Combined effects of waste bagasse ash and glass powder on the physical properties and compressive strength of construction bricks

Siriwan Artbumrung[1] Must Srila[1] Anuwat Srisuwan [2] Chiawchan Saengthong[2] Siwat Lawanwadeekul[3] Sibpawishkon Sittiakkaranon[4] Sarawut Dakaew[5] and Nonthaphong Phonphuak[1*]

[1] Department of Industrial Technology, Faculty of Engineering, Rajabhat Maha Sarakham University, Maha Sarakham 44000, THAILAND

[2] Faculty of Liberal Arts and Sciences, Sisaket Rajabhat University, Muang, Sisaket 33000, THAILAND

[3]Faculty of Industrial Technology, Lampang Rajabhat University, Lampang 52100, THAILAND

[4]Faculty of Agricultural and Industrial Technology, Nakhon Sawan Rajabhat University, Nakhon Sawan 60000, THAILAND

[5]Faculty of Education, Rajabhat Maha Sarakham University, Maha Sarakham 44000, THAILAND

**Corresponding author; E-mail address: nonthaphong@rmu.ac.th*

Abstract

The present study focused on the physical properties and the compressive strength of fired clay bricks from combined waste bagasse ash (WBA) and glass powder (GP). Clay bricks were fabricated by incorporating WBA at 10, 20, 30, and 40 wt.% in clay mixture, while the constant GP powder was added to 10 wt.%. Green samples were then fired at 900, 1000, and 1100 ^{o}C. The influences of WBA and GP powder content on the physical properties and the compressive strength were determined. The results showed that an increase of WBA and GP powder content affected the improvement of the structural pores and compressive strength of the fired clay bricks. The fired clay brick should be required a compressive strength value of more than 17.2 MPa as per ASTM C62-13a, which was obtained in 10 wt.% WBA and GP content (17.85 MPa) after firing at 1100 ^{o}C. As a combined additive, the WBA and GP-powder could be imparted a synergistic effect in producing the sufficiently high strength fired clay brick. The use of wastes WAB and GP powder in manufacturing clay brick is an important step in reducing environmental pollution and protecting natural clay resources.

Keywords: Clay brick, Mechanical properties, Bagasse ash, Waste glass powder, Compressive strength

1. Introduction

Nowadays, the approach of reusing and recycling agricultural and industrial waste has received attention due to the expansion of various industries and overuse of raw materials, an increase in the consumption of disposal and returnable materials has increased the volume of wastes produced in the societies together with the growth of the population in a world [1,2]. Furthermore, economic and environmental features and government policy and public education related to waste reusing and sustainable development are required for wide production and application of these wastes, such as utilizing wastes for development as a suitable alternative for the construction and building materials industry [3,4]. Re-utilization of waste materials in bricks production can be a successful strategy due to the waste production reduction and decreased clay replacement in the bricks production [5,6]. Many researchers have studied the use of various types of wastes additive for clay bricks production: paper waste; sugarcane bagasse ash; tea waste; fly ash and waste glass; wastewater sludge; water treatment sludge, glass, and marble waste; agro-waste [7-13].

Sugarcane has been used as the essential raw material for both sugar and ethanol industries. However, the sugarcane industry produces large amounts of sugarcane bagasse. Generally, the sugarcane bagasse is applied used for energy co-generation [14]. Waste bagasse ash (WBA) is obtained from the burning of bagasse as a heat source in the sugar industry. The WBA contains approximately 62% of SiO_2 and some minor components of Al_2O_3, CaO, Fe_2O_3, and K_2O. Quartz and cristobalite are the main crystalline phases found in the WBA. Kazmi et al. [15] reported about the advantage of sugarcane bagasse ash (SBA) and rice husk ash (RHA) in clay bricks. The results indicated that the compressive strength of bricks with 5% of SBA and RHA satisfied the requirements. Faria et al. [14] investigated SBA in the production of clay bricks. The results indicated that up to 10 wt.% and fired at 1000 ^{o}C into clay brick was thus recommended. After firing, the clay bricks increase in the water absorption and decrease in shrinkage and strength of bricks with the increase in the amount of SBA. The author's previous study investigated the utilization of sugarcane bagasse ash (SCBA) to improve the properties of fired clay brick. The compressive strength of bricks with 2.5 wt.% SCBA fired at 1000 ^{o}C had adequate strength of 19.5 MPa compared to standard [16].

