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Original Article

Sustainable unglazed and low sintering temperature wall tiles by reutilizing sediment soil from the water supply treatment process and glass cullet

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Abstract

This research aimed to reutilize sediment soil from water supply treatment process and waste glass for developing eco-friendly wall tiles. Different amounts, 30-80% of sediment soil and 10-60% of brown glass cullet were used to develop wall tiles. Specimens were moulded by uniaxial pressing at 100 bars with dimensions of 50x100x7 mm. They all fired at a heating rate of 100° C/h and maximum temperature of 950° C for 1 h. Bending strength and water absorption properties of wall tiles were tested and compared with Thai industrial standard (TIS) 2508-2555. Their properties depended on amounts of sediment soil and glass cullet. The optimal formula contained 30 wt% sediment soil and 60 wt% brown glass cullet was selected. Its bending strength and water absorption achieved Thai industrial standard (TIS) 2508-2555. It can be concluded that reutilizing sediment soil and brown glass cullet for developing eco-friendly wall tiles is feasible.

Keywords: sediment soil, glass cullet, unglazed wall tile, eco-friendly, low sintering temperature

1. Introduction

The generation of an abundance of industrial waste materials is an environmental problem faced all over the world. The management of these waste materials creates increased burden and costs for all entrepreneurs. To alleviate this problem, producing eco-friendly products from industrial waste should be carried out. Moreover, the high consumption of fuel for manufacturing products is another crucial issue facing manufacturers today. This study proposed a way to solve the aforementioned problems by utilizing industrial waste consisting of sediment soil from the water supply treatment process along with glass cullet waste from the glass industry for producing unglazed and low-sintering temperature fired wall tiles.

In Thailand, supplying water to people in the metropolitan area is the responsibility of the Metropolitan Waterworks Authority (Bangkhen Water Treatment Plant, 2018). There are four main water supply plants for supporting the increased demand. They are located in the Bangkhaen, Mahasawat, Samsen, and Thonburi areas of Bangkok with capacities of 3.6, 0.8, 0.7, and 0.17 million cubic meters/day, respectively. Bangkhaen plant is the area of focus for this research. Sediment soil generated from the clarification station of the water supply treatment process accounts for more than 0.1 million tons/ year. Disposal sediment soil waste results in high disposal costs for the MWA amounting to approximately \$63,897.76 USD (2x10^6 THB) / year. The research utilized sediment soil from this plant.

From the yearly report by the pollution control department in 2016 (Pollution Control Department, 2017) 42% of waste glass in Thailand is not utilized, amounting to 1,014,653 tons. Owing to containing fluxing agent, glass cullet can be employed as a material for reducing the firing temperature (Wangrakdiskul, Wanasbodee, & Sansroi, 2017).

Concerning energy consumption in the ceramics industry, a significant quantity of thermal energy is consumed in the firing stage of the ceramic manufacturing process (Ana, Juan, Eliseo, & Gustavo, 2014) Developing unglazed and low

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sintering temperature wall tiles is a feasible method for solving this problem.

2. Literature Review

Previous studies about utilizing industrial waste for ceramic products can be classified into two groups. The first group involves the sediment soil and sludge waste used, while the second group refers to utilizing glass cullet for ceramic and cement products. These groups are expressed in greater detail below.

The first group concerning utilization of sediment soil consists of the following studies. The application of sediment soil from water supply for ceramics products by small enterprise was reported by Suriyachat, Vichitamornpun and Ruangsumret (2004). A suitable ratio of sediment soil: sand at 70:30 can be used for forming ceramic clay ware sintered at 950° C. Boonin, Sarapol and Deesui (2012) investigated the properties of light-weight concrete by utilizing sediment soil from the water supply process as coarse aggregate. The compressive strength of products with a ratio 80:20 for plastic clay: sediment soil can pass ASTM C338. In addition, cement block mixing with 10-30% chemical sludge was proposed by Chatsatapattayakul, Wangwiang and Pengthamkeerati (2012) and compared with Thailand Institute of Scientific and Technological Research (TISTR) standard. It can achieve good strength and water resistance. The study of Wangrakdiskul *et al.* (2017) utilized 15% sediment soil for replacement of kaolin clay to produce vitreous China ceramic products. In addition, Wangrakdiskul and Neamlat (2018) also investigated non-fired wall tiles by utilizing 10% sediment soil. Although its water absorption could pass standard TIS 2508-2555, its bending strength was unable to pass the standard. These studies utilized sediment soil from the water supply treatment process. Furthermore, water treatment process waste from industrial processes was also utilized in the following work. Water treatment plant (silt, sand and clay) sludge with 20% can be used to produce ceramic bricks (Teixeira, Santos, Souza, Alessio, Souza, & Souza, 2011). The effect of incorporating waste sludge on the properties and microstructure of clay used for bricks manufacturing was assessed by Martínez-García, Eliche-Quesada, Pérez-Villarejo, Iglesias-Godino and Corpas-Iglesias (2012). They summarised that incorporating sludge by up to 5 wt% was beneficial for clay bricks. Kizinievic, Zurauskiene, Kizinievic and Zurauskas (2013) studied the physical and mechanical properties, structural parameters and mineralogical composition of ceramic products, which incorporated fresh water treatment sludge (WTS). The results of their study proposed that colorific Fe_2O_3 in WTS could be utilized as natural pigment in ceramic products for a darker, more intense red color. In addition, sludge was used by Wolff, Keller Schwabe and Vieira Conceiçao (2014) as a substitute material for the formulation of clay body with mixtures between 50-85% at 850 and 950 °C. These mixtures are suitable for producing interior coatings or acoustic bricks.

