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Fibreglass Reinforcement Integrated with Palm Kernel Shell as Partial Replacement of Sand for Brick Production

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Abstract

Malaysia's palm oil industry generates a huge amount of palm kernel shell (PKS) waste. Utilising PKS as a sand replacement in brick production is one of the viable solutions to reduce biomass waste. The water absorption test revealed that the char-PKS absorbs significantly more water than the PKS-brick. The compression strength indicated that PKS masonry bricks meet Malaysian standards and American Society for Testing and Materials. According to the density test, the bricks with the maximum sand replacement fall into the lightweight range. This research has sparked hope of reducing PKS waste by using it as a partial replacement for sand in brick production.

Keywords

Masonry brick, PKS, char PKS, compression test, fibreglass reinforcement

1 Introduction

Malaysia is blessed with plenty of natural resources, such as oil palm. It is one of the major economic crops in Malaysia, contributing about 43 % of the world's production with a total of 17.7 million tonnes.[1] Due to the high demand for vegetable oil, it is expected that by 2050, the production of oil palm in Malaysia will rise to 25.6 million tonnes of crude palm oil per year.[2]

Despite the high economic returns for the country, the palm oil industry also generates a huge amount of biomass waste. After processing and extraction of palm oil, liquid and solid residues are generated as wastes, such as palm shell, palm oil mill effluent, and empty fruit bunches. A previous study conducted by *Syed-Hassan and Saufi*[3] indicated that solid waste feedstock accounted for around 80 million tonnes in 2010, and predicted to reach 100 million dry tonnes of biomass by 2020. The generation of by-products in the palm oil industry will lead to pollution in Malaysia.

Considering the environmental impact, much research has been devoted to investigating the possibilities of using palm oil biomass and converting it into value-added products such as masonry brick. Recycling biomass in the production of masonry brick is one of the best solutions to mitigate pollution. Among the biomass present in oil palm plantations, palm kernel shell (PKS) is a viable candidate for partial sand replacement in brick production.

To develop the high load-bearing capability of PKS masonry brick, fibre-reinforced cementitious material can be implemented. Previous studies have been carried out to examine the effect of fibre reinforcement on aggregate composites.[4,5] For example, *Bentur et al*.[6] conducted several studies using bamboo, sugarcane bagasse, coconut coir, wood cement, and jute composites as concrete complements. *Boghossian* and *Wegner*[7] proposed that using fibres on aggregate could reduce cracking. This must be attributed to its ability to improve the tensile capacity of the fresh mortars and prevent the cracks from growing. According to *Frediuk et al.*[8], glass fibre-reinforced concrete provides high-strength, alkali-resistant fibres when they are mixed in a concrete matrix. Both fibres and matrix retain their physical and chemical identities while providing a synergistic combination of properties that neither of the components could achieve on their own. A study conducted by *Khan et al.*[9] revealed that fibreglass can be employed as retrofitting material to prevent the out-of-plane collapse of masonry walls. Also, according to the same author, using fibreglass reinforcement in cross pattern configuration as geosynthetic strengthening may enhance the load capacity and shear strength of wall panel.[10]

Much research has been conducted on the use of PKS as a partial replacement of aggregate in sand-crate.[11,12] Continuous investigation is required to study the possibility of using PKS for the production of commercial brick. No study to date has addressed the effect of compression strength, water absorption, and bulk density on various ratios of PKS, cement, and sand with enforcement of fibreglass. To avoid decomposition of PKS, the PKS was heated in order to produce char-PKS, and the comparative study between masonry bricks made from PKS and char-PKS was also investigated. Our findings provide additional insight into creating new lightweight bricks with low cost and relatively high strength for non-load bearing systems.

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2 Materials and methods

2.1 Material used

Raw material preparation

The cement used in this project was Castle cement portland composite. The composition of the cement was: sulphate content (SO_2) 2.1 %, chloride 0.01 %, particle fineness of 440 $m^3\ kg^{-1}$, with settling time of 155 min and soundness of 0.8 mm.

