Recycling Sugarcane Bagasse Waste into Fired Clay Brick

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Abstract— One of the agricultural by-products that is abundantly available in Malaysia is sugarcane bagasse which is being used to generate energy at sugarcane mill. This presents an investigation on the potential of incorporating sugarcane bagasse into the production of fired clay brick. It focuses on feasibility study of using sugarcane bagasse in fired clay brick mixtures with a percentage replacement up to 3% by weight. Physical, mechanical and thermal properties of the brick were tested according to standard procedure. Results found that by adding 3% of sugarcane bagasse into the brick, it reduced the density up to 15%, which makes the brick lighter and this has the potential of producing lightweight fired brick. By adding the bagasse into the brick, it has improved the brick thermal conductivity properties by 8% and also reduced the energy consumption in firing the brick up to 40%. Even though by incorporating the bagasse has resulted to decrease the mechanical properties of the brick however the brick still comply with the minimum standard of compressive strength. In conclusion, the incorporation of sugarcane bagasse into the fired clay brick gives some advantages to the brick properties and also provides an alternative way of disposing the sugarcane bagasse waste.

Keywords—sugarcane bagasse, fired clay brick, physical and mechanical properties

I. INTRODUCTION

A. Background

Agricultural by-product, especially from oil palm, paddy, cocoa, rubber, pineapple and sugarcane are produced in large quantities in Malaysia. Sugarcane bagasse is a residue produced in large quantities by sugar industries. In general, 1 tonnes of sugarcane generate 280 kg of bagasse, the fibrous by-product remaining after extraction from sugarcane. About 54 million dry tonnes of bagasse are produced annually through the world (Sun et al., 2004). Sugarcane bagasse has a strong potential in displacing fossil fuels and can be extensively used in boilers, turbines and furnaces for power generation (Shaikh et al., 2009). Other applications of sugarcane bagasse are as sources of animal feed, energy, pulp, paper and boards (Banerjee & Pandey, 2002).

The amount of organic waste obtained from the agriculture industry is abundant in Malaysia but the utilization is still limited. Large amounts of untreated waste from agricultural and industrial sector contaminate land, water and air by means of leaching, dusting and volatilisation. According to (Mannan & Ganapathy, 2003), improper treatment of sugarcane bagasse also causes similar problems. The excess bagasse accumulation presents a waste problem for the sugar industry (Shaikh et al., 2009).

In the sugar industry, sugarcane bagasse is more related as the by-product in sugarcane mills. After the sugarcane is pressed to remove sucrose or known as table sugar, the residue is called as sugarcane bagasse which contains highly fibrous residue. After the sucrose removal, the bagasse is generated and its accumulation presents as a waste problem for the sugar industry. Requirement for economic and environmental friendly materials has extended an interest in natural fibers. From the previous researchers, many natural fibers material for example natural sugarcane bagasse has been successfully incorporated into fired clay brick. Therefore in this study, natural sugarcane bagasse has been utilized for similar studies.

Brick is one accommodating unit as a building material due to its properties. From the previous research, attempts to incorporate waste in the production of brick were shown by many researchers for example limestone powder waste dust (LPW) and wood sawdust (WSW), (Turgut & Algin, 2006) process waste tea (PWT), (Demir, 2005), incinerator fly ash sludge (MSWI) (Lin, 2006) and kraft pulp (Demir, 2005). The additional of these waste materials have proven that the waste incorporation is not just environmentally advantageous but it also increases the performance of brick properties. Moreover, in Malaysia, sugarcane wastes are typically used to generate energy in the sugarcane mill. However, the burning of bags will produce the gas which is carbon monoxide and methane that will cause air pollution and will affect the people. The incorporation of bagasse in fired clay bricks could be one of the alternatives to the burning process and cost effective way as the emission from the burning of bagasse would be filtered together with the gases emitted from the brick manufacturing process.

Therefore, this study investigated the incorporation of sugarcane bagasse (SB) in fired clay brick. The physical and mechanical properties of fired clay brick containing the SB were determined and discussed.

