INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH AND ANALYSIS

ISSN(print): 2643-9840, ISSN(online): 2643-9875

Volume 08 Issue 05 May 2025

DOI: 10.47191/ijmra/v8-i05-54, Impact Factor: 8.266

Page No. 2740-2745

The Effect of Foaming Agent Variations on the Mechanical Properties and Water Absorption of CLC Lightweight Bricks

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ABSTRACT: The growing demand for environmentally friendly building materials has driven the development of alternatives to conventional bricks. Cellular Lightweight Concrete (CLC) is one such innovation, offering lightweight properties and a cleaner production process that does not require firing. This study aims to evaluate the effect of foaming agent variations on the mechanical and physical characteristics of CLC lightweight bricks made from rice husk ash and nickel slag waste. The foaming agent variations used were 0.4 l/m^3, 0.6 l/m^3, and 0.8 l/m^3. Specimens in the form of beams measuring 10 cm × 20 cm × 60 cm were prepared and tested in the laboratory. The observed parameters included compressive strength and water absorption, calculated based on the maximum load over the compression area and the difference between dry and wet mass, respectively. Results showed that the 0.6 l/m^3 foaming agent variation produced the highest compressive strength (average 0.21 MPa) and the highest water absorption (36.09%), while the 0.8 l/m^3 variation resulted in slightly lower compressive strength (0.19 MPa) but a reduction in water absorption to 27.69%. These findings affirm that selecting the appropriate foaming agent is critical for optimizing the performance of lightweight bricks. The combination of rice husk ash and nickel slag waste processed with 0.6 l/m^3 foaming agent proved to be the most effective. This contributes to the development of technically efficient and environmentally sustainable CLC products.

KEYWORDS: *CLC, rice husk ash, nickel slag, compressive strength, water absorption*

I. INTRODUCTION

In general, construction materials are often labeled as environmentally unfriendly. The raw materials used are non-renewable, require energy derived from fossil fuels, and cause air pollution. This has prompted researchers to develop new materials that do not harm the environment.

One material that has rapidly developed is the material used for building walls, room partitions, or boundary walls. A common problem encountered is that traditional bricks are prone to cracking and crumbling during use. Although bricks are still widely used in the construction industry, they are categorized as environmentally unfriendly materials. This is primarily due to their manufacturing process, which relies on wood-fired kilns and causes air pollution. As a result, alternative materials such as lightweight concrete bricks have emerged, which do not require a firing process. Furthermore, lightweight bricks offer several advantages over traditional bricks, including being lighter in weight and quicker to install. Based on the production process, there are two main types of lightweight bricks: Autoclaved Aerated Concrete (AAC) and Cellular Lightweight Concrete (CLC). Both types share the same fundamental principle, which is the formation of air bubbles within the mortar, making the bricks lighter. The difference lies in the curing method; AAC requires an autoclaving (high-pressure steam curing) process, whereas CLC can be dried manually like conventional concrete.

Current research focuses on replacing non-renewable materials with waste materials to improve quality, enhance sustainability, and reduce costs. Fly ash (a by-product of coal combustion) has been used as a substitute for cement in the production of CLC-type lightweight bricks (1). Bagasse ash, a by-product of sugarcane processing, along with white bagasse ash cement and aluminum powder, have also been used in lightweight brick production, showing significant improvements in compressive strength, dry density, and water absorption (2). Meanwhile, Gencel et al. (2022) used rice husk ash (an agricultural waste) as a foaming agent to create lightweight bricks. Blast furnace slag (a steel production waste) has emerged as a relatively new eco-friendly construction material used to produce lightweight concrete (4). Furthermore, Abraham et al. (2022) utilized palm oil industry waste—specifically, palm oil fuel ash as a cement substitute and palm oil clinker as sand. The lightweight brick products developed from this research have contributed positively to sustainable development in both the construction and agricultural sectors.

This study will focus on CLC-type lightweight bricks because their production does not require expensive autoclaving equipment. The drying process for CLC is manual, similar to conventional concrete. In this research, waste materials such as rice husk ash (agricultural waste) and nickel slag (nickel industry waste) will be used. Both waste materials are rich in silica content, which is expected to enhance the strength of the lightweight bricks. Additionally, this study will examine the composition of foaming agents to achieve lightweight bricks that meet the SNI 8640-2018 standard.

The objective of this research is to analyze the manufacturing process and characteristics of cellular lightweight concrete (CLC) bricks using rice husk ash and nickel slag waste. The results are expected to offer a meaningful comparison to conventional lightweight bricks.

