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Physical and Mechanical Properties of Fired Industrial Waste-Clay Brick from Sugarcane Bagasse

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Abstract
Fired industrial clay brick depletes clay soil, wastes energy and wastes money. Population growth has increased agricultural waste. Many studies have been conducted on the production of fired industrial waste clay brick from sugarcane bagasse ash. This research reviews the physical and mechanical properties of sugarcane bagasse fired industrial waste clay brick. Fired industrial waste clay brick- filled with sugarcane bagasse ash provide better mechanical and physical properties than normal fired bricks. Reduce clay soil mining, agricultural waste, and fired industrial bricks reduces energy and costs. This supports sustainable development and helps the environment (SDG).

Keywords: Sugar cane bagasse, Fired industrial clay brick

1.0 Introduction

As the world's population grows, so does the demand for products, which leads to an increase in waste. Conventional disposal methods such as feeding animals or composting are not sufficient for rapid decomposition, so the waste accumulates. This ecological challenge calls for innovative solutions.

1.1 Problem Statement

In Malaysia, 1.2 million tons of agricultural waste is dumped in landfills every year, which is an example of a broader problem of inefficient waste management. This not only puts a strain on landfill capacity, but also overlooks the opportunities for recycling and reusing waste materials. Researchers are exploring the use of waste materials as substitutes in various applications. Rabiatul (2021) suggests using waste as an alternative to clay soil in brick manufacturing. Such processes can reduce landfill costs and promote a healthier environment (Carlos, 2014; Velasco, 2014). Agamuthu (2009) points out the large amount of agricultural waste that represents a potential for reuse. In addition, Rabiatul (2021) reports that the incorporation of agricultural waste such as sugarcane bagasse and rice husks into fired clay bricks (FCB) improves their properties such as porosity and strength, showing a promising direction for waste management and material innovation.

1.2 Fired Clay Brick

Fired clay brick (FCB) has developed exponentially over time. In construction, FCB is used for its unique properties such as strength, durability, dimensional stability, longevity, fire and weather resistance (Brick Industry Association, 2006). Conventional clay brick has been used as a construction material since 8000 BC, and over the years it has been used to construct buildings, bridges, etc. (Kazmi, 2016). In Malaysia, most of the buildings were constructed with FCB, and it was predicted that the infrastructure development would grow to RM 64.4 trillion by 2030 (Yahaya, 2019). In addition, it was found that 65% of the world's bricks are used for residential buildings, while commercial, industrial, and institutional buildings account for the rest (Ashiq, 2019). FCB spending will increase over time. Through the life cycle assessment, it is found that traditional bricks have a higher impact on climate change (100%), human toxicity (75%), and freshwater ecotoxicity (75%) when using the ReCiPe midpoint method (Huarachi, 2020). The main processes used to extract FCB are mining, storage, firing, and transportation (Brick Industry Association, 2006). This process has significant impacts on carbon footprint, high energy consumption, mineral mining, and destruction of the surrounding environment (Atmodiwirjio, 2018).

This review focuses on sugarcane bagasse ash. Sugarcane bagasse is a biomass produced during the purification, processing, and extraction of sugarcane juice (Rabelo, 2015). Sugarcane bagasse is used because the waste is considered a non-biodegradable solid waste material. The global sugar cultivation area is about 31.3 million hectares. In Brazil, the sugarcane industry generates up to 2.5 million tons annually (Faria, 2012). The ash produced from the combustion of sugarcane bagasse is called sugarcane bagasse ash (SBA), which contains two main components: Silicon and aluminum oxides, which can be used in brick production (Kazmi, 2016). Research shows that SBA does not contain minerals or nutrients that can be used as fertilizers; instead, it contains silica, aluminum, and other metal elements, which makes SBA a pozzolanic material (aluminous materials for cement). Therefore, SBA has properties such as reducing hydration heating, improving durability of concrete, and improving wettability by incorporating SBA into building material (clay for brick) (Xu, 2018).

