UTILIZING BULU CLAM SHELL AND SIKACIM CONCRETE AS PARTIAL CEMENT REPLACEMENT IN POROUS CONCRETE PRODUCTION

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Abstract: The novelty of this research lies in the utilization of waste from bulu clam shells, which are abundantly found in Batu Bara Regency, North Sumatra, Indonesia, combined with Sikacim as a partial substitute for cement in the production of pervious concrete. Bulu clam shells are waste materials with a high calcium carbonate (CaO) content. The development of compressive strength and porosity characteristics of pervious concrete is the main objective of this study. Therefore, this research employs bulu clam shell waste and Sikacim as partial replacements for cement in the production of pervious concrete to minimize the environmental impact of waste. The methodology refers to ACI 522R-10 with a curing age of 28 days. The test specimens were cylindrical with a diameter of 15 cm and a height of 30 cm. The mix variations of pervious concrete in comparison to cement:shell:Sikacim were (100:0:0; 95:5:0; 95:0:5; 90:10:0; 90:0:10; 90:5:5)%. SEM analysis indicates that bulu clam shell waste exhibits a characteristic aragonite morphology, marked by needle-like and rough surface textures. XRF analysis shows that bulu clam shell waste has significant potential for various industrial applications due to its high CaO content and the presence of other supporting elements such as Al_2O_3 and SiO_2. The porosity test results of pervious concrete show that the addition of Sikacim tends to increase porosity, particularly at a dosage of 5%, reaching 27.3%. In contrast, the addition of bulu clam shell waste reduces porosity due to its ability to fill micro-pores. The compressive strength test results demonstrate that bulu clam shell waste is highly effective in increasing the compressive strength of pervious concrete, especially at a 10% composition, achieving 8.86 MPa, which represents a 1.7 MPa increase compared to normal concrete. It can be concluded that bulu clam shell waste has strong potential for the development of the construction industry, as it can partially replace cement while also serving as a more environmentally friendly concrete material.
Keywords: bulu clam shell; porous concrete; sikacim concrete

Abstrak: Penelitian Kebaruan penelitian adalah memanfaatkan limbah dari cangkang kerang bulu, yang banyak ditemukan di Kabupaten Batu Bara, Sumatera Utara, Indonesia, ditambah dengan sikacim sebagai pengganti sebagian penggunaan semen pada pembuatan beton berpori. Pengembangan sifat kuat tekan dan porositas beton

berpori merupakan tujuan penelitian, sehingga penelitian memanfaatkan limbah cangkang kerang bulu dan Sikacim sebagai pengganti sebagian semen dalam produksi beton berpori untuk meminimalkan dampak lingkungan dari limbah. Metode yang digunakan mengacu pada ACI 522R-10, dengan umur pengujian 28 hari. Sampel uji berbentuk silinder, dengan diameter 15 cm dan tinggi 30 cm. Hasil pengujian SEM menunjukkan cangkang kerang bulu memiliki morfologi aragonit yang khas, ditandai dengan tekstur seperti jarum dan kasar. Analisis XRF menunjukkan cangkang kerang memiliki potensi signifikan untuk berbagai aplikasi industri karena kandungan CaO yang tinggi dan adanya unsur pendukung lainnya seperti Al_2O_3 dan SiO_2. Uji porositas beton berpori menunjukkan penambahan Sikacim cenderung meningkatkan porositas, terutama pada dosis 5% sebesar 27,3%. Penambahan cangkang kerang bulu mengurangi porositas karena kemampuannya mengisi pori-pori mikro. Hasil uji kekuatan tekan menunjukkan cangkang kerang bulu sangat efektif dalam meningkatkan kekuatan tekan beton berpori, khususnya pada komposisi 10%, sebesar 8,86 Mpa, meningkat sebesar 1,7 MPa dari nilai beton normal. Hasil penelitian dapat disimpulkan bahwa limbah cangkang kerang bulu memiliki potensi dalam pengembangan industri konstruksi, karena dapat sebagian menggantikan semen sekaligus berfungsi sebagai material beton yang lebih ramah lingkungan.