Sand

Local river sand was purchased at local hardware with a fineness modulus of 3.45. The water absorption and specific gravity were 1.21 and 2.43 %, respectively. The sand had a density of about 1458 $kg\,m-^{3}$. The analysis of sand and PKS grading curve are shown in Fig. 1. From the figure, 100 % sand and PKS passed through at 4.5 and 7.1 mm. The sand was classified as poorly graded sand due to the steeper curve of particle size distribution.

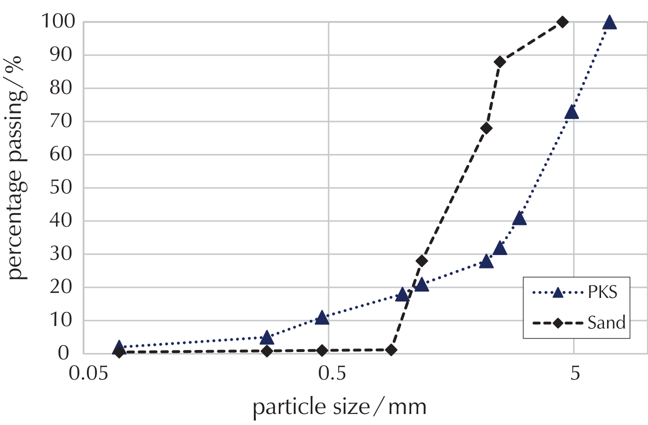

Fig. 1 – Particle size distribution

Palm kernel shell

PKS was obtained from Kilang sawit FELDA Jerangau. PKS was ground and sieved by sieve shaker OCTAGON 200CL to obtain the sizes between 1 and 3 mm. The PKS was then washed and dried in sunlight for three days. To produce char-PKS, the PKS was heated in the Carbolite chamber furnace at a temperature of 400 °C for 1 h. The PKS and char-PKS are shown in Fig. 2.

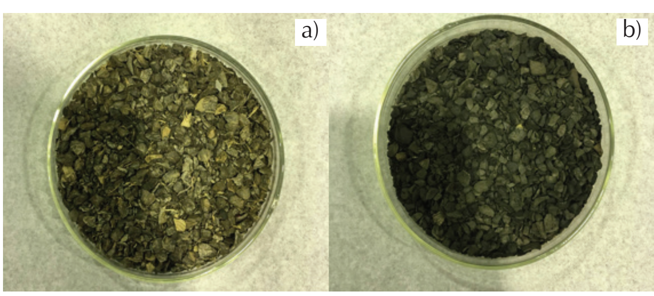

Fig. 2 – PKS (a), and char-PKS (b) used as partial replacement of sand prior to grinding process

Fibreglass

The glass fibre used in this study was roving single thread. It was obtained from ZYQ Engineering Sdn. Bhd, and cut 5 cm in length.

2.2 Sample preparation

In this research, the composition ratio of PKS/char-PKS, cement, sand was designed as 1 : 1 : 3, 2 : 1 : 2, and 3 : 1 : 1 by volume basis, as shown in Table 1. An amount of 5 g of fibre glass was added into each sample except the control. The control specimen of masonry brick was prepared at 1 : 4 cement and sand ratio. The cement to water ratio was adjusted to obtain desired workability. The samples were prepared by mixing and stirring the amount of sand, cement, and PKS using a rotating mixer to produce mortar. The duration of mixing was about 5–10 min until the mortar achieved homogeneity. The mortar was then placed into a fabricated mould, and compacted 3 layers by using a temping rod with 28 strokes *per* layer. The samples were dismantled from the mould after 24 h, and then cured for 28 days (Fig. 3). The analysis of water absorption, density, and compression tests were conducted after the curing period.

