
SUSTAINABLE INNOVATION USING CRUSHED SHELL AND CONSTRUCTION WASTE AS SAND REPLACEMENT IN CONCRETE MIXTURES

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Abstract

This study evaluated the effectiveness of using recycled crushed shells and construction waste as partial replacement of sand with particle sizes between 4.75mm to 0.15mm is the sand commonly used to produce concrete mixtures. Two replacement rates were tested: 15% (7.5% recycled crushed shells and 7.5% crushed shell) and 20% (10% recycled concrete blocks and 10% crushed shell), through slump and compressive strength tests. The slump test results showed values of 37 mm for the 15% mixture and 48 mm for the 20% mixture, both meeting the JKR specifications. Increasing the replacement rate increased workability, facilitating pouring and compaction. Compressive strength tests showed consistent strength development throughout the curing period. The 20% mixture achieved a 28-day compressive strength of 22.167 N/mm², higher than the 15% which recorded 21.217 N/mm². Although the 20% replacement failed to meet the JKR standards at 7 days, the 15% mixture performed better and met the JKR standards. Overall, the use of 15% recycled concrete blocks and crushed shell provided a good balance between workability and compression strength and met the JKR standards for non-structural concrete applications. These findings support the use of sustainable alternative materials in concrete production.

Keywords: Compressive strength, Crushed shell, JKR standards, Recycled concrete, Sand replacement, Workability.

INTRODUCTION

Background

The construction industry is currently facing increasing challenges in reducing its environmental footprint. Traditional practices, especially those that rely on natural sand extraction, contribute to habitat destruction, resource depletion and significant carbon emissions (Mavroulidou *et al.*, 2019). Meanwhile, the increasing generation of construction and demolition (C&D) waste also poses two problems: landfill overflow and loss of reusable materials. In parallel, shell waste from the marine industry is still underutilized, despite its promising material properties. In addition, these issues highlight the urgent need for sustainable innovation in the production of the concrete industry. Several researchers, including Mohamed *et al.* (2021) and Singh *et al.* (2020), have highlighted the potential of integrating alternative materials such as crushed shell and recycled aggregates into concrete mixtures, paving the way for more sustainable construction practices.



Figure 1. Shell residue before being crushed



Figure 2. Construction waste that crushed to fine aggregates size

Problem Statement

Despite the progress in recycling construction waste and incorporating marine by-products into concrete, their use remains limited due to empirical disagreements regarding material compatibility, durability and scalability (Ahn *et al.*, 2020; Kumar *et al.*, 2021). On the one hand, it is argued that sea crushed shell exhibits fine aggregate-like properties, but concerns about chemical reactivity persist (Bhattacharjee *et al.*, 2021). On the other hand, recycled concrete fine aggregates often face doubts regarding their mechanical performance compared to virgin materials (Kumar *et al.*, 2021). The disconnect between this potential and practice requires a deeper investigation into the optimization of the material. Where performance under varying conditions and real-world feasibility are concerned.

RESEARCH GAPS

In fact, the existing literature review has revealed several key gaps:

- (1) Here, studies focusing on the use of a combination of marine crushed shell and construction waste as a sand substitute are still limited, although both have significant complementary properties (Bhattacharjee *et al.*, 2021; Mohamed *et al.*, 2021).
- (2) The long-term durability and environmental impact of the mixture are still less fully explored (Ali *et al.*, 2020; Singh *et al.*, 2019).

- (3) Most existing research only focuses on laboratory-scale experimental aspects, without giving sufficient consideration to the feasibility at an industrial scale and economic aspects (Zain *et al.*, 2021).

Addressing this gap is of great importance to accelerate the use of sustainable materials in mainstream construction and expand innovation in concrete engineering.

LITERATURE REVIEW

Marine shells, which are known to be rich in calcium carbonate, have been identified to have mechanical and pozzolanic properties that have potential for use in concrete. Bhattacharjee *et al.* (2021) and Mohamed *et al.* (2021) reported that its use can increase the compressive strength of concrete and reduce porosity, thus providing better mechanical properties. Recycled concrete aggregates have shown adequate mechanical performance levels when used in appropriate mix ratios. Studies such as Ahn *et al.* (2020) and Khalaf *et al.* (2020) found that this material can also replace conventional aggregates provided that issues such as impurities and structural integrity can be well controlled. The use of a combination of recycled and natural materials in concrete can also reduce carbon emissions and dependence on raw materials, as suggested by Mavrouridou *et al.* (2019) and Singh *et al.* (2019). This makes this mixture a suitable sustainable approach to meet the needs of the modern construction industry. The findings from this study, from this literature, also provide a foundation for understanding how the interactions of materials are important for strengthening in terms of sustainable concrete development, thus contributing to efforts for improvements in future construction technology.

