Effect of bagasse and bagasse ash levels on properties of pottery products

Sutas Janbuala*, Mana Eambua, Arpapan Satayavibul, Watcharakhon Nethan
Faculty of Science, Suan Dusit University, Bangkok, 10300, Thailand
*Corresponding author.
E-mail address: sutas_jan@dusit.ac.th (S. Janbuala).

Abstract

The objective of this research was to study the effect of bagasse and bagasse ash on the properties of pottery products. In the experiments, we varied the composition of clay by adding 2%, 4%, 6%, and 8% by weight of bagasse or by adding 5%, 10%, 15%, and 20% by weight of bagasse ash and maintained the temperature of the furnace at 900 °C. The results indicate that the best composition is obtained by adding 10% by weight of bagasse ash, which yielded pottery products with improved strength (20.10 MPa), density (1.41 g/cm³), water absorption (13.91%), and porosity (25.73%). In comparison, the composition of clay with 4% by weight of bagasse yielded strength, density, water absorption, and porosity of 10.12 MPa, 1.53 g/cm³, 19.95%, and 30.17%, respectively.

Keyword: Materials science

1. Introduction

Pottery products are made from clay and molded using various methods such as ironing, pressing on dials, or compressing to the desired shape. Pottery has been practiced in Thailand over thousands of years, primarily for producing pottery products such as bricks and clay pots. Thai pottery is widespread within the country; however, the procedure for making the pottery products and the raw materials differ from one geographical location to the other, with each region contributing a unique
recipe. The differences in the pottery techniques among various regions are attributed to the respective local concepts of utilizing the available raw materials. The pottery products with properties such as high strength, good porosity, and low weight are practical and easy to transport; however, it is still a challenge to make such clay pots with the desired shape and size. Previous studies have shown that the addition of biomass such as rice husk, rice husk ash, sludge from water treatment plant, dry sewage sludge, etc. can reduce the weight of a clay pot [1, 2, 3, 4, 5]. However, clay pots made using such techniques were weaker than the conventional pots. Therefore, we set out to develop a material to enhance the strength of the lightweight pottery products. The biomass materials that we used in this study were natural materials bagasse and bagasse ash. These materials are generally produced in large amounts as industrial waste. Bagasse is typically composed of 45–55% cellulose, 20–25% hemicellulose, 18–24% lignin, and 1–4% ash. Several groups have demonstrated the applicability of bagasse in composite reinforcement and the use of bagasse ash in ceramic products [6, 7, 8, 9, 10]. Additionally, the burning of bagasse produces silica (~56%); therefore, bagasse ash could lower the weight of pottery products [7]. In our study, we utilized sugarcane bagasse, because a vast area of land in Thailand is used for sugarcane farming, which results in abundant sugarcane bagasse waste (approximately 20 megatons a year). Approximately 80% of the bagasse is used in the generation of electricity, the paper industry, and the production of plywood, whereas almost 20% of the bagasse remains unused [8].

2. Materials and method

The raw materials used in this research ball clay, bagasse, and bagasse ash were from Bangban district, Ayutthaya province, Thailand. The chemical composition of the raw materials was analyzed by using an X-ray fluorescence spectrometer (XRF, Model JSM-5800LV). Thermogravimetric, differential thermogravimetric and differential thermal analyses (TG, DTG and DTA) were used to characterize the thermal properties of the specimens. The TG, DTG and DTA were performed on the powdered samples (<1 mm) at 1000 °C, using heating rate of 5 °C/min under air. Dried clay was ground until it obtains a diameter of 1 mm and mixed with bagasse at the ratios of 0%, 2%, 4%, 6%, and 8% by weight or with bagasse ash at the ratios of 0%, 5%, 10%, 15%, and 20% by weight. The mixture was subjected to a thorough manual mixing with the addition of sufficient water to give it a shape. Then, the mix was left untouched for 24 h prior to compressing it into a mold of size 5 cm × 5 cm × 2 cm. The contained mold was sun dried for 2 days, heated in an electric furnace at a rate of 450 °C/h, and kept at 900 °C for 3 h. The product samples were characterized for density, porosity, and water absorption according to ASTM C373 [11]. The compressive strength was measured by using a universal testing machine (model Shimadzu DSS-10T), and the microstructure was visualized by using a scanning electron microscope (SEM).
3. Results and discussion

