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A Study of Sago Fine Waste (SFW) as a Pozzolanic Material in Cement Bricks with Different Water-Cement Ratio

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ABSTRACT

Cement is a key material in the construction industry. However, its widespread use has adversely affected the environment. Compiling cement with waste materials, mainly agricultural wastes, can reduce the impact of environmental pollution and result in sustainable construction. Sago fine waste (SFW) is a fibrous residue from waste from sago milling operations where physical treatment has been made. This study uses SFW as a partial cement replacement cement brick. This study investigated the effect of sago waste on cement bricks' properties based on the difference of three water-cement ratios: 0.4, 0.5, and 0.6. Brick samples were made with five partial replacements: 5%, 10%, 15%, 20%, and 25%, including control cement brick. The mortar mix was based on a ratio of 1:3, which follows Malaysian brick production standards. For compressive strength, density, and water absorption tests, all the specimens were cured for 7 and 28 days. The analysis of this study indicates that, according to extensive data collection, the ideal composition for SFW in cement brick was 5% and 0.6 water-cement ratios, indicating higher compressive strength than 0.4 and 0.5 water-cement ratios in 28 days of curing. Therefore, 5% SFW in cement brick produces the most significant results with a compressive strength of 15.63 MPa, a density of 2017 kg/m^3, and water absorption of 12.5% after 28 days of curing. This shows the promise of SFW as a pozzolanic material for creating more environmentally friendly bricks, being one of the solutions to environmental pollution problems, and aligning with Sustainable Development Goals (SDGs).

Keywords: *Sago fine waste, Pozzolanic material, Water-cement ratio*

1. INTRODUCTION

Sago is a type of food made from the stems of the *rumbia* tree (*Metroxylon* sago) or the Sago tree [1]. The sago palm tree is native to Malaysia, Indonesia, Papua New Guinea, and other Southeast Asian countries. Sarawak is one of many Malaysian states with sago commercialized crops. Sago flour is made by sifting the trunks of sago trees with water and then pressing them like coconut milk. After extraction, waste known as 'pow' or sago waste is thrown into the river, raising concerns about its potential to pollute the environment [2].

Another current environmental concern is the buildup of improperly managed solid waste. The waste generated daily after processing between 8 and 12 logs on an industrial scale can reach 3 to 5 tons [3]. Approximately 60 tons of sago waste are dumped daily in Sarawak, posing various hazards and negatively impacting that state [4]. Furthermore, sago waste combined with sago fibre indicates high levels of organic materials, chemical oxygen demand (COD), and biochemical oxygen demand (BOD), all of which violate the discharged regulations outlined in the Environmental Quality Act of 1974 [5]. As the agricultural industry grows, agricultural waste is frequently produced, and Sago production increases in direct proportion to waste generation increases [6].

Previous research has shown that sago waste could be used as a future material substitute in the construction industry. According to Kesuma [7], sago waste is used to create more lightweight, cost-effective concrete bricks that meet the class III grade brick standard. While another researcher, Darwis [8], discovered that 10% sago stem fibre in concrete brick gives compressive strength of 2.03 MPa and meets quality brick class IV, while concrete brick with 50% sago fibre replacement meets quality brick class III [9].

Another study [10] found that a 25% sago waste mixture with a compressive strength value of 0.47 MPa meets the minimum concrete block compressive strength type III standard. The compressive strength test results after 28 days of curing were 8.52-24.83 MPa, and after 56 days of curing were 8.85-25.65 MPa [11]. Another study [12] used sago husk as a filler for fly ash bricks and fly ash and sago. The results show that the sago husk has a compressive strength range of 1.3% to 3.3%, with 1.3% being the highest and 3.3% being the lowest.

