

# Experimental Evaluation of Fine Aggregate Gradation on the Mechanical Performance of Lightweight Foamed Concrete

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**Abstract**—The use of Cellular Lightweight Concrete (CLC) in the construction industry has been increasing due to its advantages, including low weight, energy efficiency, ease of installation, and suitability for multi-story structures. Among the key factors influencing the quality and structural performance of CLC is the gradation of fine aggregates, particularly sand. However, in practice, sand selection often neglects technical grading standards, resulting in variability in final product quality. This study experimentally investigates the effect of sand gradation on the compressive strength of CLC bricks. Three types of sand were used, classified into Zone II, Zone III, and Zone IV according to the Indonesian National Standard (SNI). A constant mix design was applied, consisting of 562.5 kg of sand, 225 kg of cement, 160 liters of water, and 0.6 liters of foaming agent per cubic meter. Prismatic specimens (10 × 20 × 60 cm) were tested for compressive strength at 28 days using a hydraulic press machine. The results indicate that sand gradation has a significant impact on the compressive strength of CLC bricks. Zone II sand produced the highest average strength, while Zone III and Zone IV yielded lower values, with Zone III performing the poorest. These findings provide empirical evidence to support more informed fine aggregate selection in the production of lightweight concrete, particularly in tropical climates. The study contributes to the advancement of quality control and mix optimization for achieving more uniform and high-performance CLC products.

**Keywords**— Cellular Lightweight Concrete (CLC), Compressive Strength, Lightweight Concrete Performance, Sand Gradation, Tropical Construction Materials.

## I. INTRODUCTION

The rapid development of infrastructure worldwide, including in Indonesia, has increased the demand for construction materials that are both efficient and sustainable. One material that has gained considerable attention due to its advantageous physical properties is Cellular Lightweight Concrete (CLC), a type of lightweight brick. CLC offers notable benefits, including low density, high thermal insulation, and ease of application, making it suitable for various construction projects, such as multi-storey buildings, modern residential units, and environmentally friendly developments. As a result, CLC has become a popular alternative in modern construction practices, particularly in regions aiming to enhance building performance while reducing material usage and environmental impact.

The variability of its compressive strength is a persistent problem in actual applications, despite the expanding use of CLC in building. This variability is primarily attributed to the characteristics of fine aggregates, particularly sand gradation, which directly influences the density, porosity, and bond strength of the concrete matrix. The essential function of sand characteristics in influencing the mechanical behavior of lightweight and foamed concrete has been emphasized by a number of research. Researcher [1] reported that finer sand

particles (0.6 mm) significantly enhance both the compressive and flexural strength of foamed concrete compared to coarser sands. Similarly, researcher [2] demonstrated that smaller sand grain sizes improve foam stability and refine the concrete's microstructure, leading to superior mechanical performance. Researcher [3] found that replacing quartz sand with ceramsite sand resulted in a significant reduction in strength due to the porous nature of ceramsite.

In contrast, [4] observed that lightweight aggregates, such as expanded polystyrene, compromised the overall integrity of the concrete matrix. Aggregate gradation, including particle size distribution, plays a vital role in both the workability and mechanical response of concrete [5]. Likewise, optimizing sand gradation when using manufactured aggregates can enhance durability and compressive strength [6]. Further supporting these conclusions, the use of fine foundry sand waste improved the compressive strength and density of foamed concrete [7]. Moreover, substituting conventional sand with basalt powder not only increased strength but also reduced porosity, affirming the importance of raw material quality [8]. Complementing these findings, the effect of sand gradation on the dynamic mechanical properties and energy absorption of high-density foamed concrete. Finally, various strategies for combining industrial waste and natural aggregates to enhance the structural and environmental

performance of foamed concrete [9]. Collectively, these studies confirm that sand gradation is a key determinant of concrete performance and must be carefully considered in the design of lightweight concrete.