Glass is a commonly used material in every corner of life, ranging from containers, flat glass, bottled, bulb glass windows, and screens to medical and electronic instruments. Glass can be recycled endlessly without losing quality or purity. Also, glass can be recycled for multiple uses across various industries. The recycled glass is collected either from curbsides or recycling centers waste [17,18]. Glass is made from Na_2O, CaO, and SiO_2 and thus is usually referred to as a soda-lime-glass. It is a hard, amorphous solid material with high SiO_2 content. Glass is a fluid material and solidifies in an amorphous form [10, 19]. The use of glass recycling in building materials has been identified recently as replacing traditional materials. As an additive, Glass powder (GP), when incorporated into a mixture in a clay body, could induce the vitrification in fired clay bricks after sintering. The author's previous study with soda-lime-glass found the integration of up to 10 wt.% of waste glass (WG) in bricks to improve the mechanical properties of fired clay bricks. Using 10 wt.% WG and fired at 900 °C yielded bricks with similar strength compared to that of normal clay brick fired at 1000 °C [20]. Dondi et al. [21] added waste glass up to 5 wt% of clay body improved mechanical property. Loryuenyong et al. [22] used waste glass; when incorporated into a mixture, the brick body could induce the vitrification in clay bricks, resulting in higher bulk density and strength and less water absorption after sintering 1100 °C. In substantiality, GP soda-lime-glass is vitreous silicate generated during the maturation of clay brick bodies, to reduce the firing temperature and enhance the sustainability of clay bricks manufacturing. However, there is still a need to relate the effect of GP on porosity, shrinkage and compressive strength characteristics of fired brick bodies. To extend the application of WBA and GP are mixed-used to manufacture bricks. In this study, the effects of WBA and GP content sintering in the clay body mixture will be investigated and discussed in terms of physical properties and mechanical strength. The results presented in this paper are significant for the effective reuse of WBA and GP for manufacturing fired bricks.

2. Materials and methods

2.1 Preparation raw materials

Local clay brick was used in this research as raw materials, which were selected from a local brick plant in Maha Sarakham Province, Thailand. The waste bagasse ash (WBA) used as a materials additive was obtained from sugar factories in Kosum Phisai district Maha Sarakham Province, Thailand. The glass powder (GP) was obtained by grinding the cracked transparent glass windows with ball-milling in a laboratory. The crushed raw materials powder passed through a sieve 200 mesh.

2.2 Experimental procedure

Firstly, WBA and GP are in different dosages (Table 1). The WBA, GP, and raw clay powders were manually mixed in a ball mill to obtain homogeneous mixtures in dry conditions. Afterward, water was added to the mixture at around 25-30% to supplement the plastic condition of the mixture. Then, it was formed in a rectangular mold (the soft-mud method) with the dimension of 50 x 90.5 x 300 mm^3. The brick specimens were then kept dried at room temperature for 7 days and next dried at 110 ± 10 °C in the oven for another 24 hrs to dispose of moisture content. After the drying process, the brick samples were fired at 900, 1000, and 1100 °C at a heating rate of 5 °C/min and of 30 min period of soaking time. Then the fired clay bricks were kept in a furnace and cooled to the room temperature.

Table 1 The mixing ratios of clay brick samples.

