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Transformation of Physical Characteristics in Fired Clay Bricks by Adopting Waste-based Fluxing Agent

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ABSTRACT

The current practices in the recent development of fired clay brick (FCB) by adopting waste materials have tremendously reduced the usage of the primary source of FCB, which is clay soil (CS). In this study, the main objective is to reduce the utilisation of CS as the main component in the FCB-making process. Other waste materials such as soda lime silica (SLS) glass bottles, and sea shells (SS) were also added into the precursor admixtures. The admixtures containing CS, SLS and SS were mixed according to the empirical formula of (1-x)[40SLS - 60CS]: x[SS] = 0, 10, 20, 30, 40 wt.%. A batch of 40 g mixture was prepared, and 21% water was added. The admixtures were mixed, moulded into a rectangular brick shape, and dried before the sintering process at 850 °C. The physical properties of the FCB were investigated as a function of the SS content in the form of apparent density, linear shrinkage, loss of ignition and plasticity. As a result, the apparent density and loss of ignition of the FCB increased from 1.91 gcm^{-3} to 2.31 gcm^{-3} and 10.60 % to 20.81%, respectively. The linear shrinkage and plasticity percentage decreased from 2.50% to 2.27% and 11.01% to 8.70% with an increase of SS content. This study has uncovered the above findings, and has demonstrated a promising discovery of the SS as a possible substitute in FCB.

Keywords: *fired clay brick, clay soil, waste materials, soda lime silica glass, sea shell*

1. INTRODUCTION

As one of the earliest artificial building materials created by humans, FCBs have shown to be simple to make, resilient, and long-lasting, as evidenced by numerous examples found worldwide – having withstood centuries of harsh climatic conditions and wars. FCBs are a common building material used all over the world. However, as the market for FCB continues to grow, the non-renewable resource of clay soil is increasingly used [1]. Moreover, the making of bricks through firing has the drawback of significant energy consumption that results in alternative brick-making methods to conserve energy. Alternative brick-making techniques are developed for an improved energy saving, since firing bricks consume too much energy [2].

Nowadays, many researchers have looked into using waste materials to make bricks in the interest of environmental protection, and a sustainable development [3]-[4]. The use of waste materials will economically and environmentally help reduce the cost of disposals in landfill sites [5]. According to the statistics disclosed by the Ministry of Housing and Local Government (MHLG, 2000), high-income districts like Petaling Jaya and Kuala Lumpur

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produce an average quantity of organic garbage of almost 48.32 %. Paper (23.56 %), plastic and rubber (9.57 %), metal (59.30 %), wood (4.82 %), glass and ceramics (4.0 3%), and textiles (3.97 %) are the other waste materials [6].

A previous study on the use of recycled paper in making bricks resulted in a decreasing density of bricks, down to 1.28 g cm^{-3} [7]. This research will focus on making FCBs from Malaysia's most prevalent waste materials that are soda lime silica glass, and seashells. In Malaysia, seashells (SS) are widely available as a by-product of the seafood industry [8]. Other than that, seashells can also easily found around the Malaysian beach. Across the world, 45,000 tonnes of trash seashells are produced annually [9]. Clay and water are combined to create FCBs. Their strength and durability have also grown, thanks to the evolution of hardening techniques from sun drying to industrial ovens. While insufficient raw materials and usage contamination initially reduced the longevity of FCBs, today's urban pollution and improper material use promote an even more rapid deterioration of existing bricks, adding to the general lack of maintenance, as seen in most buildings.