Table 1 – Volume proportions of prepared test brick

Sample	Volume ratio (PKS/char-PKS : cement : sand	Weight / g		
		Sample	Cement	Sand
Control	0 : 1 : 4	0	800	3200
PKS	1 : 1 : 3	800	800	2400
	2 : 1 : 2	1600	800	1600
	3 : 1 : 1	2400	800	800
Char-PKS	1 : 1 : 3	800	800	2400
	2 : 1 : 2	1600	800	1600
	3 : 1 : 1	2400	800	800

2.3 Samples testing

Compressive test

The mixture samples were prepared in accordance with BS EN 771-3:2011. The compressive test was carried out thrice for each sample, and the average values were calculated. The compression test was measured using an SIRIM Instron Testing Machine, with a ramping speed of 12 $mm\,min^{-1}$.

$$C_s = \frac{F}{A} \tag{1}$$

where C_s is compressive strength of brick (MPa), F is the maximum force exerted into sample (N), and A is the imparted surface area (mm^2).

Water absorption test

Water absorption test was carried out after 28 days of curing using the American Society for Testing and Materials (ASTM) C642 test. The samples were oven-dried at 110 °C overnight, and stored in the laboratory to cool to room temperature. The samples were then submerged completely under water at room temperature of 25 °C for 1 day. The samples were allowed to drain for a while to let the excess water out. The water absorption was measured using the following equation:

$$WA = \frac{W_w - W_d}{W_d} \cdot 100\ \% \qquad (2)$$

where WA is water absorption (%), W_w is the weight of sample after immersion (g), and W_d is weight of dry specimen (g).

Density measurement

The samples were measured using ASTM C55 density test. The density of bricks was measured by calculating the weight and volume of each sample after 28 days. The dimensions of the samples were measured using a digital calliper with ±0.01 mm sensitivity to obtain the volume.

fiberglass, while the masonry bricks contained the reinforcement of 5 g of fibreglass for each brick. A compression test was carried out after the 28th day of the curing process, and the results showed the control and PKS brick had passed the minimum standards of ASTM and Malaysian Standards, which are 4.14 MPa and 5.2 MPa, respectively. It was also noted that the PKS brick withstood about 74 % more than the control brick. It was evident from this data that the presence of fibreglass enhanced the strength of brick by retaining the loads with the help of cement and maintaining the location of the fibre reinforcement. The fibre is light in material but strong against tensile stress and tension.[15] According to *İskende et al.*[16] the fibre acts as a crack inhibitor by resisting the propagation of cracks and reducing sudden failure structures, thus increasing the load carrying capacity of brick. On the other hand, although char-PKS brick was reinforced with fibreglass, the highest compression pressure was only 4.8 and failed the Malaysian Standard for lightweight brick. This result may be explained by the amount of porosity present in char-PKS, which subsequently reduced the structural strength of the char. At high pressure, the char-PKS was crushed, which created more micro-holes in the char-PKS brick.[17] Too many holes reduced the strength of the brick, which is why it could not withstand high pressure.

Fig. 3 – Sample of control with PKS and char-PKS bricks of 1 : 1 : 3 composition after 28 days of curing process

