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Utilization of lignite bottom ash as a raw material for ceramic tile

Mateekul JIARAWATTANANON[1], Thanakorn WASANAPIARNPONG[2], and Charusporn MONGKOLKACHIT[1,*]

[1] *National Metal and Materials Technology Center (MTEC), National Science and Technology Development Agency (NSTDA), Klong Luang, Pathumthani 12120, Thailand*
[2] *Research Unit of Advanced Ceramics, Department of Materials Science, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand*

[*]**Corresponding author e-mail:** charuspm@mtec.or.th

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Abstract

This study presents a ceramic tile preparation to effectively utilize lignite bottom ash as one of raw materials. Bottom ash in the mixtures was varied in the range of 40-50 wt%. The milled raw materials were pressed at the pressure of 30 MPa to form 2×4 inch ceramic tiles. The samples were dried and tested for modulus of rupture in order to observe their green strength. Then, the samples were fired at 1150-1200°C. The sintered samples were investigated in terms of modulus of rupture (MOR), water absorption (WA) and phase composition. Tiles are classified according to their water absorption and modulus of rupture into 3 groups by following Thai Industrial Standards of ceramics tiles (TIS 2508-2555). The suitable dry strength of tiles were made from lignite bottom ash 50 wt%, Mae Tan clay 40 wt% and Lampang clay 10 wt% were obtained at 110°C is 2.82 MPa. Tiles were classified to group 2 after firing at 1150°C (WA = 7.03%, MOR = 32.48 MPa) and 1175°C (WA = 6.22%, MOR = 34.21 MPa) and group 1 after firing at 1200°C (WA = 0.72%, MOR = 34.51 MPa). This formula can be applied to both floor tile and wall tile production.

1. Introduction

Normally lignite is used as a fuel for an electricity generation about 10% in Thailand. Lignite consumption at Mae Moh power plant in Lampang province is about 40,000 tons/day. By-products from burning process are approximately 10,000-12,000 tons/day. It contains lignite fly ash about 80% or 3.0-3.5 million tons/year and lignite bottom ash about 20-25% or 1-2 million tons/year. Lignite bottom ash is black with particle size in the range of 0.1-10 mm. Lignite bottom ash is discarded in landfills and is not used in many applications. The remaining bottom ash is still the issue to be managed. Due to a limited numbers of utilizations of bottom ash, this study focuses on waste utilization based on the chemical composition and crystalline phase of bottom ash as raw materials for ceramic tiles. Bottom ash may be used as a raw alternative material. Lignite bottom ash composes of quartz (SiO_2), anorthite ($Ca(Al_2Si_2O_8)$ or $CaO{\cdot}Al_2O_3{\cdot}2SiO_2$), magnetite ($Fe_3O_4$) and hematite ($Fe_2O_3$). Utilization of a mixture of bottom ash and clay can reduce the consumption of energy and the environmental pollution due to an accumulation of waste materials in a disposal area.

Lignite bottom ash was used in construction application. Abdulmatin et al. [1] studied utilization of lignite bottom ash as a pozzolanic material in concrete construction. Before lignite bottom ash was used as a pozzolanic material, some of its properties such as chemical composition, particle size, and crystallinity should be considered. To use bottom ash as a pozzolanic material, the chemical properties should follow ASTM C618 for fly ash Class F or Class C. In addition, bottom ash needed to be milled before use. However, undesired effect on workability and setting time was found. Therefore, exploration of utilization of bottom ash is still required.

Pinheiro et al. [2] succeeded in an incorporation of a solid petroleum waste as raw materials in a porcelain stoneware tile body, by replacement natural kaolin up to 2.5 wt%, allowed the production of porcelain stoneware tiles (ISO standard 13006 - Group BIa) with good technical properties. Shu et al. [3] prepared pressed powders with excellent technical performances that consisted of solid granules with a uniform and nearly spherical shape and approximately normal grain size distribution, and presented excellent flowability and bulk density. These properties are urgently needed for the sustainable development of ceramic tile industry. Sokolar et al. [4] studied fly ash milling enable more intensive sintering of fly ash–clay bodies with possibility of decreasing in firing temperature in comparison with the use of non-milled fly ash and increased the sintering abilities of the fly ash–clay body.

Sokolar [5] studied the effect of fluidized fly ash on the properties of dry pressed ceramic tiles based on fly ash–clay body. The effects of fluidized fly ash on the properties of the sintered samples firing at 1080°C were investigated in terms of water absorption, bulk density, apparent density, apparent porosity and bending strength. It was found that fluidized fly ash decreased

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firing shrinkage and increased porosity of the sample. Maximum amount of 20 wt% of fluidized fly ash can be used in the body mixture with the required properties. The fluidized fly ash effectively increased the content of Sulphur dioxide in the flue gas.