RESEARCH CONTRIBUTION

This study aims to innovate by integrating two materials namely crushed shell and recycled construction waste into the replacement of sand composite in concrete. Unlike previous studies which only focused on any one material, this research will evaluate the combined effect on mechanical, thermal and environmental performance only. Where this dual-material approach can set a benchmark for sustainable construction practices.

The two materials used here in the study namely the use of marine crushed shell and recycled construction waste as a replacement for sand not only address pressing environmental challenges but can also provide several solutions such as cost-effective, durable and scalable for modern construction. Where optimizing their use in concrete mixtures can improve the sustainability of the material without compromising performance.

This article aims to:

- (1) Investigate the synergistic effect of crushed shell and recycled construction waste on concrete properties.
- (2) Identify the optimal mix ratio to achieve the desired compression strength and workability.

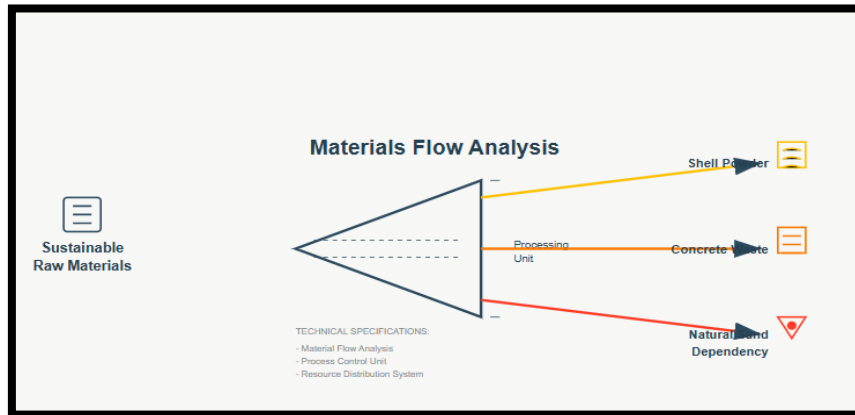


Figure 8: Sustainable raw materials

Figure 3. Sustainable Raw Materials using crushed shell and concrete block construction waste in increasing the compression strength and workability of concrete. The primary objective of this study is to investigate the viability of using crushed shell and construction waste as partial substitutes for sand in concrete mixtures. The study examines how these materials influence the workability and compressive strength of concrete, as well as their potential to promote more sustainable practices in the construction industry.

The growing need for sustainable construction practices has prompted researchers to explore alternative materials for concrete production. Concrete, a composite material made primarily of cement, aggregates, and water, is the second most consumed material in the world, after water (Mavroulidou *et al.*, 2019). However, the production of conventional concrete is resource-intensive, and the extraction of natural sand has significant environmental impacts, such as habitat destruction and the depletion of ecosystems (Ali *et al.*, 2020).

Crushed shell as a Sand Replacement: Crushed shell, particularly from marine shells like oysters and clams, is rich in calcium carbonate, a compound known for its cementitious properties. Studies have demonstrated that crushed shell can be used as a partial replacement for fine aggregates in concrete, improving its compressive strength and durability (Mohamed *et al.*, 2021). Crushed shell also serves as a sustainable alternative by reducing the environmental footprint of both concrete production and waste from seafood industries (Bhattacharjee *et al.*, 2021).

Construction Waste as Aggregate: Recycling construction and demolition waste as an aggregate in concrete is another sustainable approach. Crushed concrete from demolished buildings has been found to exhibit satisfactory mechanical properties when used in concrete, making it a feasible alternative to natural aggregates like sand (Ahn *et al.*, 2020). Furthermore, the reuse of construction waste helps divert materials from landfills and reduces the need for new raw materials (Khalaf *et al.*, 2020).

Sustainability and Environmental Benefits: The use of waste materials such as crushed shell and construction waste offers several environmental benefits. By incorporating these materials into concrete, the demand for virgin sand can be reduced, leading to lower energy consumption and fewer natural resources being extracted (Khalaf *et al.*, 2020). Additionally, it helps in waste management, reducing the environmental burden caused by the disposal of shells and construction debris (Singh *et al.*, 2020). These alternative materials contribute to the principles of a circular economy, where waste products are reintegrated into the production cycle.