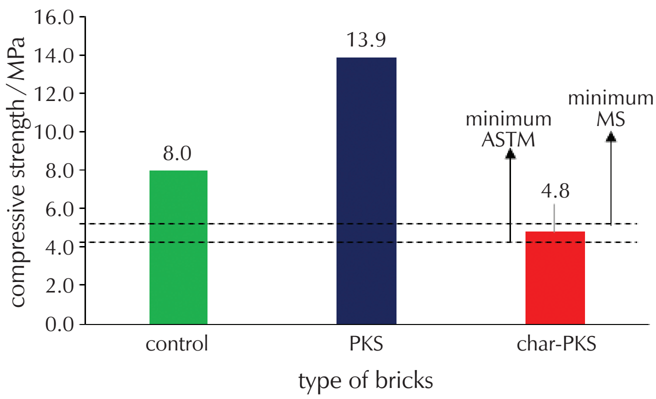

Fig. 4 – Compressive strength of different bricks

3. Results and discussions

3.1 Compressive strength test

3.1.1 Effect of fiberglass reinforcement

Non-load bearing systems are implemented in many constructions, especially in the establishment of wall panels. In order to assess the quality of cement blocks, Malaysia Standards MS 76:1972 set a minimum criterion of 5.2 MPa for three specimens of conventional bricks.[13] The American Society for Testing and Materials indicated that compressive strength must meet the minimum requirement of 4.14 MPa as a passing compressive strength.[14] An overview of the compressive strength of the bricks with different types of materials is presented in Fig. 4. The ratio of sample, cement, and sand was 1 : 1 : 3, and the ratio of cement and sand for control was 1 : 4. Control was created to resemble the commercialised brick with no additional

3.1.2 Effect of composition ratio

The compressive strength of the various composition ratios of PKS and char-PKS in the replacement of sand for brick production is shown in Fig. 5. It is interesting to note that the compression strength of all PKS bricks had passed the minimum standards of ASTM and MS, while only the lowest composition ratio of char-PKS complied with ASTM. The highest compressive strength was recorded at the lowest composition ratio of 1 : 1 : 3 for both material substitutions. The results indicated that the strength of brick was affected by the degree of replacement of sand. The compressive strength gradually decreased with increasing the ratio of PKS and char-PKS. In accordance with the present results, previous studies by various researchers[18–20] have demonstrated that the strength of bricks was also reduced as the ratio of material replacement increased. This might be due to the particle size and shape of PKS and char-PKS being relatively different to the particles of sand, which subsequently provide gaps in the brick matrix, thus lowering the mechanical strength of the brick. A comparison between PKS and char-PKS bricks showed that PKS bricks had higher compressive strength than char-PKS in all different composition ratios. During carbonisation of char-PKS, volatile components were released through thermal decomposition, producing many pores.[21] A micro-porosity of PKS and char-PKS was observed through FE-SEM, as shown in Fig. 6. The development of micro-porosity and cracking of char-PKS was significant, which created a 'weak zone' that reduced the structural strength.[22] Thus, increasing the compressive strength broke the structure of char-PKS, leaving more voids between the particles of char-PKS and the sands, which led to the reduction in strength, as in Fig. 5.

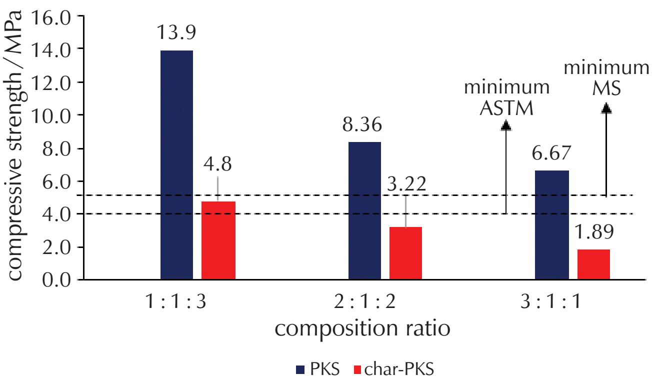

Fig. 5 – Compressive strength of masonry bricks with different ratios of replacement