While previous studies have established the critical influence of sand gradation on the mechanical properties of lightweight concrete, most experimental investigations have been conducted in subtropical or temperate regions, often without alignment to national construction standards such as the Indonesian National Standard (SNI – Standar Nasional Indonesia). Furthermore, limited attention has been given to systematically comparing the compressive strength of CLC using sand sourced from different SNI-defined gradation zones—specifically Zones II, III, and IV—under tropical environmental conditions. This condition is a significant gap, as construction practices in tropical regions frequently rely on locally available sands whose gradation and quality can vary widely. To date, there is little experimental evidence evaluating how these gradation variations affect the compressive strength of CLC when prepared using standardized mix proportions and exposed to humid, high-temperature environments. The novelty of this study lies in three main aspects: (1) the use of multiple SNI-based sand gradation zones in CLC compressive strength testing, (2) the implementation of a consistently controlled mix design across all specimens, and (3) the contextual adaptation of the experiment to tropical climatic conditions, which remain underrepresented in the international literature on lightweight concrete.

Accordingly, this study aims to analyze the influence of sand gradation on the compressive strength of CLC bricks by comparing three distinct gradation ranges: Zones II, III, and IV, as defined by the Indonesian National Standard (SNI). All mixtures were prepared using consistent mix designs and subjected to laboratory testing under conditions representative of tropical climates. The results of this research are expected to contribute to the development of a reliable material database for tropical lightweight concrete, support more informed aggregate selection in Southeast Asian construction practices, and provide a technical reference for manufacturers and contractors. From a scientific perspective, the study also offers a new benchmark for understanding how standardized sand gradation affects CLC performance under tropical environmental conditions.

## II. METHOD

This research employed a quantitative experimental approach to evaluate the effect of sand gradation on the compressive strength of CLC bricks. The study was conducted under controlled laboratory conditions to ensure that the observed variations in mechanical performance could be directly attributed to the differences in sand gradation. The objective of the study was to determine a cause-and-effect link between compressive strength (the dependent variable) and sand gradation (the independent variable).

The CLC bricks were cast using molds with dimensions of 60 × 20 × 10 cm. The concrete mix design was kept constant for all specimens and followed a formulation adapted from PT

Banon Con. The mix consisted of 562.5 kg of sand, 225 kg of cement, 160 liters of water, and 0.6 liters per cubic meter of concrete (Table I). The only variable between treatments was the gradation of sand, which followed the Indonesian National Standard (SNI) classifications for fine aggregate: Zone II, Zone III, and Zone IV.

TABLE I. Research Design Table

Sand Zone	Sand (kg)	Cement (kg)	Water (L)	Foam (L/m <sup>3</sup> )	Number of Samples	Specimen Shape
Zone II	562.5	225	160	0.6	5	Prism
Zone III	562.5	225	160	0.6	5	Prism
Zone IV	562.5	225	160	0.6	5	Prism

A For each sand gradation category, five cube specimens measuring 10 × 10 × 10 cm were prepared, resulting in a total of 15 samples. The preparation process involved mixing, casting, curing, and testing, all of which were conducted by standardized laboratory procedures.

The compressive strength test was conducted in accordance with the SNI 8640:2018 procedure. The specimens were submerged in water for 24 hours, then surface-dried before testing. The compressive load was applied using a hydraulic press machine at a constant loading rate of approximately 0.1 MPa/s until failure occurred. Compressive strength was calculated using the following formula:

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

Where  $f_c$  is the compressive strength (N/mm<sup>2</sup>),  $P$  is the maximum load (N), and  $A$  is the cross-sectional area of the specimen (mm<sup>2</sup>).

The equipment used included a digital scale for weighing materials, a sieve set for sand classification, an electric drill for mechanical mixing, and supporting tools such as buckets and trowels for manual processing. Molds, a cutting machine for sample preparation, and a hydraulic press machine for testing compressive strength were also utilized.

The collected data were analyzed both descriptively and statistically to evaluate the influence of sand gradation on compressive strength. The analysis included calculating the mean and standard deviation of results across samples to assess performance consistency and to identify trends based on sand fineness characteristics.

## III. RESULTS

The influence of variations in sand fineness on the compressive strength of CLC bricks is the subject of this study. The three types of sand used correspond to Zones II, III, and IV, as classified under the Indonesian National Standard (SNI 03-2834-2000). Each sand type was used to produce five specimens, which were then cut and tested according to the SNI 8640:2018 standard.