Nevertheless, only by understanding how bricks deteriorate, it is a series of methods and materials established for the repair of these bricks, and extending their life expectancy. Most of the bricks are placed at disposal sites to naturally deteriorate as it is hard to dispose of, due to their chemically stable properties. Thus, the improper disposals of FCBs have led to severe environmental problems such as land occupancy and greenhouse effects. Studies on using clay soil as a partial sand replacement in the production of concrete, and as a replacement for cement, and filler concrete, found an increase in material strength. However, several studies are still conducted to prove the use of waste materials as a replacement for clay soil in manufacturing FCBs made from burned industrial waste. Water, quartz sand, and clay soil must be combined to create standard FCBs [5]. The drying process will then begin, typically taking more than 5 to 7 days of exposure to sunlight for a complete drying. This prolonged drying process aims to prevent the FCBs from breaking because of a quick cooling path. After that, the dry brick was put in a kiln to be fired at a temperature of up to 1200°C. The traditional method of creating FCBs will take nearly a full day, while modern technology only needs around 2 to 5 hours to complete the firing process in an electrically powered environment [5]. It takes a lot of time and efforts to make the FCBs using the lengthy process. Glass was added into the mixture to lower the firing temperature. In this study, the utilization of soda lime glass and seashell powder was applied as an alternative method to minimize the highlighted issues. The purpose of this study is to determine the suitability of seashells as a partial substitute of clay, its impact on physical properties, and to introduce the usage of seafood industrial waste materials with green environment.

2.0 MATERIALS AND METHOD

In this study, the experimental work was divided into three parts: (1) the preparation of raw materials, (2) the preparation of Fired Clay Bricks (FCB), and (3) the testing of methods for the physical properties of FCB.

2.1 Raw Materials

The raw materials used in this study were water, seashells (SS), soda lime silica glass (SLS), and clay soil (CS). The clay soil was obtained from Xtream Craft Deco N Pottery, Kuala Kangsar, Perak. The seashells were obtained and collected from a beach in Dungun,

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Terengganu. They were later washed with tap water thrice to remove the dirt, and sun-dried for 1 day to prevent moisture. Next, the seashells were grinded using a heavy-duty blender and sieved using a 2 mm sieve. The soda lime silica glass (SLS) was acquired from used glass bottles. It was then washed with tap water thrice to remove the dirt, and ultimately with distilled water for a complete cleanliness. Next, the glass bottles were placed in an electric oven for the drying process at 82.8 °C for 30 minutes. The dried glass bottles were crushed and grounded using a heavy-duty blender, and sieved using a 2 mm sieve.

2.2 FCB Preparation

The granulated powder mixtures were mixed into homogenous state. Then, they were poured into a rectangular mould with the size of 222 mm x 106 mm x 73 mm (length x width x height). It is suggested that a standard brick size with the ratio of 2:1 is used, for length to width and 3:1 for length to height [10]. In this study, six series of bricks were cast with 74 mm x 30 mm x 24.3 mm dimensions and in different SS ratio from 0 to 40% with a step of 10 %. The admixture of the clay soil (CS), soda lime silica glass (SLS) and seashells (SS) uses the empirical formula of (1-*x*) [40 SLS - 60 CS] where *x* (SS) = 0, 10, 20, 30, 40. A batch of 40 g mixture was prepared, and 21 % water was added. The mixed design ratio of seashell bricks can be seen in Table 1. The mixture was poured into the mould and dried at room temperature for 48 hours. Next, the samples were dried at 45°C for 1 hour in an electric oven. The dried samples were fired in a laboratory electrical furnace at the rate of 6 °C/min until 850 °C, and held for 1 hour. The physical analysis was conducted on the fired bricks' apparent density, linear shrinkage, loss of ignition, and plasticity. Figure 1 shows the experimental flowchart.

