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A Study on the Properties and Leachability of Fired Clay Bricks Incorporating With Gypsum Waste

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Abstract:
The industrial waste could be generated from the manufacturing or industrial processes that use chemicals or manufactured chemicals, in consequence, produce a serious hazard to the environment. In this research, gypsum is an industrial waste generated from the wastewater treatment process in the chemical industry. More than 50,000 tons of gypsum waste has been produced in Johor per months. The average concentration of heavy metals in gypsum waste was relatively low but since the production of gypsum waste is large, the total amount of heavy metals in gypsum waste could be large too. Due to that, it could become a potential threat to the environment when it was disposed of randomly in landfills. Thus, an alternative to recycle and dispose of the gypsum waste should be investigated. Therefore, this research was conducted by incorporating a different percentage of gypsum waste (0%, 10%, 20%, 30%, 40% and 50%) into fired clay brick (FCB). The performance of gypsum brick (GB) was determined by conducting physical and mechanical testing such as water absorption, dry density and compressive strength. Besides, the leaching test which is the Toxicity Characteristic Leaching Procedure (TCLP) was also conducted in order to determine the concentration of heavy metals in GB. The results showed that the water absorption value of GB increased by increasing the percentage of gypsum waste in bricks whilst the value of dry density and compressive strength decreased when the addition of gypsum waste in the bricks increased. The leachability results from TCLP indicated that all concentrations for thirteen (13) heavy metals complied with the standard from the United States Environmental Protection Agency (USEPA, 1996). Although the addition of gypsum waste was decreased in some properties, the incorporation of gypsum wastes up to 20% have complied with the brick's requirements British Standard (BS 3921:1985).

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I. INTRODUCTION

Gypsum is a natural mineral that composed of Calcium Sulfate Dihydrate ($CaSO_4.2H_2O$) which usually were found in sedimentary rocks, halite, anhydrite, sulphur, calcite and dolomite (Tafu *et al.*, 2016; Khaled *et al*., 2014). It has various purposes in different sectors such as in the agriculture sector, gypsum can be used as a soil additive to improve water penetration whilst for surgical and dental sector, high purity gypsum can produce pottery casts (Khaled *et al*., 2014). Gypsum can also be used in building material for example gypsum boards, ceiling tiles, and partitions (Lushnikova *et al.*, 2016; Khaled *et al*., 2014). According to Lushnikova *et al.*, 2018, gypsum has a neutral pH and is inorganic.

The accumulation of gypsum waste in landfill will resulting to toxic gases such as hydrogen sulphide gas and methane gas as well as contaminate the soil and groundwater if the waste is disposed directly in the soil or landfill without any control measurement (Zhu *et al.*, 2018; Camarini *et al.*, 2014; Nawi, 2016). In addition, disposing gypsum waste in the landfill could also lead to contaminated of heavy metal elements into the soil and groundwater as it is reported in recent literature, gypsum waste contains various of toxic elements such as zinc, manganese, lead, chromium, cadmium and nickel which concern the environment (Lin *et al* 2018; Hao *et al*., 2017; Zoca & Penn, 2017).

On the other hand, Munoz *et al.*, (2016) stated in his study, there are 1500 billion bricks were produced every year and 400 million tons of clay is extract using 100,000 large-scale kilns with fixed chimneys. Due to the highest demand in brick, it is crucial to search for possible solutions to reduce clay content in bricks as well as reduce depletion of natural resources and provide another way to dispose the waste whilst producing more sustainable bricks.

Many researchers are looking forward to minimizing the volume of waste in the landfill as well as to protect the environment by investigating different types of waste to be incorporated into bricks in order to prevent the continued uses of natural resources such as clay, soil, sand and gravel. Examples of waste including glass waste (Phonphuak *et al.*, 2016), paper waste (Sutcu *et al.*, 2014) shale, fly ash, crushed bricks (Wu *et al.*, 2015), cigarette butts, dried sludge, and welding flux slag (Raut *et al.*, 2011). Based on the studies, the utilization of waste in the manufacturing of bricks give a positive result in terms of compressive strength, water absorption and bulk density by using up to 10% of waste (Fakih *et al.*, 2018). It also enhances the solution of pollution problems that were caused by the disposal of the waste.