### A. Characteristics of Fine Aggregate

The properties of the fine aggregates used in this study are summarized in Table II. The measured water content of 2.57% indicates the presence of significant natural moisture in the

sand, which must be accounted for to avoid excessive water in the mix. A silt content of 1.69% remains within the permissible limits for lightweight concrete applications, although the presence of fine particles, such as silt, can potentially interfere with the bonding between the cement and aggregate. The specific gravity of 3.1 g/cm<sup>3</sup> suggests a relatively dense aggregate, which may influence the final density of the lightweight bricks. Meanwhile, the bulk density of 1.4 kg/L represents the loose state of the sand, which is relevant for determining the material volume during batching. Collectively, these characteristics provide essential insight into the potential effects of the fine aggregates on the mechanical performance of the CLC bricks.

TABLE II. Characteristics of Fine Aggregate

Characteristic	Value
Water content	2.57%
Silt content	1.69%
Specific gravity	3.1 g/cm <sup>3</sup>
Bulk density	1.4 kg/L

### B. Compressive Strength Test

The compressive strength results are summarized in Table III. The compressive strength results indicate that Zone II sand produced the highest average value (0.21 MPa), followed by Zone IV (0.15 MPa), and the lowest by Zone III (0.08 MPa). These findings suggest that sand with moderate gradation (Zone II) contributes to better particle distribution and a denser, more homogeneous internal structure. In contrast, the finer gradation of Zone III may increase water demand, resulting in higher porosity and lower compressive strength. Although Zone IV sand provides slightly better strength than Zone III, its performance appears more variable. These differences highlight the significant impact of sand gradation on the compressive strength of CLC-type bricks.

TABLE III. Average Compressive Strength

Sand Zone	Average Compressive Strength (MPa)
Zone II	0.21
Zone III	0.08
Zone IV	0.15

## IV. DISCUSSION

### A. Effect of Sand Fineness

The results showed that variations in sand fineness had a notable impact on the compressive strength of Cellular Lightweight Concrete (CLC) bricks. Specimens made with Zone II sand exhibited the highest average compressive strength (0.21 MPa), followed by Zone IV (0.15 MPa), and the lowest was observed in Zone III (0.08 MPa).

The substantial reduction in compressive strength observed with Zone III sand suggests that excessively fine sand can disrupt particle distribution within the mix, resulting in increased porosity and weaker interparticle bonding. In contrast, the intermediate gradation in Zone II provides a balance between particle density and bond formation, resulting in a denser and more homogeneous microstructure. These findings align with those reported by [1], who found that finer sand particles (up to 0.6 mm) enhance the strength of lightweight concrete due to improved particle distribution and

better foam stability.

The adverse effect of overly fine sand gradation can also be attributed to its high surface area, which increases water demand. Excess water leads to higher capillary porosity during drying, which ultimately reduces the strength. This mechanism is supported by [10], who showed that a higher fineness modulus generally enhances compressive strength, but only up to a point—beyond which stability and compactness decrease.

Moreover, excessively fine sand reduces mechanical interlocking between aggregates and the cement matrix. These interlocks play a critical role in resisting compressive loads through internal friction and stress transfer. Researcher [11] emphasized that while finer particles may contribute to denser microstructures, they also weaken bond efficiency and overall workability due to increased water content.

In contrast, the use of moderately graded sand (Zone II) allows cement paste to effectively fill the voids between particles, forming a compact matrix with reduced porosity and improved load-bearing capacity. Researcher [2] found that such gradation supports the development of stable and cohesive microstructures in lightweight concrete.

### B. Statistical Analysis

Table IV presents descriptive statistics for the compressive strength values of the three sand gradation zones. Zone II had the highest average compressive strength (0.212 MPa) with a standard deviation of 0.046 MPa, indicating consistent performance. Zone III yielded the lowest strength (0.075 MPa) with low variation (SD = 0.019 MPa), suggesting uniformly low performance. Zone IV had an intermediate mean (0.172 MPa) but the most significant variability (SD = 0.078 MPa), implying inconsistency in mechanical behavior.