Kata kunci: cangkang kerang bulu; beton berpori; sikacim berpori

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Introduction

Pervious concrete (also known as porous concrete) is a type of concrete with high porosity (15–30%) that allows water to flow directly through the concrete layer into the ground beneath it. This concrete has been developed under the concept of green engineering (Liu et al., 2023 ; Cai et al., 2023) as an environmentally friendly solution to improve urban water management systems (Yahyaee & Mofidi, 2024) and has gained increasing attention over recent decades due to its effectiveness in managing surface runoff caused by rainfall (Sánchez-Mendieta et al., 2024). Its application in urban environments can help reduce surface runoff contamination (Wijeyawardana et al., 2022). As an innovation in sustainable concrete, pervious concrete is characterized by the absence of fine aggregates and its high porosity, which enables efficient water infiltration (Fynnisa Z et al., 2023). However, this high porosity may weaken several mechanical properties, including resistance to cracking and fatigue (Almansori et al., 2021), or result in lower strength compared to conventional concrete (RD et al., 2022).

The development of sustainable construction technology encourages the industry to pursue new methods of concrete production (Irfansyah et al., 2021) and to improve concrete quality by incorporating supplementary materials such as pozzolan, fly ash, steel slag, copper slag, and silica fume, as these materials contain CaO, SiO_2, Fe_2O_3, FeO, MgO, and MnO (Rangan, 2023). The novelty of the method and quality improvement in this research are achieved by utilizing bulu clam shell

waste and Sikacim as partial cement replacements in the production of pervious concrete. Bulu clam shell, which are widely found in coastal areas, contain high levels of calcium carbonate ($CaCO_3$). After calcination, they can produce calcium oxide (CaO), a compound that actively participates in the cement hydration process (Utami, W., Rahman, F., dan Hidayat, 2021). Calcium carbonate ($CaCO_3$) can serve as a viable recycled mineral aggregate for various construction and building materials (L. He et al., 2023). Utilizing bulu clam shell not only reduces marine environmental pollution—such as unsightly wase, environmental degradation, and foul odors (Summa et al., 2022) but also adds value as an alternative building material.

Innovation in concrete research continues to develop through the use of additives that can modify the quality of the concrete itself. For instance, (Fynnisa et al., 2025) utilized clam shell waste from Batu Bara as partial cement replacement with variations of 0%, 5%, 10%, and 15% in pervious concrete production, showing that increasing the content of clam shells in the mixture can enhance porosity and compressive strength. Additionally, (R. He & Lu, 2024) used crushed oyster shells to replace both coarse and fine aggregates in concrete applications. Furthermore, R. (R. He & Lu, 2023) and (R. He et al., 2023) used marine shells to investigate durability and their potential application in pervious concrete pavements. Based on the previously reviewed literature, the present study aims to serve as a reference for future pervious concrete research, particularly because such studies are still limited among researchers in Indonesia. The novelty of this research lies in combining bulu clam shell powder with Sikacim as partial cement replacement to improve porosity and compressive strength of pervious concrete. This study utilizes bulu clam shell waste that is not calcined but oven-dried prior to being processed into 200 mesh powder.

Method

The production of pervious concrete follows the ACI 522R-10 standard, using materials such as 200 mesh bulu clam shell powder. The material was sourced from Sejarah Beach, Batu Bara Regency, with the map shown in Figure 1 and a coordinate point of approximately 3.28° LS, 99.495° BT. Other materials used include Sika brand Sikacim Concrete, Tiga Roda cement, coarse aggregates sized 1–2 cm, and water.

The equipment used includes a Scanning Electron Microscope (SEM), X-Ray Fluorescence Spectrometer (XRF), Universal Testing Machine (UTM) WEW-300 A, digital scale, oven, mixer, cylindrical concrete molds with a diameter of 15 cm and a height of 30 cm, a 200 mesh sieve, and a beaker glass. Included are the results of the porous concrete figure 2.