The second group of research for utilizing glass cullet is described as follows. Youssef, Abadir and Shater (1998) recommended that utilizing 23% soda glass and firing at 1,100 °C for 3 h resulted in wall and floor tiles manufactured with the best mechanical strength. For concrete products, Shayan and Xu (2004) proposed the utilization of waste glass as a pozzolanic material. 30% waste glass can be used to substitute for cement with satisfactory strength. Colored glass cullet had the potential (Karamberi, & Moutsatsou, 2005) to produce various cementitious products for decorative and architectural applications. Braganc, Licenzi, Guerino and Bergmann (2006) evaluated production using foundry sand and glass waste for white ware fired between 1,100 and 1,300 °C. The results showed that producing triaxial ceramics using foundry and glass waste was feasible. Braganca and Bergmann (2005) proposed the use of waste glass as a fluxing material for porcelain, which can reduce the firing temperature from 1,340 °C to 1,240 °C with similar water absorption. Chidiac and Federico (2007) studied the effects of waste glass additions on the properties and durability of fired clay brick. They recommended that 10% fine or 15% coarse particles of waste glass could improve the properties as well as the volume stability and color change of the product. Luz and Ribeiro (2007) proposed that 5% waste glass fired at 1,240 °C was the component classified as a porcelain stoneware tile. Loryuenyong, Panyachai, Kaew simork and Siritai (2009) evaluated the effect of waste glass used on the physical and mechanical properties of clay bricks. They summarized that the proper firing temperature of 1,100 °C, waste glass 15–30 wt % was able to meet the minimum requirements in a wide range of applications. Demir (2009) proposed that the use of waste glass by up to 10% firing at 950 °C 1,050 °C was feasible to produce building bricks. Islam, Rahman and Kazi (2006) demonstrated that 15% waste glass could be used as a pozzolanic reaction material with the cement of concrete product. Tiffo, Elimbi, Manga and Tchamba (2015) investigated utilizing waste glass by up to 15% fired at 750°C. They recommended that it could be used for producing red ceramic bricks. Aliabdo, Abd Elmoaty and Aboshama (2016) suggested that the use of 15% glass powder as cement addition increased concrete compressive strength by 16% and achieved better performance compared with as cement replacement. Kazmi, Abbas, Nehdi, Saleem and Munir (2017) studied the feasibility of using waste glass sludge. They summarized that waste glass could enhance the physical and mechanical properties of clay bricks, leading to more economical and sustainable construction.

There are many researches that have investigated valorizing waste material (Velasco, Mendívil, Morales Ortiz, & Velasco, 2014) and glass cullet for producing fired clay bricks (Mohajerani, Vajna, Cheung, Kurmus, Arulrajah, & Horpibulsuk 2017). However, reutilizing sediment soil waste from the water supply treatment process and combining with glass cullet has not been proposed. This study aims to investigate the new product responding to waste utilization and low sintering temperature for reducing energy consumption.

3. Materials and Methods

3.1 Raw materials used

In this study, three types of materials were used consisting of sediment soil from the water supply treatment process, brown glass cullet, and compound clay. The first two types of materials were waste from industries, while the third material was used for facilitating easier formation of specimens. All materials have been analyzed and the chemical composition is shown in Table 1. Sediment soil originated form the water supply treatment process at the Bangkhen plant in Thailand. Brown glass cullet comprised waste from the Bangkok glass industry, which had been used for reducing the sintering temperature of specimens. Compound clay was of the commercial-grade.

