VOL. 11, NO. 13, JULY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

LIGHTWEIGHT CLAY BRICK CERAMIC PREPARED WITH BAGASSE ADDITION

Sutas Janbuala and Thanakorn Wasanapiarnpong
Department of Materials Science, Faculty of Science, Chulalongkorn University, Bangkok, Thailand
E-Mail: sutas_jan@dusit.ac.th

ABSTRACT

Lightweight clay brick has been successfully prepared with the addition of bagasse (5, 10, 15, and 20 wt%) at different firing temperatures (700, 800, 900, and 1000 °C). Higher bagasse contents resulted in higher values of porosity and water absorption, while reductions in thermal conductivity and bulk density were observed. In contrast, the increased firing temperature gave a decrease in porosity and water absorption, and higher thermal conductivity and bulk density. Porosity and water absorption were maximized with 20 wt% bagasse and a firing temperature of 700 °C. Lightweight clay brick containing 10 wt% bagasse prepared at a firing temperature of 1000 ºC gave the required bulk density (1.11 g/cm^3), compressive strength (8.14 MPa), and water absorption (20.96%) to meet the Thai industrial standard of lightweight brick C10 TIS 2601-2013.

Keywords: lightweight clay brick, porosity, bagasse.

INTRODUCTION

Fired clay bricks are key components in masonry construction and have been widely used and produced worldwide for many years. Such bricks are composed of common components, including a kneaded clay-bearing soil, sand, lime, and/or a concrete material, which are fired-hardened to give them their desired properties. The manufacturing process is straightforward and so is extremely well known [1-3]. Fired clay brick has a number of advantages, including strength, high density, and long lifetime. However, it is also particularly heavy due to its high density, and is both a thermal conductor, and a sound carrier. These properties result in low thermal insulation and low sound absorption. [4] Previous studies have attempted to solve these problems by weight reduction (lightweighting) and by the addition of biomass [5]. Lightweighting of clay brick can be achieved by the use of industrial sludge, which often contains grass, urban river sediments, tobacco waste, cigarette butts, recycled paper residues, and sugar cane [6, 7]. However, this also results in a significant reduction in strength of red brick.

Bagasse is industrial waste from countries such as Brazil, India, China, and Thailand. In particular, Thailand contains a vast area where sugar cane is grown. This results in an abundance of bagasse waste of approximately 20 million ton per year. In general, 80% of bagasse is used as electric flue, in the paper industry, and in plywood, while 20% remains unused. [8] Bagasse consists of 45-55% cellulose, 20-25% hemicellulose, 18-24% lignin, and 1-4% ash. As bagasse burns, it produces silica (~56%) [9-11]. several groups have studied the application of bagasse for reinforcement in composites, and the use of bagasse ash in ceramic products [11-15]. The concept of incorporating bagasse into fired clay brick to reduce its weight was established, and resulted in improved properties of the clay brick through improving porosity and thermal insulation. Such uses are beneficial to the environment as they allow the utilization of waste products for useful purposes.

MATERIAL AND METHODS

Characteristics of raw materials and bagasse

Clay from the Ayutthaya province, Thailand, and bagasse from a sugar factory in the Udon Thani province, Thailand were used as raw materials. X-ray fluorescence spectroscopy (XRF) was used for the chemical analysis. Thermogravimetric and differential thermal analysis (TG–DTA) were used to characterize the thermal properties of the specimens. DTA and TGA were performed on powdered samples (<1 mm) at 1000 °C at 5 °C/min under air.

Preparation of clay brick samples and firing characteristics

Clay and bagasse (particle size <1 mm) were used for the preparation of the sample clay bricks. Water was added to the bagasse (5%, 10%, 15%, and 20% bagasse) and the samples were mixed by hand before the addition of further water. The mixtures were then left for 4 h before being poured into the mold (140 × 50 × 25 mm). The specimens in the mold were left to dry under air for 48 h, and were then dried in an oven at 110 °C for 24 h, and fired in a furnace at the desired temperature (700 °C, 800 °C, 900 °C, or 1000 °C) at 5 ºC/min for 3 h. In accordance with the Thai industrial standard of lightweight brick TISI 2601-2013 [16] and the Thai industrial standard of clay brick TISI 77-2004 [17], the characteristics of this firing specimen are density, porosity, water absorption, compressive strength. Scanning electron microscopy (SEM) was used to investigate the microstructures while a hot disk thermal constant analyzer was used for thermal constant determination.