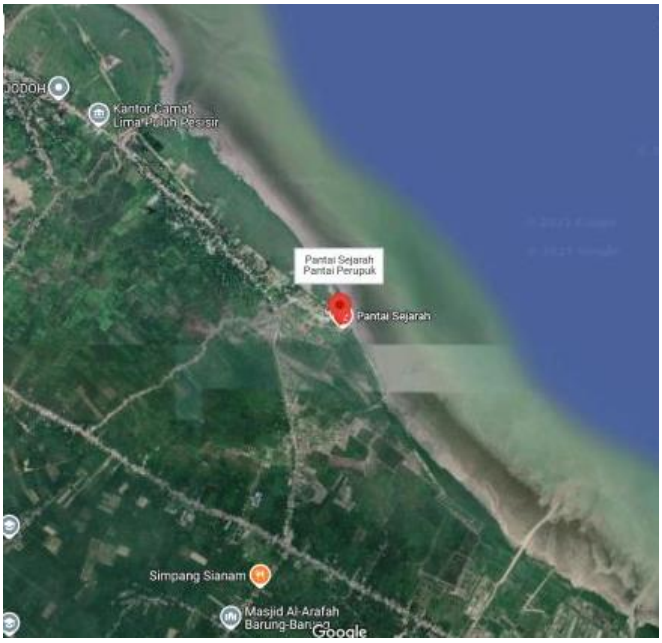


Figure 1. Map of Sejarah Beach, Batu Bara Regency



Figure 2. Porous concrete

The concrete mixture was formulated following to the mix design in Table 1 below.

Table 1. Mix design variations for porous concrete

Sample	Cement (%)	Bulu clam shell (%)	Sikacim concrete (%)	Split (kg)	Water (ml)	Number of samples (units)
I	100	0	0	47.064	4.482	6
II	95	5	0	47.064	4.482	6
III	95	0	5	47.064	4.482	6
IV	90	10	0	47.064	4.482	6
V	90	0	10	47.064	4.482	6
VI	90	5	5	47.064	4.482	6
VII	85	5	10	47.064	4.482	6
VIII	85	10	5	47.064	4.482	6

Porous concrete was produced using six cylindrical specimens for each mix variation, each made with a mold measuring 15 cm in diameter and 30 cm in height. The curing process involved submerging the samples in water for 28 days.

Following the curing period, the specimens underwent porosity and compressive strength testing.

To analyze the bulu clam shells, X-Ray Fluorescence (XRF) was employed to determine the material's elemental composition by detecting X-rays emitted from the sample (Pamungkas et al., 2024). Surface morphology was examined using Scanning Electron Microscopy (SEM), which provided detailed images of the sample's topography in specific regions (Mitaphonna et al., 2023). The compressive strength of the concrete specimens was evaluated using a Universal Testing Machine (UTM) (Nafiyanto et al., 2025).

Results and Discussion

SEM analysis of bulu clam shell

The SEM analysis shown in Figure 2 was taken at 1000x magnification with a scale of 100 µm, displaying the material surface with an irregular crystalline morphology. Clearly visible are short rod-like (acicular) structures and coarse plate-like formations oriented randomly. This surface condition indicates a rough and fractured texture, suggesting that the sample may originate from a biogenic material such as clam shells or calcium carbonate residues from processing.