All of the raw materials were dried at 150 °C for 2 hours. Then, they were ground by pot mill to get fine particles and sizing by 375-micrometer sieve. Mixture formulations for 21 formulas were conducted as illustrated in Table 2 and classified into 6 groups: A, B, C, D, E and F.

All formulas mixtures were pressed for preparing specimens by a uniaxial pressing technique in a 50x100 mm rectangular die at 100 bars and dried at 150 °C. The firing step was carried out in a laboratory in an electric kiln at a heating rate of 100 °C/h and maximum temperature 950 °C for 1 hour. After that, all specimens of each formula were tested for mechanical and physical properties, including bending strength, water absorption, shrinkage, weight loss, and bulk density. X-ray diffraction was carried out to determine the mineralogical composition of the investigated formulations. The microstructure of specimens was observed by scanning electron microscopy (SEM).

3.2 Fluxing agent

Oxide of Na_2O, K_2O and CaO content in the raw material used are the fluxing agent materials. They play an important role for reducing the sintering temperature of a ceramic body. Tiffo *et al.* (2015) recommended fluxing agent from waste glass for red brick or roofing tiles. Sokolár, Kersnerováa, and Svedab (2017) also investigated fluxing agent from bone ash mixed with potassium feldspar for producing porcelain body. It can reduce the sintering temperature by 50 °C.

In the present study, Na_2O, K_2O and CaO of raw materials mainly from brown glass cullet were considered as fluxing agent for reducing the sintering temperature and increasing bending strength. The results of improving bending strength of specimens will be compared with other un-utilized glass cullet products (Sousa, & Holanda 2005).

4. Results and Discussion

All of the material mixtures of 21 formulas were prepared and fired at 950 °C with soaking for 1 h. All were tested for physical and mechanical properties. Microscopic structure analysis using Scanning Electron Microscopy and X-ray Diffraction was also performed to characterize the fired specimens. Before revealing the test properties of all formulas the fluxing agent content of each formula will be calculated, which are presented in the following subsections.

4.1 Fluxing agent quantities

As recognition for reducing the sintering temperature, fluxing agent refers to Na_2O, K_2O, and CaO, which can enhance the bending strength of ceramic bodies. The quantity of these oxides for each mixture formulas is calculated from the chemical composition of raw materials (Table 1) and composition of mixture formulas (Table 2), as illustrated in Figure 1.

Table 1. Chemical analysis of raw materials used.

	(%wt)		
	Sediment soil	Brown glass cullet	Compound clay
SiO_2	60.95	72.1	47.8
Al_2O_3	25.96	1.6	14.9
Fe_2O_3	6.22	0.1	0.62
K_2O	1.93	0.2	1.51
Na_2O	0.33	12.9	0.73
CaO	0.91	2.4	8.86
MgO	1.41	0.05	7.22
TiO_2	0.85	0.05	0.08
MnO	0.18		
P_2O_5	0.46		
SO_3	0.33	0.15	

Table 2. Mixture formulations of the tri axial ceramic formulas (%wt).

No.	(%wt)		
	Sediment soil	Brown glass cullet	Compound clay
1A	30	60	10
2A	40	50	10
3A	50	40	10
4A	60	30	10
5A	70	20	10
6A	80	10	10
7B	30	50	20
8B	40	40	20
9B	50	30	20
10B	60	20	20
11B	70	10	20
12C	30	40	30
13C	40	30	30
14C	50	20	30
15C	60	10	30
16D	30	30	40
17D	40	20	40
18D	50	10	40
19E	30	20	50
20E	40	10	50
21F	30	10	60

4.2 Mechanical and physical properties

4.2.1 Bending strength

The three-points bending method was employed for testing. All fired specimens of 21 formulas were evaluated. They are shown and compared with each other in Figure 2. It can be analyzed that the formula having high fluxing content in each group also gives high bending strength. For this reason, formula no.1A, 7B, 12C, 16D, 19E and 21F have high content of fluxing agent and provide high bending strength in each group. Table 3 shows a comparison for bending strength of formula No.1A and the TIS 2508-2555 Standard. Formula No. 1A can meet this standard with the highest bending strength. Table 4 expresses the comparison of formula not utilizing glass cullet (Sousa, & Holanda 2005) with formula No.1A. This indicates that the firing temperature can be reduced by utilizing glass cullet.

Figure 1. Fluxing agent content of all mixtures.

