Effect of different heating rate on properties of fired brick produced from industrial waste and natural clay

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Abstract. Gypsum waste is generated from the wastewater treatment plant activities from chemical industry. The environmental issues and secured landfill costs caused by this waste increasing every year. Therefore, this study is an attempted to reuse gypsum waste as a substitution material for natural clay in fired brick production. This study consisted of two stages where in the first stage, fired brick were produced from natural clay and gypsum waste with substitution of clay with 5%, 10%, 15% and 20% gypsum waste. The second stage was the investigation of the experimental when the brick samples were fired at different heating rates (1 °C/min, 2 °C/min and 3 °C/min). Next, the shrinkage, dry density, water absorption and compressive strength for each sample were examined and were compared to the control brick. Based on the results, the shrinkage and water absorption increased with the addition of gypsum waste in brick samples. In contrast, the density and compressive strength values were decreased in the brick samples containing gypsum waste. The mechanical properties met the conditions prescribed in the specified standards for all the samples and the optimization result showed that up to 10% of gypsum waste incorporation into fired brick (fired at 1°C/min heating rate) had a sufficient compressive strength over 20 MPa. The reclamation of gypsum waste was proved for the fired brick production insights reducing the environmental pollution. Gypsum waste can be used as a natural clay substitution whilst fulfilling the demand for fired brick requisition.

Keywords: Building materials, Fired brick, Heating rate, Properties, Waste reclamation

Track Name: Advanced Technology and Renewable Energy

1. Introduction
Malaysia has experienced a number of changes in its industrial development, population growth and urbanization which had increased the amount of wastes generated every day. More than 23,000 tonnes of waste are currently produced in Malaysia and only less than 5 percent of the waste is being recycled [1]. There are various industrial wastes were produced from plants and process effluents such as sludge, sawdust, chemical solvents, paint, sandpaper, paper products, manufacturing by-products, metals and
toxic waste [2]. Approximately 50,000 metric tonnes of gypsum waste was generated per year from a chemical industry in Johor Bahru, Johor. Gypsum waste was resulted from the wastewater effluent activities, consequently, the amount keeps increasing and were dumped into landfill which inevitably becoming scarce in meantime. These potentially hazard industrial waste have a big impact to the health and harm to the environment as it contains a high amount of heavy metal such as zinc, chromium, lead, nickel copper and others [3, 4]. Hence the researches highlight the need for alternative methods developed to recover the wastes into new products.

Meanwhile, the utilization of industrial waste into the production of fired bricks is discovered by researchers as one of the promising way to reclaim the waste [5]. Towards striving to promote a sustainable and green building construction, the demands for fired brick incorporating with industrial residuals has also increased. In addition, the incorporation of industrial waste into fired clay brick able to contribute to the environmental protection, human health enhancement and lower operational costs for industry by minimizing the waste disposal cost [6].

Bricks is the oldest mansion that been manufactured as an important building materials that used by mankind in the world and were used as early as 4500 BC [7]. Fired clay brick can be formed when the particles in the clay are bond to each other in the high temperature [8]. In addition, it is made of natural clay that has strong tolerance to high temperatures with the optimal firing temperature ranges from 2 hours to 8 hours from 970°C to 1200°C [9]. Fired clay brick is commonly used in construction as it has good properties in term of durability, colour, texture, size, compressive strength and absorption [10]. The different shapes, colour, texture, intensity and consistency of the fired brick produced were varies depend on the materials and methods used [11]. Furthermore, fired brick tend to be more highly durable and highly strength when in cooling process. Different types of waste and sludge materials such as electroplating sludge, mosaic sludge and other waste have been incorporated successfully into fired clay brick by previous researchers [12-17]. Therefore, this paper is attempted to incorporate gypsum waste into fired brick as the alternative for disposal method. The effects of different heating rate (1 °C/min, 2 °C/min and 3 °C/min) on the properties of fired brick produced were compared with the control bricks and limitation set in the standard. Utilization of gypsum waste resolves the environmental concerns, providing alternative raw material instead of clay in bricks production and reduces dependable on natural resources, thus supported the development of sustainable goal approaches.

