Foaming Agent Concentration Effect on Foam Density and Microstructure for Lightweight Mortar

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Abstract

This research investigates the effect of air pressure variation in a foam generator on the physical properties of foam intended for lightweight mortar applications. The primary objective was to identify the optimal operational pressure to produce stable and high quality foam. A constan foaming agent concentration of 6 bar was used while the air pressure was varied at 2%, 4%, 6%. The study involved a laboratory experiment where the foam's density was quantitatively measured, and its bubble microstructure was qualitatively observed. The result showed a non-linear relationship between air pressure and foam density. The foam density increased foam 0,039 t/m³ at 2% concentration, to an optimal value of 0,062 t/m³ at 6%. The density 2% failed to meet the PUPR standard (0,05-0,085 t/m³), while 4% and 6% were compliant. Microstructural analysis supported these findings, revealing that the foam produced at 6% had the most uniform, small, and compact bubble structure, indicating higher sability. In contrast, 2% produced larger, highly unstable bubbles. The study concludes that a 6% is optimal for producing foam with the highest density and most favorable microstructure under the tested conditions, highlighting the critical role of precise pressure control in manufacturing lightweoght construction materials.

I. INTRODUCTION

Infrastructure development in Indonesia is often faced with the challenge of soft soil conditions, such as peat and clay, which have low bearing capacity [1], often requiring soil improvement techniques like biocementation [2]. This method, which utilizes Microbially Induced Calcite Precipitation (MICP), has also been applied in other material innovations such as fireless brick making [3]. This soil issue is a major concern for heavy constructions like bridge approach embankments [4], [5] or highways, which are at risk of settlement or even premature structural damage [6]. Therefore, the innovation of alternative materials, such as utilizing waste plastic in pavement [7], [8], [9] or developing lightweight embankments, has become a crucial necessity in modern civil engineering [10], [11].

One of the solutions currently being developed is the use of foam mortar [12], [13] with various types being explored such as fast track mortar [14] and those using admixtures like phosphogypsum [15]. This material is composed of a mixture of cement, sand, water, and foam [16]. The main advantage of this material lies in the air voids created by the foam, which results in a significantly lower density compared to conventional emabnkment materials [17].

The final quality of foam mortar is highly dependent on the properties of the foam used, as the foam is the primary determinant of the material's lightness and internal structure [18]. The characteristics of the foam, particularly its denisty, are significantly influenced by key production parameters [19] the concentration of the foaming agent [20] and the air pressure applied from the foam generator 4. Previous research by [21] has shown that air pressure between 3-8 bar is effective for the foam formation process using a foam generator.

Although various studies have examined the characteristics of foam mortar from different aspects, such as the influence of sand type [1], [22] and varying foam agent concentrations [20], [23], a specific investigation into the effect of air pressure variation at a constant foam agent concentration still requires further exploration. Therefore, this tudy focuses on analyzing and comparing the effects of air pressure variations specifically 4 bar, 6 bar and 8 bar on the density and microstuctural characteristic of the resulting foam. The foam agent concentration was held constan at 6% to ensure that observed differences were purely due to the effect of pressure. This research is expected to provide a clearer understanding of how different air pressure levels affect foam quality and, consequently, the final performance of lightweight mortar [24].

II. METHOD

This study employed a quantitative laboratory experiment method. The primary focus was to analyze and compare the effects of air pressure variations (4 bar, 6 bar, 8 bar) in the foam generator on the foam density and bubble microstructure to determine the most optimal operational condition. The foaming agent concentration was held constant at 6% to ensure that the observed differences were purely due to the effect of pressure [19].

The main materials used in this research consisted of a protein based foaming agent (AKS brand) [20], [23] and clean tap water. The primary equipment included a foam generator unit as illustrated in **Figure 1** [21], an air compressor, a 1000 ml measuring cylinder, and a precision digital scale with 0,01 gr accuracy. The pressure was controlled using a regulator knob on the foam generator, as illustrated in **Figure 2**.