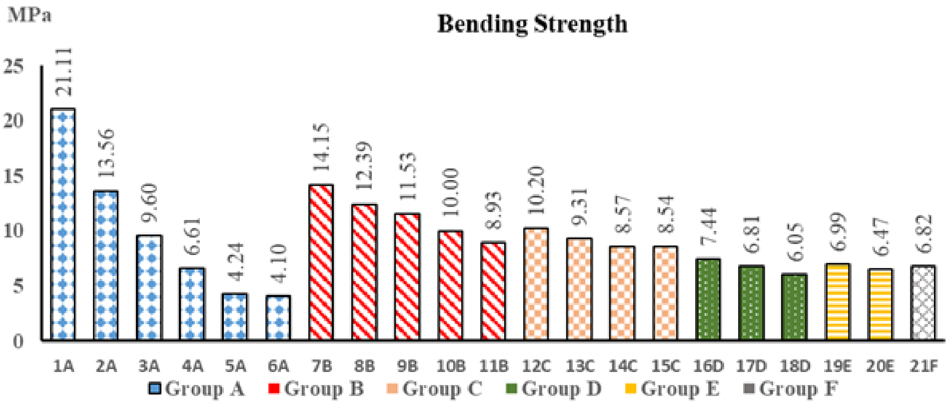

Figure 2. Bending strength of fired 21 formulas specimens.

Table 3. Comparison of bending strength of formula No. 1A with TIS 2508-2555 of sediment soil and glass cullet utilization.

	Bending strength (MPa)	%Water absorption by weight	% Proportion	
			Sediment soil	Glass cullet
TIS 2508-2558; Type BIII	12	>10% , <20%	-	-
Formula no. 1A	21.11	15.86%	30	60

Table 4. Comparing bending strength and firing temperature between unutilized wastes and No.1A formula.

	Bending strength (MPa)	%Water absorption by weight	Firing temperature (ºC)
Clay, Calcareous and Quartz formulation (Sousa & Holanda 2005)	>15	18.5%	>1100
Formula no. 1A	21.11	15.86%	950

4.2.2 Water absorption

Water absorption testing of all fired specimens was performed by calculating the weight difference between dry and water saturated samples. They were immersed in boiling water for 2 h. The water absorption value is shown in Figure 3. It can be observed that lower water absorption leads to higher bending strength (Figure 2) of specimens. In addition, water absorption compared with TIS 2508-2555 was performed (Table 3). It can also pass this standard with no greater than 20% water absorption.

4.2.3 Linear shrinkage, weight loss and density

Figure 4 shows the comparison of linear shrinkage, weight loss and density of six formulation groups (Group A, B, C, D, E and F), which consist of 21 formulas. Each group indicates that the high shrinkage of samples leads to high density, but with low weight loss as well. Formula No. 1A has the highest shrinkage and density due to having a higher composition of glass cullet (Table 2) and fluxing agent (Figure 1). This phenomenon can be explained by the fluxing agent providing a lower sintering temperature. This can fur-

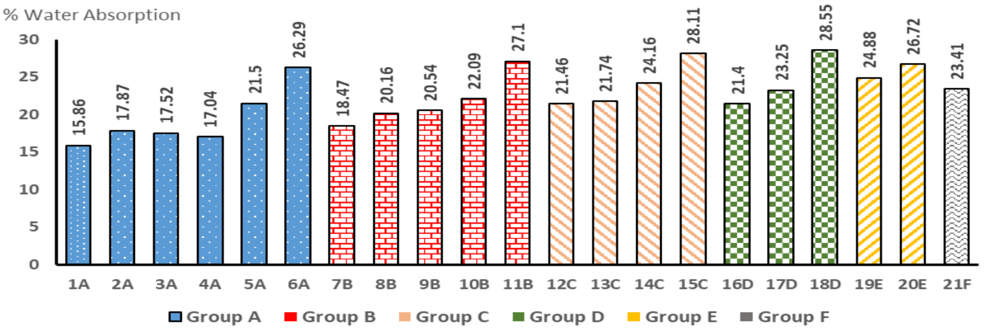

Figure 3. Water absorption of 21 formula fired specimens.