TABLE IV. Descriptive Statistics for Compressive Strength

Sand Zone	Mean (MPa)	Std. Dev. (MPa)	Min (MPa)	Max (MPa)
Zone II	0.212	0.046	0.14	0.28
Zone III	0.075	0.019	0.04	0.10
Zone IV	0.172	0.078	0.06	0.26

TABLE V. One-Way ANOVA Test Results

Parameter	Value
F-statistic	13.32
p-value	$9.4 \times 10^{-5}$

ANOVA results, shown in Table V, indicate a significant difference among the groups with an F-value of 13.32 and a p-value of  $9.4 \times 10^{-5}$  ( $p < 0.05$ ). This result confirms that the differences in compressive strength between sand gradation zones are statistically significant. A post-hoc test, such as Tukey's HSD, is recommended in future work to identify specific group differences.

TABLE VI. Shapiro-Wilk Normality Test Results

Sand Zone	Statistic	p-value	Interpretation
Zone II	0.926	0.406	Data are normally distributed.
Zone III	0.918	0.343	Data are normally distributed.
Zone IV	0.792	0.012	Data are not normally distributed.

Shapiro–Wilk normality test results are presented in Table VI. Data for Zones II and III are normally distributed ( $p > 0.05$ ), while Zone IV shows a non-normal distribution ( $p = 0.012$ ). Although ANOVA is generally robust, these results suggest the benefit of applying complementary non-parametric tests.

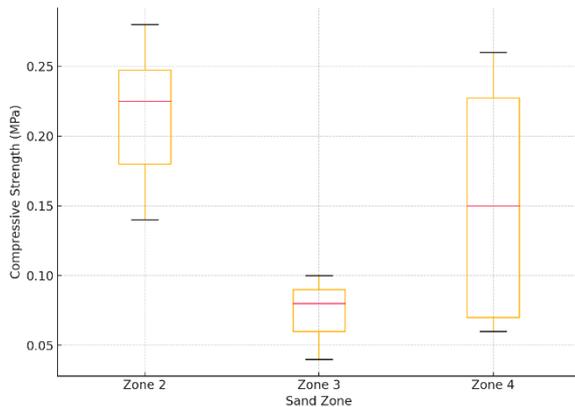


Fig. 1. Compressive Strength Distribution by Sand Zone

Fig. 1 shows the distribution boxplot of the compressive strength of light bricks based on variations in the sand zone. It can be seen that Zone II has the highest median compressive strength value and a relatively narrow distribution (interquartile), indicating that the mechanical performance of mixtures using Zone II sand tends to be more stable and consistent. In contrast, zone III showed the lowest median value, with a narrow range, indicating that all samples from this zone produced a low and uniform strength but one that was well below the minimum standard. Meanwhile, Zone IV has a higher median value than Zone III, but it also exhibits an extensive distribution. This condition reflects the high variability between samples, indicating that mixing with zone IV sand results in inconsistent performance. In general, this graph reinforces the finding that sand gradation significantly affects both the compressive strength value and the stability of the results between samples.

Fig. 2 presents a comparison of the average compressive strength of light bricks for the three sand zones used in the study, accompanied by an error bar line representing the standard deviation of each data group. It was observed that zone II sand produced the highest average compressive strength, approximately 0.21 MPa, with a relatively low level of data variation. This result shows a more stable and homogeneous performance in the formation of light brick structures at medium sand gradations. In contrast, zone III has the lowest average compressive strength, approximately 0.075 MPa, with a slight standard deviation, indicating a low but consistent level of weakness. Zone IV is in the middle position, with an average score that is better than Zone III, but it has the most significant standard deviation among the three. This result reflects a reasonably high yield inconsistency in the use of zone IV sand, which may be due to variations in particle gradation or suboptimal mixing and distribution of aggregates in the matrix. Overall, this graph indicates that sand gradation has a significant impact on both the

compressive strength and performance stability of light brick samples.