II. RESEARCH METHOD

This study is experimental research conducted in a laboratory setting. The test specimens used were beam-shaped with dimensions of 10 cm × 20 cm × 60 cm. The materials prepared for this research included sand, rice husk ash, nickel slag, cement, chemical additives, foaming agents, and water. Rice husk ash was used as a partial replacement for cement, while nickel slag served as a substitute for sand. Both materials were first tested to determine their chemical composition. The sand was also tested for fineness before use. Following the material characterization, test specimens were produced and subsequently tested in the laboratory to evaluate their compressive strength and water absorption capacity.

The data analysis technique employed in this study was descriptive analysis, which provides an overview of the data obtained from the use of specta foam as a pore-forming foaming agent and rice husk ash as a substitute for sand and cement. Compressive strength testing was carried out to assess the quality of the lightweight concrete bricks produced. The compressive strength was calculated using the following formula:

$$Fb = \frac{P}{A}$$

with:

Fb = Compressive Strength (kg/cm^2)

P = Maximum Load (kg)

A = Surface Area (cm^2)

Water absorption of the lightweight bricks was determined by measuring the dry and wet weights of the samples using a digital scale. The formula used is as follows:

$$Water\ Absorption = \frac{A \times B}{B} \times 100\%$$

with:

A = Wet Weight (gram)

B = Oven-Dry Weight (gram)

III. RESULTS AND DISCUSSION

A. Results

Water Absorption Test Results with Foam Variations

The results of the water absorption capacity calculation with different variations of the foaming agent are presented in Table 1. In this table, it can be seen that the 0.4% variation has an average water absorption value of 34.09%. Meanwhile, the water absorption values of lightweight concrete bricks with 0.6% and 0.8% variations are 36.02% and 27.69%, respectively.

Table 1. Water Absorption Test Results

Variations	Code	Volume	Weight		Water Absorption%	
			Dry (Oven-Dry Condition)	Saturated Surface-Dry (SSD Condition)	Water Absorption	Average
0.4 l/m³	1	3726058	2583	3880	33.428	34.09
	2	3724500	2597	3980	34.749	
	3	3783582	2579	3874	33.427	
	4	3650304	2580	3954	34.750	
0.6 l/m³	1	3700000	2516	3872	35.021	36.02
	2	3591522	2515	3993	37.015	
	3	3920400	2517	3879	35.116	
	4	3920300	2515	3987	36.920	
0.8 l/m³	1	390000	2976	4158	28.427	27.69
	2	3860000	2890	3956	26.946	
	3	3980000	2966	4145	28.444	
	4	3861200	2899	3967	26.929	

Compressive Strength Test of Lightweight Concrete Bricks

Table 2 shows the compressive strength test results for specimens with a foaming agent variation of 0.4 l/m^3. The compressive strength tests on 10 specimens produced maximum loads ranging from 450 N to 700 N. To determine the compressive strength, the maximum load is divided by the loaded surface area. The compressive strength values vary from 0.05 MPa to 0.07 MPa, with an average compressive strength of 0.05 MPa.

Table 2. Compressive Strength Test Results for Foaming Agent Variation of 0.4 l/m^3

Specimen Code	Dimensions		Compressive Area	Weight	Load	Compressive Strength
	l	w				
	mm	mm	mm^2	g	N	MPa
K2,F10	95	98	9310	800	600	0.06
K2,F10	96	98	9408	760	700	0.07
K2,F10	97	97	9409	760	650	0.07
K2,F10	95	90	8550	770	500	0.06
K2,F10	94	97	9118	770	450	0.05
K2,F10	99	98	9702	800	453	0.05
K2,F10	92	95	8740	790	456	0.05
K2,F10	90	100	9000	780	446	0.05
K2,F10	99	90	8910	800	452	0.05
K2,F10	98	99	9702	790	458	0.05
Average compressive strength						0.05

Table 3 shows the compressive strength test results for specimens with a foaming agent variation of 0.6 l/m^3. The compressive strength tests on 10 specimens produced maximum loads ranging from 1300 N to 2250 N. To calculate the compressive strength, the maximum load is divided by the loaded surface area. The compressive strength values vary from 0.18 MPa to 0.26 MPa, with an average compressive strength of 0.21 MPa.

Table 4 shows the compressive strength test results for specimens with a foaming agent variation of 0.8 l/m^3. The compressive strength tests on 10 specimens produced maximum loads ranging from 1500 N to 2200 N. The compressive strength values, calculated by dividing the maximum load by the loaded surface area, vary from 0.16 MPa to 1.54 MPa, with an average compressive strength of 0.19 MPa.