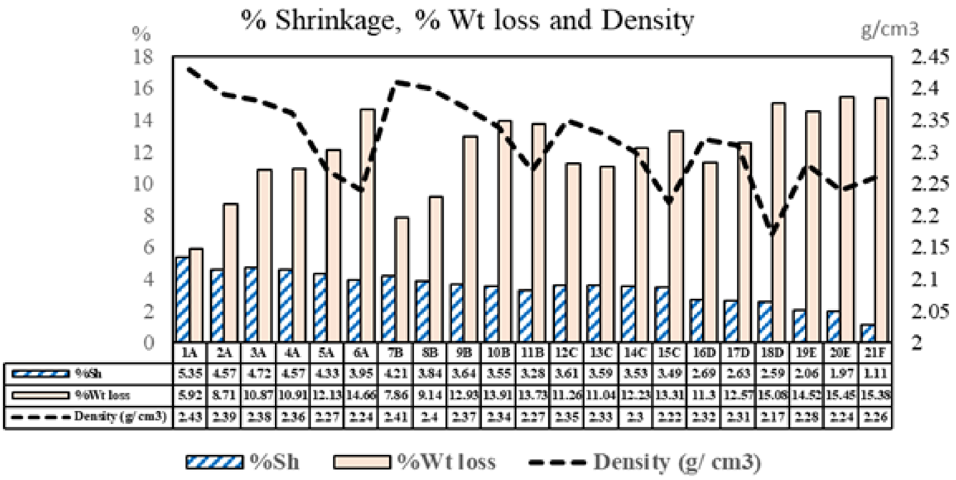

Figure 4. Comparison linear shrinkage, weight loss, and density of ceramic bodies.

ther decrease the porosity of specimens. In addition, formula No. 1A has the lowest weight loss due to having low composition of sediment soil and compound clay (Table 2). It can be analysed that sediment soil and compound clay have higher carbonaceous matter. When they are burned, high weight loss of ceramic bodies is achieved.

4.3 X-ray diffraction analysis

For analyzing the phases presented in the microstructure of specimens, X-ray diffraction was used for evaluation. Formulas having the highest and lowest bending strength (No. 1A and 21F) were selected for analysis. The results are shown in Figures 5 and 6. The main phase in the microstructure of No. 1A (Figure 5) is cristobalite, while quartz phase is the main phase of No. 21F (Figure 6). This phenomenon can be explained by clay changing phase from quartz to cristobalite at 950^{o} C (Pimkaokum 2004). Furthermore, nepheline syenite is also found, which indicates evidence of occurring feldspathic material in formula No. 1A. This can promote the lower sintering temperature of ceramic bodies.

4.4 Scanning electron microscopy analysis

Figures 7 and 8 show the scanning electron microscopy images of formulations No. 1A and 21F. It was observed that formulation No.1A consists of glassy phase and larger crystal sizes than that of formulation No.21F. This phenomenon can promote the higher strength of No.1A.

5. Summary and Conclusions

In this study, the properties of wall tiles incurporating sediment soil and glass cullet were investigated. Utilization of sediment soil and glass cullet waste as alternative materials was carried out for producing wall tiles with high impact by reutilizing industrial waste materials. It was observed that glass cullet played an important role as an efficient fluxing agent for mixing in ceramic bodies. This effect promoted low sintering temperature at 950 ^{o}C and led to higher bending strength, lower water absorption, higher bulk density, and higher shrinkage of specimens, as illustrated in Figure 9. In addition, sediment soil from the water supply treatment process containing Fe_2O_3 content can be utilized to produce rustic terracotta ceramic tiles.

It can be summarized that waste utilization of glass cullet and sediment soil has the possibility to produce Eco-friendly unglazed wall tiles. These products comprise a new approach for customers who prefer to use green construction products and enhance marketing channels for the manufacturers. For the future work, seasonal change of sediment soil and their different position should be investigated. In addition, concerning about systematic blending to get consistent raw materials also has to be taken into consideration for the next study.

