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Evaluation of Cement Brick with Cocopeat as Partial Replacement of Sand

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ABSTRACT

The rising population has fuelled construction growth, increasing the demand for bricks and raising concerns about the depletion of raw materials, especially sand. To address this, research was carried out to investigate the utilization of cocopeat (CCP) as a partial sand replacement in the construction industry. In this study, a total of 72 specimens were manufactured with varying proportions of cocopeat to replace sand, ranging from 0% to 25%. A 1:2.5 of cement-to-sand ratio and 0.5 of water-to-cement ratio were used. Performance of the cement brick was evaluated based on dimension, compressive strength, density, water absorption, crack development, and effective strength-to-weight ratio ($s - w$ ratio). Results showed that all bricks met industrial requirements. Satisfactory compressive strength was achieved with 5% to 15% of cocopeat, meeting the minimum requirements in British Standard BS 3921:1985. Bricks with 5% to 10% of cocopeat have no crack on the sample. These bricks resulted in a lower density than solid bricks, while still fulfilled the percentage of water absorption requirements of British Standard, 1985. Cement bricks with 5% and 10% cocopeat had an effective strength-to-weight ratio ($s - w$ ratio) above 1.0. Notably, brick with 10% cocopeat fulfilled all the industry requirements. Therefore, the cocopeat can be recommended as a partial replacement in brick production.

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1. INTRODUCTION

Brick is one of the building materials widely used in masonry construction. It contributes about 25% of the overall construction materials in the building (Gawatre and Vairagade, 2014), thus increasing the demand for bricks. Throughout the year, an enormous number of researchers concentrated on using waste materials for brick production to (a) increase the strength of brick, (b) reduce the density of brick, or (c) reduce the usage of sand and cement.

By way of illustration, coconut coir (Rangkuti and Siregar, 2020), tea waste (Ismail, 2006; Ozturk et al., 2019; Djamaluddin et al., 2019), windscreen glass waste powder (Anisah, Awang, and Kartini, 2020), expanded polystyrene beads (Mallick, Agarwal, and Pandey, 2020; Lim et al., 2023), bottom ash (Wahab et al., 2018), oil palm empty fruit bunches fibres (Ling et al., 2019), and silica fume (Almeida et al., 2018; Ling et al., 2021a,b) were the waste materials for partial replacement for raw materials (either sand or cement) in the brick.

Malaysia is one of the largest coconut producers in the world. Based on the statistics of the agro-food sector in 2018, Malaysia produced 495,531.1 tonnes of coconut crops (Man and Shah, 2020). Such a large amount of coconut production contributes to the generation of residual products, such as coconut husks, which are often disposed of without utilization. To overcome the problem, the coconut husk can be processed into value-added products like coconut fiber and cocopeat for fully utilized in different industries, such as the replacement of partial materials in the construction industry.

This research aims to reuse the waste material to eliminate the impact on the environment due to agricultural waste disposal. The cocopeat will be used as the raw material to partially replace the sand of the brick. It is expected to change the properties of brick by decreasing the density and compressive strength (Sathiparan et al., 2022). Since the cocopeat is a lightweight material, it could reduce the weight of the brick. Consequently, with the substitution of cocopeat, the study seeks to develop a lightweight brick that achieves industrial standards.

For that, the experimental study is designed and performed to authenticate various aspects of cocopeat in cement brick, for instance, the determination of physical and mechanical parameters of brick and identification of optimum mix proportions. The success of the application of cocopeat in the cement brick will bring the benefits such as (a) reducing the number of coconut husks to be disposed in the landfill, (b) minimizing the dependency on the sand, (c) reducing the density of the cement brick so that the load imposed onto the structural system can be lowered, and (d) develop a lightweight brick that achieves the industrial requirements.

2. MATERIALS AND PROCEDURES

2.1. MATERIALS

Table 1 shows the physical properties of materials. It shows that the density of cocopeat could affect the effectiveness of cement brick as the density of cocopeat (306 kg/m^3) is lower than the sand (1680 kg/m^3), thus lightweight brick can be produced.

