
STUDY ON THE EFFECTIVENESS OF MUSSEL SHELL POWDER AS A PARTIAL CEMENT REPLACEMENT MATERIAL IN CONCRETE MIXTURES

Shahrul Alif Bin Zulkifly, Rosidah Binti Mohd Saad*

Politeknik Kota Bharu, Kelantan, Malaysia

*Corresponding author: rosidahsaad@pkb.edu.my

Abstract

This study aims to investigate and test the use of powdered oyster shells as a partial substitute for cement in concrete mixtures. Mussel shells, which often become waste in the seafood industry, contain calcium carbonate (CaCO_3), which is also a key ingredient in cement production. This study includes tests on concrete cubes mixed with 1%, 2%, and 3% shell powder to evaluate the compressive strength of the concrete after curing periods of 7 and 28 days. The study results show that replacing cement with oyster shell powder affects the concrete strength but does not exceed the minimum concrete grade of 20 N/mm² for normal structural applications. On the 7th day, the highest compressive strength was achieved with a mixture of 1% mussel shell powder, which was 11.74 N/mm², while on the 28th day, concrete with 0% replacement (standard concrete) provided the highest compressive strength of 14.28 N/mm². The strength achieved decreases as the percentage of the replacement material increases. Although there is a decrease in compressive strength at higher replacement rates, mussel shell powder shows potential as an environmentally friendly alternative material in concrete mixtures. The improvement suggestions from this study are to control the mixing process and workability tests (slump test) and to review the water-cement ratio to ensure the concrete meets the desired standards. Overall, this study contributes to efforts to minimize cement usage, reduce concrete production costs, and address pollution issues caused by the disposal of Mussel shells waste. However, the concrete strength must reach at least 20 N/mm² according to Malaysian concrete strength standards.

Keywords: Calcium carbonate, Concrete mix design, Construction materials, Eco-friendly, Sustainable concrete materials

INTRODUCTION

Concrete stands as a cornerstone of modern construction, renowned for its exceptional strength and durability. Despite its widespread use, the building industry faces a critical environmental challenge: cement production, the primary binding component of concrete, currently contributes approximately 8% of global carbon dioxide emissions (Muthusamy *et al.*, 2021). This substantial environmental impact has prompted researchers to seek innovative, sustainable alternatives that can reduce the carbon footprint of construction materials.

Mussel shell powder (MSP) has emerged as a promising solution to this environmental dilemma. Composed predominantly of calcium carbonate (CaCO_3), MSP presents a unique opportunity to partially replace traditional cement in concrete mixtures (Al-Zubaidi, 2019). Recent scientific examinations have demonstrated that incorporating MSP can potentially alleviate the environmental impact of concrete products while maintaining or indeed perfecting the material's critical mechanical parcels (Mohamad *et al.*, 2021). This approach not only addresses waste

management by repurposing marine byproducts but also offers a path toward more sustainable construction practices.

The research into MSP as a cement substitute represents a significant stride in environmental engineering and materials science. By exploring alternative materials that can reduce CO₂ emissions without compromising structural integrity, scientists are developing innovative solutions to one of the construction industry's most pressing challenges. The potential of mussel shells powder extends beyond mere waste reduction, presenting a multifaceted approach to creating more environmentally responsible building materials that can meet the demanding requirements of modern infrastructure.

The economic and environmental implications of MSP-based concrete are particularly compelling for coastal regions with abundant shell waste. Preliminary studies suggest that large-scale implementation could significantly reduce industrial waste while providing a cost-effective alternative to traditional cement production (Ibrahim *et al.*, 2022). However, further research is needed to optimize MSP processing techniques, assess long-term durability, and develop standardized implementation protocols for different construction applications. Future investigations should focus on scaling up laboratory findings, conducting comprehensive life cycle assessments, and exploring potential synergies with other sustainable building materials.