2. Materials and Methods

2.1 Materials

The raw materials used for the study were clay soil and gypsum waste. The clay soil was obtained from a quarry in Batu Pahat, Johor. The gypsum waste was collected in sludge form and thereafter, fired brick samples were prepared. The chemical compositions of the raw materials are given in Table 1. The analysis showed that CaO and SO$_3$ were significantly higher in gypsum waste with 29.57 % and 29.56 % respectively while Al$_2$O$_3$ and SiO$_2$ in clay soil with 38.70 % and 40.80 % respectively. The flexibility of clay minerals to be bind with other minerals at optimum temperature made the fired brick feasible to be incorporated with different type of wastes [18].

| Compounds | Clay soil | Gypsum waste |
|-----------|-----------|--------------|
| CaO       | 0.10      | 29.57        |
| SO$_3$    | 0.27      | 29.56        |
| Al$_2$O$_3$ | 38.70    | 16.13        |

Table 1. Chemical compositions of the raw materials used in this study.
| Element | Mass (%) | Mass (mg/kg) |
|---------|----------|--------------|
| SiO\(_2\) | 40.80 | 8.86 |
| MgO | 0.36 | 7.82 |
| Fe\(_2\)O\(_3\) | 5.41 | 4.88 |
| Na\(_2\)O | 0.47 | 2.39 |
| P\(_2\)O\(_5\) | ND | 0.39 |
| MnO | ND | 0.15 |
| K\(_2\)O | 0.22 | 0.11 |
| Cl | ND | 418.00 mg/kg |
| TiO\(_2\) | 1.05 | 344.00 mg/kg |
| ZnO | ND | 111.00 mg/kg |
| Cr\(_2\)O\(_3\) | ND | 56.00 mg/kg |

*ND- Not Detected

### 2.2 Methods

The manufacturing process of fired brick started with the preparation of raw materials. The clay soil and gypsum waste were oven dried at 105 °C for 24 hours to remove the water content as it could affect the properties of the sample. This study was conducted in two stages. In the first stage, fired brick were produced as control brick (0 % gypsum waste incorporation) and the brick incorporated with gypsum waste at the percentages at 5 %, 10 %, 15 % and 20 %. Control brick was used as a comparative during experimental testing. The raw materials were mixed together at respective percentage followed by pre-determined water using a mechanical mixer until homogenous mixture was yielded. After that, the sample was compressed at 2000 psi using a brick machine with dimension of 215 mm x 102.5 mm x 65 mm. The brick sample was dried at room temperature for 24 hours and another 24 hours in the oven at 105 °C. Next, the brick sample was put into the furnace box for firing process at firing temperature of 1050 °C for two hours, while applying different heating rates of 1 °C/min, 2 °C/min and 3 °C/min. In order to assess the properties of the fired brick production with utilization of gypsum waste, the firing shrinkage, dry density, water absorption and compressive strength were examined. The properties were tested according to BSI [19].

For the calculation of the firing shrinkage, the following equation was used:

\[
L_s = \frac{L_w - L_d}{L}
\]  
(Equation 1.1)

where:
- \(L_s\) = Percentage of shrinkage
- \(L_w\) = Length of wet
- \(L_d\) = Length of dry
- \(L\) = Actual length

For the calculation of the dry density, the following equation was used:

\[
\rho = \frac{m}{v}
\]  
(Equation 1.2)

where:
- \(\rho\) = Dry density
- \(m\) = Mass
- \(v\) = Volume

The water absorption of the samples by volume which also represented the apparent porosity of the brick was calculated using the following equation:
\[ W_{\Delta} = \frac{M_1 - M_2}{M_2} \times 100\% \]  
(Equation 1.3)

where:
M1 = Weight of wet brick (g)
M2 = Weight of dry brick (g)
W\(\Delta\) = Water absorption (%)

For the calculation of the compressive strength, the following equation was used:
\[ \sigma = \frac{F}{A} \]  
(Equation 1.4)

where,
\(\sigma\) = Compressive strength (MPa)
\(F\) = Applied load (kN)
\(A\) = Cross section area (mm\(^2\))

3. Results and Discussion
The results of the tests conducted on the fired brick samples are discussed and presented as subsequent figures below.

3.1. Shrinkage
The shrinkage of bricks occurs when the water in the brick was lost during the drying and firing stages. The results of the shrinkage for the control brick and gypsum brick with different heating rates were presented as in Figure 1. The shrinkage result showed that the increment is in parallel with the addition of gypsum waste percentages. The shrinkage of the fired brick with gypsum waste was found to be not more than 2% with respect to the heating rates of 1 °C/min, 2 °C/min and 3 °C/min. Firing temperature is one of the factors that affecting the shrinkage of brick [20]. Besides that, it was indicated that the shrinkage of brick was increased at temperature of 650 °C to 1050 °C, while was significantly affected by the clay sintering and reorganization of the bonding particles at the temperature of 900 °C [21].