RESULTS AND DISCUSSIONS

Properties of the clay brick raw materials

Analysis of the raw materials by XRF gave the clay chemical composition as shown in Table-1. The main

VOL. 11, NO. 13, JULY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

components that soil and bagasse have in common are SiO_2, Al_2O_3, and Fe_2O_3, causing the formation of a red brick after firing. Fe_2O_3, CaO, MgO, and TiO_2 were also detected at levels above 9%, indicating that the clay used is low refectory and not suitable for burning [17].

Table-1. Chemical composition of the raw materials (%).

	SiO_2	Al_2O_3	Fe_2O_3	K_2O	MgO	TiO_2	CaO	Na_2O	MnO	BaO	SO_3
Clay	60.67	15.18	7.61	3.12	1.15	1.18	0.79	0.56	0.22	0.11	0.11

Figure-1 below shows the TG and DTG plots of clay, indicating a total weight loss of 10% during the process at 1000 ºC, with 4.18% mass reduction between 20-220 ºC due to loss of water. The steepest mass reduction rate was detected at 79 ºC, while steady mass reduction was observed between 220-980 ºC, due to decomposition of microorganisms in the soil. The second mass reduction peak was detected at 447 ºC. In the DTA plot, a large exothermic reaction between 80-650 ºC corresponded to the burning of organic components in the raw materials [2].

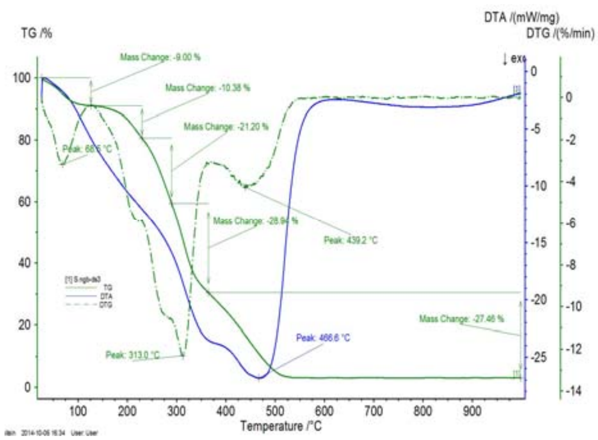

Figure-1. TG, DTG, and DTA plots of clay.

The TG and DTG plots of bagasse shown in Figure-2 indicate a total weight loss of approximately 97% at 1000 ºC. The 9% mass reduction between 20-150 ºC is a result of the evaporation of water, with a maximum being reached at ~68.5 ºC. A further mass loss was observed at 200-500 ºC (maximum at 313 °C) due to microorganism decomposition in the bagasse [18, 19]. In addition, the DTA plot shown in Figure-2 indicates a large exothermic reaction between 200-500 ºC, caused by the organic decomposition of bagasse.

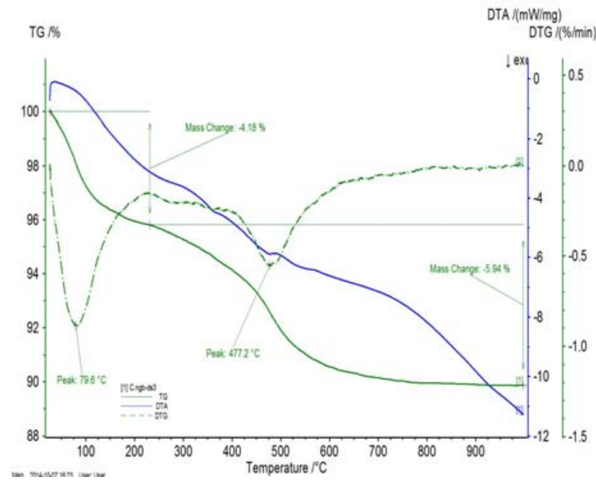

Figure-2. TG, DTG, and DTA plots of bagasse.