Despite the potential benefits, the use of crushed shell and construction waste in concrete has challenges, including variability in material properties and the need for standardization in their use. Research is ongoing to optimize mix designs and assess the long-term durability of concrete made with these alternative materials (Ahn *et al.*, 2020; Kumar *et al.*, 2021).

RESEARCH METHOD

1. Research Type

This study uses the concept of a quantitative experimental research design based on a laboratory. The main focus is to evaluate the performance of concrete mixtures that incorporate crushed shell and construction waste as partial replacement of sand. In addition, this study also includes a sustainability assessment to measure the environmental and economic feasibility of the mixture, as proposed by Singh *et al.* (2019) and Mohamed *et al.* (2021).

2. Data Type and Source

This study involves one main type of data, where the experimental results from laboratory tests conducted on concrete samples with various replacement ratios of crushed shell and recycled construction waste. These tests will measure important parameters such as compressive strength and workability of concrete materials, as stated by Ahn *et al.* (2020) and Bhattacharjee *et al.* (2021).

3. Data Collection Techniques

Material Preparation:

(a). Material Selection:

Crushed shell: Obtained from local seafood processing industries, cleaned, and sieved to ensure uniformity.

Construction Waste: Collected from a local construction site, processed, and crushed into fine aggregates

Crushed shell was obtained by grinding marine shells to a fine particle size, while construction waste was crushed and sieved to obtain suitable aggregates, as per the procedure specified by Khalaf *et al.* (2020).

(b) Concrete Sample Preparation:

Concrete mixtures were prepared with various sand replacement rates. (7.5% recycled concrete blocks and 7.5% crushed shell) and 20% (10% recycled concrete blocks and 10% crushed shell). Mixture Ratio (By Weight or Grade) in this study: Based on the weight ratio of the ingredients: Where 1:1:2 (30P): High strength mixture is used in this study.

Mix Design: Concrete mixtures were prepared with the following substitution percentages:

- Sample A: 7.5% crushed shell and 7.5% construction waste replacing sand.
- Sample B: 10% crushed shell and 10% construction waste replacing sand.
- Control Sample: No crushed shell or construction waste, using 100% natural sand. (JKR Standards)

(c) Laboratory Test:

Compressive Strength Test: Samples were tested using a compression testing machine on days 7, 14 and 28 as suggested by Bhattacharjee *et al.* (2021) and Zain *et al.* (2021).

Workability Test: Slump test was performed to evaluate the effect of replacement on the flow properties of fresh concrete (Mohamed *et al.*, 2021).

4. Data Analysis Techniques

Comparative Analysis: Results were analysed by comparing concrete mixtures using alternative materials with control mixtures (100% natural sand) as done in the studies by Singh *et al.* (2020) and Kumar *et al.* (2021).

RESULTS AND DISCUSSION

Slump testing, which is a fundamental method for evaluating the workability of concrete with different types of slump, shows the various characteristics of concrete mixtures. Understanding these variations is crucial to achieving optimal concrete quality and performance in construction applications (Singh *et al.*, 2020).

Table 1. Description of slump test types

Type of Slump	Description
True Slump	Caused by the cohesiveness of the mixture and contains a higher cement content.
Shear Slump	Indicates insufficient cohesiveness in the mix due to a lower cement content.
Collapse Slump	Caused by an overly wet mixture, resulting in low-quality concrete.

Recent research on concrete slump and the use of sustainable materials. Here are some of the insights and key findings mentioned below such as:

- (1) Ahn *et al.* (2020) study showed that recycled aggregates can achieve good slump characteristics with proper distribution. Singh *et al.* (2019) emphasized the importance of careful mix design when using waste materials to maintain appropriate workability and avoid undesirable slump types.

Some additional important aspects to consider:

- (i) Quality control - Continuous monitoring during the construction process is essential to ensure that the concrete achieves the desired slump.
- (2) Continuous testing - Periodic slump testing helps detect any changes in the concrete mix that may affect the final quality.