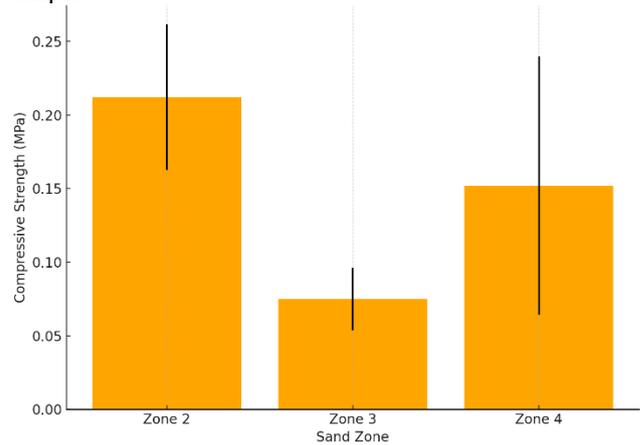


Fig. 2. Average Compressive Strength of CLC by Sand Zone

Statistical analysis of compressive strength data reveals a consistent trend, where moderately graded sand yields higher compressive strength, while very fine gradations tend to produce significant variations in compressive strength. This result indicates that the inhomogeneity of the particle distribution has a significant impact on the uniformity of the final material's strength.

These findings align with research [6], which indicates that variations in density and vibration time in lightweight concrete can lead to a compressive strength difference of up to 67%, depending on the distribution and density of the lightweight aggregate. A statistical approach was also employed by [7] through the modeling of self-compacting concrete mix designs, which revealed that the type and proportion of sand significantly affected compressive strength at different ages (2, 7, and 28 days). This modeling also confirms that the optimal combination of natural sand and processed sand provides the best strength results. In addition, the study by [12] employed an artificial neural network approach to predict the compressive strength of light concrete based on various mixed parameters, including sand fraction. It demonstrated high predictive accuracy in understanding the nonlinear relationship between input and compressive strength.

Therefore, the statistical data from this study can be strengthened with a multivariate approach and predictive modeling, as supported by the literature, to provide more confidence in the experimental results and replication potential on a larger production scale.

### C. Evaluation Against SNI Standards

According to the requirements outlined in SNI 8640:2018, the minimum compressive strength for lightweight bricks is 1.8 MPa for individual specimens and 2.0 MPa for average values. The results of this study show that none of the specimens produced using Zone II, III, or IV sand gradations met these minimum strength thresholds—either individually or on average. This finding indicates that the current mix design does not yet fulfill the structural criteria specified by national standards.

Several factors may explain this non-compliance. One of

the most critical is the water-cement ratio. An excessively high water-cement ratio can increase porosity and weaken the bond between cement particles, ultimately reducing compressive strength. Although the mixed materials were weighed accurately, no specific data on the actual water-cement ratio for each variation were provided, making it difficult to assess its effect quantitatively.

Another contributing factor may be the use of chemical admixtures, such as foaming agents, plasticizers, or strength enhancers. The performance of such additives strongly depends on the proper dosage, mixing methods, and compatibility with base materials, such as cement and water. Improper mixing or incorrect dosages may cause segregation, reduce homogeneity, and impair the internal quality of the hardened concrete.

The curing process also plays a crucial role in the development of concrete's strength. In this study, curing was conducted through natural drying, with no detailed information provided on curing duration, ambient temperature, or humidity control. Inadequate or inconsistent curing may hinder the hydration process, resulting in underdeveloped microstructures and an increased risk of cracking or weakness.

Taken together, these observations suggest that the low compressive strength values are not solely caused by the fineness of the aggregates but rather by the combined effects of suboptimal mix proportions, insufficient control over admixture integration, and unstandardized curing procedures. Therefore, to achieve compressive strength that complies with SNI requirements, future research must adopt a more comprehensive and controlled experimental framework, particularly focusing on mix optimization, additive behavior, and proper curing regimes.