Table 1. Physical Properties of Materials

Materials	Descriptions
Sand	- 90% passing through 600 µm - Density within 1540 kg/m^3 to 1600 kg/m^3
Ordinary portland cement	- 90% passing through 600 µm - Density of 1254 kg/m^3
Cocopeat	- 95.2% passing through 5 mm - Density of 373.33 kg/m^3

2.2. MIX PROPORTION

A cement-to-sand ratio of 1:2.5 and a water-to-cement ratio of 0.5 were used for mixing the materials. The percentages of cocopeat used ranged from 0% to 25% (**Table 2**). Every mix design involved 12 specimens, 9 of these bricks were tested for compressive strength (days 3, 7, and 28) with 3 bricks per day. Meanwhile, another 3 bricks were used for dimension, density, and water absorption (day 28). A total of 72 cement bricks were produced and the average results of 3 bricks will be taken.

Table 2. Number of Specimens in Each Mix Proportion

Mix	Cocopeat Content (%)	Compressive Strength (N/mm^2)			Dimension (mm), Density (kg/m^3) and Water Absorption (%)	Total
		Day				
		3	7	28		
C1	0	3	3	3	3	12
S1	5	3	3	3	3	12
S2	10	3	3	3	3	12
S3	15	3	3	3	3	12
S4	20	3	3	3	3	12
S5	25	3	3	3	3	12
					Total brick	72

2.3. Test Procedures

The size of the specimens complied with the BS 3921:1985 requirements, as shown in **Table 3**.

Table 3. Allowable Size for Bricks

Work size (mm)	Dimension	
	Minimum (mm)	Maximum (mm)
215.0	211.8	218.1
102.5	100.6	104.3
65.0	63.1	66.8

ELE International compression machine (3000 kN capacity) and, electronic balance (30 kg capacity) were used to test the compressive strength, f_c, density, ρ, and water absorption, WA (**Figure 1**). The results were calculated using equations 1 and 2 (ASTM C140-11a, 2012).

$$\rho = \frac{w_d}{w_s - w_i} \times 100\% \qquad (1)$$

$$WA = \frac{w_s - w_i}{w_d} \times 100\% \qquad (2)$$

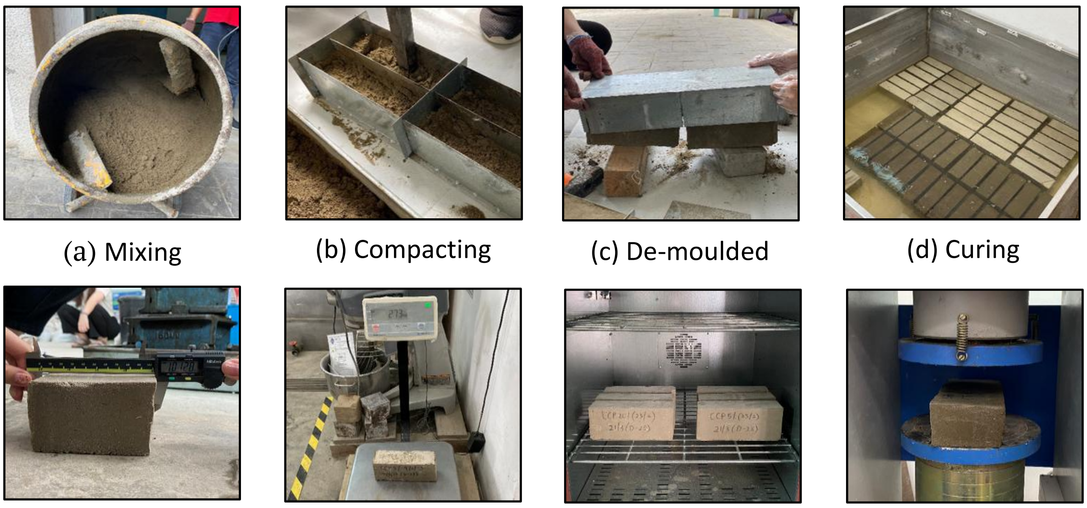
Where:

W_i = Immersed weight (kg)

W_s = Saturated weight (kg)

W_d = Oven-dry weight (kg)

The materials, including Ordinary Portland cement, sand, and cocopeat (dry mass), were prepared and thoroughly mixed in a concrete mixer until a uniform consistency was achieved. During the casting process, the mixture was placed in molds in three layers, with each layer compacted uniformly using a rod compactor. Each layer underwent 25 uniform compactions to minimize void formation. The cast specimens were then air-dried for one day at temperature maintained between 22°C and 32°C. Subsequently, the brick specimens were cured in a curing tank for 3, 7, and 28 days.