Figure 1. Foam Generator Unit

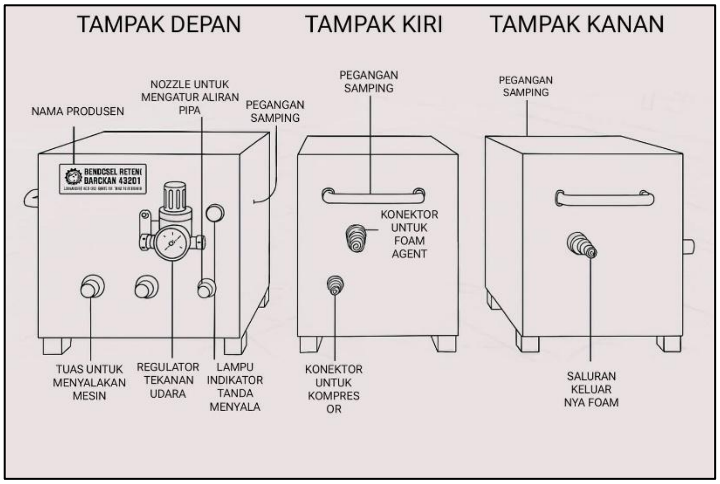


Figure 1a. The Function of Foam Generator

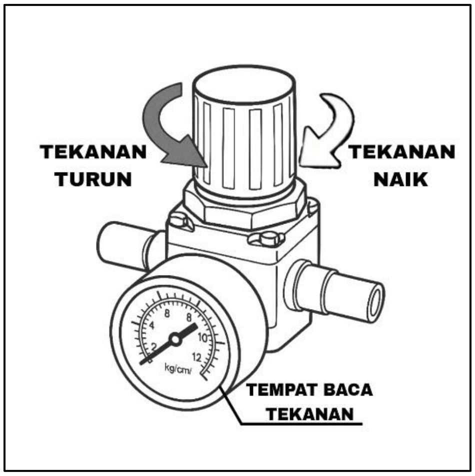


Figure 2. Pressure Control Regulator

The research procedure was carried out as follows:

1. Preparation
   A solution with 6% concentration of foaming agent in water was prepared and fed into the foam generator.
2. Foam Production
   The air compressor supplied pressurized air to the foam generator. The experiment was conducted by setting the pressure regulator to three different levels (4 bar, 6 bar, and 8 bar), as illustrated in **Figure 3**.

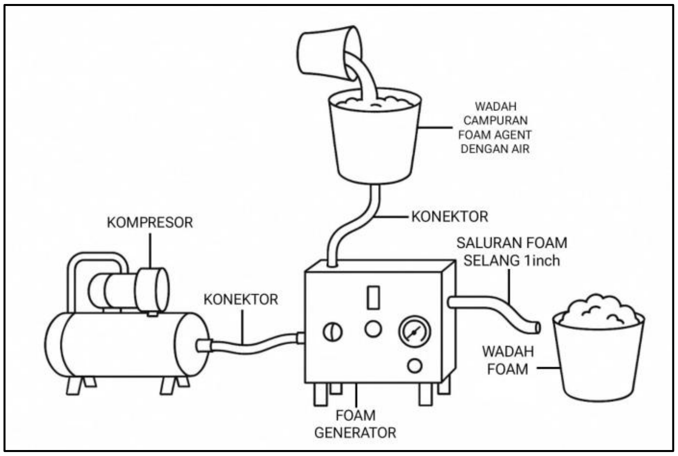


Figure 3. Foam Manufacturing Process

3. Data Collection
   For each pressure variation, the fresh foam was collected in a 1000 ml measuring cylinder and immediately its density. This procces was repeated five times for each variation to ensure data reliability, as illustrated in **Figure 4**.