Properties of the fired samples

Density and strength

Figures 3 and 4 show the bulk density and compressive strength of the fired clay brick samples, demonstrating that the bagasse content affects the density and maximum compressive strength of the specimens. An increase in bagasse content leads to a decrease in specimen density, which reduced the compressive strength through the presence of decomposed bagasse from the firing process. In addition, greater bagasse content increases specimen porosity, resulting in a reduction in density, which in turn leads to a decrease in compressive strength. These results are in agreement with research carried out on rice husk [2, 20]. The highest density was obtained in the specimen containing 5 wt% bagasse, with firing at 1000 ºC.

A comparison of different firing temperatures indicated that an increase in temperature leads to an increase in specimen density. At elevated temperatures, the glassy phases can precipitate inside the specimen due to the presence of K_2O, Na_2O, and Fe_2O_3, which are components of the clay that do not tolerate high temperatures [21]. These components gave a glass phase at 800 ºC, inducing the formation of a liquid phase, sintering bonded between the particles of the specimen, thus enhancing the density. As a result, the compressive strength of the specimen was improved [23-24]. For the specimens containing 10%-20% bagasse at different firing temperatures, their densities were in accordance with TISI

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

2601-2556, C10 (<1.2 g/cm^3). At all firing temperatures, the specimens containing 5% bagasse exhibited compressive strengths in accordance with TISI 2601-2556, C10 (2.5-5 MPa). Furthermore, the compressive strength standard of TISI 77-2004 (9 MPa) was also exceeded for the specimens containing 5% bagasse with firing at 900-1000 °C. In samples containing 10-20% bagasse fired at 900-1000 °C, the specimen also exhibited a compressive strength in accordance with TISI 2601-2013, C10 (2.5-5 MPa).

The highest compressive strength was achieved in the specimen containing 5 wt% bagasse fired at 1000 ºC. Furthermore, the addition of bagasse at 10 wt% with firing at 800-1000 ºC, gave specimens with a density and compressive strength in accordance with the Thai industrial standard of lightweight brick (C10 TIS 2601-2013), with a lower density of 1.11 g/cm^3 (<1.2 g/cm^3) and a higher compressive strength of 8.14 MPa (2.5-5 MPa).

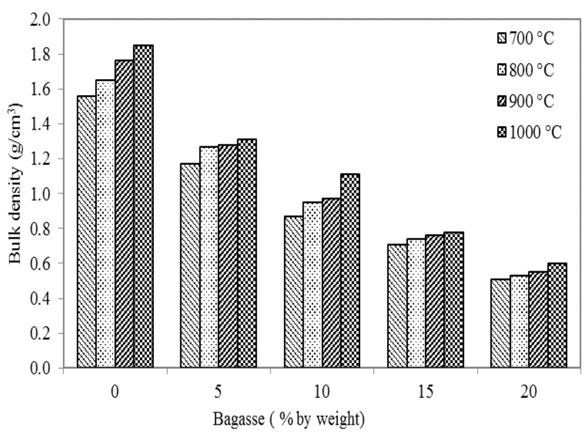

Figure-3. Bulk density of fired clay brick with varying bagasse content and firing temperature.

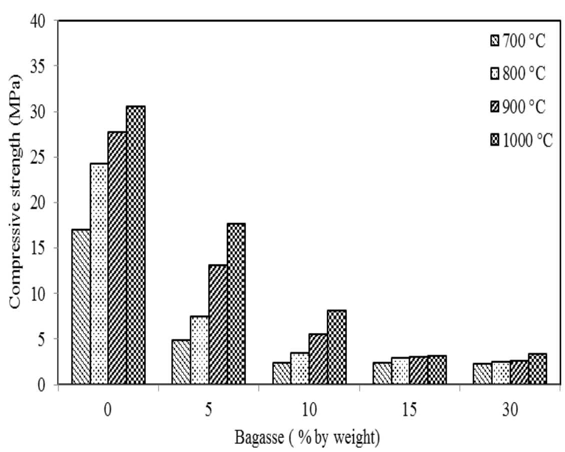

Figure-4. Compressive strength of fired clay brick with varying bagasse content and firing temperature.