Brick series	Clay (wt.%)	WBA (wt.%)	GP (wt.%)
Control	100	-	-
WBAGP 01	80	10	10
WBAGP 02	70	20	10
WBAGP 03	60	30	10
WBAGP 04	50	40	10

2.3 Characterization of raw materials and test methodology

The average particle size distribution was analyzed by diffraction (Mastersizer, Melvern Instrument Ltd, UK). The chemical composition was obtained through X-ray fluorescence (XRF). A mineral phase analysis of raw materials was conducted using X-ray diffraction patterns (XRD-Bruker D8 Advance). Properties of fired clay bricks in the parts were analyzed for physical and mechanical, including; linear firing shrinkage was measured under the standard of ASTM C326-09 (2014) [23]. The physical properties of the clay brick specimens after firing were measured by the Archimedes method based on ASTM C373-14a (2014) [24] was used to determine the water absorption, bulk density, apparent density, and apparent porosity. Compressive strengths of clay brick specimens were measured following ASTM C773-88 (2011) [25] was tested using a Universal Testing Machine.

3. Results and discussion

3.1 Characteristics of raw materials used in an experiment

Table 2 chemical analysis of the raw materials.

Components	Clay (wt.%)	WBA (wt.%)	GP (wt.%)
SiO_2	59.43	84.58	71.43
Al_2O_3	20.67	1.84	0.87
Fe_2O_3	4.81	4.26	1.85
CaO	0.72	2.11	7.65
MgO	-	-	-
TiO_2	0.95	-	0.15
MnO	1.05	-	-
Na_2O	-	0.31	18.59
K_2O	2.86	0.25	0.43
LOI	12.37	7.90	-

Chemical composition of clay, WBA and GP are presented in Table 2. It was found that SiO_2, Al_2O_3 and Fe_2O_3 had the major components of raw-brick clay. Significant presence of SiO_2 was observed as the main constituent of WBA, while the minor constituents composed CaO, Na_2O and K_2O. Whereas, GP showed the content of SiO_2, Na_2O and CaO in major amount. Loss on ignition (LOI) was observed 12.37 wt.% and 7.90 wt.% for clay and WBA. However, clay and WBA showed LOI higher which may be attributed to the decarbonation reactions (organic carbon) burnt out in clay and WBA.

XRD identified clay, WBA, and GP; X-ray diffraction is presented in Fig. 1. The following crystalline phases of clay were found; quartz as the main phase with small amounts of kaolinite, orthoclase, hematite, and muscovite. In contrast, WBA is comprised of cristobalite and quartz, for GP contains only a glassy phase.

