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The Properties of Cement Brick Containing POFA and Cockle Shell as Replacement Materials

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Abstract

The rapid increase in building construction in Malaysia for 2023 has led to an increase in the use of natural aggregate resources such as stone and sand for building development. This has led to researchers exploring alternative materials to replace natural materials in cement brick production. In this study, palm oil fuel ash (POFA) and cockle shells were used as replacement materials in cement brick production. The objective was to determine the strength of cement bricks with different percentages of cockle shells and identify the initial rate absorption and water absorption. The experiment involved 20% POFA content combined with 10%, 20%, and 30% cockle shells. The results showed that 10% of the replacement cockle shell produced the highest compressive strength value, meanwhile, 30% and 10% were the highest replacement percentages for water absorption and initial rate absorption respectively. This experimental study may be beneficial to achieve a sustainable environment.

1. Introduction

Bricks, a primary building material for 8000 years ago, are predicted to be produced globally at an annual output of 1.83 trillion units, with demand expected to rise significantly to 2.76 trillion units by 2027 [1]. The increasing in cement brick usage in the construction industry will lead to increased carbon dioxide emissions and ecological imbalance [2]. To overcome this issue, alternative materials are proposed to replace natural aggregates in cement brick production. Seashells, a type of waste from the fishing industry, are frequently used in construction and building materials. Malaysia's agriculture sector has grown alongside infrastructure development. Besides, Malaysia was known as one of major producer and exporter of palm oil. Hence, this leads to a significant amount of biomass, including empty fruit branches, oil palm shells, and POFA, being produced annually. This study aims to improve sustainability and address environmental waste by utilizing waste from the palm oil sector, specifically focusing on sustainable cement brick production for the construction sector.

Malaysia's population of 33 million is increasing, leading to a rise in housing demand. The construction sector in Malaysia has grown by 9.4% in first quarter of 2023, resulting in increased demand for residential construction. Hence, there is an increasing demand for residential construction to occupy the Malaysia's residents, which leads to up cement brick usage. Unfortunately, the sectors that produce cement bricks contribute to 7% of global carbon dioxide emissions [2]. Conventional cement bricks have a significant negative environmental impact, contributing to the global increase in CO_2 emissions. [3] and [2] mentioned that waste materials from the fisheries and agricultural industries are extremely high. According to New Straits Times, Malaysia is expected to produce 150,000 metric tonnes of cockles by 2025. Malaysian Palm Oil Board data,

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Malaysia produced 19.5 million metric tonnes of crude palm oil in 2020 for global palm oil production. Therefore, environmental issues will arise if the material is not properly maintained.

Cement is a binder, a chemical substance used for construction that hardens and adheres to other materials to bind them together. To produce mortar for masonry, cement will be mixed with fine aggregate while to produce mortar for concrete, cement need to be mixed with sand and gravels. As an alternative to replace cement quantity in bricks production, one of characteristics requirement for replacement materials is pozzolanic materials. Sand is an important element of produced brick and a precious natural resource. Sand provides to keep raw bricks from cracking, shrinking, and breaking. It also provides bulk and durability for construction materials. Bricks with a larger amount of sand will have a more uniform texture. As an alternative to replace sand quantity in cement bricks production, one of characteristics requirement for replacement materials is calcium carbonate ($CaCO_3$) [3].

POFA, which contains a high percentage of silicon dioxide (SiO_2), could potentially replace cement in cement brick production [4]. From previous studies, many researchers found that the higher percentage of POFA replacement will decrease the value of brick compressive strength value due to the pozzolanic reactivity of concrete with POFA was slower, which decreased the concrete's compressive strength [4]. According to [4], the optimum percentage to achieve highest compressive strength value is 10%. For water absorption, the higher percentage of POFA substitution in brick will increase the amount of water absorption due to physical differences between sand and palm oil fuel ash. POFA has more voids compared to sand that has no pores on its surface. According to [5] for initial rate absorption, the highest percentage material replacement is 20% of POFA shows the highest value of initial rate due to weaker bond between component in bricks.