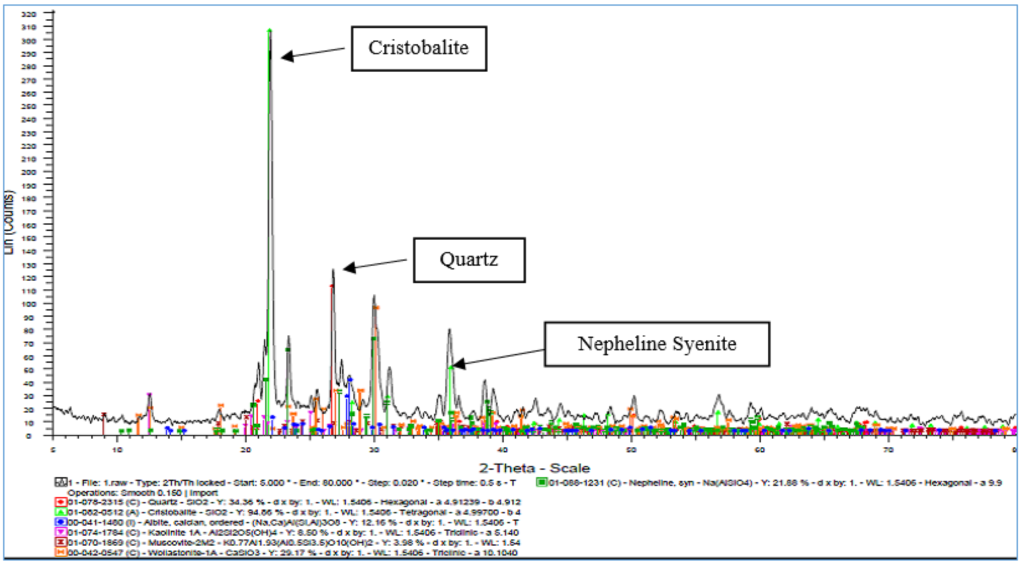

Figure 5. X-ray diffraction pattern of formula No. 1A.

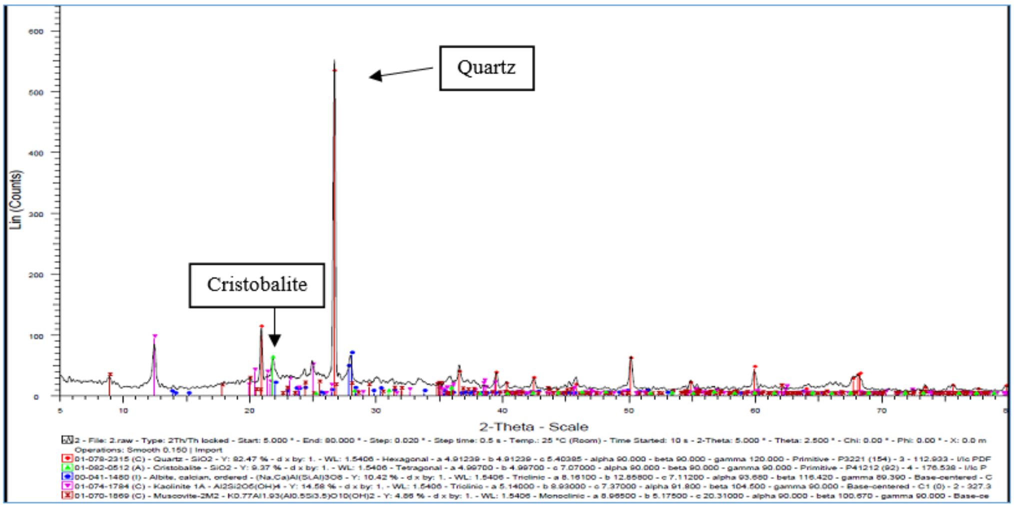

Figure 6. X-ray diffraction pattern of formula No. 21F.

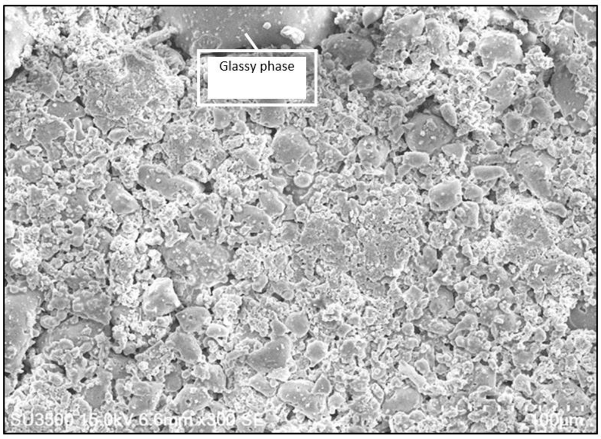

Figure 7. SEM images of formula No.1A at 300x.

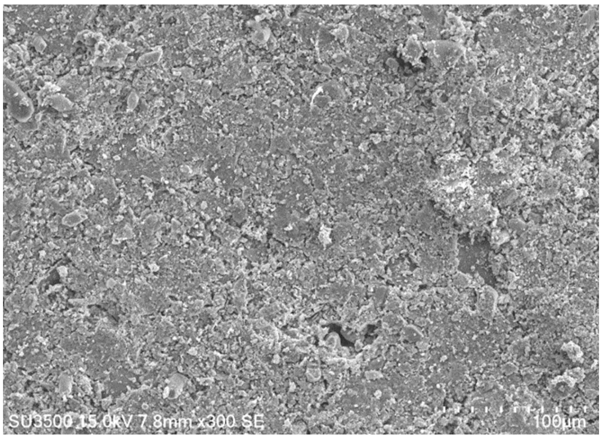

Figure 8. SEM images of formula No.21F at 300x.