II. MATERIAL AND METHODS

A. Material

1) Clay Soil
The soil used in this study is clay soil, which is available at Yong Peng Batu Bata, Jalan Muar Batu 6, 83710 Parit Yaani, Johor. The soil was grinds to ensure no impurities in the sample.

2) Sugarcane Bagasse
The sugarcane bagasse was collected near Parit Raja, Batu Pahat. After the collection, the sugarcane bagasse was dried under the sun to ensure the bags completely dried for bagasse brick manufacturing.

3) Control Brick
The clay soil and water were mixed to produce the brick. The clay has been mixed using a Hobart mechanical mixer for 30 minutes. After the clay was mixed together, the clay was compacted into the mould. It consists of three layers with 100 times compaction for every layer. To ensure that the compaction rate is uniform the samples were compacted using hand operated soil compactor. Then, the compacted clay was removed from the mould by using the hand operated soil compactor. The sample was pressed into the moulds according to the required sizes. Raw bricks produced were dried in the oven before the firing process. This stage is very important because if the brick is fired in wet condition, it will affect the perfection of the brick due to cracking, bending or splitting that will make it not suitable to be used for construction building. Therefore, the brick was dried in the oven with 105°C for 24 hours. By using the heating rate of 1°C/min, the bricks were fired in the furnace. The fired brick was tested for dry shrinkage, dry density, initial rate of absorption, thermal conductivity, and compressive strength according to British standard and energy consumption was calculated after firing the brick.

4) Sugarcane Bagasse Brick
To produce sugarcane bagasse bricks, the raw materials were first dried under the sun until it is completely dried. Then, the bagasse were grinded into smaller pieces. Two different percentages of bagasse were used which were 1% and 3% respectively. The same drying, firing and testing procedure were applied to the manufactured sugarcane bagasse brick.

B. Testing Method

1) Dry Shrinkage
Bricks were shrunk after drying and firing process. Therefore allowance is made in the forming process to achieve the desired size of finished the brick. Both drying shrinkage and firing shrinkage were determined by using this formula:

\[ LS = \frac{L_s}{L} \times 100 \]

Where
- \( LS \) = Percentage of Shrinkage
- \( L_s \) = Actual length – Dry length
- \( L \) = Actual length

2) Dry Density
To define the density of bricks, the weight of each brick has been taken to represent the ambient mass. The mass at time of measurements \( m_o \), then immersed the brick into water for two hours and allow the brick to drain less than one minute. Record the weight of bricks as \( m_1 \), and place the brick in apparatus to measure the submerged \( m_2 \). Repeat the same procedure for other brick sample and record all the data. Object mass per unit volume and the SI units for density are kg/m³. Based on Archimedes principle the submerged mass used to evaluate the volume. The volume was calculated by using the mass as stated as equation below:

\[ V(\text{mm}) = (m_1 - m_2) \times 100 \]

Where
- \( m_1 \) = mass of wet brick in grams
- \( m_2 \) = submerged mass of brick in grams

The volume then used to calculate the ambient density \( D_a \) using equation below:

\[ \rho = \frac{m_o}{V} \times 1000000 \text{ in } \text{m}^3/\text{kg} \]

Where
- \( m_o \) = ambient mass in gram

3) Compressive Strength
The compressive strength test is important for determining the load bearing capacity of the brick. The compressive strength of clay brick will vary based upon the clay source, method of manufacture and degree of burning. When the same clay and method of manufacturing are utilized, higher degrees of burning will yield higher compressive strength. 1000 psi to 20000 psi is usually a range compressive strength of brick.

Since the brick is invariably used in compression, the standard method of strength involves crushing the brick, the direction of loading being same as that, which is to be applied in practice normally perpendicular to the large (bed) face (Taylor, 2002). In order to obtain representative results, 5 bricks should be tested, these being carefully done either during unloading or from a stack. The strength of the brick was obtained after the test has been completed.