Seashells, a common waste from the fishery sector, contain over 90% calcium carbonate ($CaCO_3$). This chemical contributes to the durability and deterioration of bricks, as it acts as a filler and binder for the microstructure's pores, making them less porous and preventing moisture and ions from penetrating. Based on [3] studies, the cockle shell cement brick's compressive strength improved during the curing process but reduced when the amount of cockle shell powder was increased. From previous study suggest for only 5% as cockle shell replacement to achieve highest compressive strength value, and 15% of cockle shell powder (CSP) has highest value of water absorption due to current microstructure as materials with high permeability will absorb moisture quickly.

2. Materials Preparation and Laboratory Testing

2.1 Materials

In this experimental study, there are 5 materials were used to produce cement brick which are, Ordinary Portland Cement (OPC), Fine Aggregate, Palm Oil Fuel Ash (POFA), Cockle Shell (CS) and water

2.1.1 Ordinary Portland Cement (OPC)

This experiment used Ordinary Portland Cement (OPC) as a binder in cement brick mixtures, following Malaysian Standard MS EN 197-1:2007 and European Standard EN 197-1:2000. The cement, sourced from Tasek Corporation Berhad, was kept in a dry environment to prevent hardening and moisture absorption, ensuring quality and compliance with ASTM C150 Type 1 classification.

2.1.2 Fine Aggregates

This experiment used sand to produce cement bricks to fill air gaps between mixtures. Sand was dried in an oven for 24 hours to remove moisture and passed through 2.36mm sieving to be included in the mixture's accordance ASTM C136. The cement-sand ratio was 1:6, and the sand used was normal sand from construction materials suppliers.

2.1.3 Palm Oil Fuel Ash (POFA)

The study utilized palm oil fuel ash (POFA) as a constant at 20% in cement brick samples. POFA was collected from a nearby mill in Batu Pahat, Johor, and were dried in an oven for 24 hours to remove moisture. After sieving to achieve an average fineness of 75 microns, the material was stored in a dry, airtight place to prevent humidity.

2.1.4 Cockle Shell (CS)

The study used cockle shells in cement brick mixtures at different percentages 10%, 20%, and 30%. Cockle shells were collected from Pantai Perpat, Batu Pahat, Johor. Next, the cockle shell was dried in an oven for 24 hours. After that, cockle shell was crushed using a milling jaw crusher and sieved to achieve an average size of 2.36 mm. After sieving, the shells were stored in a dry, airtight place to prevent humidity.

2.1.5 Water

In this study utilized 0.5 for water cement ratio for all cement brick specimen.

2.2 Sample Preparation

There are four different percentage of cockle shell utilized in cement brick production which are 0%,10%,20% and 30%. The percentage of POFA was constant for 20% in every cement brick sample. The cement sand ratio is 1:6 with water cement ratio is 0.5. There are 48 cement brick sample were produced to proceed with three different type of laboratory testing. All specimens will be curing for 7 days and 28 days. Table 1 shows the number of cement brick sample. Table 2 shows mix proportion for cement brick containing POFA and cockle shell. The flowchart of cement brick production was indicated in Fig. 1.

Table 1 *Number of specimens needed for laboratory testing*

Percentage of cockle shells (%)	Compressive strength test		Water absorption test		Initial rate absorption	
	7 days	28 days	7 days	28 days	7 days	28 days
0	3	3	-	3	-	3
10	3	3	-	3	-	3
20	3	3	-	3	-	3
30	3	3	-	3	-	3
Total	48					

Table 2 *Mix proportion for cement brick containing POFA and cockle shell*

Sample	Cement (g)	POFA (g)	Cockle Shell (g)	Sand (g)	Water (g)
P20CS10	4246.04	73.96	367.2	3304.8	306
P20CS20	4246.04	73.96	734.4	2937.6	306
P20CS30	4246.04	73.96	1101.6	2570.4	306

2.3 Laboratory Testing

All the cement brick specimen containing 20% of POFA with different percentage of containing cockle shells were tested by compressive strength test, water absorption test and initial rate absorption test in laboratory after curing for 7-day and 28-day.

2.3.1 Compressive Strength Test

Compressive strength testing is a mechanical procedure that determines a material's ability to withstand compression before fracturing. According to BS 3921, a brick's compressive strength must not be less than the manufacturer's specified minimum of 5 N/mm^2. The test was conducted in a materials laboratory at UTHM Parit Raja using a compression testing machine (CTM) after curing for 7 days and 28 days. Before continuing with laboratory testing, the machine was checked to make sure the machine is in good condition. Next, the specimen was placed at the center of the bearing surface compression machine, the axial load was applied vertically until cracks appeared on cement bricks specimen and the maximum value of axial load applied on cement brick were recorded.