Table 3. Compressive Strength Test Results for Foaming Agent Variation of 0.6 l/m^3

Specimen Code	Dimensions		Compressive Area	Weight	Load	Compressive Strength
	l	w				
	mm	mm	mm^2	g	N	MPa
K2,F11	98	99	9702	810	2200	0.23
K2,F11	98	100	9800	860	2200	0.22
K2,F11	90	100	9000	720	1300	0.14
K2,F11	98	98	9604	740	2500	0.26
K2,F11	97	98	9506	720	1700	0.18
K2,F11	100	98	9800	860	1750	0.18
K2,F11	90	94	8460	700	1770	0.21
K2,F11	97	99	9603	740	1805	0.19
K2,F11	95	98	9310	710	1840	0.20
K2,F11	95	95	9025	740	1875	0.21
Average compressive strength						0.21

Table 4. Compressive Strength Test Results for Foaming Agent Variation of 0.8 l/m^3

Specimen Code	Dimensions		Compressive Area	Weight	Load	Compressive Strength
	l	w				
	mm	mm	mm^2	g	N	MPa
K2,F11	K2,F12	100	100	10000	810	2200
K2,F11	K2,F12	95	95	9025	930	1756
K2,F11	K2,F12	95	90	8550	820	1500
K2,F11	K2,F12	92	98	9016	800	1700
K2,F11	K2,F12	98	95	9310	890	1600
K2,F11	K2,F12	95	100	9500	940	1580
K2,F11	K2,F12	95	96	9120	860	1560
K2,F11	K2,F12	97	95	9215	710	1540
K2,F11	K2,F12	99	100	990	780	1520
K2,F11	K2,F12	95	98	9310	800	1500
Average compressive strength						0.19

B. Discussion

The Influence of Foaming Agent Percentage in Water Absorption

Based on the research data in Table 1 regarding the water absorption test results on lightweight bricks with foam agent variations of 0.4 l/m^3, 0.6 l/m^3, and 0.8 l/m^3, a comparison was made between the foam agent variations and the control specimen. The control specimen was the one using a 0.4 l/m^3 variation (Figure 1).

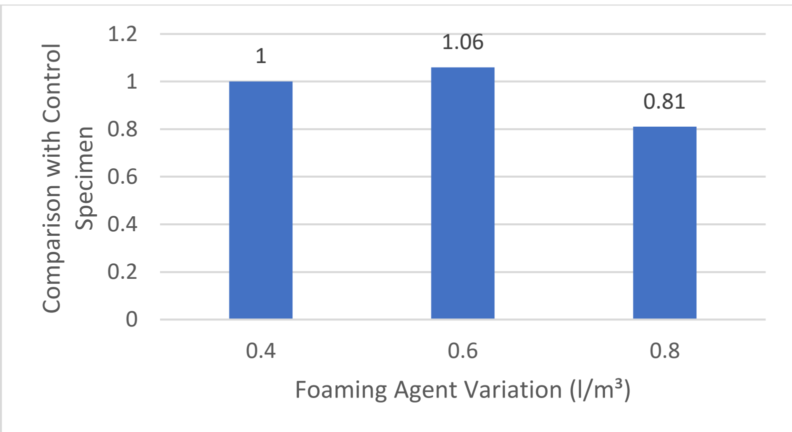

Figure 1. Comparison of water absorption on Foaming Agent Variations

The water absorption of lightweight bricks using 0.6 l/m^3 foaming was 1.06 times the absorption of bricks using 0.4 l/m^3 foaming. Meanwhile, the water absorption of lightweight bricks using 0.8 l/m^3 foaming was 0.81 times the absorption of bricks using 0.4 l/m^3. This illustrates an increase in absorption by 6% for lightweight bricks using 0.6 l/m^3 foaming. Conversely, for bricks using 0.8 l/m^3 foaming, there was a 19% decrease in absorption.

This study shows that the variation of 0.4–0.6 l/m^3 foam agent caused the formation of many air cavities in lightweight bricks, increasing water absorption and reducing durability (6). Research by Ningrum et al. (2021) reported a water absorption rate of 6.830% with 0.6 l/m^3 foam, which is much lower than in this study, which reached 36.02%. Furthermore, Mey Setyowati (2019) found a water absorption rate of 28.85% with 0.3% foam, almost similar to this study at 27.69%. Santoso & Miftah (2023) reported a water absorption rate of 29.30% with 25% foaming, close to the result in this study at 34.09%. Meanwhile, Bella et al. (2017) found a water absorption rate of 38.184% with 1-liter foam agent, which is higher than the value in this study of 36.02%.