(a) Mixing (b) Compacting (c) De-moulded (d) Curing

(e) Dimension test (f) Weighting (g) Oven-dry (h) Compressive

Figure 1. Preparation and Testing

On day 28, a dimensional test was conducted using an electronic vernier calliper and measuring tape to measure the length, width, and height of the bricks. Any dimensional changes were recorded accurately. Additionally, the immersed weight, saturated weight (after wiping off visible surface moisture), and oven-dry weight (following one day of drying in an electric oven at 100°C to 115°C) of the cement bricks were measured. Furthermore, a compressive strength test was performed on days 3, 7, and 28, where a continuous and uniformly applied compressive force was exerted on the specimens until failure occurred.

3. RESULTS AND DISCUSSION

Table 4 and **Table 5** show the results of the specimens. From the results on day 28:

(a) Dimension: Length (212.0 mm to 218.0 mm), width (100.7 mm to 101.5 mm), and height (64.4 mm to 66.3 mm)

(b) Compressive strength between 3.43 $\mathrm{N/mm^2}$ to 11.90 $\mathrm{N/mm^2}$

(c) The number of cracks increased as the percentage of cocopeat increased

(d) Density between 1442.76 $\mathrm{kg/m^3}$ to 2052.45 $\mathrm{kg/m^3}$

(e) Water absorption between 17.91% to 31.29%

The mixes were evaluated based on the criteria below:

(a) Length (211.9 mm to 218.1 mm), width (100.6 mm to 104.4 mm), and height (63.1 mm to 66.9 mm) as stated by BS 3921:1985 (1985).

(b) Compressive strength must achieve a minimum requirement of 7 $\mathrm{N/mm^2}$ according to BS 3921:1985 (1985).

(c) Density should not exceed 1680 $\mathrm{kg/m^3}$ (ASTM International, 2011b) for lightweight brick.

(d) Water absorption should not be greater than 20% based on BS 3921:1985 (1985) as excessive moisture will affect the bonding.

Effective strength-to-weight ratio ($s-w$ ratio) must be at least equivalent to 1 (Lim and Ling, 2019) for better performance than solid brick. Based on the result, it can be observed that:

(a) All the specimens within the requirement dimension (length, width, and height)

Table 4. Dimension Results

Specimen	Measured*1			Requirements			Conformability (√/X)			Remarks
	Length (mm)	Width (mm)	Height (mm)	Length (mm)	Width (mm)	Height (mm)	Length (mm)	Width (mm)	Height (mm)	
C1	218.0	101.5	66.3	211.9 – 218.1	100.6 – 104.4	63.1 – 66.9	√	√	√	Adequate
S1	213.0	101.1	65.0	211.9 – 218.1	100.6 – 104.4	63.1 – 66.9	√	√	√	Adequate
S2	215.0	100.8	65.6	211.9 – 218.1	100.6 – 104.4	63.1 – 66.9	√	√	√	Adequate
S3	212.0	100.7	65.4	211.9 – 218.1	100.6 – 104.4	63.1 – 66.9	√	√	√	Adequate
S4	215.7	101.0	64.4	211.9 – 218.1	100.6 – 104.4	63.1 – 66.9	√	√	√	Adequate
S5	212.7	101.4	64.8	211.9 – 218.1	100.6 – 104.4	63.1 – 66.9	√	√	√	Adequate

Note: *1Dimensions of the bricks obtained were taking the average value of three specimens.

Table 5. Test Results of Specimens

Specimen	Results					Evaluation criteria		
	Compressive strength (N/mm^2)			Density (kg/m^3)	Water absorption, (%)	Strength	Density	Water absorption
	Day 3	Day 7	Day 28	Day 28	Day 28	$\geq 7\ N/mm^2$	$\leq 1680\ kg/m^3$	$\leq 20\%$
C1	6.85	8.22	11.90	2052.45	17.91	√	X	√
S1	4.27	5.50	10.93	1826.72	18.15	√	X	√
S2	2.93	4.07	9.70	1663.83	19.16	√	√	√
S3	2.63	3.77	7.50	1601.00	22.82	√	√	X
S4	2.37	3.23	5.53	1486.98	24.10	X	√	X
S5	1.93	2.30	3.43	1442.76	31.29	X	√	X

(b) 66.67% achieved the requirement strength of 7 N/mm^2 as stated by BS 3921:1985. The specimens failed to attain 7 N/mm^2 as the substitution of cocopeat reached 20%.

(c) Majority of the cement bricks (66.67%) were classified as lightweight bricks (density lower than 1680 kg/m^3).