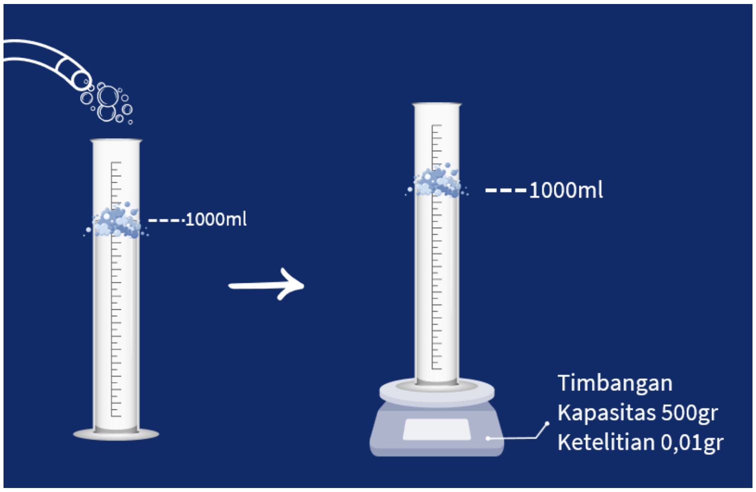


Figure 4. Density Data Collection

4. Microstructure Observation
   Concurrently, foam samples from each pressure variation were qualitatively observed to analyze their bubble characteristics [25], such as size, uniformity, and shape.

III. RESULT

This section presents the findings on the influence of foaming agent cencentration variation on foam density and mincrostructure, cunducted at a constant optimal a pressure of 6 bar. The primary investigation focused on how different foaming agent concentrations (2%, 4%, and 6%) affect the density of the foam produced, all tasted at a constant 6 bar pressure. The foam density standard used a benchmark is form the PUPR, which specifies a range of 0,05-0,085 t/m³. The average results of the density tests are summarized in **Table 1** and **Figure 5**.

Table 1. Average Results of Foam Density Test

Test Variation	Foam Agent (%)	Tekanan Udara (bar)	Average Foam Density (t/m³)
Sample A	2	6	0,039
Sample B	4		0,052
Sample C	6		0,062

The data in table 1 shows a clear positive correlation. As the foaming agent also increased, the foam density also increased steadily. This aligns with research indicating thath higher concentration of surfactant provides more material to form bubble walls, leading to a more robust and denser foam structure [20], [23].

At 2% concentration, the density was 0,039 t/m³, which is below the minimum PUPR standard. This suggests that a 2% concentration is insufficient to create stable foam. At 4%, the density increased to 0,052 t/m³, and at 6% it reached the maximum density of 0,062 t/m³. Both 4% and 6% concentrations produce foam that meets the requaired strandards. A further interesting point of discussion is the rate of density increase. The increase from 2% to 4% was 0,013 t/m³, while the increase from 4% to 6% was smaller, at 0,010 t/m³. This usggest a pattern of diminishing returns, where adding more foaming agent beyond a certain point yields less significant gains in density. This indicates that 6% is likely approaching an optimal mix design [15].