Water absorption and porosity

Figures 5 and 6 show the water absorption and porosity of the fired clay brick samples. The increase in bagasse gives an increase in both porosity and water absorption, corresponding to a decrease in density. This occurs as water inside the organic bagasse evaporated during the firing process, resulting in increased porosity [22].

The results shown in Figures 5 and 6 demonstrate that higher firing temperatures contribute to lower water absorption and porosity. This occurs because during the firing process at temperatures exceeding 850 ºC, precipitation of the glassy phase takes place, generating additional spaces within the specimen. Our optimization studies show that the addition of 10% bagasse with a firing temperature between 900-1000 ºC gave the desired water absorption of 20.96%, which is in accordance with the Thai industrial standard of lightweight brick C10 (<25%) [15].

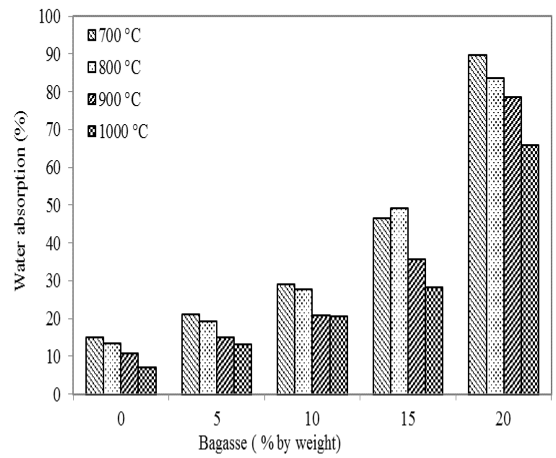

Figure-5. Water absorption (%) of fired clay brick with varying bagasse content and firing temperature.

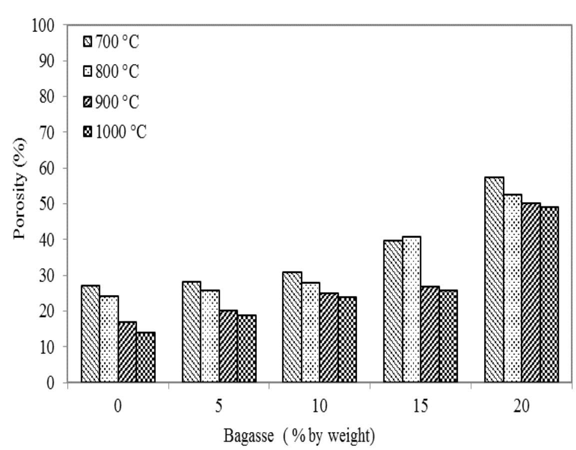

Figure-6. Apparent porosity (%) of fired clay brick with varying bagasse content and firing temperature.

Thermal conductivity

Figure-7 shows the variation in thermal conductivity of the fired clay brick samples, indicating that increased bagasse content leads to a decrease in thermal conductivity. This occurs due to bagasse creating porosity inside the specimen through its decomposition, thus decreasing the amount of heat conducted through the specimen. It also found that the lowest thermal conductivity (0.11 W/mK) was achieved with 20 wt% bagasse fired at 700 ºC. In contrast, with higher firing temperatures, thermal conductivity increased. This is due to a reduction in porosity at high firing temperatures, which contributes to an increase in both density and thermal conductivity.

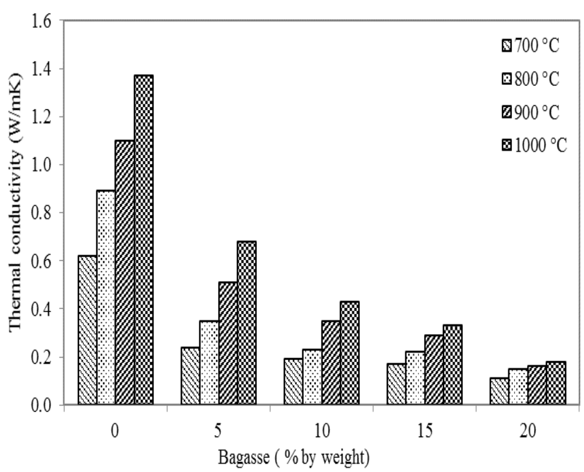

Figure-7. Thermal conductivity of fired clay brick with varying bagasse content and firing temperature.