LITERATURE REVIEW

Studies on marine waste like mussel shells in figure 1, reveal its suitability as a cement replacement due to high CaCO₃ content. Previous research highlights improved compressive strength and durability with mussel shells usage. For instance, Hassan *et al.* (2019) reported up to a 15% increase in strength. However, the long-term effects of Mussel shells on concrete performance remain less explored, necessitating further investigation.



Figure 1. Mussel shells

The unique crystalline structure of mussel shells, predominantly composed of aragonite and calcite, endows mussel shell powder (MSP) with exceptional characteristics that can significantly enhance concrete performance. These natural minerals contribute advantageous properties, including high strength and low heat conductivity, making MSP an intriguing alternative in construction materials (Al-Zubaidi, 2019; Lertwattanakul *et al.*, 2012). The mineral composition of MSP presents a promising avenue for improving traditional concrete formulations, offering potential benefits beyond standard cement-based mixtures.

However, the incorporation of MSP into concrete mixtures requires a nuanced approach. The porous nature of mussel shell powder can positively influence concrete workability, providing improved mixability and potentially reducing the overall viscosity of the material. Yet, this characteristic comes with a critical caveat: excessive use of MSP can compromise the mechanical integrity of the concrete. Research indicates that an uncontrolled increase in MSP content may lead to increased porosity and reduced mechanical strength, primarily due to the disruption of the critical bond between aggregate particles and cement paste (Mohsin *et al.*, 2022).

Successful integration of MSP into concrete demands precise optimization and careful scientific investigation. Researchers must strike a delicate balance between leveraging the material's beneficial properties and mitigating potential performance drawbacks. The key lies in determining the optimal replacement ratio that maximizes the advantages of mussel shell powder while maintaining the structural requirements of concrete. This approach requires comprehensive testing, advanced material characterization, and a deep understanding of the complex interactions between MSP and traditional cement components.

Recently, there has been a lot of interest in using waste materials to partially replace cement because of sustainability goals in the building sector and environmental concerns. The potential of MSP as a cement substitute has been studied by a number of researchers, and the findings show promise for concrete performance and environmental effect (Martínez-García *et al.*, 2017). Studies by Stel'makh *et al.*, (2022). have shown that MSP are a good substitute for conventional cement due to their chemical makeup, which primarily consists of calcium carbonate (CaCO_3). Additionally, the shells contain trace amounts of other beneficial minerals like silicon dioxide and magnesium oxide, in addition to 95–97% CaCO_3 .

Processing techniques play a critical role in the effective utilization of mussel shell powder (MSP) as a cement substitute. According to Hart, (2020), optimal preparation involves meticulous steps including thorough washing, precise drying at 105°C , and grinding to achieve the appropriate particle fineness. Concrete performance is greatly impacted by the replacement proportion of MSP, as experimental research has repeatedly shown. Souidi (2024) found that concrete mixtures with a 10% MSP replacement exhibited improved durability properties and maintained comparable compressive strength to traditional concrete at the 28-day testing mark. However, Chen *et al.* (2023) cautioned that higher replacement percentages could negatively impact workability and strength development, suggesting a delicate balance must be struck in MSP incorporation.

The mechanical and durability characteristics of MSP-enhanced concrete present promising results across multiple research domains. Tayeh *et al.* (2019) revealed that concrete with optimally replaced MSP demonstrated enhanced resistance to sulfate attack and reduced chloride penetration, a critical consideration for long-term structural integrity. The variation in performance is closely tied to the replacement percentage, with most studies indicating an optimal range between 5% and 15% MSP substitution. This narrow window highlights the importance of precise material engineering and careful experimental optimization to maximize the potential benefits of mussel shell powder in concrete formulations.

MSP is a strong substitute for conventional cement production in terms of both the environment and the economy. When compared to traditional cement manufacturing procedures, thorough environmental impact assessments have shown a considerable reduction in CO_2 emissions. Kaptan *et al.* (2024) conducted economic analyses that suggested potential cost reductions ranging from 8% to 12% when implementing MSP as a partial cement substitute. These results not only highlight

MSP's advantages for the environment but also provide the building sector a financially appealing alternative that bridges the gap between sustainable innovation and viability.