In the Jau study [13], Sago Pith Waste (SPW) is an exciting choice for biodegradable composites. SPW was successfully plasticized to form a natural fibre-filled thermoplastic starch composite without adding synthetic polymer. Based on Rohaizad's study [14], the SPW and the SPW burning ashes, called SPWA, have the potential raw material for producing ceramic and geopolymer products. In addition, sago waste is used as partial cement replacement in peat stabilization [15]. Results show that 25% of sago waste replaced OPC and measured 17 times higher unconfined compression strength than the untreated peat sample.

Cement is an essential building material. It is one of the world's most widely used manufactured goods today and is essential in developing nations [16]. However, its widespread use is detrimental to the environment, becoming an alarming concern. Recycling solid waste to create valuable auxiliary raw materials in new construction materials is a technique that can reduce pollution and create sustainable development. Furthermore, previous research has shown that sago waste also has the potential to be utilized to replace building materials.

This study used solid waste, namely Sago Fine Waste (SFW), as a partial replacement for cement to produce green cement brick. The fundamental engineering properties of the brick's specimen, such as density, water absorption, and compressive strength, were investigated.

2. EXPERIMENTAL WORK

This study was divided into three sections: preparing the raw materials, brick samples, and brick testing.

2.1. Material

The materials used to produce brick were Ordinary Portland Cement (OPC), fine aggregate (sand), Sago Fine Waste (SFW) and tap water. OPC played an important role as a binding material in construction. The particle density of OPC used in this study was 1454 kg/m^3. The sand had a particle density of 1680 kg/m^3 and a fineness modulus of 2.7.

Sago waste was collected from the factory River Link Sago Resources Sdn. Bhd. at kampung Dalat, Mukah, Sarawak (2°46'14.2"N 111°55'50.3"E). Fresh sago waste was wet, greyish, and light brown and turning brownish after drying [1]. Therefore, before being reused, the moisture content of sago waste needed to be reduced. Drying is a well-known method for inhibiting bacterial and fungal growth in various food industries, helping to maintain product quality characteristics like such as colour, texture, and residual polyphenol content [17].

To produce fine waste, Sago waste underwent physical processing such as sun-drying, grinding, and sieving (SFW). The factory's wet sago waste was sun-dried for at least 18 hours before being processed through a grinding machine to create a fine powder, resulting in a light brown colour. The process of making SFW is shown in Figure 1, and Figure 2 displays the SEM image of the SFW. SFW contains fibre scraps in irregular shapes [18], and granules are oval with a temple bell-like shape [19]. SFW's particle density was 1270 kg/m^3. The chemical component of SFW and OPC by XRF analysis are shown in Table 1. The content of calcium oxide (CaO) and silicon dioxide (SiO_2) in SFW indicated its potential for replacement, similar to the content found in OPC [20].

Figure 1 Preparation of (SFW: a) Drying sago wet waste. b) Breaking up lumps of waste c) SFW after physical treatment

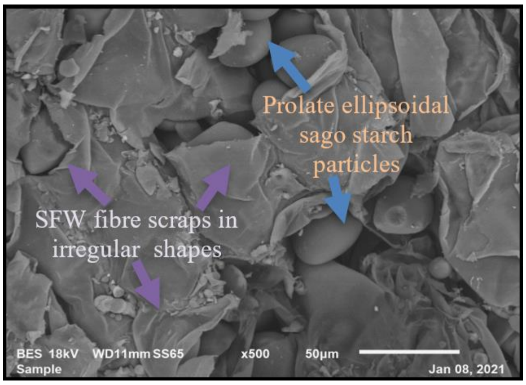

Figure 2 SEM image on Sago Fine Waste (SFW) (magnification of 500x)

Table 1 Chemical component of SFW and OPC

Chemical Composition	SFW	OPC
Silicon Dioxide (SiO_2)	63.8	19.7
Calcium Oxide (CaO)	23.5	60.7
Magnesium Oxide (MgO)	2.23	-
Potassium Oxide (K_2O)	1.68	2.7
Sulphur Trioxide (SO_3)	0.992	2.1
Ferric Oxide (Fe_2O_3)	0.866	12.3
Aluminium Oxide (Al_2O_3)	0.584	0.03

2.2 Brick Design Preparation

Material content and density have an impact on brick dimensions. Therefore, brick dimensions were recorded after the curing period at 7 and 28 days before the samples underwent a compressive strength test. Brick samples were measured in length, width, height, area, and volume. The average brick dimension was calculated from 36 for each water-cement ratio, where the size of bricks was 215 mm x 102.5 mm x 65 mm, as shown in Figure 3.