2.0 Issues faced with fired clay brick

Fired clay bricks contain two main components, silica and alumina. Due to these ingredients, fired clay brick is able to withstand high temperatures. Some applications of fired clay brick include use as inner lining of kilns, furnaces, and , construction of fireproof structures, and use as inner lining of wood-fired stoves (Ahimbisibwe, 2016). Some constituents of fired clay brick made it temperature resistant. These constituents are silica (SiO2), alumina (Al2O3), iron oxide (Fe3O4), limestone and other calcareous rocks. SiO2 is abundant in fired clay brick, making it capable of resisting head. Varnagiris et al. (2017) found that when SiO2 films were used as coating material, the results were obtained by scanning electron microscopy, energy dispersive X-ray spectroscopy, and X-ray photoelectron spectroscopy analysis. The result shows that SiO2 is an excellent heat resistant material. Therefore, fired clay brick contained abundant SiO2, and SiO2 has excellent heat resistance, which makes fired clay brick suitable for high temperature applications.

The use of clay as a building block material leads to the depletion of clay resources because it is a non-renewable resource that takes thousands of years to produce. Therefore, the extensive use of natural clay resources for brick production has led to an alarming deficit of clay raw material, which may cause the destruction of clay bricks and other environmental problems associated with clay mining (Kazmi, 2016 & Huarache, 2020).

The second problem is that the traditional fired clay brick is time-consuming, costly and requires high energy consumption (Wahab, 2021). This is because the process requires 2-7 days of washing and 24 hours of firing at a temperature of 1200° C. This process is not suitable for mass production because the use of energy, labour and time deliberately increases the total cost of producing clay bricks.

In addition, the use of agricultural waste is required to reduce the overall energy consumption and the firing temperature of conventional FCB (Wahab, 2021). To achieve this, two problematic agricultural wastes are used. The first is sugarcane bagasse ash. The problem with sugarcane bagasse is that it is a non-biodegradable waste (Faria, 2012). In China, over 1.25 million tons of SBA is produced annually, most of which ends up in landfills; the ash cannot be used as fertilizer because SBA has low mineral content (Xu, 2018). Thus, the problem arises when the number of sugarcane bagasse increases, which leads to an increase in solid waste material, causing many environmental impacts and pollution.

Fired clay bricks have been used since 8000 BC, and mining is required to obtain the raw material, clay. Fired clay bricks are used for building construction, and the increase in human population led to an increase in demand for burnt clay bricks to meet supply and demand. An increase in demand leads to an increase in the mining of clay soil. Clay soil is a non-renewable source. The production of clay bricks requires a significant amount of energy, resulting in high carbon emissions and global warming (Rabiatul 2021 & Huarachi 2020). These two disadvantages, the reduction of clay soil and the energy consumption of the manufacturing process, have made fired clay bricks an unfavourable building material in today's era of green technology. The cost of using 100% coal (standard energy) for 1000 bricks is about 2780 rupees or RM 61.23 (Nawab et al., 2016). However, blending other materials to the fired brick could significantly reduce the overall energy consumption and help to reduce the mining of alumina. There are many ways to solve the problem of energy consumption and clay degradation and reduce the cost of producing fired clay brick. One of these ways is the admixture of agricultural wastes to the brick (Rabiatul, 2021).

Jamal et al (2022) investigated the production of innovative eco-efficient composite bricks based on low zeolite rock and chicken meat. Their research showed that the samples had high compressive strength, lower density, and better thermal conductivity compared to the standard for load-bearing ceramic bricks. In addition, Faria et al. (2012) found a similar result for different types of waste materials: sugarcane bagasse ash. Their research found that sugarcane bagasse ash can be used as a filler in bricks, increasing the possibility of sustainable reuse. A similar research objective was pursued by Rabiatul et al. (2021) looking at the physical and mechanical properties of low-consumption burnt industrial waste bricks made from cockle shell and soda-lime glass. Their research showed that the best reduction in bulk density, linear shrinkage, and water absorption rate was achieved by firing at a temperature of 900°C, adding soda-lime-silica glass of 50%, and cockle shells of 0.05%. From this, it can be seen that the use of waste material with clay soil can significantly counteract the disadvantages of fired clay brick.