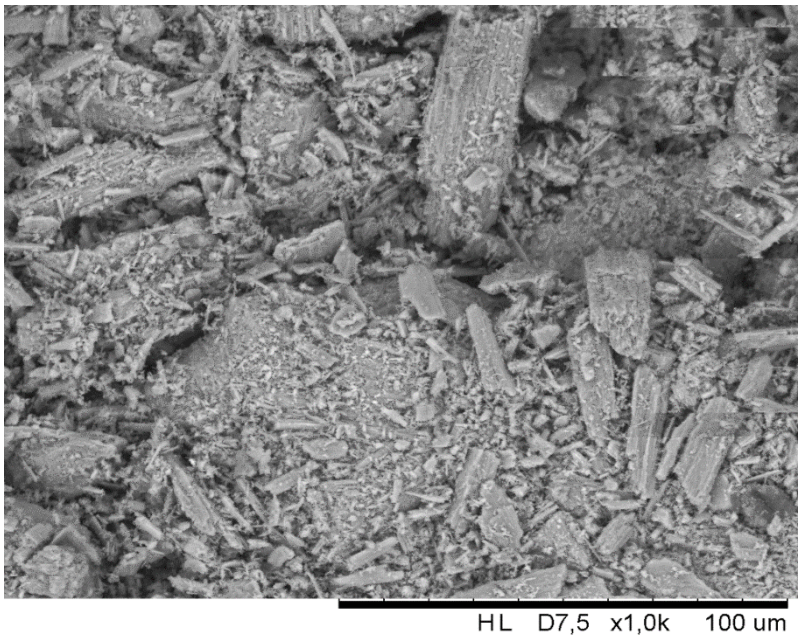


Figure 2. SEM of sampel 1bulu clam shell from Batu Bara Regency

These characteristics are consistent with the crystalline morphology of aragonite, one of the polymorphic forms of $CaCO_3$ commonly found in biominerals. According to (Zhang, Y., Liu, J., & He, 2023), aragonite often forms under marine environmental conditions and exhibits columnar or acicular rod-like shapes, as seen in Figure 2. The microstructure in Figure 2 reveals the following acicular crystals, indicate the presence of the aragonite phase. Non-homogeneous particle

distribution, suggests mechanical fragmentation, thermal treatment, or biogenic degradation processes. Microporosity, indicates that the material may possess good adsorptive properties, making it suitable for applications such as filtration or heavy metal adsorption.

This is supported by a study conducted by (Kaur, G., Singh, R., & Mehta, 2024), which states that the microporous structure and acicular shape of $CaCO_3$ enhance the specific surface area and ion-exchange capacity in environmental applications. Materials with such morphology are suitable for various applications, including filler material in polymer composites to improve mechanical strength, biomaterial scaffolds in bone tissue engineering applications, as acicular structures support cell growth, adsorbents in water purification, particularly for absorbing heavy metals such as Pb^{2+} or Cd^{2+}, raw material for CaO through calcination processes, for use in cement or gas adsorption applications.

According to (Al-Harbi, H., Omar, M., & Rahman, 2025), the acicular morphology of $CaCO_3$ derived from shell waste demonstrates superior performance when used in biodegradable composites and ion-absorbing materials. The microstructure observed in the image originates from clam shells dominated by aragonite composition, and the texture formed by biological recrystallization is very typical of such materials. Mollusk shells are known to possess complex microstructural layers that contribute to their strength and durability, as described by (Li, N., Zhao, Y., & Chen, 2023) in their study on shell biomineralization.

XRF analysis of bulu clam shell

XRF (X-ray Fluorescence) is a commonly used characterization technique for identifying and quantifying the content of metal elements and metal oxides in solid samples. This technique is non-destructive and highly accurate for analyzing inorganic materials such as seashells, which are typically composed of calcium carbonate and small amounts of other elements derived from their natural environment.

Table 2. Elemental composition of sampel 1 bulu clam shell from Batu Bara Regency

Compound	wt (%)	Element	wt (%)
CaO	84.60	Ca	3.69
Al_2O_3	5.80	Al	1.48
SiO_2	5.63	Si	1.74
Fe_2O_3	2.05	Fe	6.40
SrO	0.42	Sr	14.16
Sc_2O_3	0.36	Sc	4.09
SO_3	0.47	S	2.30
K_2O	0.31	K	3.31
TiO_2	0.17	Ti	4.51
MnO	0.09	Mn	5.89
Cl	0.05	Cl	2.62
ZrO_2	0.03	Zr	15.77
ZnO	0.02	Zn	8.63

Compound	wt (%)	Element	wt (%)
Br	0.01	Br	11.92
CoO	0.01	Co	6.93

Table 2 shows that the main component in the clam shell is CaO, which originates from $CaCO_3$, the primary structural component of the shell. Function: CaO provides structural strength to the shell and serves as a major calcium source for industrial applications such as cement, ceramics, and fertilizers (Pratiwi, A. D., Ramadhan, M. I., Handayani, D., & Sari, 2021). Al_2O_3 (6.80%) and SiO_2 (5.63%) are elements typically derived from contaminant minerals such as sand or fine sediments adhering to the shell. The presence of Al and Si opens up potential applications in the production of geopolymer materials and heat-resistant materials (Wahyuni, S., Zainuddin, S., & Hidayat, 2020).