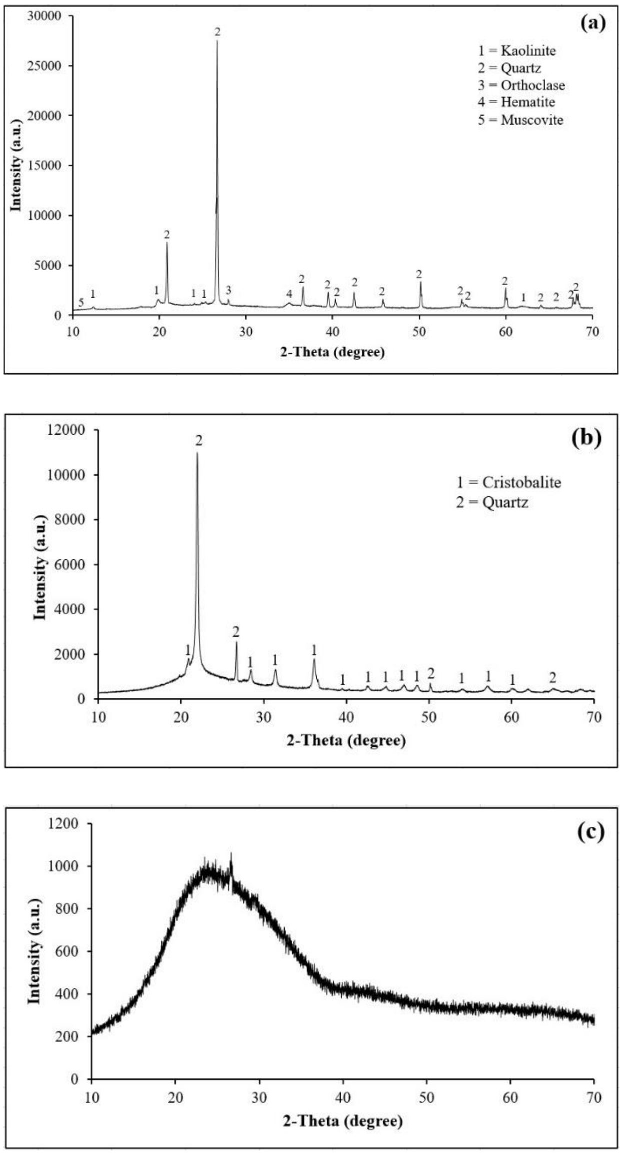

Fig. 1 XRD pattern of (a) clay (b) WBA (c) GP.

Fig. 2 shows raw materials' particle size distribution curves (clay, WBA and GP). The results revealed that the raw materials presented a wide range of average particle size D [4, 3] of clay, WBA and GP were 15.06, 81.30, and 30.22 microns, respectively.

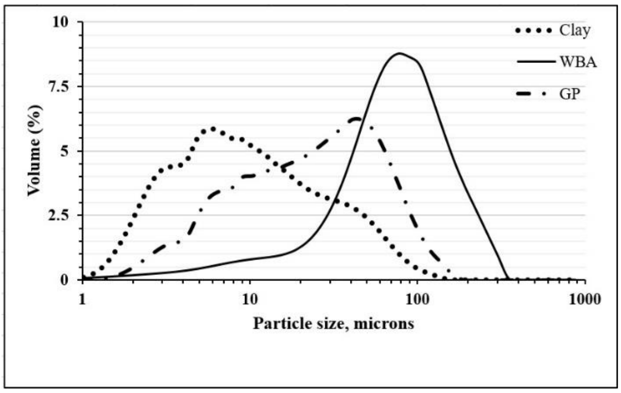

Fig. 2 Particle size curves for clay, WBA, and GP.

The scanning electron micrographs-SEM and texture of the clay particles, WBA, and GP are presented in Fig. 3.

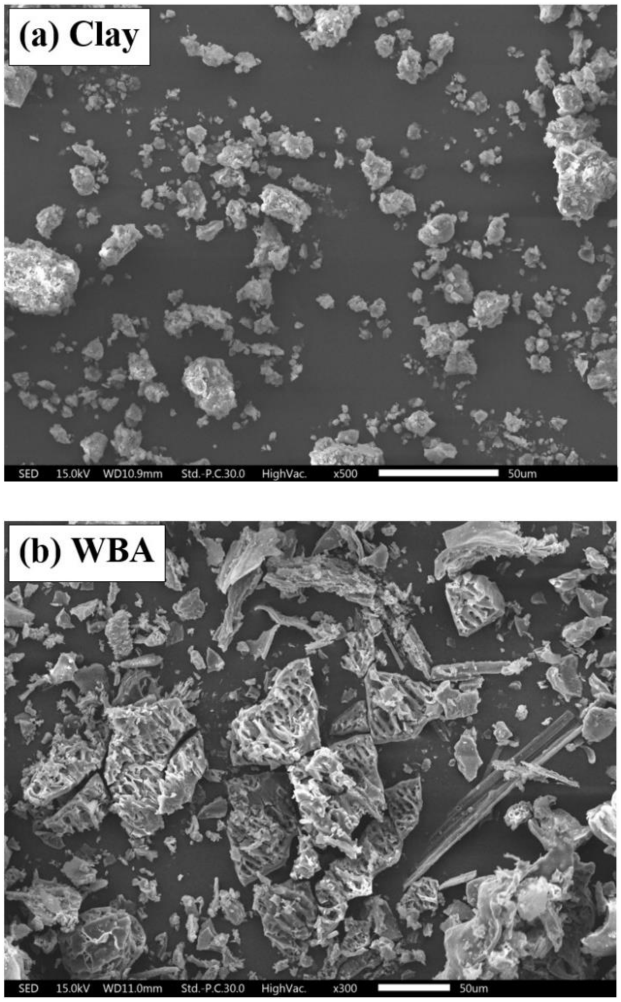

Fig. 3 SEM images of clay, WBA, and GP.