Microstructure

Figures 8 and 9 show the microstructures of the fired clay brick samples. When bagasse was added to the specimen, its porosity increased due to the decomposition of bagasse in the form of carbon dioxide gas release during the firing process. However, this also reduced the density and compressive strength. With higher firing temperatures, porosity was lower, due to changing of the liquid phase in the specimen during the firing process. In addition, this resulted in an increase in specimen density [22-24].

CONCLUSIONS

We successfully demonstrated that the density of clay bricks is reduced by the addition of bagasse into the raw materials. While an increase in bagasse content results in a decrease in the compressive strength of the specimen, an increase in firing temperature leads to an increase in density and compressive strength. Furthermore, an increase in bagasse content also results in increased porosity and absorption of specimen. In contrast, porosity and absorption decrease with an increase in firing temperature. Other effects of bagasse addition include a decrease in thermal conductivity of the clay brick and a decrease in heat conduction. In contrast, head conduction was improved with a rise in firing temperature. The properties of the produced clay bricks meet the TIS standard of lightweight clay brick upon the addition of 10 wt% weight bagasse with a firing temperature of 900-1000 °C. These properties include density (1.11 g/cm^3), compressive strength (8.14 MPa), and water absorption (20.96%). Furthermore, the optimized porosity and thermal conductivity were 23.15% and 0.43 W/mK, respectively.

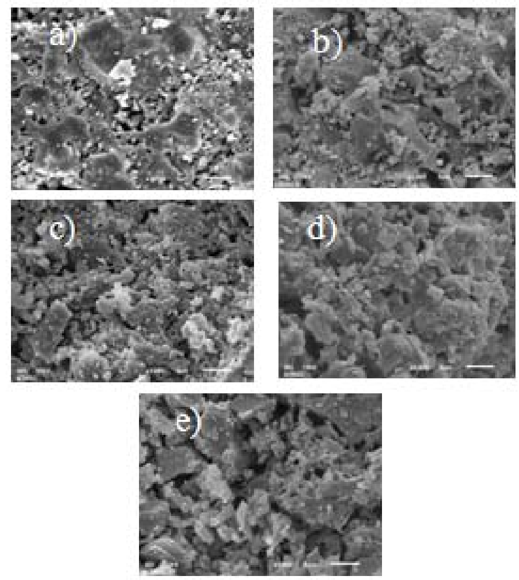

Figure-8. Microstructure of fired clay bricks with added bagasse at (a) 0 wt%, (b) 5 wt%, (c) 10 wt%, (d) 15 wt%, and (e) 20 wt% at a firing temperature of 900 °C.

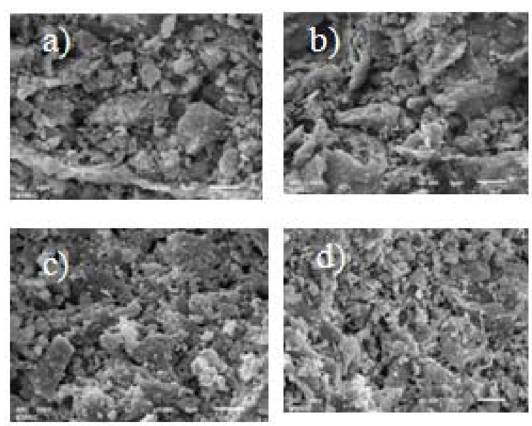

Figure-9. Microstructure of fired clay brick containing 10 wt% bagasse at firing temperatures of (a) 700 °C, (b) 800 °C, (c) 900 °C, and (d) 1000 °C.

ACKNOWLEDGEMENTS

The authors would like to thank the Faculty of Science and Technology, Suan Dusit University and

Department of Materials Science, Faculty of Science, Chulalongkorn University for support of this project.

REFERENCES

[1] Janbuala S, Wasanapiarnpong T. 2015. Effect of rice husk and rice husk ash on properties of lightweight clay bricks. Key Eng. Mat. 659: 74-79.

[2] Janbuala S, Kitthawee U, Aermbua M. 2013. Effect of rice husk ash to mechanical properties of clay bricks. Adv. Mater. Res. 770:50-53.