Cement bricks with a cement-sand ratio of 1:3 made with cement partially replaced by SFW and water-cement ratios of 0.4, 0.5 and 0.6. Brick designs replaced cement by 0%, 5%, 10%, 15%, 20%, and 25% respectively. The SFW bricks were water-cured for 7 and 28 days after being cast for a day. Table 2 lists the design mix ratio of SFW bricks

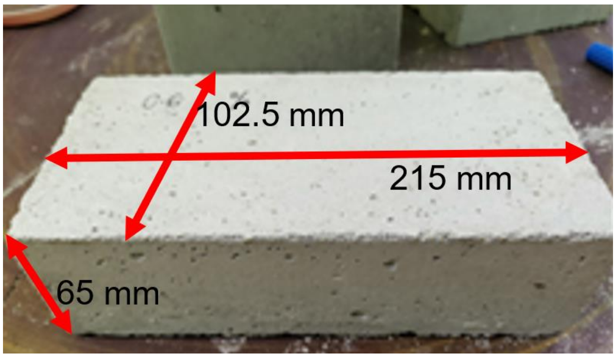

Figure 3 Dimension of brick

2.3 Testing Method

All specimens were prepared in the Concrete Technology laboratory at UTHM Campus Pagoh. The brick samples were tested with density (ρ), water absorption (W/A) and compressive strength (σ) tests. These tests involved 108 samples for compressive strength and density tests, and 54 samples for water absorption. Each test was completed following the standard listed in Table 3.

Table 2 A design mix ratio of SFW bricks

Water-cement 0.4	Cement (%)	SFW (%)	Water-cement 0.5	Cement (%)	SFW (%)	Water-cement 0.6	Cement (%)	SFW (%)
SFW0W0.4	100	0	SFW0W0.5	100	0	SFW0W0.6	100	0
SFW5W0.4	95	5	SFW5W0.5	95	5	SFW5W0.6	95	5
SFW10W0.4	90	10	SFW10W0.5	90	10	SFW10W0.6	90	10
SFW15W0.4	85	15	SFW15W0.5	85	15	SFW15W0.6	85	15
SFW20W0.4	80	20	SFW20W0.5	80	20	SFW20W0.6	80	20
SFW25W0.4	75	25	SFW25W0.5	75	25	SFW25W0.6	75	25

*SFW-Sago fine waste, W-water-cement ratio

Table 3 List of standards of brick testing

Properties	Laboratory test	Standards
Mechanical properties of materials	Density	BS EN 12390-7 [21]
	Compressive strength	BS EN 771-1:2011 [22]
	Water Absorption	BS 1881: Part 122 [23]

3. RESULTS AND DISCUSSION

The results and discussion for various tests are discussed as follows.

3.1 Density

The bricks' dimensions were summed and divided by the average volume of 0.0014 m^3. The average densities of the brick samples at 7 and 28 days with different water-cement ratios are shown in Figure 4. The lowest density of 1529 kg/m^3 was obtained by brick SFW25W0.4, 17.05% less than the control sample SFW0W0.4. The highest density was received at 5% SFW at 28 days of curing; SFW5W0.6 was 2018 kg/m^3. However, its value is still reduced by 2.53% compared to the 2070 kg/m^3 control brick. From that graph, it can be observed that the densities decreased in parallel with the addition of SFW. The percentage reduction was around 3.22% to 17.05% for 7 days of curing and 2.52% to 11.84% for 28 days compared to control bricks.