As a conclusion, the incorporation of brick with waste gives an effective way to dispose of the waste whilst contributed to the brick industry in reducing the use of natural resources. Hence, the main focuses of this research were developed by investigating the feasibility of using gypsum waste which derived from the wastewater treatment industry as partial replacement of clay in the composition of fired clay bricks.

II. MATERIAL AND METHOD

Clay soil and gypsum waste (Figure 1) were collected from the factory of JFC Hardware in Parit Sulong, Johor and Premier Bleaching Earth Sdn Bhd in Pasir Gudang, Johor respectively. The manufacturing of clay bricks was separated into two which is controlled brick (0% gypsum) and gypsum brick (GB) with ratio 10%, 20% 30%, 40% and 50% of gypsum waste. Firstly, the raw materials which are clay soil and gypsum waste were dried in the oven at 105°C for 24 hours before being grind. After the grinding process, the raw materials were mixed together with different percentage according to Table 1. Then, the samples were pressed into the mould with size 215 mm x 102.5 mm x 65 mm using automatically compressor at 2000 psi to form a brick. The compacted brick was dried in the oven for 24 hours at 105°C before undergoes the firing process in a furnace at 1050°C with heating rates of 1°C/min for another 24 hours. This dried process in the oven was carried out to remove the moisture content in the brick as during the firing process the water can cause the brick to crack. The samples then were cooled down at room temperature before being tested with several testing of physical and mechanical test. All tests were carried out according to the British Standard (BS 3121:1985). The leachability test was conducted by using TCLP method. The concentration for thirteen (13) heavy metals in gypsum brick which is Iron (Fe), Barium (Ba), Vanadium (V), Zinc (Zn), Chromium (Cr), Silver (Ag), Lead (Pb), Nickel (Ni), Copper (Cu), Arsenic (As), Selenium (Se), Cadmium (Cd) and Beryllium (Be) were analyzed by using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and the leachability results were compared with United States Environmental Protection Agency (USEPA, 1996).

Figure 1: (a) Clay soil and (b) Gypsum waste

(a) (b)

Table 1
The proportion of bricks that were formed

Percentage (%)	Weight of gypsum (g)	Weight of clay soil (g)
0 (Control)	0	2800
10	209	2591
20	470	2330
30	805	1995
40	1253	1547
50	1879	921

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III. RESULT AND DISCUSSION

The results and discussion with physical and mechanical properties and leachability testing for six different percentages (0%, 10%, 20%, 30%, 40% and 50%) of GB were explained in the graph. For this research, 48 samples were manufactured and are chosen averagely with size 207 mm x 100 mm x 70 mm. Although the manufactured brick was not accurate as standard brick, but it is quite approximately to it.

A. Water Absorption

Figure 2 shows that the control brick has the lowest water absorption with percentage of 3.03%, followed by brick with 10% and 20% gypsum content with water absorption of 8.59% and 12.66% respectively. Figure 2 also depicts that the bricks with 30%, 40% and 50% of gypsum are not complying with the standard as it exceeded the range of standard requirement with moisture content of 27.50%, 33.62% and 41.89%. From the result, it can be observed that the water absorption increases with the increase of gypsum waste incorporated into the brick. This is due to the nature of the gypsum that possesses high water absorption. Based on the British Standard, all the bricks produced from this study can be used in non-loading application as it exceeded the maximum water absorption of Engineering Brick A and B which is 4.5% and 7% except for control brick. Plus, based on the ASTM standard, only brick with 10% and 20% gypsum content can be classified as moderate-weather-resistant brick since the water absorption for both of the bricks is not exceeding 22%.