Fe may originate from seawater or the mud where the shellfish lived. The iron content can influence the final color of the material and acts as an impurity in applications that require pure white materials (e.g., ceramics) (Widodo, A., Sutarno, S., Roesyanto, E., & Wijaya, 2020). Based on the chemical composition obtained from the XRF analysis, bulu clam shells from Batubara Regency have great potential for use in various applications, including cement industry, the high CaO content makes clam shells a promising alternative raw material for cement production. Agricultural fertilizers, calcium from clam shells can be used as a calcium source in fertilizers. Geopolymer materials, the presence of SiO_2 and Al_2O_3 enables the use of clam shells in the production of geopolymer materials. Heavy metal adsorbents, the porous structure and chemical composition of clam shells allow their use as adsorbents for heavy metals in waste treatment processes.

Porosity of porous concrete

Table 3 presents the porosity values of eight types of porous concrete mix variations based on three tests, from which the average was calculated. The variations include normal concrete, the addition of bulu clam shell ash, and combinations with the additive material Sika.

Table 3. Porosity measurements of porous concrete

Samples	Porosity (%)			Average Porosity (%)
	1	2	3	
Normal concrete	28	25	26	26,3
Concrete mixture with 5% bulu clam shell	22	28	24	24,6
Concrete mixture with 10% bulu clam shell	26	20	27	24,3
Sika concrete 5 %	27	29	26	27,3
Sika concrete 10 %	25	32	23	26,6
Concrete mixture with 5% bulu clam shell + Sika 5 %	24	25	29	26
Concrete mixture with 5% bulu clam shell + Sika 10 %	25	25	25	25
Concrete mixture with 10% bulu clam shell + Sika 5 %	26	22	23	23,6

The addition of clam shell ash to the concrete reduces porosity compared to normal concrete. This indicates that the material functions as a filler, filling micro-pores within the concrete mix and reducing the total pore volume. This finding is consistent with the study by (Putra, D. A., Wibowo, A., & Salim, 2021), which states that marine shell ash, rich in calcium carbonate, can enhance concrete density.

Sika additives contain superplasticizers that improve the flowability and pore formation in porous concrete. However, excessive addition may reduce the effectiveness of cavity filling, resulting in high porosity. The 10% ash + 5% Sika mixture proved to be the most effective in reducing porosity. This combination provides a synergistic effect between the filler capability of shell ash and the plasticizing properties of the Sika additive. The reduction in porosity can positively impact the strength and durability of concrete by minimizing the pathways for water and aggressive substances.

Figure 4 shows the average porosity values of various porous concrete mix variations. This study evaluates the effect of adding bulu clam shell ash and Sika additives on the porosity of porous concrete. The normal concrete sample has a porosity of 26.3%, which is in the mid-range of all variations. This confirms that the use of supplementary materials (both shell ash and Sika) can be employed to control porosity levels according to specific application needs, such as drainage concrete or lightweight concrete.