The raw material and manufacturing method affect the density of cement bricks. The increase in SFW has an impact on density. Because of the density of the source material, this outcome corresponded. SFW has a density of 1270 kg/m^3, lower than OPC's 1454 kg/m^3 density. This has a direct impact on brick density. This aligns with other research that uses agricultural waste, such as SFW, which has produced lightweight bricks [24, 25]. SFW5W0.5 and SFW5W0.6 at 28 days of curing can be categorized as normal-weight bricks; the rest were classified as medium-weight bricks. While on the 7th curing day, an additional 20-25% of SFW could produce lightweight bricks.

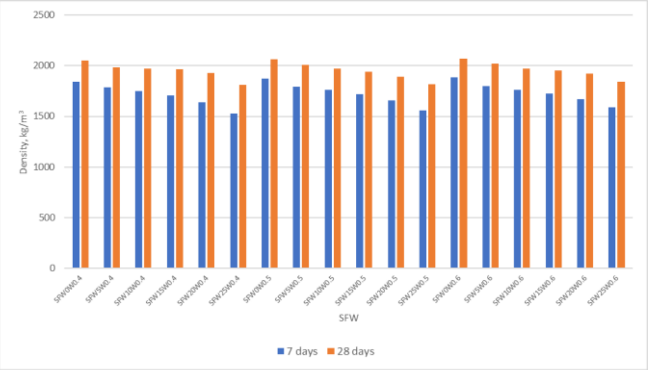

Figure 4 The brick density of different water-cement ratio

3.2 Compressive Strength

The brick strength for brick is shown in Figure 5. The graph showed a continuous decline in brick strength as the SFW percentage increased from 17.72 to 99.31%, with an increase of 5% SFW. However, the strength of bricks for a water-cement ratio of 0.6 is significantly increased compared to a water-cement ratio of 0.4 and 0.5 with an increment of SFW as cement replacement. The control sample had a compressive strength of 13.87 MPa, 14.52 MPa, and 15.92 MPa for water-cement ratios of 0.4, 0.5, and 0.6, respectively, at 7 days. At the same time, brick strength for 28 days of curing is 17.37 MPa, 17.85 MPa and 19 MPa, respectively. This indicated that the higher the water-cement ratio used, the higher the strength value of the brick.

The lowest strength of bricks is 0.13 MPa at 7 days and 0.15 MPa at 28 days of curing. While the highest strength of bricks is 11.01Mpa for 7 days of curing and 15.63 MPa for 28 days, at a water-cement ratio of 0.6, a brick's compressive strength must be considered when determining its load-bearing capacity. According to MS1933: Part1: 2007, adding 5% SFW could produce bricks for classes 1 and 2, while 10-15% could produce bricks for load-bearing internal and non-loading partition walls. However, more than 20% of the SFW was unsuitable for construction because its strength value was below 1.4 N/mm^2. The resulting pattern demonstrated that the brick is weaker the higher the SFW replacement. Resources made from agro-waste like Palm Oil Fuel Ash (POFA) [20][26], Oil Palm Empty Fruit Bunches (EFB) [27], coconut fibre [28], Sugarcane Bagasse Ash (SBA) [29], and Rice Husk Ash (RHA) [16, 30, 31] produced comparable results.