Fig.1 *Cement Brick Production*

2.3.2 Water Absorption Test

Water absorption test was carried out to determine the amount of water absorption by the brick. Cement bricks specimen was dried in the oven at 100^0C for 24 hours. This test carried out accordance to the BS 1881:122. After leaving the cement brick specimen to cool, the specimen was submerged in the water tank for another 24 hours. Before and after the specimen's immersion in the tank, the specimen's weights were recorded to calculate the percentage of water absorption.

2.3.3 Initial Rate Absorption Test

Initial rate absorption (IRA) test was carried out within 1 minute. This testing is based on ASTM C67-11. Before start IRA test, the cement brick specimen was placed in the oven with 100^0C for 24 hours. Next, the specimen was left for cool at room temperature and weighed. The specimen's dimensions and weight will be recorded. The specimen is placed on two rods. Next, the specimen is immersed to a depth of 3 mm of water for the duration of 1 minute. After 1 minute, cement bricks were weighed again.

3. Results and Discussion

Results and discussion part indicated data and analysis of the laboratory testing in term of compressive strength test, water absorption test and initial rate absorption test. All the laboratory testing was carried out accordance to ASTM.

3.1 Compressive Strength

For compressive strength test there were 24 cement brick samples were tested for the study. There are 12 samples went through a 7-day curing time, while the remaining 12 samples undergo a 28-day curing period. The gathered data is displayed in the Table 3, and the bar chart of compressive strength for each mix percentage is shown in Fig.2.

Table 3 shows the higher percentage of cockle shell replacement in cement brick sample shows the compressive strength are decreasing. As mentioned by [6], cockle shells contain pores and voids, which can introduce higher porosity into the cement brick when they are used as replacements material as fine aggregates. This increased porosity can weaken the interfacial transition zone between the shell and cement paste, leading to reduced compressive strength.

Fig.2 shows the compressive strength of cement brick containing POFA 20% combine with CS 10% indicates the second highest value of compressive strength after control cement brick specimen which are 6.16 N/mm² for curing after 7- day meanwhile for 28-day indicates 11.49 N/mm². It shows that the results for all cement brick specimen in compressive strength test achieved the targeted compressive strength for non-load bearing. The pattern of the bar chart shows the compressive strength was decreased with increased the percentage of cockle shell replacement.

Table 3 *Compressive strength of cement brick contain different percentage of CS*

Percentage of CS	Compressive Strength (N/mm²)	
	7-days	28-days
0%	6.75	11.49
10%	6.16	11.22
20%	5.15	10.00
30%	6.05	9.94

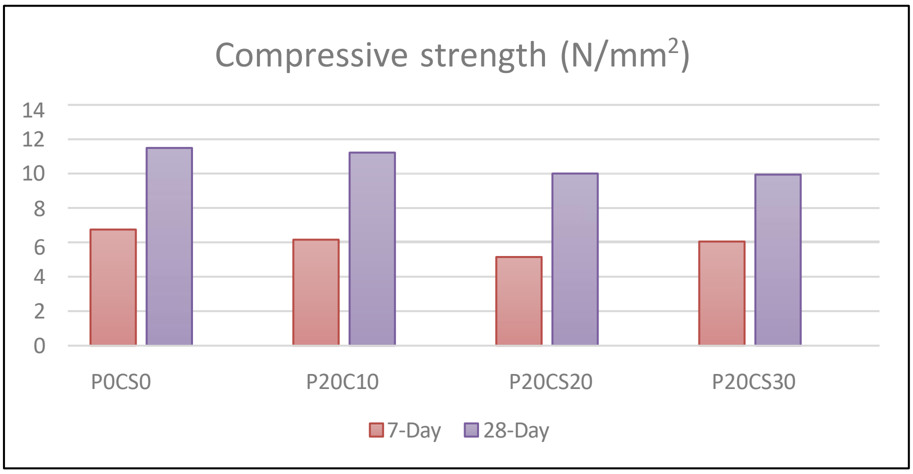

Fig.2 *Compressive strength against different percentage of cockle shell*

3.2 Water Absorption Test

For water absorption test there were 12 brick samples were tested for the study. There are 12 samples undergo a 28- day curing period. This test was carried out to determine the amount of water absorption by the cement brick accordance to ASTM C90.