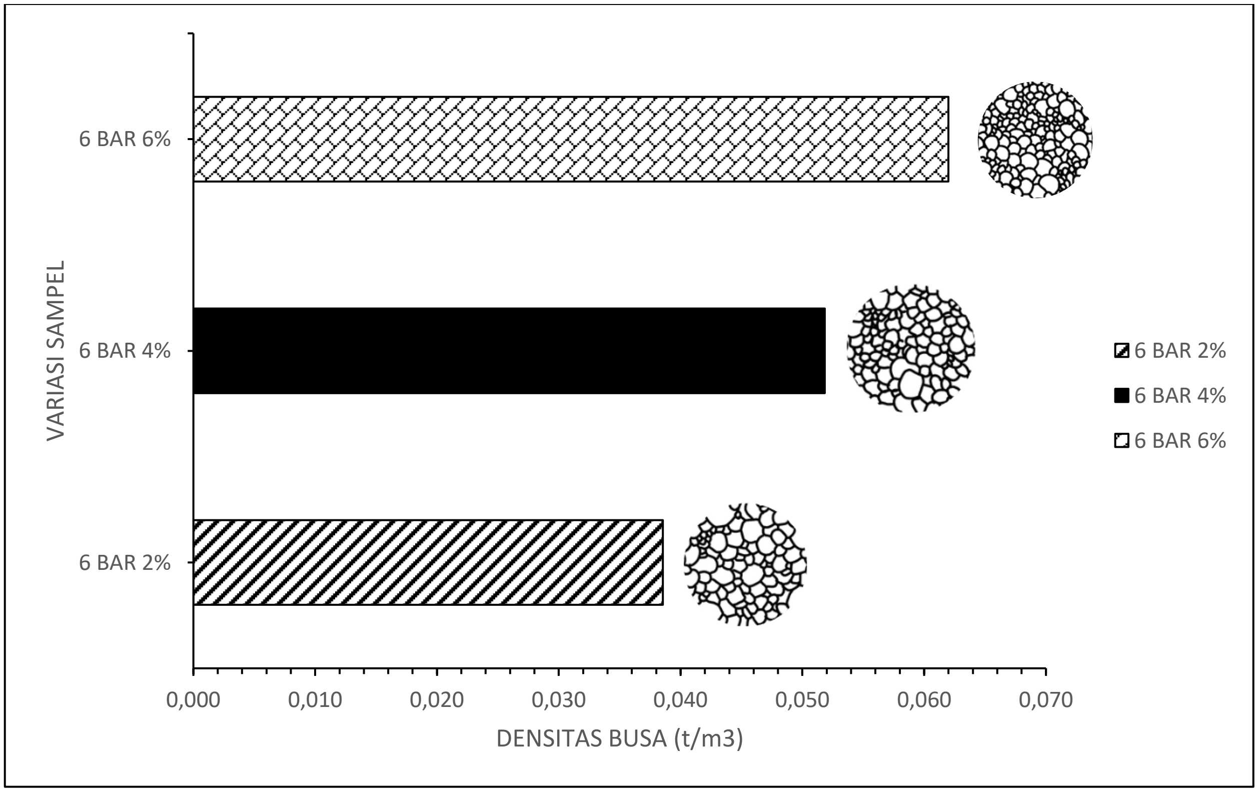
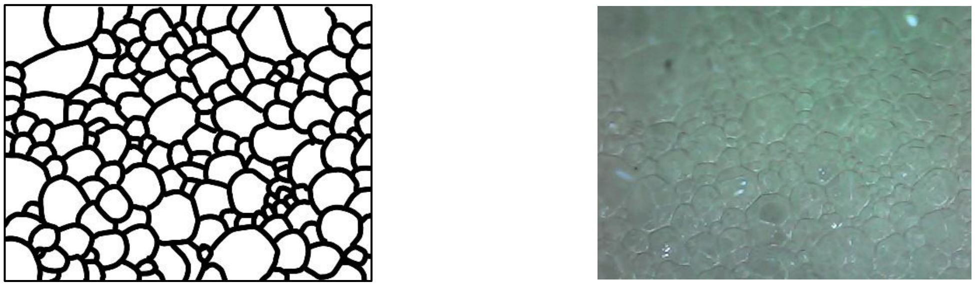


Figure 5. Comparison of Foam Bubble Characteristic

Foam Micrstructure Analysis

A qualitative observation of the foam’s microstructure was conducted [25]. The bubble characteristic shown in Figure 5 explain the variations in foam density. Comparison fo foam bubble microstructure at 6 bar pressure with foam agent variations:

1. 2% Foaming Agent

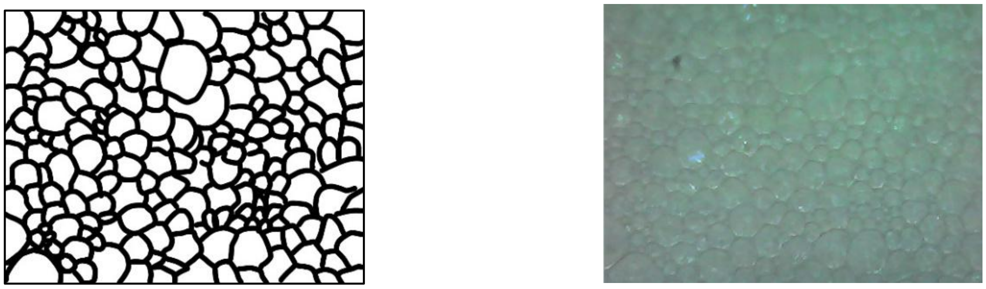


(a) (b)

Figure 6a,b. Bubble Characteristic 2% Foaming Agent

The foam structure is poor at **Figure 6**, characterized by very large, inconsistent, and non uniform bubbles. This morphology indicates instability, where bubbles quickly rupture and coalesce [13]. This directly explains why its density was the lowest.

2. 4% Foaming Agent

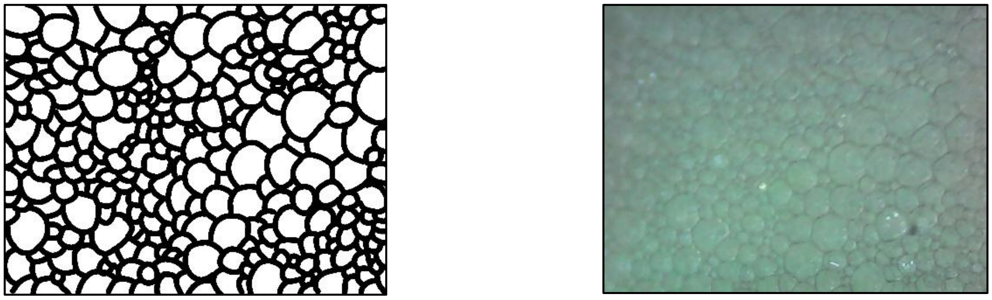


(a) (b)

Figure 7a,b. Bubble Characteristic 4% Foaming Agent

The microstructure shows significant improvement at **Figure 7**. The bubbles are smaller, more uniform, and more tighly packed compared to the 2% sample. This stable structure is the reason for its compliant density (0,052 t/m³).

3. 6% Foaming Agent



(a) (b)

Figure 8a,b. Bubble Characteristic 6% Foaming Agent

This concentration yielded the most superior microstructure. The visualization at **Figure 8** shows the smallest, most uniform, and most densely packed bubbles. This ideal morphology, where the foam to water ratio is optimal [19], maximizes the foam's density and stability.

From this analysis, it is evident that a minimum concentration of 4% is required to meet standards, while 6% foaming agent produces the foam with the highest density and most superior microstructure.

IV. CONCLUSION

This reasearch concludes that the concentration of the foaming agent has a significant and direct influence on the density and microstructure of the foam produced at a constant 6 bar air pressure.

1. There is positive correlation between concentration and density. The foam density increased from 0,039 t/m^3 at 4%, and reached a maximum of 0,062 t/m^3 at 6%. The 2% concentration failed to meet the PUPR standard, while 4% and 6% were compliant.
2. The 6% foaming agent concentration was determined to be the optimum setting, producing foam with the highest density and the most superior microstructure, characterized by small, uniform, and stable bubbles.
3. Low concentration 2% resulted in insufficient bubble wall formation, leading to an unstable microstructure and low density.

This finding confirms that precise control over foaming agent concentration is critical factor in producing stable, high quality foam, which is fundamental fot optimizing the properties if lightweight materials.