3.1. Chemical composition

Chemical composition of raw materials as shown in Table 1. The main component of clay and bagasse ash is silicon dioxide (SiO₂), which constitutes 60.67% and 58.00%, respectively, of the material. The other chemical contents of clay include Fe₂O₃, CaO, MgO, and TiO₂ constituting approximately 9% of the total clay material. Therefore, the clay used in this study could be a low refractory material [12]. In contrast, bagasse contains 60–65% volatile chemicals, which are mostly carbon-based compounds and are lost when bagasse is burned [13].

3.2. TG, DTG and DTA

Fig. 1 shows the TG, DTG and DTA plots of clay, indicating a total weight loss of 10.12% when the process reaches 1000 °C. The loss of water in the temperature range of 20–202 °C contributes to a reduction of 4.18% in the mass of the clay. The steepest mass reduction rate due to the loss of water from evaporation was observed at 79 °C, whereas a steady reduction in the mass presumably due to the decomposition of the organic materials of clay was observed in the temperature range of 220–980 °C. The second mass reduction peak was observed at 447 °C. In the DTA plot, the large exothermic reaction that is observed in the temperature range of 80–650 °C corresponds to the burning of the organic components of clay.

The TG, DTG and DTA plots of bagasse, shown in Fig. 2, indicate a total weight loss of approximately 97% at 1000 °C. The 9% reduction in the mass in the temperature range of 20–150 °C is the result of the evaporation of water with the maximum evaporation occurring at a temperature of ~68.5 °C. In addition, the DTA plot, shown in Fig. 2, indicates a large exothermic reaction in the temperature range of 200–500 °C caused by the organic decomposition of bagasse. The TG and DTG plots of bagasse ash, shown in Fig. 3, indicate that the reduction in weight was 18.58% at 1000 °C. In comparison, the DTA graph shows the highest endothermic reaction at 477.2 °C caused by the decomposition of the organic matter in bagasse ash.

3.3. XRD

Fig. 4 shows the XRD pattern of clay indicating the main constituent quartz (SiO₂) with smaller proportions of various silicates such as kaolinite (Al₂Si₂O₅(OH)₄) and albite (NaAlSi₃O₈). The XRD patterns of bagasse (Fig. 5) and bagasse ash (Fig. 6) also showed quartz as the main component, which confirms the chemical composition data in Table 1. This quartz component found in bagasse and bagasse ash is also found in fine sand, which is typically used in pottery to decrease the plastic properties of clay.
### Table 1. Chemical composition (%) of materials.

| Composition     | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | K$_2$O | TiO$_2$ | TIO$_3$ | MgO | CaO | Na$_2$O | Mn$_2$O | BaO | SO$_3$ | LOI |
|-----------------|---------|-------------|-------------|--------|---------|---------|-----|-----|---------|---------|-----|-------|-----|
| Clay            | 60.67   | 15.18       | 7.61        | 3.12   | 1.18    | 0.79    | 0.56| 0.22| 0.11    | 0.11    | 0.11| 9.10   | 9.10|
| Bagasse ash     | 58.00   | 2.10        | 1.30        | 4.21   | 0.29    | 4.01    | 3.31| 0.20| 0.30    | 0.01    | 24.5|       |     |
3.4. Bulk density and strength

Consider the amount of bagasse and bagasse ash as a function of density and compressive strength as shown in Fig. 7. It was observed that the increase in bagasse or bagasse ash showed a decrease in the density and compressive strength of the pottery specimens. The decrease in compressive strength is due to the fact that sugarcane ash contains silica crystals with high porosity than clay [14, 15]. In addition, the combustion of bagasse and bagasse ash can break down the organic matter of clay and increase the porosity. Based on the findings shown in Fig. 7, 2–4% bagasse or 5–15% bagasse ash can be added to make the Thai industry standard pottery bricks (compressive strength >10 MPa) [16].
By comparing the composition containing 2–8% bagasse and that containing 5–20% bagasse ash, we observed that the compressive strength due to bagasse is significantly lower than the strength due to bagasse ash. The optimum properties of the pottery specimen with bagasse and bagasse ash are as follows: a compressive strength of 10.12 MPa is obtained with the addition of 4% bagasse and 20.10 MPa with the addition of 10% bagasse ash. Interestingly, the bulk density is not affected significantly by the proportion of either bagasse or bagasse ash. This suggests that the reduction in the weight of the pottery product due to bagasse or bagasse ash is small, whereas the decrease in the compressive strength is large [2].
3.5. Water absorption and porosity