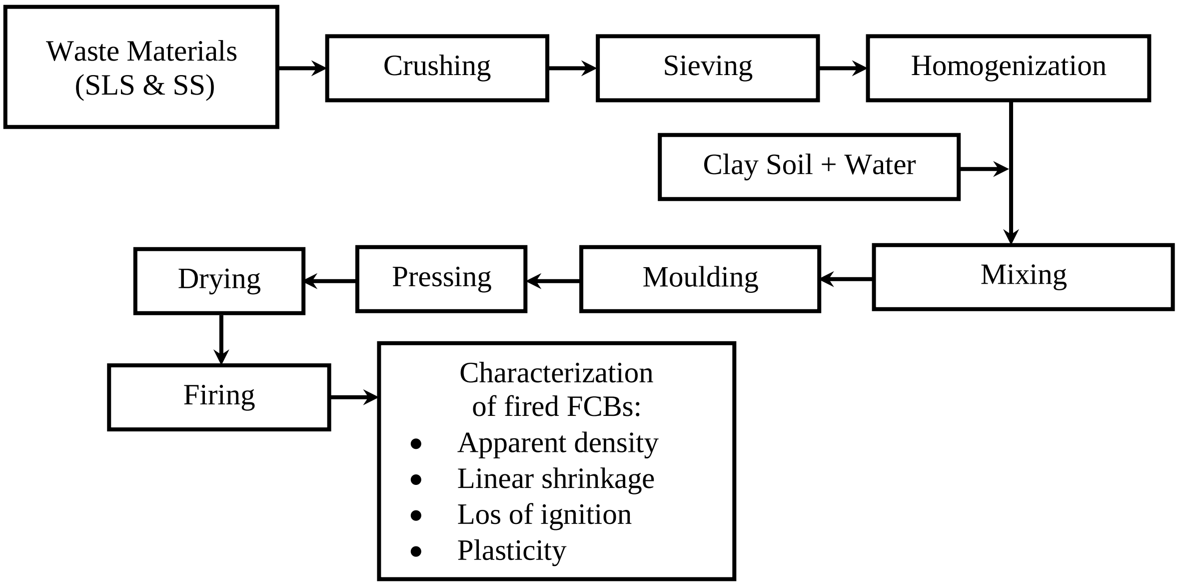

Figure 1: Preparation sample flowchart.

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Table 1: Mixed design ratio of seashell FCB.

Sample No.	CS (wt.%)	SLS (wt.%)	SS (wt.%)
S1	100	0	0
S2	60	40	0
S3	60	40	10
S4	60	40	20
S5	60	40	30
S6	60	40	40

2.3 Testing Method for physical properties

The apparent density test, linear shrinkage test, loss of ignition, and plasticity test were conducted.

2.3.1 Apparent Density Test

This analysis concerns the physical behaviors of bricks containing different percentages of SS in samples S1, S2, S3, S4, S5, and S6. Thus, this analysis was done by applying Archimedes' principle to analyze the effect of the incorporated SS on the density of FCB. The value of density, ρ, can be identified and interpreted according to the formula in the equation below [8]:

$$\rho = \frac{m_{dry}}{m_{air} - m_{water}} \times \rho_{water} \tag{1}$$

Where m_{dry} is the mass of dried FCB, m_{air} is the mass of water-saturated FCB, m_{water} is the mass of FCB in water, and ρ_{water} is the density of distilled water.

2.3.2 Linear Shrinkage

Linear shrinkage is the changes in the dimension of FCB in terms of length before and after the sintering process. It is the decrease in the sample length during the oven drying of soil sample with moisture content at the liquid limit. The linear shrinkage, *LS*, can be calculated using the formula [11]:

$$LS = \frac{l_0 - l_1}{l_0} \times 100\% \tag{2}$$

Where, l_o is the initial length , l_1 is the final length in cm.

2.3.3 Loss of Ignition

This method estimates soil organic matter based on gravimetric weight change associated with high-temperature oxidation of organic matter. Loss of ignition measures the weight change of a sample after it has been heated to a higher temperature. After the initial oven drying at 45 °C, the samples are ignited in a laboratory furnace for 1 hour at 850 °C. The calculation of loss of ignition, *LOI*, is based on the following formula:

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$$LOI = \frac{m_d - m_f}{m_d} \times 100\% \quad (3)$$

Where m_d is the mass oven-dried specimens and m_f is the mass of sintered specimen.

2.3.4 Plasticity

Plasticity is defined as the ability of the bricks to flow or to change shape permanently when subjected to stresses of intermediate magnitude between those producing temporary deformation. An equation for calculating plasticity is as follows:

$$PL = \frac{m_w - m_d}{m_d} \times 100\% \quad (4)$$

Where m_w is the wet state weight of the sample and m_d is the mass of oven dried specimens.