4) Initial Rate of Suction (IRS)

Initial rate of absorption test or the IRS is intended to measure the weight of water absorbed by the brick per unit area within 60 seconds. The test is based on British Standard, BS 3921:1985. The apparatus that will be used in this test is a large and shallow container and two photographic plates of the same metal. A total of 5 samples of brick randomly selected were tested in a test measuring the dimension.

According to the British Standard, the sample of bricks will be placed in the oven (ventilated drying oven) to dry for 24 hours at the temperature of 1100°C. After drying for 24 hours in the oven, the sample of brick will be removed from the oven and cooled at room temperature for about 4 hours. The dimension (mm²) in contract of the brick samples will be measured and weighted to obtain the dry weight (m₁). Then the sample will be placed on an iron rod. The iron rods are placed in the containers filled with water. The size of iron rod should be same and the distance of the rod, between 75 to 100 mm. The water level should always be kept at the level of 3±1 mm from the lower surface. The sample will be placed on the rod for 60 seconds to allow the water absorption in the specific brick and then wipe it by using pieces of tissue immediately. The weight of wet brick samples will be recorded. These measures will be repeated with other sample of bricks. The Initial rate of absorption of brick was calculated by using this equation:

Initial rate of suction (IRS) = [(m₂-m₁)/A]*1000

Where:

- \( m_1 \) = weight of dry brick (g)
- \( m_2 \) = weight of wet brick (g)
- \( A \) = net area of the contact surface of the brick with water (mm²)

5) Thermal Conductivity

Thermal conductivity performance is an important criterion of building materials, as the thermal conductivity influences the usage of the material in engineering applications. The thermal conductivity of a brick is the rate at which a brick conducts heat. Heat losses from buildings are dependent on the thermal conductivity of the materials in the walls and roof. Building bricks have to minimize the heat flow from one side of the brick to the other side. The thermal conductivity of bricks and other masonry materials depends on the density and therefore porosity of the material.

\[ k = \frac{Q \times L}{A \times \Delta T} \]

Where:

- \( q \) = flow rate (W)
- \( k \) = thermal conductivity, (W/m.K)
- \( A \) = surface area, (m²) (brick)
- \( T_1 \) = temperature, (°C)
- \( T_2 \) = temperature, (°C)
- \( L \) = thickness, (m)
- \( \Delta T \) = Differential Temperature (°F)
6) Energy Measurement of Fired Clay Brick

The specific firing energy for bricks can be calculated by knowing the energy used for firing (MJ) divided by the mass of the brick (kg) (Mason, 1998; 2007). According to Whitttemore (1994; 1999), specific firing energy varies from 2 MJ/kg to 10 MJ/kg depending on the type of brick and kiln used. A survey (1993-1994) conducted in ASEAN countries showed that the specific firing energy consumption was between 2 to 3 MJ/kg (Prasertsan, 1995).

In the present investigation, the firing energy for control and SB bricks was calculated by assuming 2 MJ/kg as the specific firing energy (an estimated minimum value). For SB bricks, the calculation was done by taking into account the mass of SBs incorporated and the calorific value of the sugarcane bagasse. Inside the SB bricks, the calculation was done as shown in the figure. The specific firing energy consumption was between 2 to 3 MJ/kg (Prasertsan, 1995).

Energy saved, \( E \) (%), can be calculated by assuming the energy used for brick firing is the same as the estimated firing energy saved by incorporating SBs into fired clay brick compared to control. The calorific value of sugarcane bagasse was 6.3 MJ/kg. Therefore, the estimated firing energy saved by incorporating SBs into fired clay brick compared to control was calculated as follows:

\[
E = \frac{(q.m_1 - (q.m_2 - CV.m_3))}{(q.m_1 - CV.m_3)} \times 100\%
\]