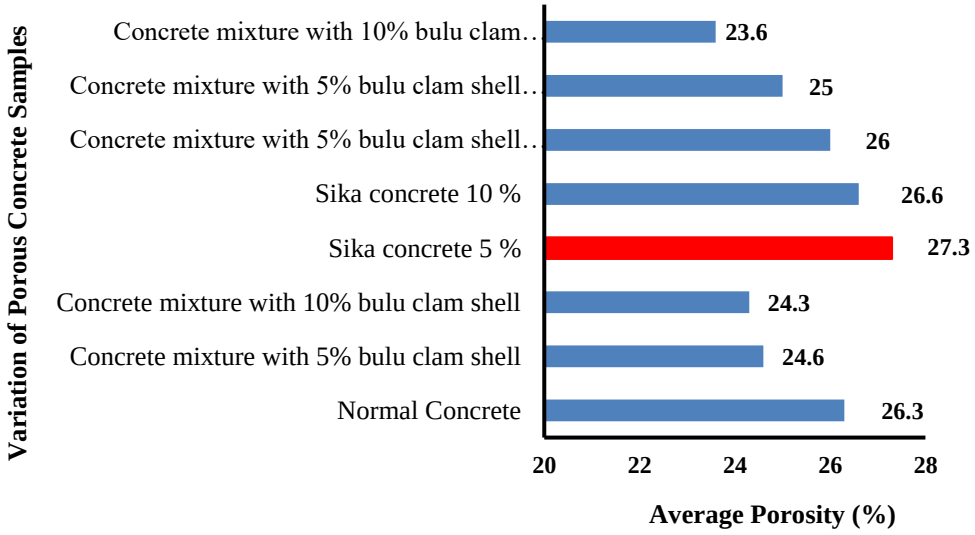


Figure 4. Average porosity of porous concrete

The 5% Sika concrete sample exhibited the highest porosity value at 27.3%, followed by the 10% Sika concrete sample with a porosity of 26.6%. This indicates that the addition of Sika admixture, particularly at a 5% dosage, significantly increases porosity. Admixtures like Sika typically contain superplasticizers that can influence the air distribution within the concrete mix and enhance workability,

potentially leading to the formation of more voids within the porous concrete structure.

Concrete samples with the addition of 5% and 10% clam shell ash without Sika had porosity values of 24.6% and 24.3%, respectively. This shows that clam shell ash tends to reduce porosity compared to normal concrete 26.3%. This reduction is likely due to the calcium carbonate ($CaCO_3$) content in the shell ash, which can fill micro-pores in the concrete, thus decreasing the total pore volume (Putra, D. A., Wibowo, A., & Salim, 2021).

The use of a combination of clam shell ash and Sika showed more complex variations. The mixture with 10% ash + 5% Sika produced the lowest porosity at 23.6%, indicating that this combination is the most effective in reducing porosity. This is likely due to the synergy between the pore-filling capability of the shell ash and the plasticizing effect of Sika, which improves concrete compaction. Conversely, the combination of 5% ash + 10% Sika resulted in a porosity value of 25%, higher than the Sika-only mixtures, suggesting that the dosage of admixtures also affects the final outcome in a non-linear manner.

Compressive strength of porous concrete

Table 4 presents the compressive strength values of eight variations of porous concrete mixtures, including normal concrete, concrete with bulu clam shell, and combinations with chemical admixtures (Sika) at 5% and 10% dosages. The following is an analysis of each variation.

Table 4. Compressive strength of porous concrete

Samples	Compressive Strength (MPa)			Average Compressive Strength (MPa)
	1	2	3	
Normal concrete	5.3	8.4	7.8	7.16
Concrete mixture with 5% bulu clam shell	10.2	3.8	9.8	7.93
Concrete mixture with 10% bulu clam shell	6.9	12.8	6.9	8.86
Sika concrete 5 %	5.9	5.7	6.0	5.86
Sika concrete 10 %	6.6	4.5	7.7	6.26
Concrete mixture with 5% bulu clam shell + Sika 5 %	9.7	8.6	5.2	7.83
Concrete mixture with 5% bulu clam shell + Sika 10 %	6.1	7.2	7.3	6.86
Concrete mixture with 10% bulu clam shell + Sika 5 %	6.3	9.0	9.2	8.16

The average compressive strength test result for normal concrete is 7.16 MPa. This result serves as a baseline, with normal concrete without any additives showing moderate strength, which reflects the typical performance of porous concrete (Yahya, M., Yani, A., & Putri, 2021). The variation with 5% bulu clam shell has an average compressive strength of 7.93 MPa, and the 10% bulu clam shell variation reaches an average of 8.86 MPa. The addition of bulu clam shell significantly increases the compressive strength of the concrete. This improvement is linked to the high CaO content (~84.60%) in the ash, which acts as an active

pozzolanic material that speed up the production of Calcium Silicate Hydrate (C–S–H) (Kusuma, I. G. A. D., Darmawan, R., & Suryana, 2020).