Table 4 indicates the results of the water absorption test. It shows the percentage of the water absorption that the highest percentage of the study resulted the highest percentage of water absorption. Due to the porosity of cockle shell make it possible to absorb more water with high percentage of cockle shell replacement in brick sample. The graph in Fig. 3 shows bar chart for water absorption results of brick samples. The higher percentage of cockle shell as sand replacement in cement brick sample will increase the percentage of water absorption in cement brick.

One primary factor is that cockle shells have a porous nature, which means they contain small openings that allow water to penetrate more easily [7]. When these shells are used as a replacement for a portion of the aggregate in cement bricks, the overall porosity of the bricks increases. This increased porosity creates more pathways for water to enter the bricks, resulting in higher water absorption percentages. Additionally, the chemical composition of cockle shells, particularly their calcareous content, can also contribute to increased water absorption [7].

Table 4 *Water absorption of cement brick contain different percentage of CS*

Percentage of CS (%)	Water absorption (%)
0	14.88
10	12.38
20	13.17
30	14.60

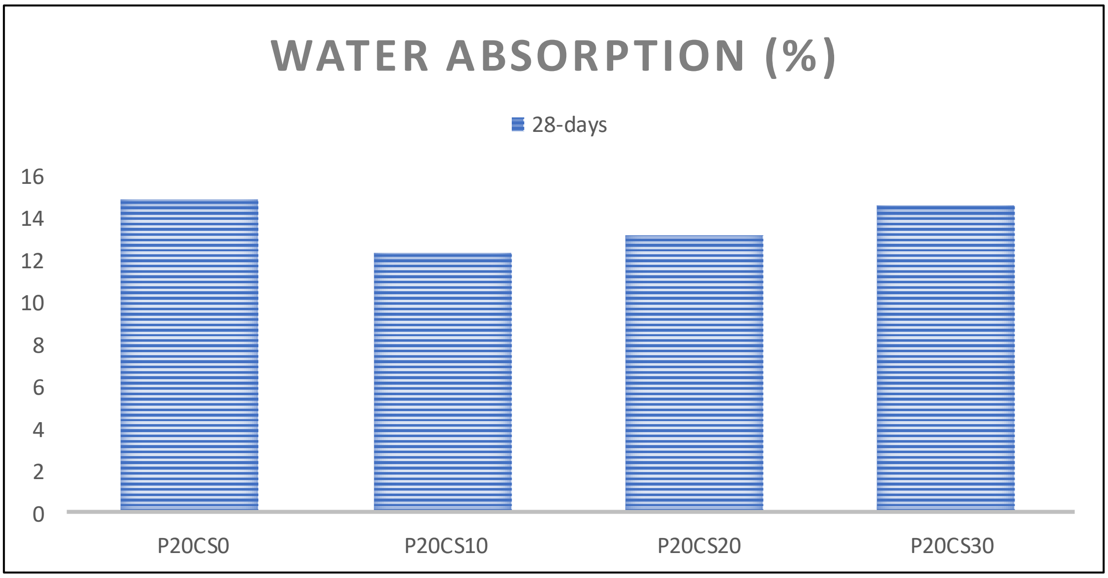

Fig.3 *Water absorption against different percentage of cockle shell*

3.3 Initial Rate Absorption Test

The amount of water absorbed in one minute across a specific area of the brick surface is known as the initial rate of absorption. A typical test procedure for figuring out how quickly bricks absorb water at first is provided by ASTM C67-11. A significant measure that shows how fast bricks absorb water is the IRA of bricks. It's critical to assess the performance and quality of bricks when developing. If the IRA value is higher, bricks will often absorb water from the mortar more quickly, resulting in a weaker bond.

Table 5 shows the value of IRA for each mix proportion after 28-days. It shows the data for IRA the higher percentage of cockle shell replacement in cement brick samples will decrease the initial rate absorption. Due to the characteristics in cockle shell that has porosity make it fast to absorb water within 60 seconds. Besides, bricks with a higher IRA absorb moisture from mortar more quickly, resulting in a weaker bond between the two components.