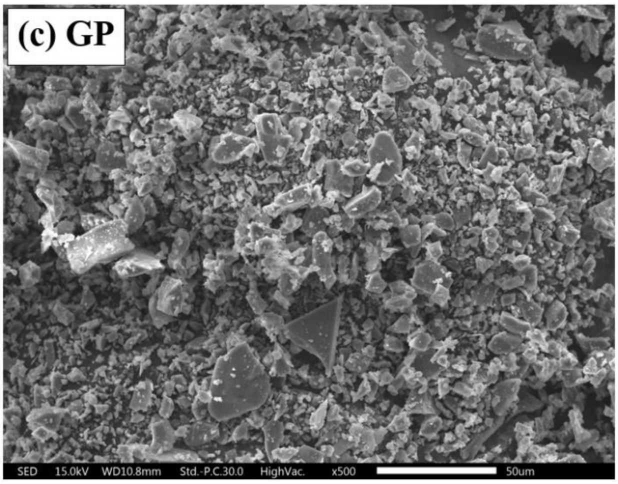

Fig. 3 (continue).

3.2 Physical properties of fired clay bricks

3.2.1 Linear firing shrinkage

The firing shrinkage behavior knowledge of a brick-body during firing is significant in clay brick bodies. Then firing temperature is a key factor to be controlled to minimize the shrinkage in the firing process [2, 9, 14]. The linear shrinkage value of the fired clay bricks tended to increase with the additives of WBA and GP, as shown in Fig. 4. Linear shrinkage increased with increasing firing temperatures from 900 to 1100 °C were in the range of 1.63% - 3.86% because of the connected neck growth during the firing mechanism process [10]. The part of the WBA and GP addition effect investigated that the percentage of firing shrinkage was enhanced with increasing WBA and GP additives. The reference clay bricks without any WBA and GP additive had a comparable firing shrinkage of 1.32% to 2.17%.

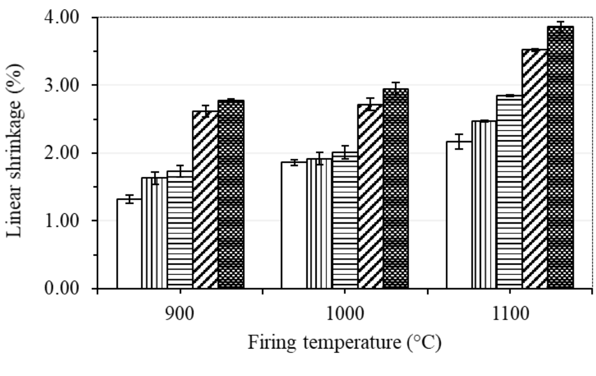

Fig. 4 Linear shrinkage of fired clay bricks.

3.2.2 Bulk density

The bulk density of clay bricks (Fig. 5) decreased with increasing WBA content in the clay bricks. This trend was expected, and it was associated with the generated open porosity during the combustion of WBA. The increased sintering temperature and the addition of the GP enhanced the bulk density of clay bricks. The test results indicated that the bulk density values of specimens containing WBA-GP varied from 0.96 to 1.45 g/cm^3. As the sintering temperature and the addition of GP rose, the GP eventually melted and formed into a liquid phase, with the clay particles tightly bonded and an increase in the bulk density and linear shrinkage [26]. The densities of fired clay bricks without additive of WBA-GP fired at 900 to 1100 °C was presented in the range of 1.68 – 1.77 g/cm^3.

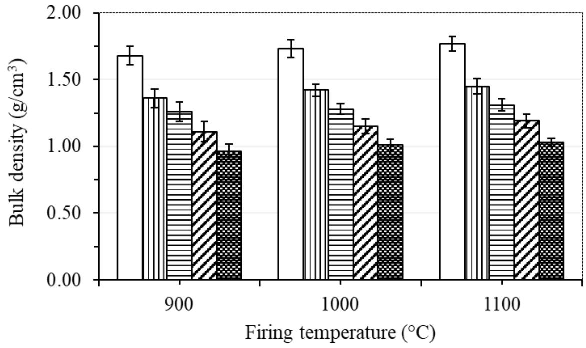

Fig. 5 Bulk density of fired clay bricks.