3. RESULTS AND DISCUSSION

3.1 Apparent Density

Table 2 presents the results obtained from the apparent density test of each sample. The apparent density for each sample is represented graphically in Figure 2. It can be seen that the apparent density increases from 1.912 g cm^{-3} to 2.306 g cm^{-3} with the increasing percentage of SS addition into the FCBs. It was suggested that the increase in apparent density is due to the increase of waste material (SS) content in FCBs. The apparent density increases when the glass content (waste material) increases from 30 wt.% to 45 wt.% [12]. However, the apparent density in sample 1 cannot be calculated since the FCBs were totally broken. The breaking of FCBs in sample 1 that only contained clay soil happened due to the absence of a binder between the clay soil and other components – making them becoming more brittle, and easy to break. Thus, the composition of 40 wt% of SLS as the binder in FCBs is the best composition.

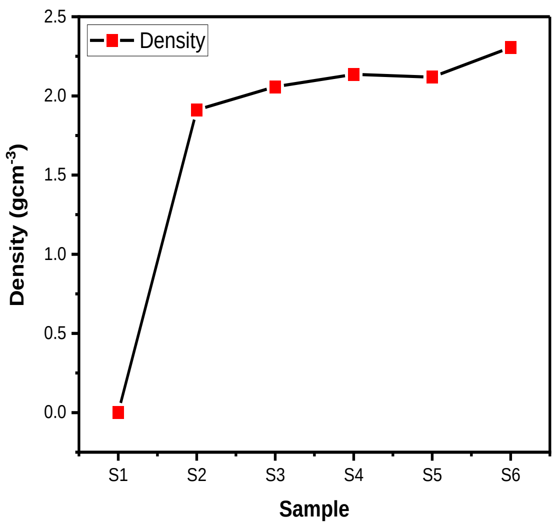

Figure 2: Apparent Density of FCBs with different wt.% of SS.

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Table 2: Apparent density, linear shrinkage, loss of ignition and plasticity of FCBs.

Properties	Sample of FCBs					
	S1	S2	S3	S4	S5	S6
Apparent density (g cm^{-3})	Totally broken	1.91	2.06	2.14	2.12	2.31
Linear Shrinkage (%)	Totally broken	2.50	2.44	2.38	2.33	2.27
Loss of Ignition (%)	40.68	10.60	16.73	19.01	20.67	20.81
Plasticity (%)	11.01	10.34	9.84	9.96	9.64	8.70

3.2 Linear Shrinkage

The linear shrinkage percentage of different percentage composition of FCBs from CS and SLS **doped** SS is shown in Figure 3. The linear shrinkage indicates how effectively the clay samples were fired. Sample 2 which contained CS and SLS has the highest percentage of linear shrinkage of 2.50 %, compared to the other samples. A higher linear shrinkage will increase the risk of crack appearances, and dimensional defects on the fired bricks, where it was observed that after firing them at 850 °C, no original bricks survived without cracking [13]. Sample 1 proves this matter since the brick that only contained CS became totally broken after firing. However, it was supported that the addition of waste material will decrease the linear shrinkage [12]. This can be seen in Figure 4, as the percentage of SS was increased, the linear shrinkage decreased from 2.44 % in sample 3, to 2.27 % in sample 6.

This could be due to the expansion of the ceramic body during the firing stage. This is also due to the burning of the organic matter inside, that eventually caused the expansion. Therefore, the higher the organic content of SS in the samples, the higher the expansion in the ceramic mass, which in turn causes the lower shrinkage [14].