In this study, an adaptive dry process is used so air pollution from sulfur dioxide and energy waste problems of wet process pressed powder preparation were reduced. Dry mixing, milling and granulation technique were developed in lab scale for making a good granule.

2. Experimental

Bottom ash used in this work was obtained from EGAT (Electricity Generating Authority of Thailand). As received bottom ash, limestone and milled sand were dried at 110°C for about 24 h. Then the dried powders were crushed in a vibratory mill and passed through a 100 mesh metal sieve. For phase composition analysis, -200 mesh bottom ash powder was characterized by XRD (D8-Advance, Bruker AXS Model D8 Discover). Other plastic materials such as Mae Tan ball clay and Lampang kaolin clay were dried at 110°C for 24 h. Then the dried powders were crushed in the vibratory mill and passed through 30 mesh. The batch compositions of the samples are shown in Table 1. The bottom ash preferred to be used as much as possible and still retained the main properties of the samples. The target of this study is to use bottom ash up to 50 percent by weight. Moreover, compositions were designed in order to follow the ceramic industry. In the industry, Mae Tan ball clay was mixed with pottery stone and Lampang kaolin clay. In this study, pottery stone was replaced by lignite bottom ash due to non-plastic property of both raw materials.

The dry process was used to prepare the batch formulations. The resulting compositions were sieve through 30 mesh and crushed in the vibratory mill again for 1 minute. The mixtures were pressed to form samples of 2×4 inch using uniaxial pressing machine at a pressure of 30 MPa. All pressed green-body specimens were dried at 110°C for about 24 h. The dried samples were fired at 1150, 1175 and 1200°C, and heated at 5°C·min^{-1} for 15 minutes in an electrical laboratory furnace. The fired tiles were measured in terms of firing shrinkage, modulus of rupture (MOR) (Universal Testing Machine Instron® 5843 and water absorption (WA) (ASTM C20-00(2015)).

Table 1. Batch composition (wt%).

Component (wt%)	No.1	No.2	No.3
Bottom Ash	40	45	50
Mae Tan Ball Clay	40	25	40
Lampang Kaolin Clay	10	25	10
Milled Sand	10	-	-
Limestone	-	5	-

3. Results and discussion

The raw materials were chemically analyzed by XRF and the results are given in Table 2. The analysis in Table 2 shows that a bottom ash contains SiO_2, Al_2O_3, CaO and Fe_2O_3 as major oxide constituents. Figure 1 demonstrates XRD pattern confirmed the presence of quartz, anorthite, magnetite and hematite in bottom ash. Therefore, there is a possibility to replace raw materials such as a flux in ceramic tile compositions.

Table 2. Chemical composition of raw materials.

Oxide	Bottom ash	Mae tan ball clay	Lampang kaolin clay	Milled sand	Limestone
SiO_2	39.02	62.47	57.87	97.84	0.50
Al_2O_3	21.33	23.17	29.07	0.86	0.24
CaO	16.28	0.28	0.13	0.03	68.30
Fe_2O_3	14.59	1.79	1.13	0.14	0.10
K_2O	2.59	1.88	5.16	0.20	-
SO_3	2.37	0.19	0.02	0.03	-
MgO	1.77	0.53	0.24	0.05	0.73
Na_2O	0.71	0.16	0.94	0.04	-
TiO_2	0.65	0.75	0.07	0.23	-
P_2O_5	0.19	0.05	0.01	0.01	-
BaO	0.16	0.07	-	-	-
MnO	0.11	0.01	-	-	0.019
SrO	0.11	0.02	0.15	-	0.04
L.O.I.	39.02	8.60	5.20	0.50	30.15

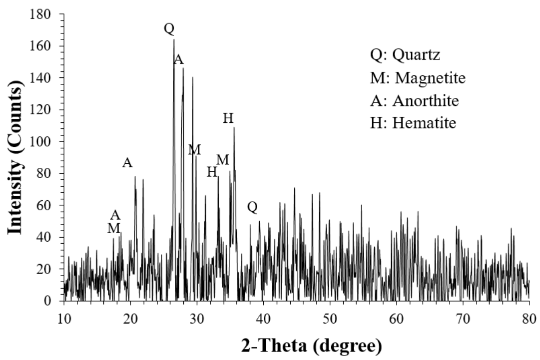

Figure 1. X-ray diffraction pattern of bottom ash.

XRD pattern of tile No.3 fired at 1150, 1175 and 1200°C shown in Figure 2 confirms phase composition after fired as quartz, mullte and anorthite. The intensity of quartz spectra increased significantly with temperature corresponding to firing strength.