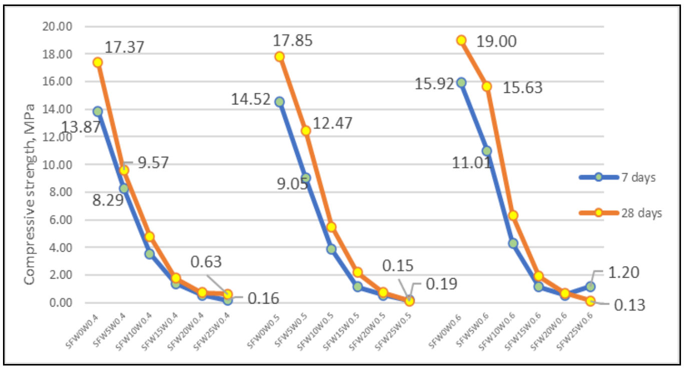

Figure 5 Compressive strength graph of different water-cement ratio

3.3 Water Absorption

According to Figure 6, the control brick with such a water content of 0.4 (SFW0W0.4) absorbed water at a rate of 12.06%., whereas the control brick with a water-cement ratio of 0.5 (SFW0W0.5) was 11.97% and for 0.6 (SFW0W0.6) was 11.93%. The percentage of water absorption showed a linear increase after an increase in SFW. The maximal water absorption is 18.28% for SFW25W0.5. The water absorption rate increased from 6.79% to 68.33% compared to the control sample. When comparing three different water content values, 60% of water was slightly lower than 40% and 50% water content. However, all values were obtained to meet the Indian standard IS1077 [32], i.e., less than 20% water absorption. Due to the characteristics of SFW, which are very absorbent materials, all absorption values were crucial [33].

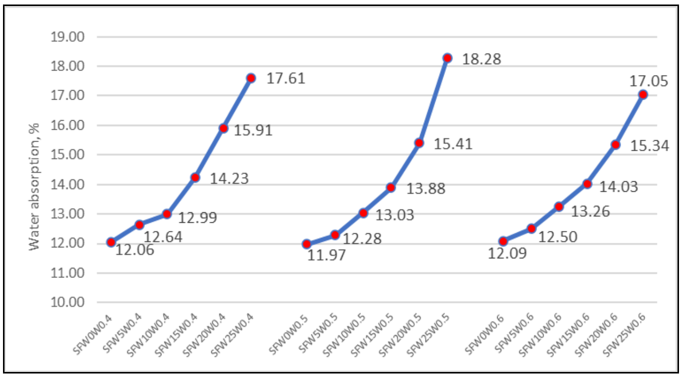

Figure 6 Water absorption at 28 days

3.4 Correlation of Increment of Sago Fine Waste

Correlation and regression are statistical techniques used to estimate the relationship between a dependent variable and one or more independent variables. The dependent variable in this analysis was the percentage of SFW.

Figure 7 indicated the relationship between density and the percentage of SFW, which exhibited a linear inverse relationship. For all design and curing days, the coefficient of determination, R^2, represented a strong relationship with an average R-square of 0.9527. Using a percentage of 25 and above would produce lightweight bricks based on that graph.

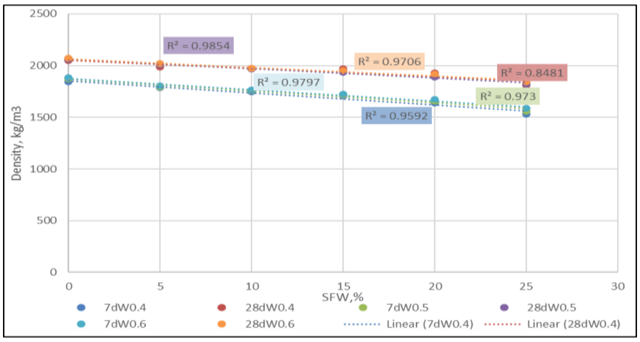

Figure 7 Regression analysis for density with different percentages of SFW

Figure 8 demonstrated the correlation between compressive strength and percentage SFW. It showed a strong correlation with R-squared ranging from 0.8431 to 0.8932. Based on the resulting inversed linear line, it could be predicted that the brick's strength did not reach the minimum required strength when using more than 25% SFW.