3.2.3 Water absorption and apparent porosity

Water absorption is accorded to the high porosity and directly affects the durability of fired clay brick. The water absorption results for clay bricks incorporating WBA-GP are shown in Fig. 6. The control clay bricks without any WBA-GP showed water absorption of 14.80% - 16.94% for sintering 900 – 1100 °C, respectively. Normally, the water absorption of fired bricks decreases with an increase in sintering temperature and the associated increase in the local liquid phase, resulting in reduced pores [10]. Apparent porosity directly affects the water absorption in the fired bricks. If the porosity of bricks is high, the humidity of bricks will be high [8, 13]. Fig. 7 shows that the apparent porosity of fired clay bricks that was related to the amounts of WBA-GP addition. The highest apparent porosity of 41.05% was obtained with clay bricks with WBA-GP addition fired at 900 °C, while lowest of 22.89% was obtained with 10 wt.% WBA-GP addition fired at 1100 °C. The control specimens without any WBA-GP addition had 21.59% - 24.60% comparable porosity.

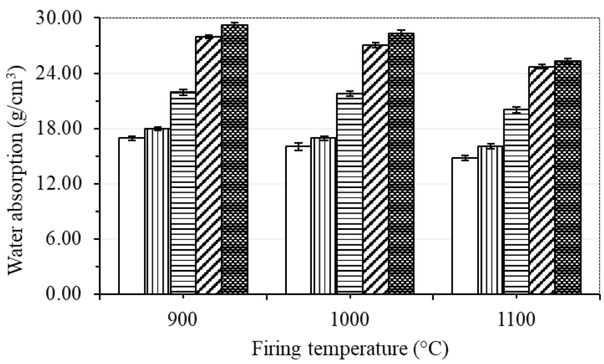

Fig. 6 Water absorption of fired clay bricks.

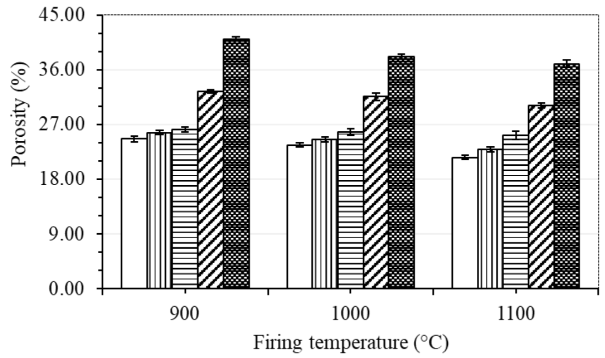

Fig. 7 Apparent porosity of fired clay bricks.

3.3 Compressive strength

The compressive strength is one of the most important parameters for construction materials since such materials serve a structural function in the building [10]. In this study, the compressive strength of specimens fired at 900 - 1100 °C depended on the WBA and GP content in the clay bricks. Compressive strength presents the deteriorated effect depending on the WBA-GP content in fired clay bricks, as be seen in Fig. 8. The compressive strength values of fired clay bricks range between 8.63 MPa with 40 wt.% WBA-GP addition fired at 900 °C and 17.85 MPa with 10 wt.% WBA-GP addition and fired at 1100 °C. On the other hand, the reference fired clay bricks without any WBA-GP addition fired at 900 °C to 1100 °C, showed a compressive strength of 14.5 – 20.14 MPa, respectively. The results indicate that the compressive strength is greatly dependent on the amount of WBA-GP in the clay bricks and the firing temperature. Compressive strength increases due to a decrease in porosity and an increase in bulk density with increasing temperature with increasing the sintering.