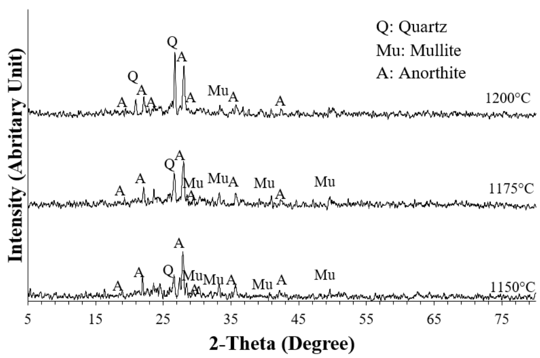

Figure 2. X-ray diffraction patterns of ceramic tile No. 3 fired at 1150, 1175 and 1200°C.

It has been known that quartz, mullite and anorthite phase can provide high mechanical strength in stoneware and porcelain materials corresponding to research of Bragança [6], Nyongesa [7] and Martin-Márquez [8] as corresponded to modulus of rupture results.

An appearance and color of fired tile No. 3 as shown in Figure 3, a shade of color changed from a light brown to dark brown color when temperature increased resulting from hematite and magnetite. The firing shrinkage of tile No. 2 slightly increased when compare with tiles No. 1 and No. 3 at the same firing temperature from 1150 to 1200°C shown in Figure 4. The firing shrinkage of No. 2 is increased from 0.29 to 1.13% for the samples firing at 1150 and 1200°C, respectively, only from an influence of 5% limestone addition. Figure 5 shown the water absorption of No. 1 and No. 3 decreased significantly to lower than 3% when fired at 1200°C showing a capability of these components to produce floor tiles. Tile No. 3 showed low water absorption (less than 1%) that can be made granito tiles or non-glaze bodied porcelain floor tiles. These tiles are extremely hard wearing and are suitable for all domestic and commercial applications modulus of rupture (MOR) of tiles No. 1 to No. 3 is shown in Figure 6. MOR of No. 1 increased significantly to 47 MPa when firing temperature increased to 1200°C compared with No. 3 that was stable at 32-35 MPa when temperature increased. Strength of No. 2 slightly increased corresponding to firing shrinkage.

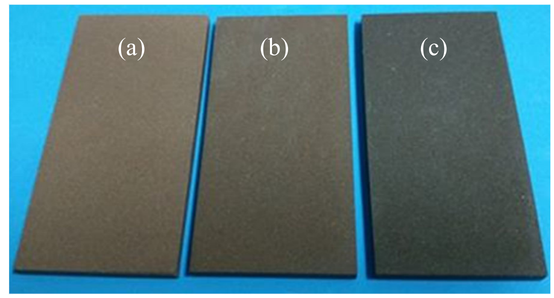

Figure 3. Ceramic tiles No. 3 (2×4 inch) fired at (a) 1150, (b) 1175 and (c) 1200°C.

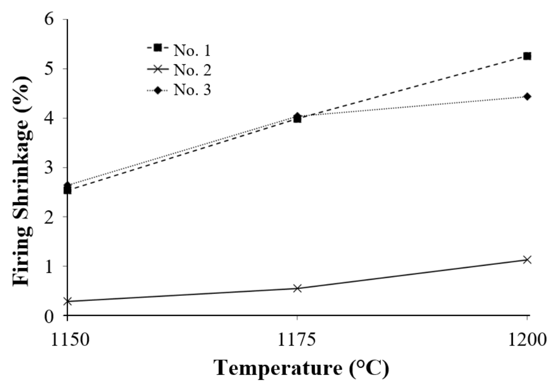

Figure 4. Firing shrinkage of 2×4 inch ceramic tiles No. 1 to 3 fired at 1150, 1175 and 1200°C.

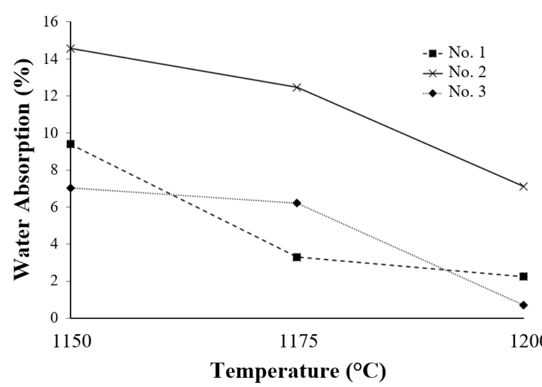

Figure 5. Water absorption of 2×4 inch ceramic tiles No. 1 to 3 fired at 1150, 1175 and 1200°C.

The physical properties of ceramic tiles No.1 to 3 are shown in Table 3. The firing properties of tiles classified to 3 groups followed Thai Industrial Standards of ceramic tiles (TIS 2508-2555) are shown in Table 4. Tiles are

classified according to their water absorption and modulus of rupture into 3 groups:
Group 1: Low water absorption (less than 3%) and the average modulus of rupture of tiles not less than 30 MPa.
Group 2: Medium water absorption (3%-10%) and the average modulus of rupture of tiles not less than 18 MPa.
Group 3: High water absorption (more than 10%) and the average modulus of rupture of tiles not less than 12 MPa.