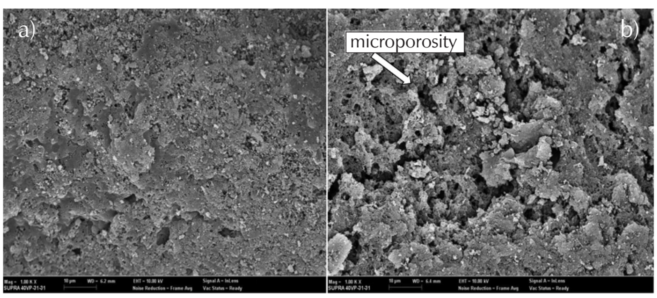

Fig. 6 – FE-SEM image of PKS (a) and char-PKS (b) at 1000× magnification

3.2 Water absorption test

One of the indicators to test the durability performance of brick is by measuring the water absorption capacity. There are crucial parameters to observe in the pore system and mechanical strength of the brick. The high number of pores in the cement bricks will increase the vulnerability of water passing through. In general, increasing the material as a replacement for sand would increase the water absorption of the brick. Previous studies have also observed the same pattern whereby the absorption of water increased as more waste material was used to replace sand. The study of the structural behaviour of agricultural lightweight concrete bricks by *Sathiparan et al.*[23] showed that water absorption increased significantly by replacing sand with various agricultural wastes. It was also noted that a high percentage of sand removal would affect the bonds between the agricultural wastes and cement, leading to high porosity and subsequently increased water absorption. A water absorption test was conducted following ASTM C 642 after 28 days of the curing process. It can be seen in Fig. 7 that all replacement sand bricks, regardless of the composition ratio, have higher water absorption uptake in comparison to control bricks. This finding is consistent with previous research, which showed that substantial water uptake was observed by replacing sand with other materials. A possible explanation for these results may be related to the lower bulk density of PKS and char-PKS than sand, and the presence of many holes in the mortar mixture. On the other hand, all ratios of char-PKS resulted in higher water absorption than PKS and control. This might be due to the existence of micropores that generate greater interparticle-voids. Therefore, the water could easily be absorbed inside the matrix of bricks.[24]

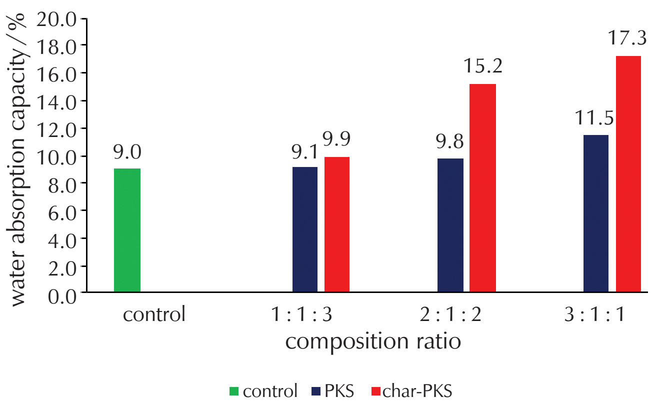

Fig. 7 – Water absorption capacity of masonry bricks with different ratios of replacement

3.3 Bulk density test

Density is defined as the number of particles that are squeezed into a given volume. The density of brick is higher when the mixture of particles is closely packed together. It is an important parameter to classify the categories of brick as either light-, medium-, or normal-weight. According to the ASTM C55 method, a brick is classified as a lightweight brick when its bulk density is lower than 1680 $kg\,m^{-3}$, while medium weight is between 1680 and 2000 $kg\,m^{-3}$. The brick has a normal weight when its bulk density is higher than 2000 $kg\,m^{-3}$.[25] Fig. 8 presents the density of all samples and control brick. The result shows that the PKS and char-PKS bricks in all compositions had lower density compared to control bricks. In general, the density of brick decreased as more sand was replaced. It can also be observed that only the composition ratio of 3 : 1 : 1 of PKS and char-PKS was regarded as lightweight. This might have been due to the lower density of PKS and char-PKS in relation to the density of sand. In addition,