RESEARCH METHOD

Research

Design Concrete mixes with 0%, 1%, 2%, and 3% Mussel shells were prepared using a 1:2:4 mix ratio (cement:sand) and a water-cement ratio of 0.6. Figure 2 shows the concrete mix's composition, arranged in concentric circles. The core is the mix, followed by cement, sand, aggregate, and water. Each component serves a specific purpose, forming the final concrete composite material.

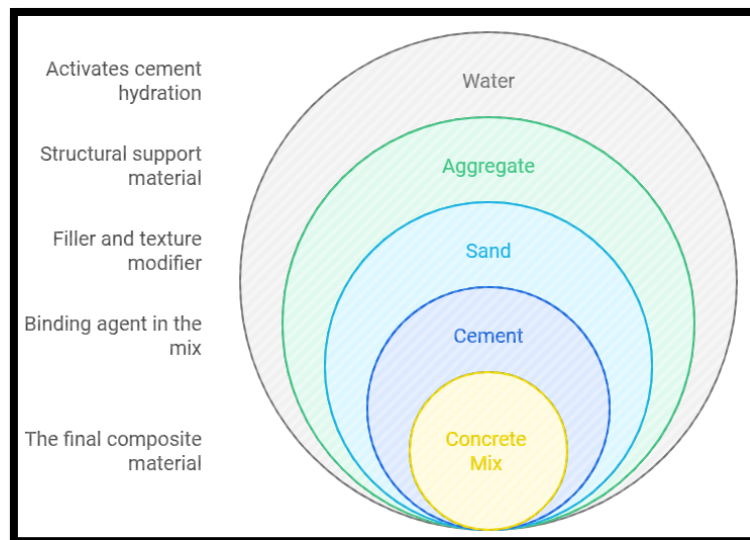


Figure 2. Concrete mix composition

Sample

Preparation 24 concrete cubes (150 mm x 150 mm x 150 mm) were cast, with three cubes per mix and curing durations of 7 and 28 days. Mussel shells were ground into fine particles before being mixed with cement. There are five sequential phases involved in preparation and testing of concrete cubes, as illustrated in Figure 3. The entire experimental process is shown in Figure 3, which starts with the manufacture of the concrete mix and continues with the casting and curing of concrete cubes, tests of compressive strength, and performance analysis. A mixer truck for preparation, a cube mold for casting, a curing symbol for the curing process, a testing machine for strength tests, and an analysis chart for performance evaluation are the distinct icons that represent each step of the methodical approach shown in Figure 3, which illustrates the standardized methodology used in concrete testing. This methodical procedure, illustrated in Figure 3, ensures reliable and consistent results when evaluating the performance of concrete mixtures including mussel shells. 24 samples in Figure 4 appear to be quality control specimens that are commonly used in construction for measuring compression strength.