Fig.4 shows decreased pattern of value initial rate absorption with increased the percentage of cockle shell replacement in brick samples. The graph in Fig. 4 shows the initial rate absorption of cockle shell after completely undergo curing for 28-day. From the graph, the higher percentage cockle shell reduces the value of IRA. 10% of cockle shell replacement in cement brick shows the highest value of IRA compared to control specimen 173.64 g/min/193.55cm^2. This result can be concluded that cockle shell absorbs faster compared to sand.

Table 5 *Initial rate absorption of cement brick contain different percentage of CS*

Percentage of CS(%)	Initial Rate Absorption (g/min/193.55cm^2)

0	167.22
10	173.64
20	164.72
30	159.60

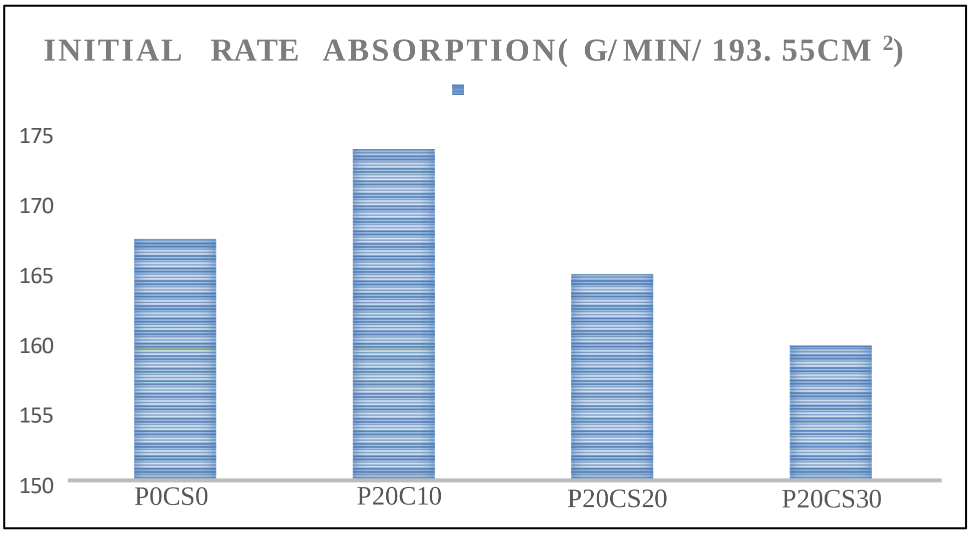

Fig. 4 *Initial rate absorption against different percentage of cockle shell*

4. Conclusion and Recommendation

The first objective is to determine the strength properties of cement brick using various percentage of cockle shell. The compressive strength test was performed on cement brick containing cockle shell waste. The outcome demonstrates that cement brick with 10% cockle shell waste has a stronger structure than brick with a larger proportion of cockle shell replacement. Consequently, when using cockle shell as a replacement material, the optimum result for compressive strength in this investigation is 10% cockle shell replacement in cement brick. Additionally, all specimens meet the desired compressive strength for bricks that are non-load bearing. Examining the water absorption and beginning rate absorption of cement brick with varying cockle shell percentages was the following objective. As per the guidelines provided by ASTM C90, the water absorption of cement brick specimens is not more than 12%. Thus, it can be demonstrated that using cockle shell to produce cement brick may result in cement brick that complies with ASTM C90 standards while contributing in reducing the amount of cockle shell waste. The higher proportion of cockle shell for initial absorption indicates a reduction in IRA value. Bricks with a high IRA value tend to absorb water quickly and develop a weak bond.

A few recommendations were made to improve the accuracy of the results that were found. Many restrictions occurred while the study was being completed. Even though the objectives were met, future research must consider the suggestions and recommendations into consideration. The following recommendation are as follows:

1. Further research can be made by having a longer curing time such as up to 90- day for data comparison instead of 7-day and 28-day.
2. The specimen sample can be increase for each mix proportion instead of 3 sample to have better in average value.
3. Further study can be made by utilize different type of waste materials to analyses whether the waste materials can achieve the targeted strength according to ASTM standard or not.

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