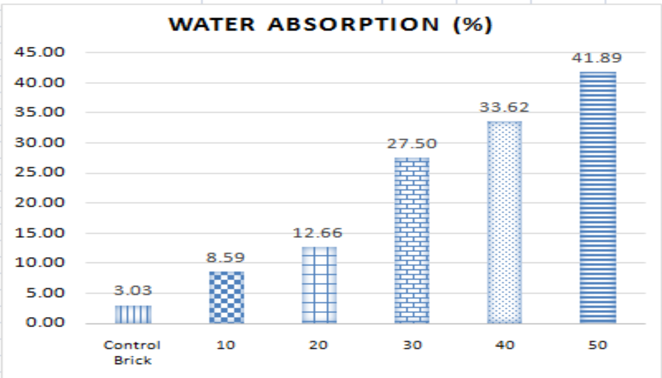

Figure 2: Water absorption with different percentages of GB

B. Density

Based on the Figure 3, it shows that the control brick has the highest density which is 1830 kg/m^3 meanwhile the brick with 50% of gypsum content has the lowest density which is 1216 kg/m^3**.** It can be seen from the graph that the density after the firing process decreased as the amount of gypsum waste increased. This result is in agreement with the previous study conducted by Sarani (2019) and Kadir *et al.* (2017). It can be concluded that the decreasing value of dry density is affected by the increasing amount of gypsum waste percentages in fired clay brick. Brick with the addition of gypsum waste has low density because there is the possibility that there are losses of gypsum waste or other components during the firing process. This is caused by the tendency of gypsum waste to be burnt at the elevated temperature. The lower density value obtained can also be caused by the elimination of excess water from the brick structure. Brick with the low density has more advantages as it can reduce transportation costs and cause easier handling in the construction industry.

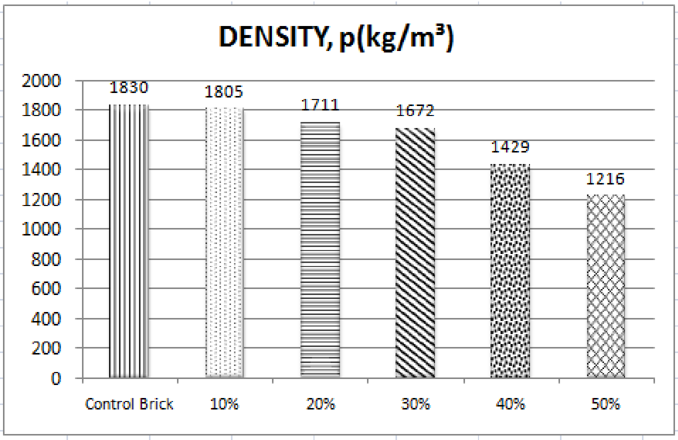

Figure 3: Density with different percentage of GB

C. Compressive Strength

From the Figure 4, it shows that control brick (0% gypsum) obtained the highest compressive strength with 26.34MPa, followed by brick that content 10% and 20% of gypsum waste with 20.00 MPa and 10.72MPa respectively. However, the graph indicated that bricks with 30%, 40% and 50% of gypsum waste do not comply with the standard which is below the minimum requirement standard with having 0.62 to 4.48MPa. The compressive strength of the bricks becomes lower because the brick contents high porosity value compared to other bricks. When the porosity value was increased, the compressive strength of the brick was reduced because it is lower in density. The result can be concluded that, by increasing the percentage of gypsum waste in the brick, the compressive strength and density of bricks becomes decreasing due to the increasing in porosity.

