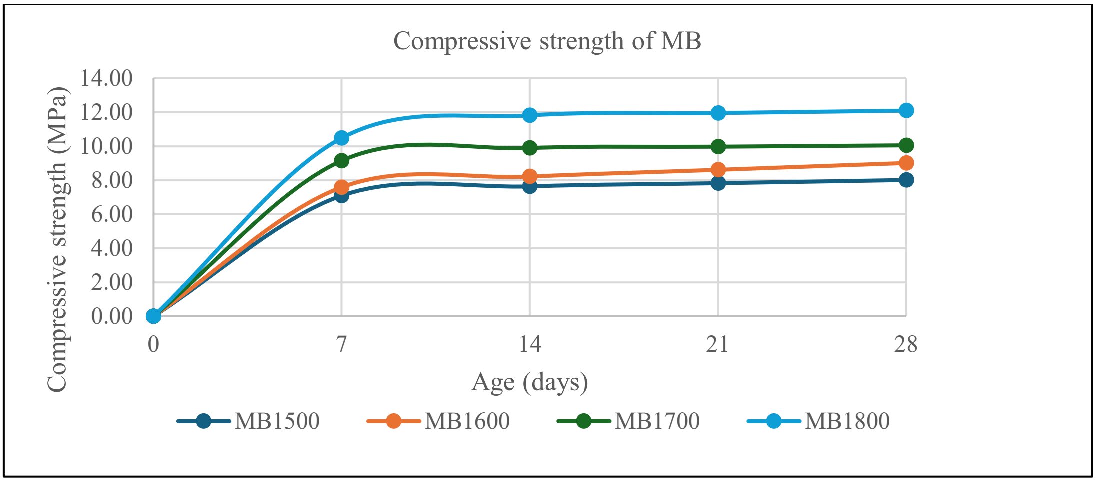

Figure 7. Compressive strength development of MB

Compressive strength between MA and MB had revealed two distinct patterns. At a lower densities of 1500 kg/m^3 and 1600 kg/m^3, MB, which utilized sand passing 1.18 mm sieve, outperformed MA which utilized sand passing 2.36 mm sieve, which achieved higher compressive strength for all ages. These phenomena may be attributed to a denser microstructure of finer sizing in sand particles. However, at a higher density (1700 kg/ m^3 and 1800 kg/ m^3), MA presents a much higher compressive strength compared to MB. This counterintuitive finding suggests that coarser size aggregates may enhance interlocking between particles, which helps the particles fit together more tightly (Al-Baghdadi et al., 2021). This tight fit increases the surface area available for bonding between cement paste and aggregates, leading to better adhesion (Siddique, 2004). Additionally, coarser aggregates may retain moisture more effectively during curing process, which is essential for proper hydration of the cement. This moisture is pivotal for concrete to achieve optimal strength because it facilitates chemical reactions needed for strength development to occur (Alhozaimy & Alnuaimi, 2015). Therefore, this combination of better interlocking and moisture retention helps to ensure that concrete becomes strong as possible.

3.3 Water Absorption

The results of the water absorption of foamed concrete are tabulated in Table 3 and plotted in Figure 8. Based on the plots in Figure 8, it is clearly show that water absorption of foamed concrete decreases as density increases for both Mix A (MA) and Mix B (MB). This trend explained the effectiveness of higher density mix in reducing the permeability of concrete, enhancing its resistance towards moisture ingress. Besides, all foamed concretes with smaller particle size of fine aggregate (MB) recorded lower water absorption compared with foamed concretes containing bigger size of fine aggregate (MA). The lower water absorption rate observed in MB can be attributed to the usage of finer sand size, which contributes to a denser microstructure with fewer voids in comparison to the coarser size sand utilize in MA. This denser packing reduced permeability of concrete, making it less susceptible to moisture ingress. Smaller size of fine aggregate leads to improved durability by minimizing porosity and enhancing resistance to water penetration (Kwan, et al., 2015).