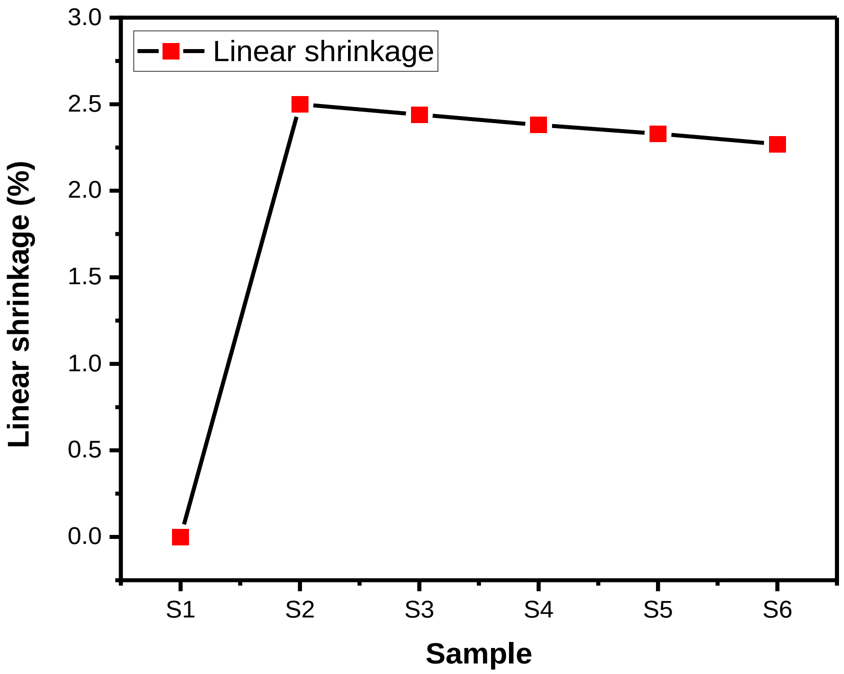

Figure 3: LS of FCBs incorporated with different wt.% of SS.

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3.3 Loss of Ignition

Based on Figure 4, the highest loss of ignition is in sample 1, that only contained CS at 40.68 %. When SLS was introduced to the FCBs in sample 2, the loss of ignition dropped drastically to 10.60 %. However, this value increased when SS was added into the FCBs as a fluxing agent. The loss of ignition started to increase from 10.60 % to 16.73 % when 10 wt. % of SS was added in sample 3. This value keeps going up in samples 4, 5, and 6 at 19.01%, 20.67 % and 20.81 % respectively. This suggested that by the increasing the fluxing agent, the loss of ignition will also increase [7]. It also suggested that by increasing the content of the fluxing agent, the SS will produce a high content of calcite ($CaCO_3$) resulting in a highly porous structure because of the decomposition of calcite ($CaCO_3$) into CaO, which releases CO_2. This is due to the fact that the CaO is highly reactive and can readily react with different materials in the structure. The combustion of SS with the release of CO_2 creates pores which enhances the loss of ignition, that means the loss of weight in the FCBs after they have been heated, leading to the production of higher quality FCBs [15].

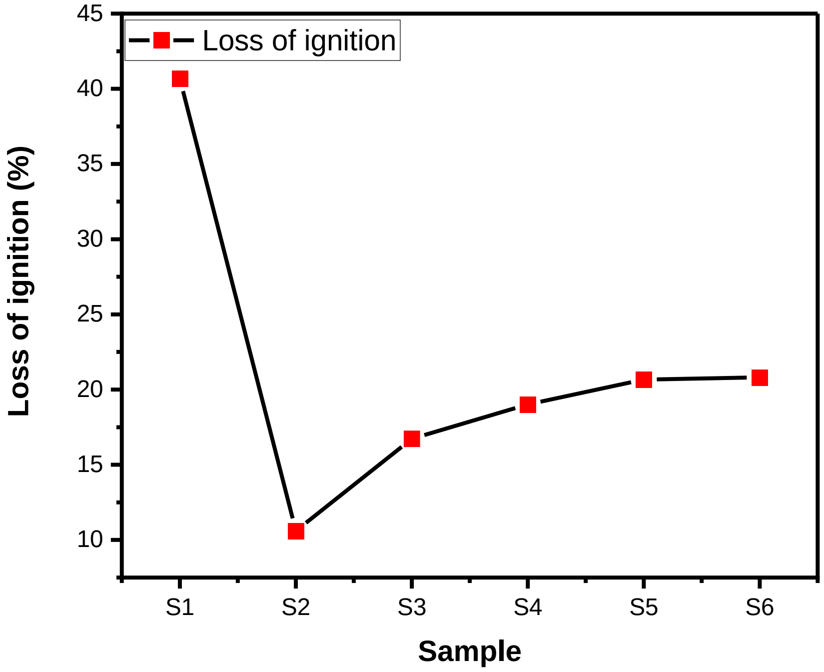

Figure 4: Loss of ignition of FCBs with different wt.% of SS.