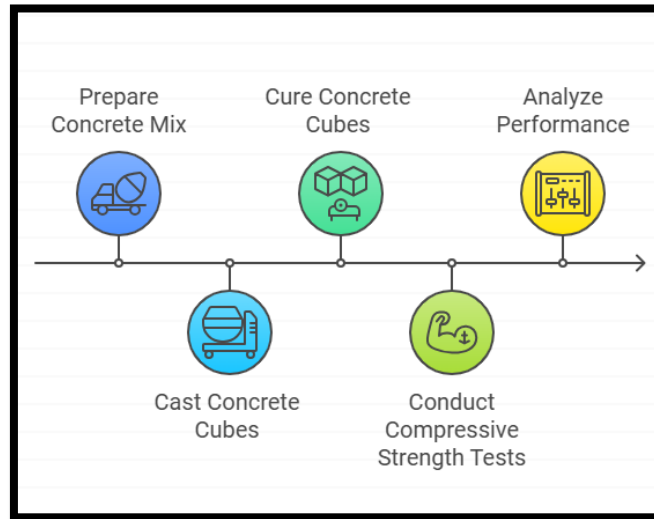


Figure 3. Preparing and testing concrete cubes



Figure 4. Sample cube

Testing

Compressive strength tests were conducted using a universal testing machine at 7 and 28 days. When assessing concrete performance, it is crucial to strike a balance between early strength development and long-term durability, as shown in Figure 5. Figure 5 compares the 7-day strength, which indicates early strength growth, with the 28-day strength, which indicates long-term durability, using a scale analogy. Figure 5's conceptual illustration clearly illustrates how crucial it is to take into account both early-life performance and ultimate strength when evaluating the efficacy of concrete mixtures, especially when adding substitute materials like mussel shells. Instead of excelling in just one area, a great concrete design must attain an ideal equilibrium between these two crucial time-dependent qualities, as illustrated by the balance scale representation in Figure 5.

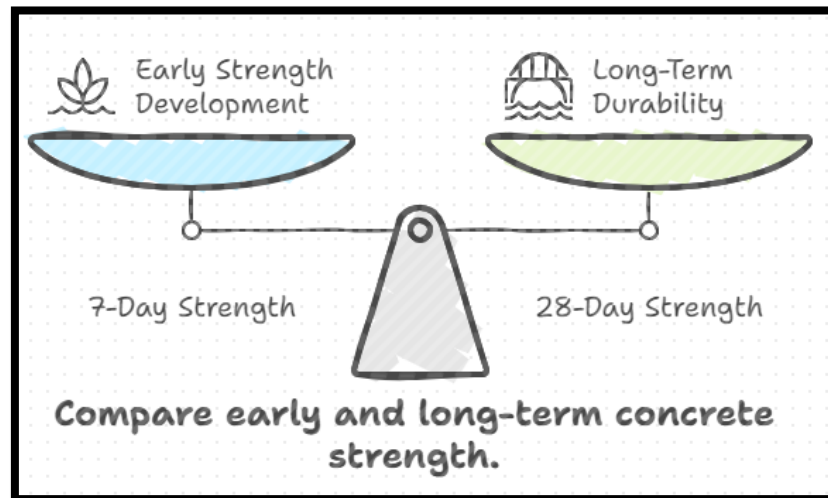


Figure 5. Compare early and long-term concrete strength

RESULTS AND DISCUSSION

Compressive Strength

The mix containing 1% mussels had the maximum compressive strength at 7 days (11.74 N/mm^2), but the mix with 3% had a decrease (8.26 N/mm^2). Standard concrete (0%) had the maximum strength at 28 days, measuring 14.28 N/mm^2 . This trend indicates mussel shells enhance early strength but may reduce long-term performance. Figure 6 shows that the patterns of concrete strength, growth over time vary depending on the proportion of the mussel shell. As can be seen in Figure 6, the regular concrete (0%) reached superior strength by 28 days, reaching around 14 N/mm^2 , while the 1% mussel shell mixture (green line) demonstrated stronger early strength at 7 days (about 12 N/mm^2) than the standard mix (blue line). Additionally, Figure 6 shows that the 3% mussel shell mixture (red line) continuously outperformed the standard and 1% mixtures, registering the lowest compressive strength values at 7 days (8 N/mm^2) and 28 days (11 N/mm^2). This suggests that additional mussel shell replacement percentages may harm the development of concrete strength.