Figure 9. Samples of fired specimens in this study.

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References

Aliabdo, A., Abd Elmoaty, A., & Aboshama, A. (2016). Utilisation of waste glass powder in the production of cement and concrete. *Construction and Building Materials*, *124*, 866-877. Retrieved from https://www.sciencedirect.com/science/article/pii/S095006181631279X

Ana, M., Juan, B. M., Eliseo, G., & Gustavo, M. G. (2014). Energy saving in ceramic tile kilns: Cooling gas heat recovery. *Applied Thermal Engineering*, *65*, 1–2. Retrieved from https://www.sciencedirect.com/science/article/pii/S1359431114000088

Bangkhen Water Treatment plant. (2018). Retrieved from https://www.mwa.co.th/ewtadmin/ewt/mwa_internet eng/download/question/bkplant eng.pd.

Braganc, S. R., Licenzi, J., Guerino, K., & Bergmann, C. P. (2006). Recycling of iron foundry sand and glass waste as raw material for production of white ware. *Waste Management Research*, *24*, 60–6. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/16496871

Braganca, S. R., & Bergmann, C. P. (2005). Waste glass in porcelain. *Material Research*, *8*, 39 - 44. Retrieved from www.scielo.br/scielo.php?script=sci_arttext&pid=S1516...

Boonin, K., Sarapol, S., & Deesui, S. (2012). *Properties of lighted weight concrete used sediment soil from water supply process as coarse aggregate* (Senior Project, Department of Civil Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen, Thailand). Retrieved from https://app.enit.kku.ac.th/mis/project/project_detail.php?projectID...23...

Chatsatapattayakul, N., Wangwiang, M., & Pengtham keerati, P. (2012). Potential use of chemical sludge from water treatment system with cement in cement mortar and soil cement block. *Rajabhat Journal of Science, Humanities and Social Sciences*, *13*(1), 48-54. Retrieved from https://www.tci-thaijo.org/index.php/psru/article/view/16993

Chidiac, S. E., & Federico, L. M. (2007). Effects of waste glass additions on the properties and durability of fired clay brick. *Canadian Journal of Civil Engineering*, *34*(11), 1458–1466. Retrieved from https://www.researchgate.net/.../237151861_Effects_of_waste_glass_add...

Demir, I. (2009). Reuse of waste glass in building brick production. *Waste Management and Research*, *00*, 1–6. Retrieved from journals.sagepub.com/doi/abs/10.1177/0734242X08096528

Islam, G., Rahman, M., & Kazi, N. (2006). Waste glass powder as partial replacement of cement for sustainable concrete practice. *International Journal of Sustainable Built Environment*, *6*, 37-44. Retrieved from https://www.sciencedirect.com/science/article/pii/S2212609016301157

Karamberi, A., & Moutsatsou, A. (2005). Participation of coloured glass cullet in cementitious materials. *Cement and Concrete Composite*, *27*, 319–27. Retrieved from https://www.sciencedirect.com/science/article/pii/S0958946504000381

Kazmi, S. M., Abbas, S., Nehdi, M. L., Saleem, M. A., & Munir, M. J. (2017). Feasibility of using waste glass sludge in production of ecofriendly clay bricks. *Journal of Materials in Civil Engineering*, *29*(8), 04017056. Retrieved from https://ascelibrary.org/doi/10.../%28ASCE%29MT.1943-5533.0001928

Kizinievic, O., Zurauskiene, R., Kizinievic, V, & Zurauskas, R. (2013). Utilisation of sludge waste from water treatment for ceramic products. *Construction and Building Materials*, *41*, 464–473. Retrieved from https://www.sciencedirect.com/science/article/pii/S0950061812009981

Loryuenyong, V., Panyachai,T., Kaewsimork, K., & Siritai, C. (2009). Effects of recycled glass substitution on the physical and mechanical properties of clay bricks. *Waste Management*, *29*, 2717-2721. Retrieved from https://www.sciencedirect.com/science/article/pii/S0956053X09002062

Luz, A. P., & Ribeiro, S. (2007). Use of glass waste as a raw material in porcelain stoneware tile mixtures. *Ceramics International*, *33*, 761–765. Retrieved from https://www.sciencedirect.com/science/article/pii/S0272884206000599