## V. CONCLUSION

This study investigated the effect of sand fineness variation—categorized into SNI-defined Zones II, III, and IV—on the compressive strength of Cellular Lightweight Concrete (CLC) bricks. The findings lead to the following conclusions:

1. Sand fineness significantly influences compressive strength. Among the tested gradation zones, Zone II (moderate fineness) produced the highest average compressive strength at 0.21 MPa, followed by Zone IV (0.15 MPa) and Zone III (0.08 MPa). These results confirm that sand gradation has a direct impact on the density and internal structure of CLC bricks.
2. None of the tested mixtures met SNI 8640:2018 requirements. The average and individual compressive strength values for all sand variations fell below the minimum threshold of 1.8 MPa (individual) and 2.0 MPa (average). This outcome suggests that the current mix design is not suitable for structural applications without further optimization.
3. Zone II sand provides better structural performance. Its intermediate gradation facilitates better particle packing, lower porosity, and improved load transfer, making it more favorable for producing stronger and more consistent

lightweight bricks compared to coarser or finer alternatives.

4. Multiple interacting factors influence compressive strength. In addition to aggregate gradation, other critical parameters—including water-cement ratio, admixture compatibility, and curing conditions—play significant roles in determining final strength outcomes.

## REFERENCES

- [1] Lim SK, Tan CS, Zhao X, Ling TC. Strength and toughness of lightweight foamed concrete with different sand grading. *KSCE J Civ Eng* [Internet]. 2014;19(7):2191–7. Available from: <http://dx.doi.org/10.1007/s12205-014-0097-y>
- [2] Shi P, Falliano D, Celi AB, Yang Z, Marano GC, Briseghella B. Workability and Mechanical Properties of Structural Foamed Concretes with Different Dry Densities, and Fine Sand Grain Sizes: Preliminary Study. In: 2024 IEEE International Workshop on Metrology for Living Environment (MetroLivEnv). 2024. p. 379–83.
- [3] Xie Y, Zhou Q, Long G, Chakraborty P, Shi Y, Umar HA. Experimental Investigation on Mechanical Property and Microstructure of Ultra-high-performance Concrete With Ceramsite Sand. *Struct Concr*. 2021;23(4):2391–404.
- [4] Pokorný J, Ševčík R, Šál J, Zárbybnická L, Žák J. Lightweight Concretes With Improved Water and Water Vapor Transport for Remediation of Damp Induced Buildings. *Materials (Basel)*. 2021;14(19):5902.
- [5] Guo M, He Y, Zhi X. Experimental Research on Dynamic Mechanical Properties of High-Density Foamed Concrete. *Materials (Basel)*. 2024;17(19):4781.
- [6] Shah SJ, Naeem A, Hejazi F, Mahar WA, Haseeb A. Experimental Investigation of Mechanical Properties of Concrete Mix With Lightweight Expanded Polystyrene and Steel Fibers. *Civileng*. 2024;5(1):209–23.
- [7] Lermen RT. Waste Reduction in Industry: A Study on Using Fine Green Foundry Sand Waste in Foamed Concrete Production. *Corpus Online J Civ Eng*. 2023;1(2):1–6.
- [8] Al-Zubaidi H, Allouzi R. Flexural Behavior of Slabs Made of Lightweight Foamed Concrete With Basalt Powder. *J Eng Des Technol*. 2023;23(1):249–63.
- [9] Raj IS, Karthiyami S. Sustainable Usage of Waste Materials in Aerated and Foam Concrete: A Review. *Civ Eng Archit*. 2021;9(4):1144–55.
- [10] Nikzad Y, Mazloom M, Parhizkari MH. Effect of sand fineness modulus on SCC and SCLC properties. *Constr Build Mater* [Internet]. 2024;421:135761. Available from: <https://www.sciencedirect.com/science/article/pii/S0950061824009024>
- [11] Salari F, Alengaram UJ, Alnahhal AM, Ibrahim ZB, Yusoff S, Ibrahim MSI, et al. Promulgation of sustainable palm oil clinker sand in the development of structural and non-structural lightweight foamed concrete. *Struct Concr* [Internet]. 2023 Jun 1;24(3):3952–68. Available from: <https://doi.org/10.1002/suco.202200323>
- [12] Khajehzadeh M. Compressive strength prediction of structural lightweight concrete by applying the recurrent neural network-fractional order bat optimization algorithm. *Concurr Comput Pract Exp* [Internet]. 2022 Jul 10;34(15):e6975. Available from: <https://doi.org/10.1002/cpe.6975>