(d) 50% achieved the water absorption of less than 20%. The specimens did not fulfill the requirement when the replacement of sand reached 15%.

(e) Specimens S2 achieved all construction industry requirements.

3.1. Dimension

Based on **Table 4**, the dimension of bricks produced was still within the range of industrial requirements which was standardized by British Standard BS 3921:1985. It was obvious that all bricks fulfilled the dimensions with sharp edges and cuboidal shapes. The construction work will be easy to undergo with consistent brick size.

3.2. Compressive Strength

From the results, the compressive strength increases with age because of the cementitious mix. Moreover, cocopeat affects the compressive strength of the specimens (Maheswari et al., 2022). The compressive strength decreased as the percentage of cocopeat increased, as shown in **Figure 2**. The brick specimens with 5% cocopeat content (S1) had a compressive strength of 10.93 N/mm^2 while the brick specimens with 25% cocopeat content (S5) had a further compressive strength reduction to 3.43 N/mm^2. This was due to increasing the presence of the cocopeat reducing the cohesion between aggregates and cement. The softness of the cocopeat and high porosity can also be attributed to the reduction in compressive strength (Sathiparan et al., 2022).

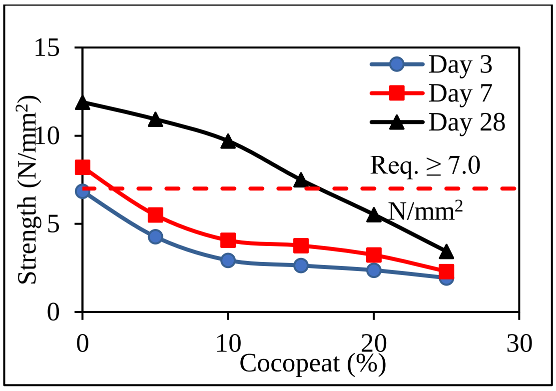


Figure 2. Compressive Strength of Specimens

3.3. Crack Development

Cracks on the brick specimens were observed through visual inspection using a crack width gauge to measure crack development after the compression test (**Table 6**). The presence of the cracks was due to the increasing percentage of cocopeat which led to the lower compression strength. Those cracked bricks are averted to be used in the construction field to prevent the failure of structural buildings. With that, cement bricks (5% to 10% of cocopeat) have no cracks were recommended for industry application.

3.4. Density

The density decreases as the percentage of cocopeat increases as shown in **Figure 3**. It was observed that specimen S1 had the highest density of 1826.72 kg/m^3 while specimen S5 had the lowest density of 1442.76 kg/m^3. This was 11.00% and 29.71% lesser than the solid brick. The observation was compatible with previous research (Sathiparan et al., 2022). The main reason for the reduction in density was the cocopeat was a lightweight material that had a low density as compared with the sand.

Based on the result, 66.67% had a density lower than 1680.0 kg/m^3 which are categorized as lightweight bricks. Hence, the bricks are recommended due to lower self-weight and provided convenience in the laying activities.

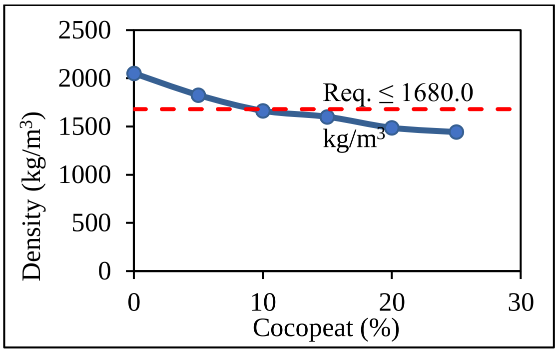
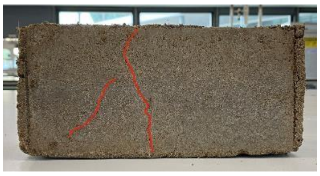
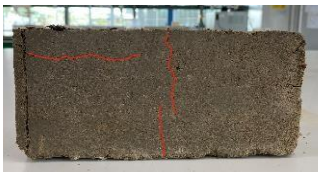


Figure 3. Density of Specimens

Table 6. Test Results of Specimens

Specimen	Compressive Strength at Day 28 (N/mm^2)	Number of Crack Samples	Figure	Remarks
S1	10.93	0		Adequate
S2	9.70	0		Adequate
S3	7.50	1		Adequate
S4	5.53	2		Inadequate
S5	3.43	3		Inadequate

3.5. WATER ABSORPTION

The water absorption increased as the percentage of cocopeat increased as shown in **Figure 4**, which had the same response as previous research (Sathiparan et al., 2022). The brick specimen with 5% cocopeat (S1) had water absorption of 18.15%, while the brick specimen with 25% cocopeat (S5) had increased to 31.29%. This was due to the large portion of cellulose present in the cocopeat may improve the absorption of water and thus cause the water absorption to increase. Besides, the water-absorbent nature of cocopeat provides a medium for the brick specimens to absorb more water.