Martínez-García, C., Eliche-Quesada, D., Pérez-Villarejo, L., Iglesias-Godino, & F. J., Corpas-Iglesias, F. A. (2012). Sludge valorisation from wastewater treatment plant to its application on the ceramic industry. *Journal of Environmental Management*, *95*, S343-S348. Retrieved from https://www.sciencedirect.com/science/article/pii/S0301479711002131

Mohajerani, A., Vajna, J., Cheung, T. H. H., Kurmus, H., Arulrajah, A., & Horpibulsuk, S. (2017). Practical recycling applications of crushed waste glass in construction materials: A review. *Construction and Building Materials*, *156*, 443–467. Retrieved from https://www.sciencedirect.com/science/article/pii/S0950061817318068

Pimkaokum, P. (2004). *Ceramics* (3rd), Bangkok, Thailand: Chulalongkorn University Press.

Pollution Control Department, Ministry of Natural Resources and Environment, Thailand State of Pollution Report 2016. (2017), Retrieved from http://www.pcd.go.th/public/Publications/print_report.cfm?task=pcdreport-59final

Shayan, A., & Xu, A. (2004). Value-added utilisation of waste glass in concrete. *Cement and Concrete Research*, *34*(1), 81–89. Retrieved from https://www.sciencedirect.com/science/article/pii/S0008884603002515

Sokolár, R., Kersnerováa, L., & Svedab, M. (2017). The effect of different fluxing agents on the sintering of dry pressed porcelain bodies. *Journal of Asian Ceramic Societies*, *5*, 290-294. Retrieved from https://www.sciencedirect.com/science/article/pii/S2187076416301208

Sousa, S., & Holanda, J. (2005). Development of red wall tiles by the dry process using Brazilian raw materials. *Ceramic International*, *31*, 215–222. Retrieved from https://www.sciencedirect.com/science/article/pii/S0272884204003402

Suriyachat, D., Vichitamornpun, P., & Ruangsumret, W. (2004). Application of Sediment Soils, Metallurgical Technology Group, Bureau of Primary Industries, Department of Primary Industries and Mines, Country Report. Thailand. Retrieved from www.dpim.go.th/service/download?articleid=3247&F=4765

Teixeira, S. R., Santos, G. T. A., Souza, A. E., Alessio, P., Souza, S. A., & Souza, N. R. (2011). The effect of incorporation of a Brazilian water treatment plant sludge on the properties of ceramic materials. *Applied Clay Science*, *53*, 561–565. Retrieved from https://www.sciencedirect.com/science/article/pii/S0169131711001724

Tiffo, E., Elimbi, A., Manga, J. D., & Tchamba, A. B. (2015). Red ceramics produced from mixtures of kaolinite clay and waste glass. *Brazilian Journal of Science and Technology*, 2(4), 1-13. DOI 10.1186/s40552-015-0009-9.

Velasco, M. P., Mendívil, M. A., Morales Ortiz, M. P., & Velasco, M. L. (2014). Fired clay bricks manufactured by adding wastes as sustainable construction material—A review. *Construction and Building Material*, *63*, 97–107. Retrieved from https://www.sciencedirect.com/science/article/pii/S0950061814003080

Wangrakdiskul, U., & Neamlut, R. (2018). Reutilising sediment soil wastes from water supply treatment process as replacement materials of non-fired wall tiles. *Materials Science Forum*, *917*, 303-310. Retrieved from https://doi.org/10.4028/www.scientific.net/MSF.917.303

Wangrakdiskul, U., Wanasbodee, J., & Sansroi, P. (2017). Ceramics vitreous China produced by utilising sediment soil from water supply treatment process. *MATEC Web of Conferences*, *95*, 02005. doi:10.1051/matecconf/2017950200.

Wolff, E., Keller Schwabe, W., & Vieira Conceiçao, S. (2014). Utilisation of water treatment plant sludge in structural ceramics. *Journal of Cleaner Production*, *96*, 1-8. Retrieved from https://www.researchgate.net/.../273855229_ Utilization_of_water_treatm.

Youssef, N. F., Abadir, M. F., & Shater, M. A. O. (1998). Utilisation of soda glass (cullet) in the manufacture of wall and floor tiles. *Journal of the European Ceramic Society*, *18*(12), 1721–1727. Retrieved from https://ac.els-cdn.com/S0955221998000892/1-s2.0-S0955221998000892-main.pdf?_tid=1b2fc787-653d-41f8-8d07-0a01c92c29c5&acdnat=1546571208_00f48c02a06ff8c704fd99b2120ee114