The Influence of Foaming Agent Percentage in Compressive Strength

Figure 2 also shows the comparison of compressive strength across different foaming agent variations. The comparison was made against the control specimen using 0.4 l/m^3 foaming agent. The average compressive strength ratio of specimens with 0.6 l/m^3 foaming agent to the control specimen was 3. Furthermore, the compressive strength ratio for specimens with 0.8 l/m^3 foaming agent compared to the control was 2.71.

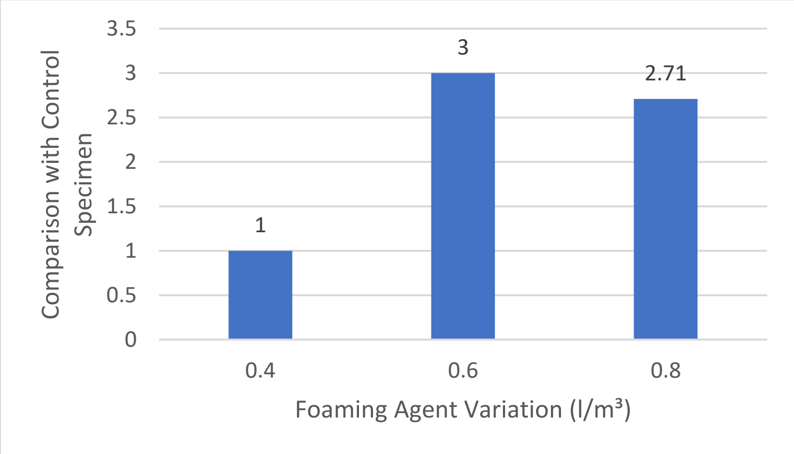

Figure 2. Comparison of Compressive Strength on Foaming Agent Variations

The average compressive strength of specimens with 0.6 l/m^3 foaming agent experienced a significant increase, reaching 3 times (300%) the compressive strength of the control specimen. Meanwhile, the average compressive strength of specimens with 0.8 l/m^3 foaming agent also increased significantly, reaching 2.71 times (271%) that of the control. It is evident that the use of 0.6 l/m^3 and 0.8 l/m^3 foaming agents both enhanced the compressive strength, but the 0.6 l/m^3 variation produced a greater increase (11).

Research by Solikin & Parmono (2018) showed that using a foaming agent with a water ratio of 1:30 and 1:40 led to a decrease in foam concrete compressive strength as the foam amount increased, with compressive strength improvements of 0.63 MPa for foam 1:30 and 0.60 MPa for foam 1:40. Taufik et al. (2017) obtained an optimal compressive strength of 0.667 MPa with a 0.9% foaming variation. Eban et al. (2018) reported a compressive strength of 0.683 MPa with 0.5% foaming, while Sumiati et al. (2020) found compressive strengths exceeding 17.42 MPa with 0.5% and 1.5% foaming in structural lightweight concrete.

The results of this study show that the average compressive strength was lower than in previous studies, likely due to the use of different types of foaming agents. This study used Spectafoam Edema, whereas previous studies used ADT-type foam, and there were differences in the foaming percentages used in the mix. The foaming agent serves as a foam-producing additive that traps air and forms pores within the wet mixture, making the bricks lighter. However, the more pores formed, the lower the compressive strength. Nevertheless, this study's results indicate that the compressive strength for the 0.4 l/m^3 foaming agent variation was lower than for the 0.6 l/m^3 variation, and the compressive strength for the 0.8 l/m^3 variation even increased, which differs from the general trend found in previous studies.

The research indicates that the 0.6 l/m^3 foaming agent offers the best balance between water absorption and compressive strength, making it the optimal variation for developing eco-friendly lightweight CLC bricks that meet minimum mechanical requirements.

V. CONCLUSIONS

Although the 0.6 l/m^3 foaming agent resulted in the highest water absorption, the 0.8 l/m^3 variation actually showed a decrease in water absorption. This suggests that higher amounts of foaming agent do not always lead to increased porosity, as the interaction between pore quantity and distribution is a determining factor. Therefore, selecting the right foaming agent composition is key to controlling water absorption properties in lightweight bricks.

The use of foaming agent significantly influences the compressive strength of CLC lightweight bricks. The 0.6 l/m^3 variation led to the highest increase in compressive strength, approximately three times greater than that of the 0.4 l/m^3 variation. Although the 0.8 l/m^3 variation also showed improved compressive strength, it was not as high as that of the 0.6 l/m^3. This confirms that the 0.6 l/m^3 foaming agent is the most optimal composition for enhancing the mechanical strength of lightweight bricks.

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