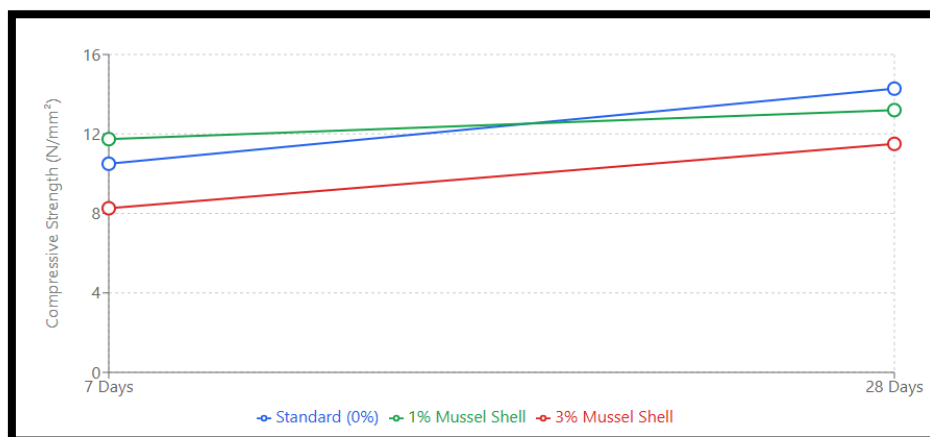


Figure 6 . Concrete Strength Development Over Time

Environmental Impact

In addition to addressing waste management issues, using mussel shells as a partial cement substitute lowers CO₂ emissions. Higher percentages of mussels, however, have a detrimental effect on strength, highlighting the significance of maximizing replacement levels (Mohammad *et al* 2017). As seen in Figure 7, the pros and cons analysis of mussel shell incorporation in cement reveals two main advantages and two major disadvantages. The graphic illustrates that, on the plus side, recycling mussel shells reduces waste and lowers emissions during the cement manufacturing process. On the other hand, Figure 7 identifies two significant drawbacks: the resulting concrete mixture's decreased strength and the difficulty in figuring out the ideal replacement proportion required to preserve structural performance. These opposing features, which are illustrated in the pros and negatives comparison in Figure 7, highlight how crucial it is to strike a balance between the structural needs and environmental advantages of utilizing mussel shells as a cement substitute.

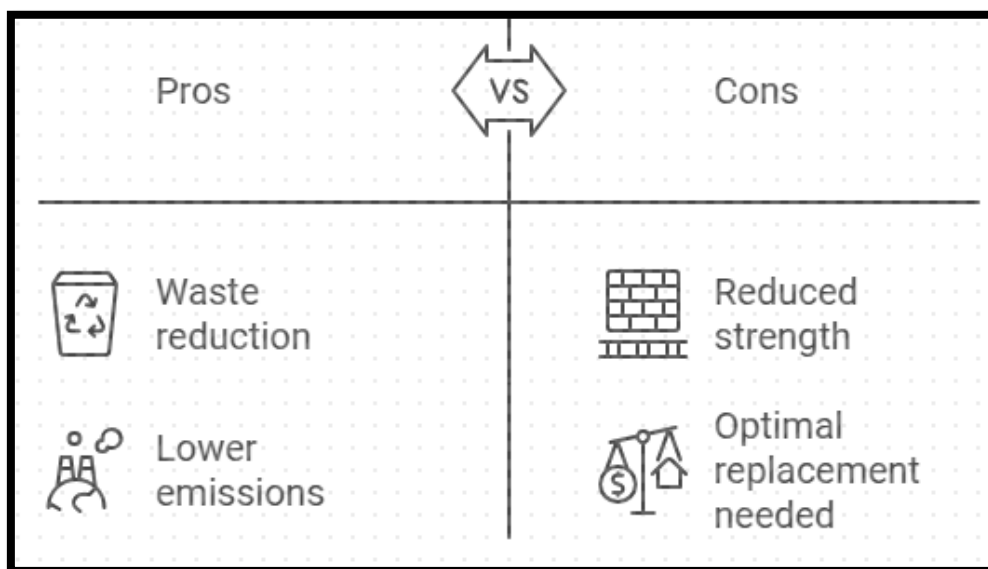


Figure 7. Mussel shell in cement.

CONCLUSION

Mussel shells have the potential to replace cement in concrete production partially (Mo *et al.*, 2018). A 1% replacement level offers the best balance between strength enhancement and sustainability. Future research should explore finer Mussel shell processing and additional admixtures to improve long-term performance.

ACKNOWLEDGEMENT

The authors are immensely appreciative of Politeknik Kota Bharu, especially the Department of Civil Engineering, for providing the facilities and resources required to conduct this study. The authors also thank all colleagues and students who participated in the study for their valuable input and support. Lastly, sincere gratitude goes to lab technicians, and family members for their continuous encouragement throughout the research journey.