3.4 Plasticity

As shown in Figure 5, the percentage of plasticity in general decreased from 11.01% to 8.7% as the wt.% of SS increased from 0 wt.% to 40 wt.%. Sample 1 had the highest percentage of plasticity at 11.01%, only contained CS. When SLS and SS were introduced into the FCBs in samples 2 and 3, the percentage of plasticity decreased from 10.34% to 9.84%. However, the percentage of plasticity increased slightly to 9.96% in sample 4. Again, the percentage of the plasticity decreased from 9.64% to 8.7% in samples 5 and 6 respectively. It was much related to the apparent density of the bricks. When the percentage of plasticity is decreased, the apparent density is increased. The apparent density of FCBs is inversely proportional to the plasticity properties [16]. As a result, the FCBs which contained SS powder become denser

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with the increasing SS powder content. Nevertheless, the plasticity decreased due to the higher SS powder content that leads to a higher ability of FCBs to undergo a permanent deformation.

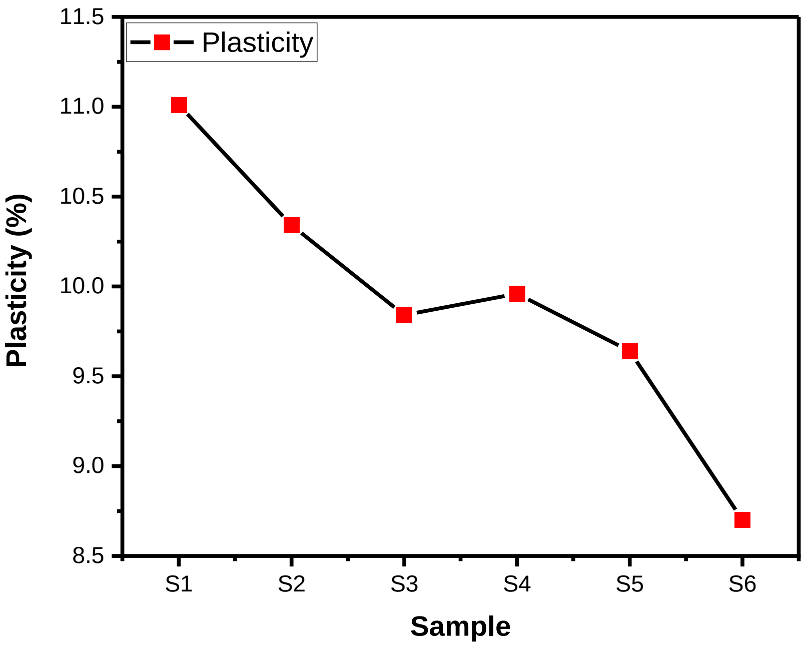

Figure 5: Plasticity of FCBs with different wt.% of SS.

3. CONCLUSION

Based on the results of this study, the FCBs were successfully fabricated with the incorporation of waste materials as the precursors. SLS glass bottles and SS can be mixed with clay in different proportions to prepare good quality bricks. The results showed that with a proper firing temperature at 850°C, sea shells addition up to 40 wt.% did not harmfully influence the properties of the FCBs, and it was able to meet the minimum requirements in a wide range of applications. The apparent density and loss of ignition of the FCBs increased as the sea shells content increased. However, the percentage of linear shrinkage and plasticity decreased when the content of sea shells increased. It can be concluded that the SS powder is compatible to be used as a constituent component in FCBs. Overall, S6 resulted the highest density, loss of ignition, and low linear shrinkage and plasticity. The addition of 40 wt% of SS is suitable to improve the properties of FCBs, thus suggesting it being the optimum percentage that is suitable to be used in the design of FCBs.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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REFERENCES