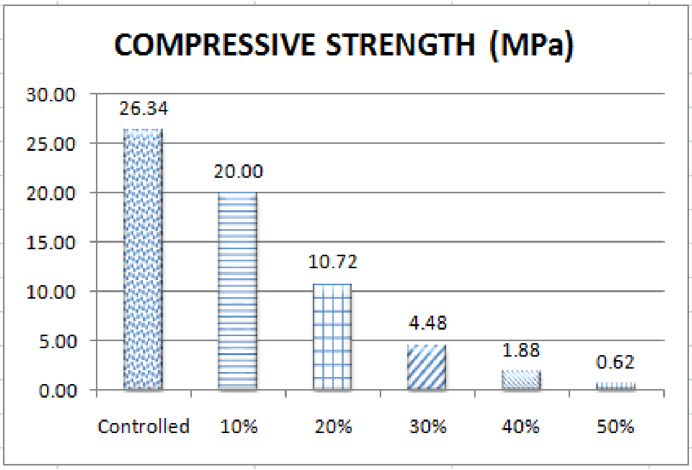

Figure 4: Compressive strength with different percentages of GB

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D. LEACHABILITY (TCLP)

Figure 5 shows the highest concentration of heavy metal in gypsum brick for 10%, 20%, 30%, 40% and 50% is Al which is 9.43ppm, 9.19ppm, 18.97ppm, 9.97ppm and 33.11ppm respectively. The Al concentration in gypsum brick also show a large difference with the Al concentration in control brick which is 30.16ppm. Meanwhile, the concentration of Fe is for 10%, 20%, 30%, 40% and 50% is 4.48ppm, 3.83ppm, 3.74ppm, 3.74ppm and 0.84ppm respectively. Whilst for Ba, the concentration for each percentage is 0.19ppm, 0.28ppm, 0.13ppm, 0.42ppm and 0.11ppm respectively. All the heavy metals in control brick and gypsum brick have complied with the standard concentration limits of USEPA 1996. It should emphasize that the concentrations of the metals in the leachate from the test was in race amounts which do not exceed the regulatory that stated by USEPA, 1996.

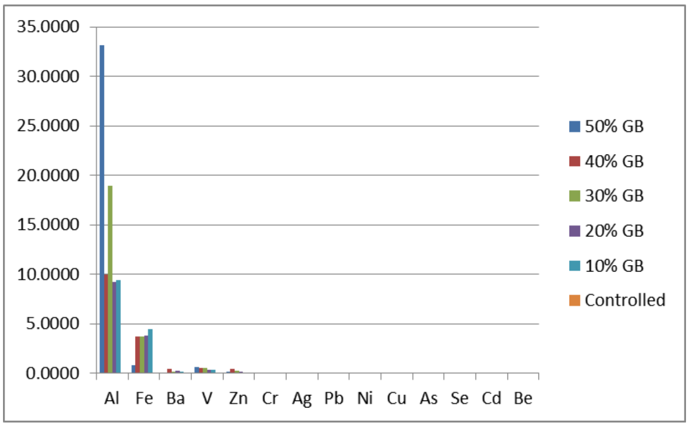

Figure 5: Heavy metals existed in the sample

IV. CONCLUSION

In conclusion, all the characteristics of gypsum waste percentages, physical and mechanical properties and leachability bricks incorporated with gypsum waste were determined. The characteristics obtained by XRF showed that the chemical composition of raw material clay soil and gypsum waste was high in magnesium oxide and aluminum oxide. The recommended percentages of gypsum waste which is up to 20% with better physical and mechanical properties. The results showed that the 10% utilization of GB brick obtained the highest compressive strength up to 20MPa. On the other hand, increasing the gypsum ratio, in general, will increase the water absorption. The water absorption for the bricks was satisfied with the standard which is in the range of 12% to 22% except for gypsum brick with 30%, 40% and 50%. Moreover, the density for bricks was satisfied with an average mass of 1600 $kg/m3$ except for the 40% and 50% mixture of gypsum waste.

It was found that the concentrations of heavy metals in gypsum brick for all percentages have complied with the USEPA standard. Overall, it can be concluded that gypsum brick is potential and suitable waste to be incorporated in fired clay brick as it could produce lightweight brick and potential to generate new low cost building materials as well as increasing the lifespan of the landfill and reduce the pollution towards the environment.

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