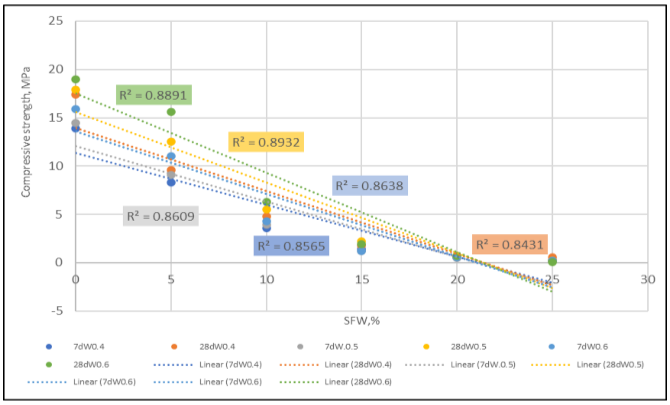

Figure 8 Regression analysis for compressive strength with different percentages of SFW

Figure 9 illustrated the relationship between water absorption and the proportion of SFW. Brick's water absorption increased linearly as the percentage of SFW increased. Since all R-squared values are near 1, the coefficient of determination was reliable and appropriate for all water-cement ratios and types of material replacement.

This statistical analysis provides an analytical description of how the percentage of SFW affected the properties of bricks, and the regression equation could be used to predict the SFW brick properties' value with a certain value of SFW.

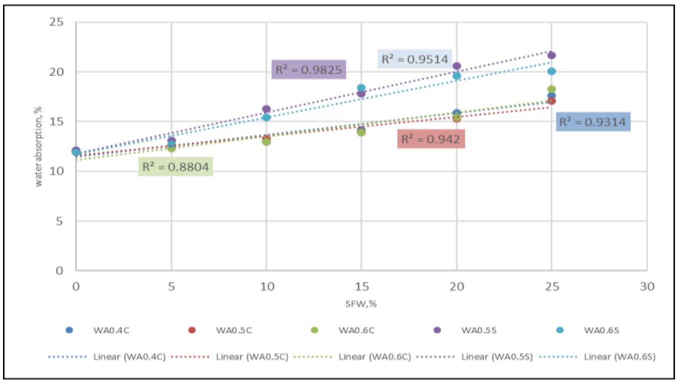

Figure 9 Regression analysis for water absorption with different percentages of SFW

4. CONCLUSION

The experiments' findings demonstrated that a suitable percentage of SFW can be substituted for some of the cement by using agricultural wastes. Brick's compressive strength was significantly impacted by SFW. The study indicated that SFW should not be used more that 10% of the brick mixture for load-bearing constructions. It had been suggested that non-load bearing structures use no more than 20% SFW.

Thus, after 28 days of curing, the best combination is SFW5W0.6, which yielded the best results with a compressive strength of 15.63 MPa, a density of 2017 kg/m^3, and water absorption of 12.5%. It is considered medium-weight brick and had the best compressive strength and typical water absorption rate.

Using SFW in brick production would provide pozzolanic material and reduce the consumption of Ordinary Portland Cement. Additionally, it contributed to environmental clean-up, the production of more environmentally friendly bricks and it may have been in line with five Sustainable Development Goals (SDGs), such as SDG 9: Industry, innovation, and infrastructure; SDG 11: Sustainable cities and communities; SDG 12: Responsible consumption and production; SDG 13: Climate action and SDG 15: Life on land.

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REFERENCES

[1] A. W. Norhayati, A. Suraya Hani, and I. Abdul Hadi Izaan, “Physical properties of sago fine waste as a fine aggregate in material of construction,” *Multidisciplinary Engineering Science and Advanced Technology Series 1*, pp. 11-18, 2022.

[2] R. M. Sabri, M. J. Jamaliah, and Y. Nurleyna, “Treatment of sago mill effluent for methane production using anaerobic sequencing batch reactor (ASBR),” *Journal of Engineering and Science Research*, vol. 2, no. 1, pp. 18–22, 2018.