Table 3. Water absorption of foamed concrete

Density (kg/m^3)	Water absorption (%)	
	MA	MB
1500	22.4	21.3
1600	21.9	20.5
1700	21.1	20.2
1800	20.7	19.5

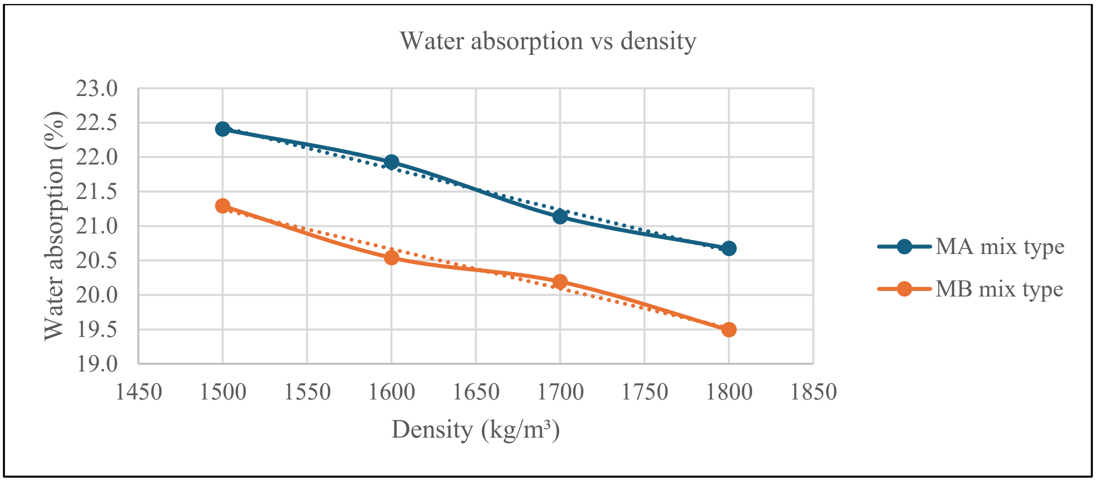

Figure 8. Water absorption of foamed concrete

4. Conclusion

This study highlights the potential of using a plant-based eco-foaming agent in the production of sustainable foamed concrete. The findings demonstrate that the material offers sufficient compressive strength for construction applications, with values ranging from 8.0 MPa to 12.1 MPa at 28 days across densities of 1500 to 1800 kg/m^3. At lower densities, Mix B (with finer aggregates) achieved higher strength, likely due to its denser microstructure. However, at higher densities, Mix A (with coarser aggregates) outperformed Mix B, possibly due to improved particle interlocking and moisture retention, which support optimal cement hydration. Water absorption results, ranging between 19% and 22%, further showed that finer aggregates led to reduced permeability and enhanced durability. Overall, the use of eco-foaming agents in foamed concrete not only addresses environmental concerns but also ensures performance suitable for various construction needs.

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Declaration of Conflicting Interests

All authors declare that they have no conflicts of interest.

Author Contributions

Conceptualisation, Chai Teck Jung, Haspina binti Sulaiman. Methodology, Chai Teck Jung, Haspina binti Sulaiman, Koh Heng Boon. Validation, Koh Heng Boon. Analysis, Chai Teck Jung, Haspina binti Sulaiman, Koh Heng Boon. Investigation, Chai Teck Jung, Haspina binti Sulaiman, Koh Heng Boon. Resources, Chai Teck Jung, Koh Heng Boon. Data Curation, Chai Teck Jung, Haspina binti Sulaiman, Koh Heng Boon. Writing-Draft Preparation, Chai Teck Jung, Haspina binti Sulaiman. Writing-Review & Editing, Koh Heng Boon. Visualisation, Koh Heng Boon. Supervision, Chai Teck Jung, Koh Heng Boon. Project Administration, Chai Teck Jung, Haspina binti Sulaiman, Koh Heng Boon. Funding Acquisition, Chai Teck Jung, Haspina binti Sulaiman, Koh Heng Boon. All authors have reviewed and approved the final version of the manuscript for publication.

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