Despite the progress made in incorporating various waste materials for sustainable brick production, there is still a significant research gap in terms of fully understanding and optimizing the use of non-traditional, environmentally friendly constituents to efficiently replace conventional clay in brick production while maintaining or improving functional properties.

2.1 Engineering properties of fired clay brick

Compressive strength testing is required to determine the durability of bricks in construction. Compression moulding and hydraulic pressure are some of the most commonly used machines to determine the compressive strength of a specimen (Yap, 2010). The addition of other materials, such as agricultural wastes, has a significant effect on improving the clay soil structure. Table 1 below shows the standard for compressive strength based on BS 3921:1985, with a reference value of 5 N/mm2 for other brick types (British Standard, 1995).

Brick is a ceramic material with a fine-pored structure that can absorb water. The absorption of water is an indicator of the durability of bricks. Based on the water absorption capacity, we can study the effects of weathering and moisture on the brick. Table 2 shows the standard for water absorption according to BS 3921:1985, which uses other brick types as a reference value without a limit, but was set at a maximum value of 15% based on MS76:1972 Part 2 (British Standard, 1995).

2.2 Sugarcane bagasse

Table 3. XRF result of SCBA at different temperature conditions (Gupta et al., 2021)

Chemical composition	Calcination temperature				
	400 °C	500 °C	600 °C	700 °C	800 °C
1. CaO	20.33	15.80	10.44	3.32	3.35
2. SiO_2	25.32	56.30	64.62	85.32	86.98
3. Al_2O_3	15.32	7.30	4.28	5.33	5.32
4. Fe_2O_3	5.33	7.70	5.30	1.38	3.58
5. MgO	0.32	1.98	3.03	0.48	0.89
6. TiO_2	0.38	0.54	0.43	0.28	0.54
7. P_2O_5	1.32	1.52	0.89	0.56	1.28
8. Na_2O	2.12	0.46	0.48	1.30	0.38
9. K_2O	2.42	3.33	1.25	1.20	1.40
10. MnO	1.43	0.31	0.20	0.47	0.72
11. LOI	17.9	5.23	5.03	3.50	2.30

(Gupta et al., 2021)

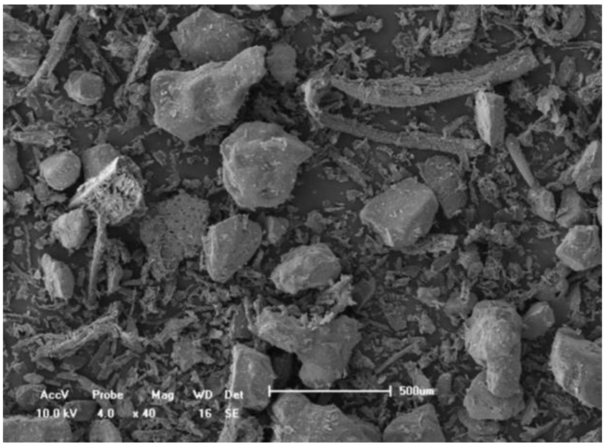

Fig. 1: Morphology of the sugarcane bagasse ash waste powder particle
(Faria et al., 2012)

Sugarcane bagasse is a solid waste material. Sugarcane bagasse is a byproduct of agro-industry, produced in sugar factories after the extraction of sugar and alcohol. Sugarcane bagasse ash is a waste material with high reactivity to lime and cement. Some studies show a significant improvement in the mechanical properties and durability of cement-based engines to which motor that has been incorporated with sugarcane bagasse ash has been added (Gupta, 2021). In countries such as Brazil, sugarcane is used to produce 34.6 million tons of sugar and 25.8 billion liters of ethanol. This increase in the number of sugarcane extracts leads to an increase in sugarcane bagasse ash. In Brazil, more than 2.5 million tons of sugarcane bagasse ash are disposed annually (Faria et al., 2012). Therefore, over time, increasing demand for sugarcane will increase solid waste production and lead to excess sugarcane bagasse fibre