[3] T. H. Rasyid, Y. Kusumawaty, and S. Hadi, “The utilisation of sago waste: Prospect and challenges,” *IOP Conference Series: Earth and Environmental Science*, vol. 415, no. 1, 2020.

[4] Patricia Gari, “Teknologi rawatan sisa secair sagu akan diperluaskan atasi pencemaran,” *Utusan Borneo*, 19-Oct-2020.

[5] D. S. Awg-Adeni, S. Abd-Aziz, K. Bujang, and M. A. Hassan, “Bioconversion of sago residue into value-added products,” *African Journal of Biotechnology*, vol. 9, no. 14, pp. 2016–2021, 2010.

[6] K. B. Bujang and M. A. Hassan, “Recovery of glucose from residual starch of sago hampas for bioethanol production,” July 2014.

[7] M. Kusuma, “Batako ringan dengan campuran limbah ampas sagu,” Universitas Gadjah Mada, 2015.

[8] D. Darwis, A. Astriana, and M. S. Ulum, “Pemanfaatan limbah serat batang sagu untuk pembuatan batako,” *Gravitasi*, vol. 15, no. 1, pp. 1–9, 2016.

[9] M. Z. Umar, L. O. A. Hasan, and M. Arsyad, “The use of sago fiber waste (*Metroxylon sagu* Rottb.) as added material to concrete bricks,” ADRI International Conference on Sustainable Coastal-Community Development, vol. 1, no. January, pp. 25–29, 2020.

[10] M. Rahayu, "Karakterisasi sifat fisis papan komposit berbahan dasar limbah ampas sagu," *Magistra*, vol. 3, no. 2, pp. 125–133, 2016.

[11] Petrus Patandung and Suroto Hadi Saputra, "Pengaruh kosentrasi serat sagu dan lama penyimpanan terhadap karakteristik paving blok," *Jurnal Riset Teknologi Industri*, vol. 9, no. 2, pp. 129–137, 2015.

[12] K. Ornam, M. Kimsan, L. O. Ngkoimani, S. B. Amri, Santi, and S. Amsyar, "Evaluation of bottom ash composition on modified hollow brick design with sago husk as filler," *IOP Conference Series: Materials Science and Engineering*, vol. 797, no. 1, 2020.

[13] J. C. Lai, W. A. Rahman, and W. Y. Toh, "Characterisation of sago pith waste and its composites," *Industrial Crops and Products*, vol. 45, pp. 319–326, 2013.

[14] M. R. Mohamed Rashid, M. J. A. Mijarsh, H. Seli, M. A. M. Johari, and Z. A. Ahmad, "Sago pith waste ash as a potential raw material for ceramic and geopolymer fabrication," *Journal of Material Cycles and Waste Management*, vol. 20, no. 2, pp. 1090–1098, 2018.

[15] S. Nordzaima, A. Mohammad, W. K. Ming, G. Tang, Y. Sam, and Y. Xiaoxian, "Effectiveness of sago waste as partial cement replacement in Sibu peat stabilisation," *Borneo Journal of Sciences and Technology*, no. November 2020, pp. 93–98, 2021.

[16] I. H. Ling and D. C. L. Teo, "Lightweight concrete bricks produced from industrial and agricultural solid waste," in *2011 World Congress on Sustainable Technologies (WCST)*, pp. 148–152, 2011.

[17] M. I. Rosli, A. M. Nasir, M. S. Takriff, and L. P. Chern, "Simulation of a fluidised bed dryer for the drying of sago waste," *Energies*, vol. 11, no. 9, 2018.

[18] J. C. Lai, W. A. Rahman, and W. Y. Toh, "Mechanical, thermal and water absorption properties of plasticised sago pith waste," *Fibers and Polymers*, vol. 15, no. 5, pp. 971–978, 2014.

[19] H. Ehara, Y. Toyoda, and D. V. Johnson, "Sago palm: Multiple contributions to food security and sustainable livelihoods," *Springer Open*, 2018.