[1] I. Labaied, O. Douzane, M. Lajili, and G. Promis, "Bricks Using Clay Mixed with Powder and Ashes from Lignocellulosic Biomass: A Review," *Appl. Sci.*, vol. 12, no. 20, 2022, doi: 10.3390/app122010669.
[2] L. Zhang, "Production of bricks from waste materials - A review," *Constr. Build. Mater.*, vol. 47, pp. 643–655, 2013, doi: 10.1016/j.conbuildmat.2013.05.043.
[3] "Yongliang_2011_Preparation of eco-friendly construction bricks from hematite tailings.pdf." .
[4] "Lingling, 2005_Study on fired bricks with replacing.pdf." .
[5] P. Muñoz Velasco, M. P. Morales Ortíz, M. A. Mendívil Giró, and L. Muñoz Velasco, "Erratum: Fired clay bricks manufactured by adding wastes as sustainable construction material - A review," *Constr. Build. Mater.*, vol. 68, p. 783, 2014, doi: 10.1016/j.conbuildmat.2014.06.023.
[6] M. A. A. Samah, L. A. Manaf, A. Ahsan, W. N. A. Sulaiman, P. Agamuthu, and J. L. D'Silva, "Household solid waste composition in Balakong City, Malaysia: Trend and management," *Polish J. Environ. Stud.*, vol. 22, no. 6, pp. 1807–1816, 2013.
[7] M. Sutcu and S. Akkurt, "The use of recycled paper processing residues in making porous brick with reduced thermal conductivity," *Ceram. Int.*, vol. 35, no. 7, pp. 2625–2631, 2009, doi: 10.1016/j.ceramint.2009.02.027.
[8] M. S. Sainudin, N. H. Othman, N. N. Ismail, M. H. Wan Ibrahim, and M. A. Rahim, "Utilization of Cockle Shell (Anadara granosa) Powder as Partial Replacement of Fine Aggregates in Cement Brick," *Int. J. Integr. Eng.*, vol. 12, no. 9, pp. 161–168, 2020, doi: 10.30880/ijie.2020.12.09.019.
[9] B. A. Tayeh *et al.*, "Durability and mechanical properties of seashell partially-replaced cement," *J. Build. Eng.*, vol. 31, no. March, p. 101328, 2020, doi: 10.1016/j.jobe.2020.101328.
[10] P. Rodney Fernando, "Mechanical and Physical Properties of Fired Clay Brick Partial Doped with Coconut Shell Ash," *J. Energy Nat. Resour.*, vol. 6, no. 5, p. 58, 2017, doi: 10.11648/j.jenr.20170605.11.
[11] Department of Sustainable Natural Resources, "Soil Survey Standard Test Method Linear Shrinkage," pp. 1–4, [Online]. Available: file:///R:/LITERATURE/Chris/10.1.1.164.7761.pdf.
[12] V. Loryuenyong, T. Panyachai, K. Kaewsimork, and C. Siritai, "Effects of recycled glass substitution on the physical and mechanical properties of clay bricks," *Waste Manag.*, vol. 29, no. 10, pp. 2717–2721, 2009, doi: 10.1016/j.wasman.2009.05.015.
[13] R. A. A. Wahab *et al.*, "Physical properties of low energy consumption fired industrial waste-clay bricks from cockle shells and soda lime silica glass," *AIP Conf. Proc.*, vol. 2332, pp. 1–6, 2021, doi: 10.1063/5.0042888.
[14] A. Ukwatta, A. Mohajerani, N. Eshtiaghi, and S. Setunge, "Variation in physical and mechanical properties of fired-clay bricks incorporating ETP biosolids," *J. Clean. Prod.*, vol. 119, pp. 76–85, 2015, doi: 10.1016/j.jclepro.2016.01.094.
[15] A. N. Raut and C. P. Gomez, "Utilization of waste as a constituent ingredient for enhancing thermal performance of bricks - A Review paper," *Indian J. Sci. Technol.*, vol. 9, no. 37, 2016, doi: 10.17485/ijst/2016/v9i37/87082.
[16] L. Aouba, C. Bories, M. Coutand, B. Perrin, and H. Lemercier, "Properties of fired clay bricks with incorporated biomasses: Cases of Olive Stone Flour and Wheat Straw residues," *Constr. Build. Mater.*, vol. 102, pp. 7–13, 2016, doi: 10.1016/j.conbuildmat.2015.10.040.

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