![Figure 1. Shrinkage of fired brick.](image)

3.2. Dry density
Density is the relationship between the solid mass and the overall volume of the sample which depend on the temperature and manufacturing process applied. Based on the results, the heating rate has an insignificant effect on the dry density of the fired brick [22]. The trends showed that the dry densities were quite similar within the fired brick samples. The increasing amount of gypsum waste added caused the results to decrease ranging from 1900 kg/m\(^3\) to 1743 kg/m\(^3\) for gypsum brick (5 %, 10 %, 15 % and 20 %) at respective heating rates (1 °C/min, 2 °C/min and 3 °C/min). This condition was related to
sintering process where residual carbon phase were forming voids and eventually increased the porosity of the bricks [23]. This is supported where the waste marble powder (WMP) obtained from the marble processing factory which contained a high amount of calcium carbonate (CaCO₃) demonstrated the increase of density at higher temperature which is possibly caused by the incline of consolidation or vitrification within the particles in the brick bodies [24]. Meanwhile, another observation on the utilization of aluminium filter dust (AFD) into fired clay brick showed that the addition of waste did not change the mineral composition of brick but it had modified the amount and size of the pore formed after the firing process [25]. The pore-forming effect occurs at high temperature due to the increasing amount of AFD has resulted to the decrease of bulk density.

![Figure 2. Dry density of fired brick.](image)

### 3.3. Water absorption

Water absorption testing was performed to assess the hardness characteristics of the brick by indicated its porosity. The higher water absorption reading would cause cracks to the surface of brick samples. According to the standard limit monitored, the water absorption for severe weathering resistance bricks may not be exceed from 17 %, for moderate weathering resistance bricks may less than 22 % and for negligible weathering resistance bricks has no limit specified but must be in acceptable condition [26]. The results showed that the gypsum waste addition had caused a gradual increase of water absorption for all the gypsum brick samples for all respective heating rates. For gypsum brick 20 % fired at a heating rate 1 °C/min had water absorption at 12 % while for control brick fired at the same heating rate was recorded 3 % value which is explained the existence of higher amount of pores in the brick samples containing gypsum waste. The result is in parallel to the findings obtained by recycling waste marble sludge into fired clay bricks [27]. The apparent high porosity behaviour was formed by the dehydroxylation and combustion of calcium carbonate known as amorphous phase occurred during various reaction at higher temperature [28].
3.4. Compressive strength

The compressive strength test was conducted to determine the ability of the brick to hold the load under compression. This test is important in properties of fired brick classification. The values of compressive strength showed that control bricks fired at respective 1 °C/min, 2 °C/min and 3 °C/min had 31.00 MPa, 30.00 MPa and 29.68 MPa respectively. The amount of gypsum waste added had decreased the compressive strength for the gypsum bricks of 5 %, 10 % and 15 % due to high porosity compared to control bricks with ranges from 26.30 MPa to 20.63 MPa, 20.6 MPa to 18.5 MPa, 15.90 MPa to 14.60 MPa for respective heating rate of 1 °C/min, 2 °C/min and 3 °C/min. The lowest compressive strength results were from gypsum brick 20 % with 13.80 MPa, 9.06 MPa and 8.80 MPa at respective heating rate of 1 °C/min, 2 °C/min and 3 °C/min. However, the results showed that gypsum brick 10 % that fired at 1 °C/min had the sufficient requirement for compressive strength with 20.6 MPa for loading bearing application as stipulated in Malaysian standard [29]. This explained that the linear relation between density and water absorption was established and was validated that the pore amount and density have increased the amount of water penetrated into the brick bodies hence lowering the compressive strength of the brick samples [25].
4. Conclusion

This study was conducted to reclaim the gypsum waste from the chemical industry by recycling into fired brick as an alternative disposal method of landfilling. The natural clay composition in fired brick was replaced by incorporating gypsum waste at 5%, 10%, 15% and 20%. Three different heating rates were applied for firing stage which were 1 °C/min, 2 °C/min and 3 °C/min. The gypsum waste addition in brick samples had directly increased the shrinkage and water absorption readings. Meanwhile, the dry density and compressive strength were gradually decreased with the increment in gypsum waste incorporation. However, up to 10% of gypsum waste incorporation which was fired at 1 °C/min, showed the acceptable value of compressive strength with 20 MPa and adequate requirement for other properties as well. In addition, the fired brick produced from different heating rates assemble changes in their properties due to different period of time for completing the sintering process. The results indicated that 1 °C/min was the most appropriate heating rate to manufacture fired bricks as it complimented the shrinkage, dry density, water absorption and compressive strength properties. Therefore, this study demonstrated that gypsum waste could be used as a replacement for natural clay in the brick manufacturing industry insight conserving the environment and human health.

References

[1] Johari A, Alkali H, Hashim H, Ahmed S I, Mat R 2014 Municipal solid waste management and potential revenue from recycling in Malaysia. Modern Applied Science 8 (4) 37

[2] Renitaa A, Kumarp P S, Srinivash S, Priyadharshiniv S, Karthikab M 2017 A review on analytical methods and treatment techniques of pharmaceutical wastewater. Desalination and Water Treatment 87 160-78.