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REFERENCES

[1] D. R. Basri, E. E. Putri, B. M. Adji, A. Hakam, and K. Kunci, “Pengaruh Gradasi Pasir Pada Pemanfaatan Mortar Busa Sebagai Pengganti Lapisan Pondasi Jalan Pada Tanah Gambut,” *J. Tek. Sipil*, vol. 10, no. 2, pp. 203–214, 2024.

[2] A. M. Indriani, G. Utomo, and N. Fitriyani, “Pengaruh Kultur Bakteri Pada Proses Biosementasi Tanah Laterit Terhadap Nilai CBR,” *Media Ilm. Tek. Sipil*, vol. 11, no. 2, pp. 143–149, 2023, doi: 10.33084/mits.v11i2.4590.

[3] E. A. A. Saputri, A. M. Indriani, and G. Utomo, “Fireless Brick Making using Water Treatment Sewage Sludge with MICP Action,” *Cived*, vol. 10, no. 3, pp. 1099–1111, 2023, doi: 10.24036/cived.v10i3.327.

[4] A. Y. Prastika, W. Febrianto, D. Indriyana, and B. W. Adhi, “Alternatif Penanganan Stabilitas Timbunan dan Lereng pada Oprit Jembatan dengan Mortar Busa (Studi Kasus : JU Rel KA Cibitung – Cilincing),” vol. 5, no. 1, pp. 45–55, 2025, [Online]. Available: https://journal.unisnu.ac.id/CES/article/download/1286/553

[5] N. Azami, M. A.; Lastiasih, “Alternatif Perencanaan Oprit Jembatan Batanghari (STA 15+750) di Jalan Tol Ruas Jambi–Rengat,” *JURMATEKS, UNIK Kediri*, vol. 9, no. 1, pp. 1–8, 2024, doi: 10.30737/jurmateks.v7i2.6288.

[6] Y. Wijiastuti, “Pengaruh Jenis Air Rendaman Terhadap Kuat Tekan Mortar Busa Sebagai Pengganti Timbunan Pada Konstruksi Jalan,” 2021. [Online]. Available: http://repository.uir.ac.id/id/eprint/8337%0Ahttps://repository.uir.ac.id/8337/1/173121005.pdf

[7] R. G. Arlita, G. Utomo, and A. M. Indriani, “Pengaruh Temperatur Pelelehan Plastik Polypropylene Terhadap Kuat Tekan Paving Block,” *J. Teknol. Terpadu*, vol. 13, no. 1, 2025.

[8] R. D. Anggraeni, A. M. Indriyani, and G. Utomo, “Pengaruh Plastik Polietilena Tereftalat Sebagai Perekat Terhadap Kuat Tekan Paving Block,” vol. 13, no. 1, 2025.

[9] Khairul Fadli, Andi Marini Indriani, and Gunaedy Utomo, “Analisis Kuat Lentur Beton Menggunakan Plastik Jenis Polyhyhlene Terepthele (Pet) Sebagai Rigid Pavement,” *Konf. Nas. Tek. Sipil*, vol. 1, no. 2, pp. 16–17, 2024, doi: 10.62603/konteks.v1i2.27.

[10] M. Amran *et al.*, “An ultra-lightweight cellular concrete for geotechnical applications – A review,” *Case Stud. Constr. Mater.*, vol. 17, 2022, doi: 10.1016/j.cscm.2022.e01096.

[11] U. Jusi, P. Dhamrodji, and H. Maizir, “Foam Mortar Layer in Soft Subgrade Embankment: A Review,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1321, no. 1, 2024, doi: 10.1088/1755-1315/1321/1/012040.

[12] Z. Ge, H. Yuan, R. Sun, H. Zhang, W. Wang, and H. Qi, “Use of green calcium sulphoaluminate cement to prepare foamed concrete for road embankment: A feasibility study,” *Constr. Build. Mater.*, vol. 247, 2020, doi: 10.1016/j.conbuildmat.2019.117791.