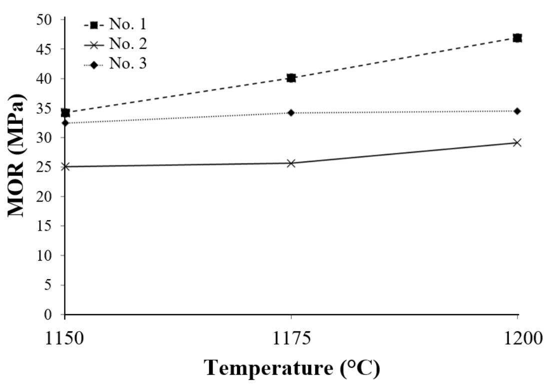

Figure 6. MOR of 2×4 inch ceramic tiles No. 1 to 3 fired at 1150, 1175 and 1200°C.

Tile No. 1 and Tile No. 3 are group 2 after firing at 1150 and 1175°C and group 1 after firing at 1200°C so this formula can use to make floor tiles and wall tiles. Tile No. 2 is group 3 after firing at 1150 and 1175°C and group 2 after firing at 1200°C that is suitable for a wall tile only. This study aims to use bottom ash up to 50 wt% as a substitution for natural raw materials. The composition No. 3 shows a suitable green strength at 2.82 MPa and it is selected to prepare 8×8 inch as shown in Figure 7. It demonstrated good strength for handling and a green tile finishing process before glazing in an industrial production process.

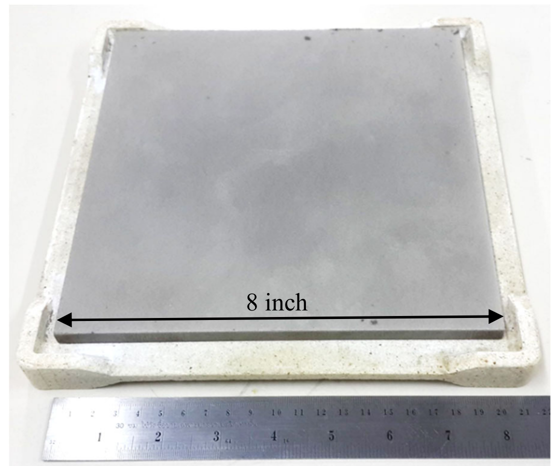

Figure 7. 8×8 inch tile No. 3 (green body).

An addition of lignite bottom ash in the composition quartz, mullite and anorthite phase achieved desired mechanical property in the tiles. Ceramic tile with bottom ash 50 percent (Tiles No. 3) was successfully prepared and followed Thai Industrial Standards of ceramic tiles (TIS 2508-2555). Further study needed to be carried on to meet the industrial condition.

Table 3. Physical properties of ceramic tiles No. 1 to 3.

Temperature (°C)	Physical properties	No. 1	No. 2	No. 3
1150	Firing shrinkage (%)	2.54	0.29	2.64
	Water absorption (%)	9.4	14.56	7.03
	MOR (MPa)	34.22	25.07	32.48
1175	Firing shrinkage (%)	3.99	0.55	4.04
	Water absorption (%)	3.3	12.46	6.22
	MOR (MPa)	40.14	25.66	34.21
1200	Firing shrinkage (%)	5.26	1.13	4.44
	Water absorption (%)	2.25	7.12	0.72
	MOR (MPa)	46.94	29.16	34.51
Green body	MOR (MPa)	2.79	1.62	2.82

Table 4. Tiles classification followed Thai Industrial Standards of ceramic tiles (TIS 2508-2555).

	No. 1			No. 2			No. 3		
	1150°C	1175°C	1200°C	1150°C	1175°C	1200°C	1150°C	1175°C	1200°C
Group 1			✓						✓
Group 2	✓	✓				✓	✓	✓	
Group 3				✓	✓				

4. Conclusions

It is successfully prepared tiles with 50 wt% bottom ash. Tiles No. 3 (lignite bottom ash 50 wt%, Mae tan clay 40 wt% and Lampang clay 10 wt%) have a suitable dry strength of 2.82 MPa and classified to group 2 after firing at 1150°C (WA = 7.03%, MOR = 32.48 MPa) and 1175°C (WA = 6.22%, MOR = 34.21 MPa) and group 1 after firing at 1200°C (WA = 0.72 %, MOR = 34.51 MPa). Therefore, this formula is suitable for both floor tile and wall tile preparation.

5. Acknowledgements

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