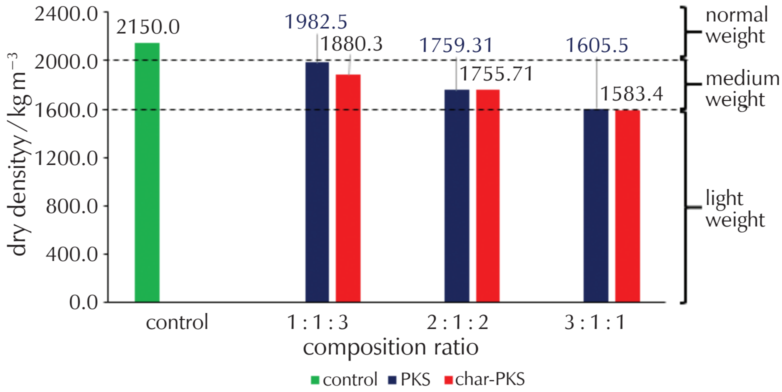

Fig. 8 – Dry density of masonry bricks with different ratios of replacement

with a high amount of sand being replaced, the weight of brick had also reduced significantly. Meanwhile, a comparison between PKS and char-PKS brick showed that char-PKS brick was lighter in all composition ratios. Similar reasoning in terms of microporosity, as discussed in the compressive strength and water absorption tests, applies to this observation. The findings in this study are in agreement with previous research conducted by *Muntohar et al.*[26] which reported that bulk density can be reduced to as low as 1300 $kg\,m^{-3}$ by increasing the percentage of sand. However, this affects the structural strength of non-load bearing systems.

3.3 Cost analysis

The result of the cost analysis is shown in Table 2. The result showed that around 26 % cost reduction could be achieved by replacing sand with PKS. This is because the price of PKS is much cheaper than sand. However, the exact cost calculation should consider the number of bricks produced *per* day.

Table 2 – Cost/pallet of bricks (price in Ringgit Malaysia, RM)[a]

Material	Cost / RM	Material	Cost / RM
Sand	39.00	Conventional brick	120.00[27]
OPC Cement	40.00		
Fibre glass	5.00		
Palm kernel shell	4		
Total	88		

[a]1 dollar = RM 4.00

4 Conclusions

This study examined the physical and mechanical properties of bricks for non-load bearing systems with additional fibreglass reinforcement and partial replacement of sand. Three variations of mix proportion were evaluated, incorporating the effect of the ratio of PKS/char replacement and fibreglass reinforcement. The existence of fibreglass enhances the strength of brick. The highest compressive strength of brick was about 13.9 MPa, which was obtained by mixing PKS, cement, and sand in ratio 1 : 1 : 3. Increasing the replacement amount of sand would decrease the strength of the brick. However, all the PKS bricks at different ratios were compliant with the MS and ASTM standards for non-load bearing systems. Char-PKS tended to absorb more water due to the high amount of microporosity. Both PKS and char-PKS with a composition ratio of 3 : 1 : 1 fell into the lightweight brick category, while the others were classified as medium-weight bricks. PKS with reinforcement of fibre brick of composition 2 : 1 : 2 has excellent commercial potential due to its significant high strength (passing ASTM and MS), minimum water absorption, and acceptable low density, as demonstrated in mechanical and physical testing.

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Conflict of interest

The authors declare that they have no conflict of interest.

List of abbreviations

PKS – Palm Kernel Shell
ASTM – American Society for Testing Materials
MS – Malaysian Standards
FE-SEM – Field Electron Scanning Electron Microscopy
RM – Ringgit Malaysia

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SAŽETAK

Upotreba ljuski palmi uljarica uz ojačanje stakloplastikom kao djelomična zamjena za pijesak pri proizvodnji opeke

Mohd Saufi Md Zaini[a*] i *Mohamad Adam Bin Mohd Za'aim*[b]

Industrija proizvodnje palminog ulja u Maleziji generira kao otpad ogromnu količinu biomase u vidu ljuski palminih zrna (PKS). Upotreba ljuski kao zamjene za pijesak pri proizvodnji opeke jedno je od održivih rješenja za smanjenje otpadne biomase. Analizom je utvrđeno da pougljeni PKS apsorbira znatno više vode od PKS-a opeke. Tlačna čvrstoća pokazala je da zidarske opeke s PKS-om zadovoljavaju malezijske standarde i standarde koje propisuje American Society for Testing and Materials. Analizirajući gustoću, opeke s maksimalnom zamjenom pijeska spadaju u kategoriju lakih opeka.

Ključne riječi
Zidarska opeka, PKS, pougljeni PKS, ispitivanje tlačne čvrstoće, ojačanje stakloplastikom

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