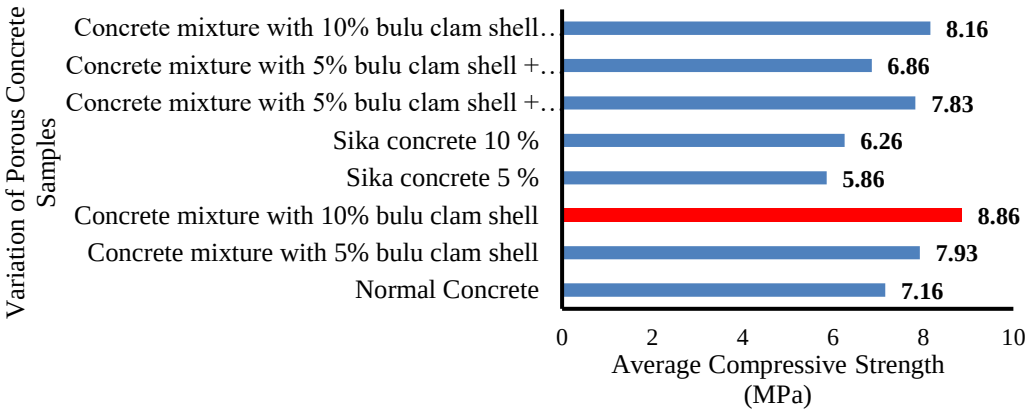


Figure 5. Comparison of average compressive strength in porous concrete

Figure 5 shows that normal concrete has a compressive strength of 7.16 MPa. When 5% bulu clam shell ash is added, the compressive strength rises to 7.93 MPa. Adding 10% bulu clam shell ash results in the highest compressive strength of 8.86 MPa. This indicates that bulu clam shell ash positively contributes to enhancing concrete strength due to its calcium oxide (CaO) content, which reacts with water to form C–S–H, a key phase responsible for providing strength to concrete (Pratiwi, A. D., Ramadhan, M. I., Handayani, D., & Sari, 2021).

Concrete with 5% Sika has a compressive strength of 5.86 MPa, which increases to 6.26 MPa with 10% Sika. These values are lower than that of normal concrete. This suggests that although Sika (a superplasticizer) improves the workability of concrete, its performance in increasing compressive strength is not significant without the combination of filler materials such as clam shell (Aziz, M. A., Al-Kharabsheh, B., Abdullah, S., & Alrshoudi, 2023). The combination of 5% Sika with 5–10% clam shell improves compressive strength. However, 10% Sika combined with 5% clam shell reduces compressive strength. This is likely due to excess Sika reducing aggregate bonding and introducing excess moisture into the mix (Gunasekara, C., Law, D. W., Setunge, S., & Mendis, 2020).

Conclusion

The results of SEM and XRF analyses indicate that the material exhibits a characteristic aragonite morphology, with an acicular and rough texture commonly found in biogenic materials such as seashells. The XRF results show that the bulu clam shell from Batubara contains a high concentration of CaO and other supporting elements such as Al_2O_3, SiO_2, and trace elements, highlighting its great potential for use in various industrial applications.

Porosity testing reveals that the addition of Sika tends to increase porosity, particularly at a 5% dosage, whereas the inclusion of bulu clam shell reduces

porosity due to its ability to fill micro-pores. The combination of 10% clam shell and 5% Sika is the most effective formulation for producing concrete with the lowest porosity (23.6%), which is highly beneficial for enhancing concrete resistance to water and environmental exposure. Compressive strength tests show that bulu clam shell ash is highly effective in increasing the compressive strength of porous concrete, especially at a 10% composition. Sika as an admixture yields better results when combined with clam shell, though an optimal dosage is necessary. The combination of 10% bulu clam shell without Sika demonstrates the optimum performance, with a compressive strength of 8.86 MPa, which is greater than that of normal concrete 7.16 MPa. The use of biowaste as cement substitute has the potential to lower clinker consumption, thereby supporting sustainability goals

Conflict of Interest

The first author was responsible for designing, coordinating, analyzing, and evaluating the research procedures in detail, and assigning tasks to the research team. The second author was responsible for coordinating students, analyzing the results of porous concrete compressive strength tests, and assisting with the drafting of the journal. The third author was responsible for coordinating students, assisting with material preparation, sample preparation, and drafting the journal and research report. The fourth and fifth authors assisted the first, second, and third authors in preparing the tools, materials, and test samples.

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