or ash in landfills. Since it takes years for sugarcane bagasse to decompose, another method has been found to use sugarcane bagasse ash in engineering production, such as engineered cementitious composite (Muhammad et al., 2020) and for the production of sustainable bricks (Micheal, 2022). According to Faria et al. (2012), X-ray diffraction of sugarcane bagasse ash revealed the following chemical composition: Quartz (SiO2), cristobalite (SiO2), potassium carbonate (K2CO3), hydrated calcium phosphate (Ca3(PO4)2.H2O), primary mullite (3Al2O3.2SiO2), and hematite (F2O3), with quartz predominating. In addition, the results of Gupta et al. (2021) show that the composition collected by Faria et al. (2012) is similar, and Gupta et al. (2021) uses X-ray fluorescence to determine the composition of sugarcane bagasse ash at different temperatures. The results can be seen in Table 3.
The microstructure of sugarcane bagasse ash can provide information on whether the material will have ductile or ceramic properties. Faria et al. (2012) discovered that the microstructure of sugarcane bagasse ash was rich in angular-shaped particles that were likely silica. It contained many long porous cylindrical plates of sugarcane bagasse that were not burned. They also conducted various tests to determine the plasticity of the material. However, in their tests, they found that sugarcane bagasse is classified as a non-plastic material. The microstructure of sugarcane bagasse determined by Faria et al. (2012) is shown in Figure 1.

2.4 Engineering properties of clay brick incorporated with sugarcane bagasse ash
Engineering properties of clay brick incorporated with sugarcane bagasse ash was added show that the brick has better mechanical and physical properties. Based on the research of Salim et al. (2014) to improve the bearing strength of brick made of compressed earth blocks of sandy loam soil using sugarcane bagasse ash, sugarcane bagasse ash was added to the sandy loam soil, which increased the compressive strength of the brick. Figure 2 shows the compressive strength of the compressed clay bricks at different percentages of sugarcane stabilization. The figure shows that the compressive strength increases with increasing sugarcane bagasse ash content. The addition of 10% sugarcane bagasse results in a compressive strength of 65%. The increase is due to progressive densification of the soil/sugarcane bagasse ash matrix due to hydration and pozzolanic reaction (reaction in which calcium hydroxide and silica react to enhanced material strength).
.Phonphuak et al. (2017) also researched the utilization of sugarcane bagasse ash to improve the properties of fired clay brick. Their finding found that an increase in firing temperature can increase the strength of the brick due to the decrease in porosity and increase in density. Moreover, ASTM C62-12a gives a grade molecular weight for brick with minimum compressive strength of 17.2 MPa. Phonphuak et al. (2017) found that the best power could be obtained with 2.5 % sugarcane bagasse ash fired at 1000 °C and 2.5, 5.0 and 7.5% sugarcane bagasse ash fired at 1100 °C.

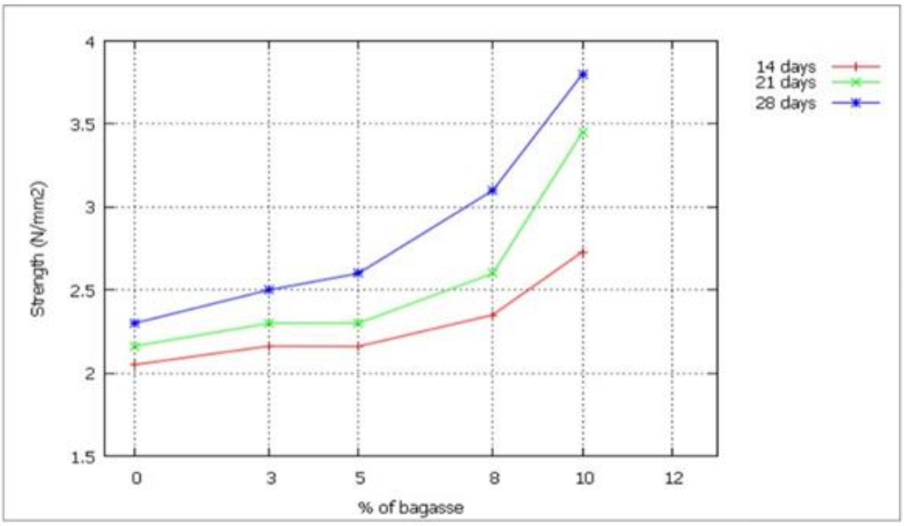

Fig. 2: Graph of compressive strength of compressed earth brick at different % of sugarcane stabilization
(Salim et al., 2014)

Table 1. Compressive strength requirement (BS 3921:1985) (British Standard, 1995).