[3] Kadir AA, Mohajerani A, Roddick F, Buckeridge J. 2010. Density, strength, thermal conductivity and leachate characteristics of light-weight fired clay bricks incorporating cigarette butts. World Acad. Sci., Eng. Technol. 53: 1035-1040.

[4] Bories C, Borredon ME, Vedrenne E, Vilarem G. 2014. Development of eco-friendly porous fired clay bricks using pore-forming agents: A review. J. Environ. Manage. 143: 186-196.

[5] Demir I. 2014. Effect of organic residues addition on the technological properties of clay bricks. Waste Manage. 28: 622-627.

[6] Xu Y, Yan C, Xu B, Ruan X, Wei Z. 2014.The use of urban river sediments as a primary raw material in the production of highly insulating brick. Ceram. Int. 40: 8833-8840.

[7] Sutcu M, Akkurt S. 2009. The use of recycled paper processing residues in making porous brick with reduced thermal conductivity. Ceram. Int. 35: 2625-2631.

[8] Faria KCP, Gurgel RF, Holanda JNF.2012. Recycling of sugarcane bagasse ash waste in the production of clay bricks. J. Environ. Manage. 101: 7-12.

[9] Chulalongkhon University. 2013. Study the feasibility of producing ethanol from cellulose - commercial use. Chulalongkhon.

[10] Punsuvon V, Saeneeyuth S, Sariman S, Intarat K. 2001. Production of high alpha-cellulose pulp and xylose from bagasse by steam explosion, The 39th Kasetsart University Symposium. 79-85.

[11] Phonsaen K, Uriyapongson S, Patarajinda V, Tatsapong P, Polsan Y. 2012. Effect of improve bagasse with urea and urea with soybean meal on nutritive value and in vitro digestibility. J. Khon Kaen Arg. 40: 531-535.

[12] Hajima H, Sain M. 2015. The use of sugarcane bagasse fibres as reinforcements in composites, Biofiber Reinforcements in Composite Materials. 525-549.

[13] Szczerbowski D, Pitarelo AP, Zandoná Filho A, Pereira Ramos L. 2014. Sugarcane biomass for biorefineries: Comparative composition of carbohydrate and non-carbohydrate components of bagasse and straw. Carbohydr. Polym. 114: 95-101.

[14] Loh YR, Sujan D, Rahman ME, Das CA.2013. Sugarcane bagasse - The future composite material: A literature review. Resour. Conserv. Recy. 75: 14-22.

[15] Souza AE, Teixeira SR, Santos GTA, Costa FB, Longo E. 2011. Reuse of sugarcane bagasse ash (SCBA) to produce ceramic materials. J. Environ. Manage. 92: 2774-2780.

[16] Thailand Industrial Standard Institute. 2013. Thai industrial standard of lightweight brick TISI. 2601-2013.

[17] Thailand Industrial Standard Institute. 2004. Thai industrial standard of clay brick TISI. 44-2004.

[18] Musthafa AM, Janaki K, Velraj G. 2014. Microscopy, porosimetry and chemical analysis to estimate the firing temperature of some archaeological pottery shreds from India. Microchem. J. 95: 311-314.

[19] Williams PT, Nugranad N. 2000. Comparison of products from the pyrolysis and catalytic pyrolysis of rice husk. Energy. 25: 493-513.

[20] Yariv S. 2003. The role of charcoal on DTA curves of organo-clay complexes: an overview. Appl. Clay Sci. 24: 225-236.

[21] Milheiro FAC, Freire MN, Silva AGP, Holanda JNF. 2005. Densification behavior of red firing Brazilian kaolinitic clay. Ceram. Int. 31: 757-763.

[22] Gorhan G, Simsek O. 2013. Porous clay bricks manufactured with rice husks. Constr. Build. Mater. 40: 390-396.

[23] Musthafa AM, Janaki K, Velraj G. 2010. Microscopy, porosimetry and chemical analysis to estimate the firing temperature of some archaeological pottery shreds from India. Microchem. J. 95: 311-314.

[24] Raut NS, Biswas P, Bhattacharya TK, Das K. 2008. Effect of bauxite addition on densification and mullitization behaviour of West Bengal clay. Bull. Mater. Sci. 31: 995-999.