[13] J. Wu *et al.*, “The stability and durability of silt-based foamed concrete: A new type of road engineering material,” *Constr. Build. Mater.*, vol. 304, 2021, doi: 10.1016/j.conbuildmat.2021.124674.

[14] M. R. Aziz, Muhammad Syafiq; Maula, “Analisa Beton Fast Track Mortar Busa Untuk,” 2023.

[15] B. Xu, A. Gao, Z. Chen, Y. Zhou, K. Lu, and Q. Zheng, “Mechanical Properties and Optimal Mix Design of Phosphogypsum Cement Mineral Admixture Foam Light Soil,” *Coatings*, vol. 13, no.

11, 2023, doi: 10.3390/coatings13111861.

[16] F. Hamdi *et al.*, *Teknologi Beton*, vol. 1, no. 1. 2022. [Online]. Available: http://www.nutricion.org/publicaciones/pdf/prejuicios_y_verdades_sobre_grasas.pdf%0Ahttps://www.colesterolfamiliar.org/formacion/guia.pdf%0Ahttps://www.colesterolfamiliar.org/wp-content/uploads/2015/05/guia.pdf

[17] X. Shi, J. Huang, and Q. Su, "Experimental and numerical analyses of lightweight foamed concrete as filler for widening embankment," *Constr. Build. Mater.*, vol. 250, 2020, doi: 10.1016/j.conbuildmat.2020.118897.

[18] G. Bramantya, "Analisis Nilai Stabilitas Dan Penurunan Pada Timbunan Ringan Mortar Busa Dan Timbunan Tanah Konvensional Pada Oprit Jembatan (Analysis," 2021. [Online]. Available: https://dspace.uii.ac.id/handle/123456789/34467

[19] A. Subrianto, Amiruddin, Ibrahim, I. Sulianti, Nudia, and S. Beladin, "Influence of foam to water ratio on compressive strength of foamed mortar as the road construction material," *J. Phys. Conf. Ser.*, vol. 1500, no. 1, 2020, doi: 10.1088/1742-6596/1500/1/012081.

[20] M. M. F. Santoso T. B., "Pengaruh Penambahan Foam Agent Terhadap Density, Daya Serap Air Dan Kuat Tekan Mortar," *J. Ris. Tek. Sipil dan Sains*, vol. 2, no. 1, pp. 61–70, 2023.

[21] Ibrahim, Amiruddin, I. Sulianti, A. Subrianto, I. Fajriani, and N. F. Habib, "The Effect of Air Pressure on Foamed Mortar Production," *Proc. 4th Forum Res. Sci. Technol.*, vol. 18, 2021, doi: 10.2991/ahe.k.210205.051.

[22] S. T. Azzahara, A. S.; Oprit, "Pengaruh Penggunaan Tiga Jenis Pasir Terhadap Kuat Tekan Mortar Busa Sebagai Timbunan Oprit," 2020. [Online]. Available: https://repository.uir.ac.id/8759/

[23] D. N. Rachman, S. Riwayati, A. Hidayat, and T. N. Pratiwi, "Penggunaan Foam Agent Pada Beton Untuk Pembuatan Beton Ringan," *J. Tekno Glob. UIGM Fak. Tek.*, vol. 11, no. 1, pp. 19–24, 2022, doi: 10.36982/jtg.v11i1.2345.

[24] D. G. Cai, S. W. Wei, Y. S. Ye, Q. L. Zhang, Z. G. Li, and S. Li, "Mechanical properties of lightweight foam concrete filler for roadbed of high-speed railway," *Arab. J. Geosci.*, vol. 14, no. 10, 2021, doi: 10.1007/s12517-021-07115-1.

[25] N. H. Sari, S. Suteja, A. D. Catur, and D. P. Jaya, "Karakteristik tekan, bending dan morphology komposit mortar ringan diperkuat serat limbah tekstil," *Din. Tek. Mesin*, vol. 13, no. 1, p. 38, 2023, doi: 10.29303/dtm.v13i1.593.