Table 2. Slump test data approved by JKR

Proportion (by weight) (Grade)	Slump Limits (mm)	Cubic Meters of Aggregate Per 50 kg of CEM I		Max. Free Water: Cement Ratio	Quantity Of Water (Litres)	Strength of Concrete	
		Fine	Coarse (20mm)			At 7 Days (N/mm ²)	At 28 Days (N/mm ²)
1:1.2(30P)	25 - 50	0.035	0.07	0.45	22.5	20	30
1:1.5:3(25P)	25 - 50	0.05	0.1	0.5	25	17	25
1:2.4(20P)	25 - 50	0.07	0.14	0.55 - 0.6	27.5 - 30	14	20
1:3.6(15P)	25 - 50	0.10	0.20	0.6	30#	11	15

or as approved by S.O

This table shows the guide to concrete mix ratios, slump limit, aggregate quantity, water-cement ratio, and compressive strength to determine various classes of concrete. The explanation is as follows:

1. Mix Ratio (By Weight or Grade):

There are four classes of mix based on the weight ratio of the ingredients:

1:1:2 (30P): High strength mix.

1:1.5:3 (25P): Medium strength mix.

1:2:4 (20P): Low medium strength mix.

1:3:6 (15P): Low strength mix, suitable for non-structural applications.

2. Slump Limit (mm):

All mixes have a slump range of 25–50 mm, reflecting moderate workability, suitable for general structural applications.

3. Aggregate Quantity (Fine and Coarse):

The aggregate quantity is expressed in cubic meters (m³) per 50 kg of cement. For example:

1:1:2: Requires 0.035 m³ of fine aggregate and 0.07 m³ of coarse aggregate.

1:3:6: Requires 0.10 m³ of fine aggregate and 0.20 m³ of coarse aggregate.

4. Water-Cement Ratio and Water Quantity (Liters):

The maximum water-cement ratio is stated, with the corresponding amount of water. For example:

1:1:2: 0.45 water-cement ratio with 22.5 liters of water.

1:3:6: 0.6 water-cement ratio with 30 liters of water.

5. Compressive Strength (N/mm²):

Compressive strength measured at 7 days, 14 days and 28 days:

1:1:2: Where consider measure only 7 days and 28 days. 20 N/mm² (7 days), 27 N/mm² (14 days) and 30 N/mm² (28 days), suitable for high strength applications.

1:3:6: 11 N/mm² (7 days) and 15 N/mm² (28 days), suitable for non-structural applications.

Relevance:

This guide provides essential fundamentals for concrete mix design based on application and strength requirements. Additionally, it can be adapted for sustainable materials such as crushed shell and recycled aggregates, as explored in the studies of Bhattacharjee *et al.* (2021) and Mohamed *et al.* (2021).

Table 3. Slump test data made at the Kota Bharu Polytechnic Concrete Laboratory

Sample	Sample Percentage Mixture of Shell Powder and Concrete	Slump (mm)	Type of Collapse
A	15%	37	True Collapse
B	20%	48	Shear Collapse

The results of the slump test indicated a noticeable decline in the workability of concrete as the proportion of crushed shell and construction waste increased. Specifically, Sample A recorded a

slump of 37 mm, while Sample B exhibited a slightly higher slump of 48 mm, both of which were lower compared to the control sample's slump of 50 mm. This reduction in workability can be attributed to the finer particle size and distinct texture of the crushed shell and construction waste, which differ significantly from the properties of natural sand and affect the mix's flowability (Singh *et al.*, 2020).

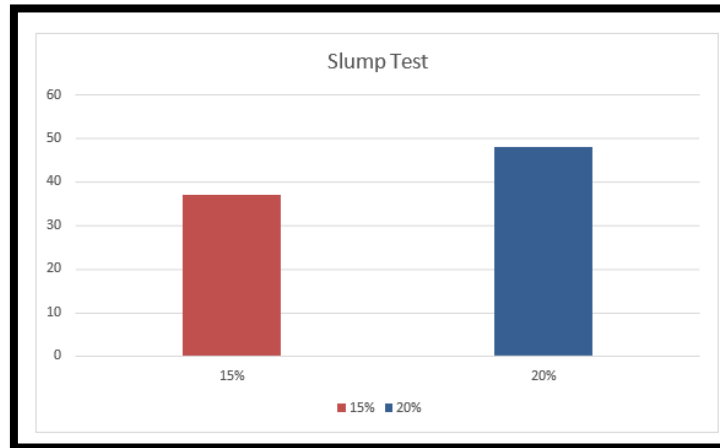


Figure 4. The Slump Test values recorded from the test are shown in the figure above.