Type of brick	Compressive strength (N/mm²)
Engineering A	> 70
Engineering B	> 50
Damp proof course 1	> 5
Damp proof course 2	> 5
Others	> 5

(BS 3921:1985) (British Standard, 1995)

Table 2. Water absorptivity requirement (BS 3921:1985) (British Standard, 1995).

Type of brick	Water absorptivity (% by mass)
Engineering A	≤ 4.5
Engineering B	≤ 7.5
Damp proof course 1	≤ 4.5

Damp proof course 2	≤ 7.0
Others	No limits

(BS 3921:1985) (British Standard, 1995)

2.5 Water absorptivity

Phonphuak et al. (2017) studied the water absorption capacity of sugarcane bagasse ash in fired clay brick. Their study found that the brick should be dense enough to reduce water absorption. Increasing the content of sugarcane bagasse ash shows that the water absorption capacity ranges from 13.1% to 22.7%. Phonphuak et al. (2017) concluded that the water absorption capacity of clay brick decreases as the sintering temperature increases, with the brick becoming more substantial, and they found that water absorption increases when 2.5% sugarcane bagasse ash is used for all firing temperatures. In addition, Faria et al. (2012) studied the recycling of sugarcane bagasse ash to produce clay bricks. They found that water absorption tends to increase from 22.88% to 25.66% with the addition of sugarcane bagasse. In addition, the composite has an acceptable absorptivity value for the clay brick industrial production. Figure 3 shows the relationship between the water absorption capacity and absorptivity with the percentage of clay brick formulations.

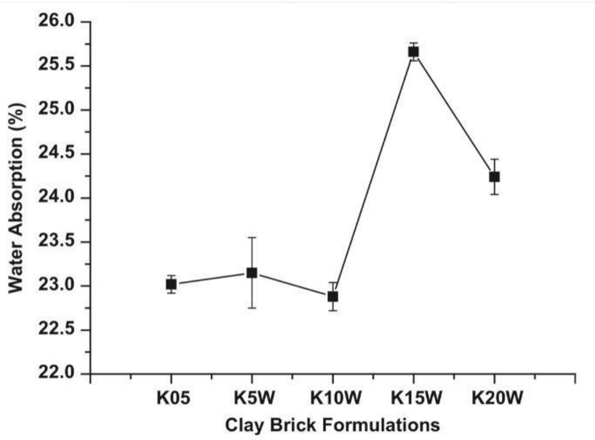

Fig. 3: Water absorption of the clay brick versus waste content
(Faria et al., 2012)

3.0 Conclusions

Our research points to significant problems with traditional fired brick production, such as excessive energy consumption, high costs and ecological damage due to the depletion of clay resources. The extraction of clay has a negative impact on ecosystems, which underlines the need for sustainable practices. We have found that the use of sugarcane bagasse ash, which is rich in silica, can effectively replace clay in brick production. The addition of calcium carbonate, derived from eggshells, to the clay mix also improves the mechanical and physical properties of the bricks. This innovative approach of adding sugar cane bagasse ash and eggshells to fired clay bricks not only improves their properties, but also reduces the cost and energy required for production. This strategy represents a viable, environmentally friendly alternative to conventional brick production and is an answer to the pressing environmental problems in the construction industry.

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Paper Contribution to Related Field of Study

The article is related to the theme of the conference held in the context of eco-products that use sugarcane bagasse to produce burnt industrial waste bricks. By using cockle shells, which are easy to find, pollution of the environment can be avoided. It also reduces the mining of alumina, agricultural waste, and the energy and cost of fired industrial bricks.

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