Where:
- \( q = 2 \text{ MJ/kg energy used for brick firing} \)
- \( m_1 = \text{mass of clay in control clay brick, (kg)} \)
- \( m_2 = \text{mass of clay in SB brick, (kg)} \)
- \( m_3 = \text{mass of SBs in SB brick, (kg)} \)
- \( Q_1 = q.m_1 = (2 \text{ MJ/kg}) \text{ (mass of clay in control clay brick)} \)
- \( Q_2 = q.m_2 - CV.m_3 = (2 \text{ MJ/kg}) \text{ (mass of clay in control clay brick)} - (6.3 \text{ MJ/kg}) \text{ (mass of SBs in SB brick)} \)
- \( CV* = 6.3 \text{ MJ/kg} \)

*Calorific value of sugarcane bagasse

III. DATA ANALYSIS

A. Dry Shrinkage

Fig. 8 shows the shrinkage of bricks were decreased during the drying and firing process. The decreasing of shrinkage could be due to increasing percentage of SB in the bricks. The shrinkage value obtained was in descending order, which were 2.336%, 2.242% and 1.971% for 0%, 1% and 3% of SB content fired at heating rate 1°C/min respectively. The natural fibre material manages to stabilise the drying and firing behaviour support with other previous study. Shrinkage was lower with the additives which were up to 15.63%. Incorporating of sugarcane bagasse tends to reduce the shrinkage. A decreased of shrinkage is observed with the increase of fibre proportion. This could be attributed to a sufficient length of sugarcane bagasse for improving the bond at the fibre-soil interface to oppose the deformation and soil contraction (Lertwattanaruks & Choksirivanna, 2010).

B. Density

Fig. 9 shows the density of control bricks is 1792.46 kg/m³. However, the result shows the density of 1% and 3% of SB bricks decreased compared to control brick. Brick manufactured with 1% SB slightly decreased by a density value of 1636.214 kg/m³ compared with control brick. The lowest value of the density of this experiment was 3% SB brick with 1523.950 kg/m³ that decreased by 14.98% when it compared to the value of control brick density. The additional of sugarcane bagasse makes the bond between them become weak due to the pores after firing of the fired clay brick. Low-density or light-weight bricks have great advantages in construction including, for example, lower structural dead load, easier handling, lower transport costs, lower thermal conductivity, and a higher number of bricks produced per tonne of raw materials. Light bricks can be substituted for standard bricks in most applications except when bricks of higher strength are needed or when a particular look or finish is desirable for architectural reasons.

According to Grimm (1996), the density of bricks was affected by the manufacturing and raw material used, which could vary between 1300 kg/m³ until 2200 kg/m³. Therefore, although the rate of density for 1% and 3% SBs bricks were lower than the control bricks, but it still comply with the density requirement. Some manufacturers prefer light-weight brick for their brick production because it can reduce in weight.
C. Initial Rate of Suction (IRS)

Based on Fig. 10, it shows that the 3% of SB bricks obtained the highest IRS value which is 7.917 kg/m².min. It shows the highest value because when the percentage of SBs increased, the IRS also increased because fibre absorb water quickly than less SB. The control brick shows the lowest value between the different percentages because the 0% SB didn't have pores that allow immersed area through the water into the brick. The characteristic of brick which is consist high porosity will absorb more water compared to the brick with high density which is consist low porosity.

SBs fibre burn during firing creates more pores. Pores in the SB brick absorb more water. Therefore a higher percentage of SB will increase the IRS. The preferable value of the IRS was 2.93 kg/m².min which were control brick. Therefore SB Brick is still in the range or not, according to BS 3921:1985 there was no limited value of IRS, the 1% and 3% SB brick can still be utilized in construction works.

Wetting bricks before lying is more critical in hot weather construction since suction of bricks is influenced by the temperature of the bricks and the surrounding temperature (Davidson, 1982). Warmer units will absorb more water from the mortar and in addition, the water from the mortar evaporates at a faster rate. For this reason, in hot weather construction, brick with high suction rates (over 1.5 kg/m².min) should be well wetted before lying. On this basis, the IRS should be regards an important property of brick from Malaysia, which experience hot water throughout the year (Ali, 2005).