[20] A. Suraya Hani, M. Y. Nurain Izzati, S. Shahiron, A. Sallehuddin Shah, O. Mohamad Hairi, A. Mohd Sufyan, A. J. Mohamad Luthfi, J. Zalipah, W. A. Mohamad Nor Akasyah, and K. Nurul Amirah, "Strength and water absorption properties of lightweight concrete brick containing expanded polystyrene and palm oil fuel ash," *IOP Conference Series: Materials Science and Engineering*, vol. 513, no. 1, 2019.

[21] *BS EN 12390-7*, "Testing Hardened Concrete. Density of Hardened Concrete," British Standard, 2009.

[22] *BS EN 771-1:2011*, "Method of Test for Masonry Units: Determination of Compressive Strength," London: British Standard, pp. 1–61, 2011.

[23] *BS 1881: Part 122*, "Method of Determination of Water Absorption," British Standard, 1983.

[24] A. A. Kadir and N. A. Sarani, "Utilisation of palm oil fuel ash in brick manufacturing for lightweight fired clay brick production," *International Journal of Sustainable Construction Engineering and Technology*, vol. 11, no. 1, pp. 136–150, 2020.

[25] T. K. Loong, S. Shahiron, A. M. Adib Fikri, K. Faisal Sheikh, M. Z. Sharifah Salwa, A. R. Mustaqqim, W. I. Mohd Haziman, A. Suraya Hani, A. M. Mustafa Juma, and M. A. Mohamad Azim, "Sound absorption for concrete containing polyethylene terephthalate waste," *Journal of Critical Reviews*, vol. 7, no. 8, pp. 1379–1389, 2020.

[26] N. A. Kamarulzaman, S. H. Adnan, K. A. Mohd Sari, M. H. Osman, M. L. Ahmad Jeni, M. S. Abdullah, P. Ang Soon Ern, N. F. Yahya, N. I. M. Yassin, and M. N. A. Wahee Anuar, "Properties of cement brick containing expanded polystyrene beads (EPS) and palm oil fuel ash (POFA)," *Journal of Science and Technology*, vol. 10, no. 4, 2018.

[27] J. H. Ling, Y. T. Lim, W. K. Leong, E. Jusli, and H. T. Sia, "Properties of cement brick with partial replacement of sand and cement with oil palm empty fruit bunches and silica fume," *Journal of the Civil Engineering Forum*, vol. 5, no. 3, pp. 289, 2019.

[28] N. M. Rangkuti and N. Siregar, "Coconut fiber usage for the compressive strength brick materials," *International Journal of Civil Engineering, Construction and Estate Management*, vol. 8, no. 1, pp. 12–19, 2020.

[29] S. M. S. Kazmi, M. J. Munir, S. Abbas, M. A. Saleem, A. Khitab, and M. Rizwan, "Development of lighter and eco-friendly burnt clay bricks incorporating sugarcane bagasse ash," *Pakistan Journal of Engineering and Applied Sciences*, vol. 21, 2017.

[30] J. Alex, J. Dhanalakshmi, and B. Ambedkar, "Experimental investigation on rice husk ash as cement replacement on concrete production," *Construction and Building Materials*, vol. 127, pp. 353–362, 2016.

[31] M. Ali, M. S. Fadzil, and S. A. Saad, "Effect of rice husk ash (RHA) on physical property and mechanical strength of concrete," *Advanced Materials Research*, vol. 1115, pp. 150-155, 2015.

[32] IS 1077:1992, Bureau of Indian Standard (BIS), 1992.

[33] I. Abdul Hadi Izaan, A. Suraya Hani, A. W. Norhayati, O. Mohamad Hairi, J. Zalipah, A. H. Noor Azlina, S. Norhafizah, and Mia Wimala, "Preliminary study of sago fine waste as a sand replacement material for cement brick," *IOP Conference Series: Earth and Environmental Science*, vol. 1022, no. 1, 2022.