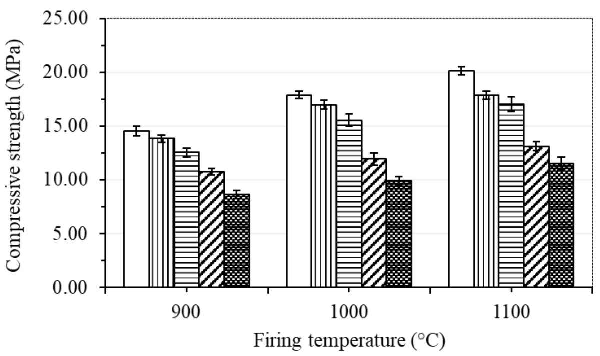

Fig. 8 Compressive strength of fired clay bricks.

4. Conclusions

This study investigated the effects of combined WBA and GP on the physical property and the compressive strength of fired clay bricks. The WBA powder dosages of 10-40 wt.% mixed GP 10 wt.% and sintering of 900 to 1100 °C were used. The following conclusions can be made from this study. An increase in firing temperature and WBA-GP content resulted in higher density with an associated decrease in the pore volume of the brick bodies, which led to increased mechanical strength. The compressive strength of fired clay bricks increases, and water absorption decreases with an increase in firing temperature (900-1100 °C). The compressive strength of fired clay bricks containing 10 wt.% WBA-GP is 17.85 MPa fired at 1100 °C. The ASTM C62-13a specifies that the Grade MW bricks must have the minimum compressive strength of 17.2 MPa. Conclusively, the use of WBA-GP as an additive in clay brick manufacturing is, therefore, recommended. The reuse of WBA-GP reduces the burden on the environment and makes the bricks production sustainable and eco-friendly**.**

5. Acknowledgment

The authors also would like to acknowledge the financial support from Rajabhat Maha Sarakham University.

References

[1] Heidari, L. and Jahili Ghazizade, M. (2021). Recycling of spent industrial soil in the manufacturing process of clay brick. Process Safety and Environmental Protection, 145, pp. 133-140.

[2] Njindam, O.R., Njoya, D., Mache, J.R., Mouafon, M., Messan, A. and Njopwouo, D. (2018). Effect of glass powder on the technological properties and microstructure of clay mixture for porcelain stoneware tiles manufacture. Construction and Building Materials. 170, pp. 512-519.

[3] Sutcu, M., Alptekin, H., Erdogmus, E., Er Y. and Gencel, O. (2015). Characteristics of fired clay bricks with waste marble powder addition as building materials. Construction and Building Materials. 82, pp. 1-8.

[4] Ngayakamo, B.H., Bello, A. and Onwualu, A.P. (2020). Development of eco-friendly fired clay bricks incorporated with granite and eggshell wastes. Environmental Challenges. 1, pp. 100006.

[5] Sutcu, M., Erdogmus, E., Gencel, O., Gholampour A., Atan, E. and Ozbakkaloglu, T. (2019). Recycling of bottom ash and fly ash wastes in eco-friendly clay brick production. Journal of Cleaner Production. 233, pp. 753-764.

[6] Reis dos, G.S., Cazacliu, G.B., Cothenet, A., Poullain, P., Wilhelm, M., Sampaio, C.H., Lima, E.C., Ambros, W. and Torrenti, J.M. (2020). Fabrication, microstructure, and properties of fired clays using construction and demolition waste sludge as the main additive. Journal of Cleaner Production. 258, pp. 120733.

[7] Srisuwan, A. and Phonphuak, N. (2020). Physical property and compressive strength of fired clay bricks incorporated with paper waste. Journal of Metals, Materials and Minerals. 30 (1), pp. 103-108.

[8] Maza-Ignacio, O.T., Jiménez-Quero, V.G., Guerrero-Paz, J. and Montes-García, P. (2020). Recycling untreated sugarcane ash and industrial wastes for the preparation of resistant, lightweight and ecological fired bricks. Construction and Building Materials. 234, pp. 117314.

[9] Ozturk, S., Sutcu, M., Erdogmus, E. and Gencel, O. (2019). Influence of tea waste concentration in the physical, mechanical and thermal properties of brick clay mixtures. Construction and Building Materials. 217, pp. 592-599.