D. Compressive Strength

Based on Fig. 11, it shows that the compressive strength for the control brick was 22.80 kN/mm² and it is the highest value between the three percentages. It is, followed by 1% of sugarcane bagasse that obtained (14.16 kN/mm²) and the lowest value for compressive strength was determined with of 3% sugarcane bagasse is 5.84 kN/mm².

From the results, it was found that the additional sugarcane bagasse reduced the strength of the fired clay brick compared to the central brick as the brick become more porous with a higher percentage of SB. Generally, the compressive strength value required for load bearing capability of brick. The additional of the SB weaken the bond strength between it.

E. Thermal Conductivity

Based on Fig. 12, it shows that the value of thermal conductivity decreases while the percentage of the sugarcane bagasse increases. The highest thermal conductivity value was 0.011739225 W/m.°K for the control brick. The thermal conductivity of 1% sugarcane bagasse brick was 0.011069471 W/m.°K and it’s followed by 3% sugarcane bagasse brick 0.010689318 W/m.°K which is the lowest value. Pores were created during the firing process thus decreased the thermal conductivity. Porosity related to heat transfer, that is the higher of the porosity the lower the heat transfer.

From the results above, it found that the sugarcane bagasse improved the value of thermal conductivity. Sugarcane bagasse could be an additive that could improve the insulation properties. The incorporation of bagasse will make the brick sufficient for load bearing purposes. The thermal conductivity influences the usage of the material in engineering applications (A.Kadir, 2010).
F. Energy Consumed for Fired Clay Brick

![Figure 13. Energy saved during firing](image)

From Fig. 14, it shows the 3% SB brick was the highest percentage energy saved which is 30.768% and it is followed by 1% SB which is 22.742% and lowest was the control brick 18.297%. Based on the result, we found that the utilization of sugarcane bagasse into fired clay brick saved the energy during firing. Due to its calorific value these wastes generate heat input during firing thus reduce the energy required in the firing process. Brick manufacturer preferred to utilize these types of brick because it can save the energy during firing.

G. Physical and Mechanical Properties of 0%, 1% and 3% SB Brick Sample

Overall of this study, the additional of 3% SB into clay brick shows the lowest of quality bricks compared to 1% SB brick and control brick. From all the results obtained from this study, control brick shows the best performance in all the properties tested followed by 1% SB and 3% SB. However, all the properties still comply with the requirement and suitable for construction work application. Nevertheless in terms of thermal properties and energy saving 3% SB Brick shows advantages but improving the thermal by 8.94% and save the energy by 30.768% compared to 18.297% and 22.742%, for control brick and 1% SB brick respectively. Table I shows the value of different percentages of SB Bricks.

| TABLE I. Physical and Mechanical Properties of 0%, 1% and 3% SB Brick Sample |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| SB Incorporation | Compressive strength | Initial Rate of Section | Density | Dry Shrinkage | Thermal Conductivity | Energy Consumed |
| (%) | kN/m² | kg/m³/min | kg/m³ | (%) | W/m·K | (%) |
| 0 | 22.8 | 2.93 | 1792.46 | 2.336 | 0.011739225 | 18.297 |
| 1 | 14.16 | 4.502 | 1636.214 | 2.242 | 0.01069471 | 22.742 |
| 3 | 5.84 | 7.917 | 1523.95 | 1.971 | 0.010689318 | 30.768 |

IV. CONCLUSIONS

The utilization of sugarcane bagasse waste into fired clay brick could act as pore formers to produce lightweight brick and improved the thermal properties. Furthermore, the calorific value of the sugarcane bagasse also helps to reduce the energy consumption during firing. Even though some of the brick properties such as compressive strength is decreased by the incorporation of the waste, but it is still producing adequate fired clay brick which is comply with the standard for non-load bearing purposes. This also provides an alternative disposal method for sugarcane bagasse.

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