Fig. 8 illustrates the percentage of water absorption and the porosity of the samples with the addition of bagasse and bagasse ash. The result showed that the porosity and water absorption increased with the addition of bagasse or bagasse ash. The highest porosity was achieved with 8% bagasse (36.4% porosity) and 20% bagasse ash (35.21% porosity). Similarly, the water absorption was the highest with 8% bagasse (27.44% water absorption) and 20% bagasse ash (22.30% water absorption). Hence,
Fig. 7. (a) Bulk density and (b) compressive strength of pottery specimens with the addition of bagasse and bagasse ash.

Fig. 8. (a) Porosity (b) Water absorption of samples with the addition of bagasse and bagasse ash.
it can be concluded that the highest proportion of bagasse and bagasse ash could further increase the porosity and water absorption because bagasse and bagasse ash have low densities compared to clay. When mixed with clay, bagasse and bagasse ash lowered the density of the pottery specimen. Furthermore, the sample was burnt, which caused the organic matter to combust and form carbon dioxide (CO$_2$). Hence, the pottery enriched with bagasse or bagasse ash was porous [14, 15]. When comparing the composition containing 2─8% bagasse and that containing 5─20% bagasse ash, we observed that the addition of bagasse resulted in higher porosity and water absorption than the addition of bagasse ash. This was because of the organic matter content, which is combustible and volatile, is more in bagasse than in bagasse ash.

3.6. Microstructure

The microstructure of pottery, illustrated as the SEM images in Fig. 9, proves that the addition of bagasse and bagasse ash to clay increases the porosity of the clay pot. With the increase in the bagasse or bagasse ash content, there is a significant change in the microstructure morphology evolving from a less porous to a highly porous material as shown in Fig. 8 (a). The material density and its compressive strength decreases with an increase in the porosity, as shown in Fig. 7. This is because the

![SEM images of modified component pottery with varied amount of bagasse (B) or bagasse ash (BA).](https://doi.org/10.1016/j.heliyon.2018.e00814)
carbon dioxide gas resulting from the decomposition of bagasse and bagasse ash is released during the firing process [14, 15].

4. Conclusions

The objective of this study was to determine the influence of bagasse and bagasse ash on the porosity, density, compressive strength, water absorption, and microstructure of the pottery materials. In this study, it was demonstrated that bagasse and bagasse ash can affect the properties of pottery products by reducing the density and compressive strength. With a bagasse weight fraction of 4%, the pottery product exhibited the desired properties in compressive strength (10.12 MPa), density (1.53 g/cm³), porosity (30.1%), and water absorption (19.95%). Similarly, with a bagasse ash weight fraction of 10%, the pottery product exhibited a compressive strength of 20.1 MPa, density of 1.41 g/cm³, 25.73% porosity, and 13.91% water absorption. Therefore, these differences in the material properties are due to the varying amounts of silica crystals and organic matter in bagasse and bagasse ash. Fig. 10 illustrates that the weight of the pottery product containing 10% bagasse ash is lower than that containing no bagasse ash.

Declarations

Author contribution statement

Dr. Sutas Janbuala: Conceived and designed the experiments; Performed the experiment; wrote the paper.

Dr. Mana Eambua: Performed the experiments; Analyzed and interpreted the data.

Dr. Watcharakhon Nethan: Contributed reagents, materials, analysis tools or data.

Fig. 10. Pottery with 10% bagasse ash and (B) 0% bagasse ash.
Dr. Arpapan Satayavibul: Analyzed and interpreted the data and Wrote the paper.

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**Competing interest statement**

The authors declare no conflict of interest.

**Additional information**

No additional information is available for this paper.

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