[10] Chindaprasirt, P., Srisuwan, A., Saengthong, C., Lawanwadeekul, S. and Phonphuak, N. (2021). Synergistic effect of fly ash and glass cullet additive on properties of fire clay bricks. Journal of Building Engineering. 44, pp. 102942.

[11] Juel, M.A.I., Mizan, A. and Ahemd, T. (2017). Sustainable use of tannery sludge in brick manufacturing in Bangladesh. Waste Management. 60, pp. 259-269.

[12] Gencel, O., Kazmi, S.M.S., Munir, M.J., Sutcu, M., Erdogmus, E. and Yaras, A. (2021). Feasibility of using clay-free bricks manufactured from water treatment sludge, glass and marble wastes: An exploratory study. Construction and Building Materials. 298, pp. 123843.

[13] Kazmi, S.M.S., Munir, M.J., Patnaikuni, I., Wu, Y.F. and Fawad U. (2018). Thermal performance enhancement of eco-friendly bricks incorporating agro-wastes. Energy and Building. 158, pp. 1117-1129.

[14] Faria, K.C.P., Gurgel, R.F. and Holanda, J.H.F. (2012). Recycling of sugarcane bagasse ash waste in the production of clay bricks. Journal of Environmental Management. 101, pp. 7-12.

[15] Kazmi, S.M.S., Abbas, S., Saleem, M.A., Munir, M.J. and Khitab, A. (2016). Manufacturing of sustainable clay brick: Utilization of waste sugarcane bagasse and rice husk ashes, Construction and Building Materials. 120, pp.29-41.

[16] Phonphuak. N. and Chindaprasirt, P. (2018). Utilization of sugarcane bagasse ash to improve properties of fired clay brick. Chiang Mai Journal of Science. 45(4), pp. 1855-1862.

[17] Dong, W., Li, W. and Tao, Z. (2021). A comprehensive review on performance of cementitious and geopolymeric concretes with recycled waste glass as powder, sand or cullet. Resources, Conservation and Recycling. 172, pp. 105664.

[18] Robert, D., Baez, E. and Setuge, S. (2021). A new technology of transforming recycled glass waste to construction components. Construction and Building Materials. 313, pp. 125539.

[19] Park, Y.J. and Heo, J. (2002). Conversion to glass-ceramics from glasses made by MSW incinerator fly for recycling. Ceramics International. 28, pp. 689-694.

[20] Phonphuak, N., Kanyakam, S. and Chindaprasirt, P. (2016). Utilization of waste glass to enhance physical-mechanical properties of fired clay brick. Journal of Cleaner Production. 112, pp. 3057-3062.

[21] Dondi, M., Guarini, G., Raimondo, M. and Zanelli, C. (2009). Recycling PC and TV waste glass in clay bricks and roof tiles. Waste Management. 29, pp. 1945-1951.

[22] Loryuenyong, V., Panyachai, T., Kaewsimork, K. and Siritai, C. (2009). Effects of recycled glass substitution on the physical and mechanical properties of clay bricks, Waste Management. 29, pp. 2717-2721.

[23] ASTM C326-09 Standard Test Method for Drying and Firing Shrinkages of Ceramic Whiteware Clays, ASTM International, West Conshohocken, PA, (2014) ASTM Book of Standards Vol. 15.02.

[24] ASTM C373-14a. Standard Test Method for Water Absorption, Bulk Density, Apparent Porosity, and Apparent Specific Gravity of Fired Whiteware Products, Ceramic Tiles, and Glass Tiles, ASTM International, West Conshohocken, PA, (2014) ASTM Book of Standards Vol. 15.02.

[25] ASTM C773-88 Standard Test Method for Compressive (Crushing) Strength of Fired Whiteware Materials, ASTM International, West Conshohocken, PA, (2011) ASTM Book of Standards Vol. 15.02.

[26] Mao, L., Wu, Y., Zhang, W. and Huang, Q. (2019). The reuse of waste glass for enhancement of heavy metals immobilization during the introduction of galvanized sludge in brick manufacturing. Journal of Environmental Management. 231, pp. 780-787.