Referring to the result, 50% of the specimens had a water absorption of less than 20%, despite the high water absorption capacity of cocopeat. As a result, these specimens were able to prevent excessive water extraction from the mortar during bricklaying. This prevention likely enhanced mortar strength by ensuring sufficient water retention for proper cement hydration, leading to stronger and better-bonded mortar joints. However, further study is required to verify such findings.

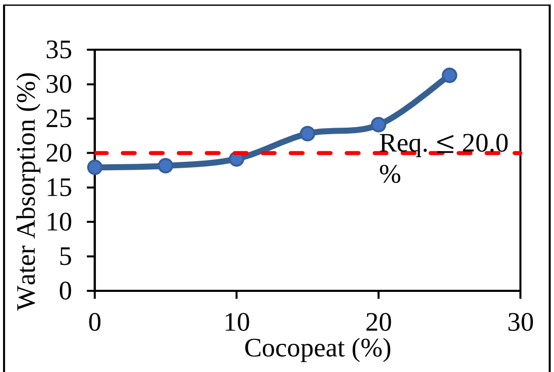


Figure 4. Water Absorption of specimens

3.6. EFFECTIVE STRENGTH TO WEIGHT RATIO

The performance of cement brick was assessed using the effective strength-to-weight ratio ($s - w$ ratio) in Equation 3. For effective brick, the *s*-*w* ratio must be at least equal to 1. Conversely, the performance of lightweight brick was viewed as ineffectual when it reduces more strength than its weight (Lim and Ling, 2019).

$$s - w \text{ ratio} = \frac{100 - S}{100 - W} \quad (3)$$

where:

$$W = \frac{W_S - W_C}{W_S} \times 100\% \quad (4)$$

$$S = \frac{S_S - S_C}{S_S} \times 100\% \quad (5)$$

W = Percentage of weight reduction

W_S = Solid brick weight (kg)

W_C = Cement brick weight (kg)

S = Percentage of strength reduction (%)

S_S = Solid brick strength (N) (day 28)

S_C = Cement brick strength (N) (day 28)

From **Table 7**, specimens S1 and S2 had $s - w$ ratio greater than 1.0. The bricks were workable as the weight reduction had exceeded the strength reduction. However, specimen S1 did not achieve the lightweight requirement which was contemplated as a medium-weight brick. With that, specimen S2 was preferred for the construction industry. Such brick performed better than solid brick thus suitable to be used in the construction industry.

Table 7. Strength to Weight Ratio of Specimens

Specimens	Reduction of strength, S (%)	Reduction of weight, W (%)	Strength to weight ratio, ($s - w$ ratio)	Remarks (A/NA)*1
Equation	5	4	3	-
C1	-	-	1.00	A
S1	8.12	10.88	1.03	A
S2	18.49	19.05	1.01	A
S3	36.97	22.11	0.81	NA
S4	53.50	28.91	0.65	NA
S5	71.15	29.59	0.41	NA

Note: *1A = Adequate ($s - w\ ratio \geq 1.0$), NA = Non-adequate ($s - w\ ratio < 1.0$)

4. CONCLUSION

This research was conducted to (a) determine the mechanical and physical properties of cement bricks, (b) identify the optimum mix proportion of cocopeat, and (c) evaluate the suitability of cement bricks. Based on the results, it was concluded that (a) all specimens were within the allowable dimensions, (b) the compressive strength decreased as the cocopeat increased, (c) the number of cracks increased as the cocopeat increased, (d) the density decreased as the cocopeat increased, (e) the water absorption increased as the cocopeat increased, and (f) specimen S2 (10% cocopeat) achieved all the requirements of the industry. With that, it was recommended that the cocopeat can be used as partial replacement material at 10%. Less sand was used to produce the cement bricks which had a comparable performance with the control brick.

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