[3] Mishra S, Bharagava R N, More N, Yadav A, Zainith S, Mani S, Chowdhary P 2019 Heavy metal contamination: an alarming threat to environment and human health. InEnvironmental biotechnology: For sustainable future pp. 103-125

[4] Sankhla M S, Kumari M, Nandan M, Kumar R, Agrawal P 2016 Heavy metals contamination in water and their hazardous effect on human health—a review Int. J. Curr. Microbiol. App. Sci. 5 (10) 759-66

[5] Sutcu M, Erdoganus E, Gencel O, Gholampour A, Atan E, Ozbakaloglu T 2019 Recycling of bottom ash and fly ash wastes in eco-friendly clay brick production Journal of Cleaner Production 233 753-64

[6] Shakir A A, Mohammed A A 2013 Manufacturing of Bricks in the Past, in the Present and in the Future: A state of the Art Review. International Journal of Advances in Applied Sciences (IJAAS) 2 (3) 145-56

[7] Perkins D 2013 Encyclopedia of China: History and culture. Routledge

[8] Phonphuak N, Kanyakam S, Chindaprasirt P 2016 Utilization of waste glass to enhance physical–mechanical properties of fired clay brick. Journal of Cleaner production 112 3057-62

[9] Monatshebe T. Artisanal Fired Clay Bricks in Dididi and QwaQwa 2017 Their Production and Related Environmental Issues. University of Johannesburg (South Africa)

[10] Lourenço P B, Fernandes F M, Castro F 2010 Handmade clay bricks: chemical, physical and mechanical properties. International Journal of Architectural Heritage 4 (1) 38-58

[11] Dogan-Saglamtrimur N, Biligil A, Szychsńa-Hebda M, Parzych S, Hebda M 2021 Eco-friendly fired brick produced from industrial ash and natural clay: A study of waste reuse Materials 14 (4) 877

[12] Zhang M, Chen C, Mao L, Wu Q 2018 Use of electroplating sludge in production of fired clay bricks: Characterization and environmental risk evaluation Construction and Building Materials 159 27-36.

[13] Sarani NA, Kadir A A, Rahim A S, Mohajerani A 2018 Properties and environmental impact of the mosaic sludge incorporated into fired clay bricks Construction and building materials183 300-10.

[14] Ukawatta A, Mohajerani A, Setunge S, Eshighi N 2015 Possible use of biosolids in fired-clay bricks Construction and Building Materials 91 86-93.

[15] Hamid N J et al 2021 Influence of Gypsum Waste Utilization on Properties and Leachability of Fired Clay Brick. Materials. 14 (11) 2800

[16] Chemani B and Chemani H 2012 Effect of adding sawdust on mechanical-physical properties of ceramic bricks to obtain lightweight building material. International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering 6 (11) 36-55

[17] Sarkar R et al 2017. Use of paper mill waste for brick making. Cogent Engineering 4 (1)1405768.

[18] Rehman M U et al 2020 Influence of fluxing oxides from waste on the production and physico-mechanical properties of fired clay brick: A review Journal of Building Engineering 27100065.

[19] B S 12 3921, B.S.I British Standards Institution. British Standard Specification for Clay Bricks; B.S.I British Standards Institution: London, UK, 1985

[20] Sahu M K et al 2016 Critical review on bricks. International Journal of Engineering and Management Research (IJEMR) 6 (5) 80-8

[21] Karim H M 2019 Production of lightweight thermal insulating clay bricks using papyrus Polytexnic Journal 9 (1) 74-81
[22] Ukwatta A and Mohajerani A 2017. Characterisation of fired-clay bricks incorporating biosolids and the effect of heating rate on properties of bricks Construction and Building Materials 142 11-22
[23] Taurino R, Karamanova E, Barbieri L, Atanasova-Vladimirova S, Andreola F and Karamanov A 2017 New fired bricks based on municipal solid waste incinerator bottom ash Waste Management & Research 35(10)1055-63
[24] 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 182 1-8.
[25] Bonet-Martínez E, Pérez-Villarejo L, Eliche-Quesada D and Castro E 2018 Manufacture of sustainable clay bricks using waste from secondary aluminum recycling as raw material Materials 11 (12) 2439
[26] ASTM C62, 2017 Edition, October 1, 2017 - Standard Specification for Building Brick (Solid Masonry Units Made From Clay or Shale)
[27] Munir MJ, Kazmi SM, Wu YF, Hanif A and Khan MU 2018 Thermally efficient fired clay bricks incorporating waste marble sludge: An industrial-scale study Journal of Cleaner Production 174 1122-35
[28] Eliche-Quesada D and Leite-Costa J 2016 Use of bottom ash from olive pomace combustion in the production of eco-friendly fired clay bricks Waste Management 48 323-33
[29] Standard M 1972 Clay bricks. Malaysia, MS 76

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