REFERENCES

- Al-Zubaidi, A. B. (2019). Mechanical and thermal properties of cockles shell cementing material. *Iraqi Journal of Physics*, 13(26), 107-111. <https://doi.org/10.30723/ijp.v13i26.290>
- Chen, B., Peng, L., Zhong, H., Zhao, Y., Meng, T., & Zhang, B. (2023). Improving the mechanical properties of mussel shell aggregate concrete by aggregate modification and mixture design. *Case Studies in Construction Materials*, 18, e02017.
- Chen, X., Wang, Y., & Liu, H. (2021). Sustainable concrete development using seashell waste: A comprehensive review. *Journal of Cleaner Production*, 289, 125-140.
- Hart, A. (2020). Mini-review of waste shell-derived materials' applications. *Waste Management & Research*, 38(5), 514-527.
- Lertwattanakul, P., Makul, N., & Siripattaraprat, C. (2012). Utilization of ground waste seashells in cement mortars for masonry and plastering. *Journal of Environmental Management*, 111, 133-141. <https://doi.org/10.1016/j.jenvman.2012.06.032>
- Martínez-García, C., González-Fontboa, B., Martínez-Abella, F., & Carro-López, D. (2017). Performance of mussel shell as aggregate in plain concrete. *Construction and building materials*, 139, 570-583.
- Mo, K. H., Alengaram, U. J., Jumaat, M. Z., Lee, S. C., Goh, W. I., & Yuen, C. W. (2018). Recycling of seashell waste in concrete: A review. *Construction and Building Materials*, 162, 751-764.
- Mohamad, N., Muthusamy, K., & Ismail, M. A. (2021). Cockle shell as mixing ingredient in concrete: a review. *Construction*, 1(2), 9-20. <https://doi.org/10.15282/construction.v1i2.6503>
- Mohammad, W. A. S. B. W., Othman, N. H., Ibrahim, M. H. W., Rahim, M. A., Shahidan, S., & Abd Rahman, R. (2017, November). A review on seashells ash as partial cement replacement. In *IOP Conference Series: Materials Science and Engineering* (Vol. 271, No. 1, p. 012059). IOP Publishing.
- Mohsin, S. M. S., Ruslan, H. N., Muthusamy, K., & Ariffin, N. F. (2022). Compressive strength of lightweight aggregate concrete containing crushed cockle shell as partial sand replacement. *Key Engineering Materials*, 912, 111-118. <https://doi.org/10.4028/p-ght9fy>
- Muthusamy, K., Embong, R., Mohamad, N., Bahrin, N. S. H. K., & Yahaya, F. M. (2021). Setting time and compressive strength of mortar containing cockle shell powder as partial cement replacement. *Key Engineering Materials*, 879, 62-67. <https://doi.org/10.4028/www.scientific.net/kem.879.62>
- Rodriguez, C., & Smith, B. (2022). Economic and environmental assessment of shell waste utilization in concrete production. *Resources, Conservation and Recycling*, 178, 106-118.
- Souidi, A., Maaloufa, Y., Amazal, M., Atigui, M., Oubeddou, S., Mounir, S., ... & Aharoune, A. (2024). The effect of mussel shell powder on the thermal and mechanical properties of plaster. *Construction and Building Materials*, 416, 135142.
- Stel'makh, S. A., Shcherban', E. M., Beskopylny, A. N., Mailyan, L. R., Meskhi, B., Tashpulatov, S. S., & Tyutina, A. (2022). Composition, technological, and microstructural aspects of concrete modified with finely ground mussel shell powder. *Materials*, 16(1), 82.
- Tayeh, B. A., Hasaniyah, M. W., Zeyad, A. M., & Yusuf, M. O. (2019). Properties of concrete containing recycled seashells as cement partial replacement: A review. *Journal of Cleaner Production*, 237, 117723.