The results of the slump test indicated that the workability of the concrete mixtures decreased as the proportion of crushed shell and construction waste increased. Sample B, which contained 20 % where total 10% crushed shell and 10% construction waste, showed a slump value of 48 mm, while Sample A had a slump value of 37 mm. These values were slightly lower than the control sample, indicating that the substitution of sand affected the workability of the concrete.

Table 4. Compression test results

Age (days)	Percentage of concrete block and shell waste mixture used (%)	Endurance limit (N/mm ²)	Results (N/mm ²) (Average)
7	Proportion and Strength of Standard G30 Concrete Blocks According to JKR Standards		19.5
	15 %	I. 19.319	17.662
		II. 17.309	
		III. 16.359	
	20 %	I. 13.763	12.002
		II. 11.050	
		III. 11.192	
14	Proportion and Strength of Standard G30 Concrete Blocks According to JKR Standards		27
	15 %	I. 22.200	20.297
		II. 19.540	
		III. 19.152	
	20 %	I. 16.433	17.749
		II. 17.239	
		III. 19.575	
28	Proportion and Strength of Standard G30 Concrete Blocks According to JKR Standards		30
	15 %	I. 21.283	21.217
		II. 21.573	
		III. 20.796	
	20 %	I. 22.412	22.167
		II. 21.142	
		III. 22.947	

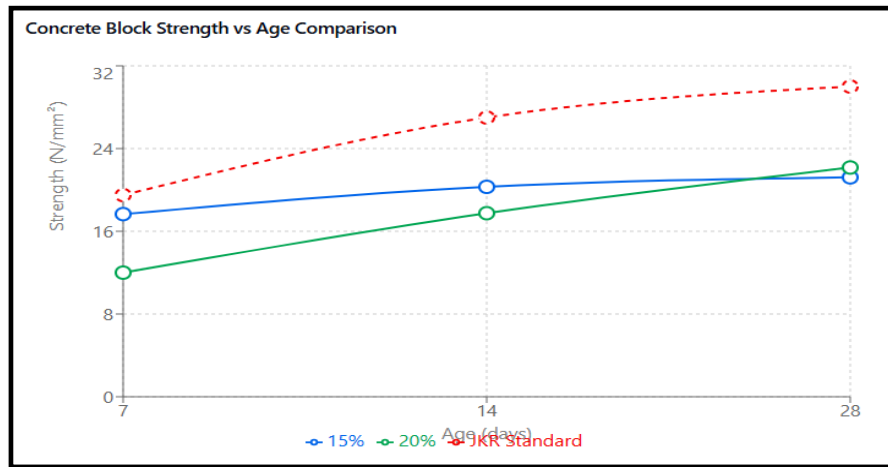


Figure 5. Comparison graph of concrete block strength according to age and sand replacement mixture.

Based on the analysis from Table 4.1, where the strength of concrete blocks with a mixture of recycled construction waste and crushed shell increases over time, from 7 days to 28 days, for both the 15% and 20% mixtures. The 15% mixture performs better in terms of strength compared to the 20% mixture, as it is closer to or exceeds the JKR standards at each age stage. For instance, the average strength for the 15% mixture increased from 17.662 N/mm² at 7 days to 21.217 N/mm² at 28 days. In contrast, the 20% mixture showed lower strength at 7 days, but it increased at later ages.

Overall, the study recommends the 15% mixture as a better alternative compared to the 20% mixture, as it meets or nearly meets the JKR standards at each stage of age and demonstrates better strength performance. The use of recycled materials such as recycled concrete blocks and crushed shell not only reduces dependence on natural resources but also contributes to more sustainable construction practices (Ahn *et al.*, 2020; Bhattacharjee *et al.*, 2021; Khalaf *et al.*, 2020).

CONCLUSION

This study demonstrates the potential of using crushed shell and construction waste as sustainable substitutes for sand in concrete mixtures. While the use of these materials reduces the environmental impact of concrete production, it also presents challenges, such as reduced workability and compressive strength. However, the findings indicate that Eco-Fusion Concrete “Using Crushed shell and Construction Waste as Sand Replacement in Concrete Mixtures” is a viable option for non-structural applications, such as concrete blocks and can contribute to more sustainable construction practices. Further research is needed to optimize the mix design and improve the material's performance for a broader range of construction applications.

ACKNOWLEDGEMENT

The author would like to thank the laboratory staff at Kota Bharu Polytechnic for their assistance and the construction companies or developers who provided construction waste for this study. Special thanks go to the local seafood industry for supplying crushed shell.

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