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Durability Properties and Leaching Behavior of Fired Clay Brick Incorporated with Gypsum Waste

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Abstract: The chemical industry produced a large amount of gypsum, which was categorized as scheduled waste (SW205). Due to the high content of heavy metals, which poses a threat to the environment, it will have a huge impact. The utilization of gypsum waste in fired clay brick is a method for the elimination of waste that should be disposed of in landfill sites. Brick was manufactured by incorporating 5%, 10%, 15%, 20%, 25% and 30% of gypsum waste and fired at 1050ºC using 1ºC per minute heating rate. This study focused on durability properties that included wetting drying cycle and compressive strength tests were conducted, while the Toxicity Leaching Behavior Procedure (TCLP) was performed for environmental impact. The results showed that the addition of gypsum waste to bricks would decrease the compressive strength. The optimum amount of waste that can be used to be incorporated into fired clay bricks is 10% with value 22 MPa that fulfill the requirements as non-loading brick. The leachability test highlights that Al with value 8.377ppm and Fe elements with value are 4.530ppm the highest among others element. However, most heavy metals are complied with the United States Environmental Protection Agency (USEPA) and Environmental Protection Agency Victoria (EPAV) standard except Aluminum element not passed the EPAV standard. Based on this study gypsum brick can be an alternative that provides advantages in terms durability properties and environmentally friendly disposal method.

Keywords: Gypsum Waste, Durability Properties, Toxicity Leaching Behavior Procedure

1. Introduction

Chemical industry waste encourages disposal difficulties such as huge area is required for the disposal to the landfills and soared up the operating cost. More than 90% of total waste in Malaysia is disposed of in landfill sites [1]. The improper disposal of hazardous waste causes adverse effects on human health and the environment. After 30 years, Malaysia produced approximately 400,00 m^3 of hazardous waste in 1987, which increased to 2.02 million tonnes in 2017 [2]. Gypsum waste is the huge

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quantities generated by industries and the source of the most hazardous waste. Due to the toxic and high-risk nature of a particular type of waste, gypsum waste from the chemical industry was categorized as scheduled waste containing primarily inorganic constituents.

The massive amount of gypsum waste production that contributes to sewage waste is known as scheduled waste (SW 205). Gypsum waste contains principally heavy metals such as copper, chromium, lead, aluminum, zinc, tin, vanadium, cadmium, beryllium, and nickel [3]. The impact of heavy metal leaching would be allocated in rivers, posing a risk to public health, pollution, and groundwater contamination. Gypsum waste contains high concentrations of heavy metals that are harmful to the environment, however incorporating it into fired clay brick could be an alternative disposal method.

Eco-friendly bricks that are incorporating with waste are increasing on-demand to be used in sustainability development [3-5]. Durability properties features help to protect the environment by conserving natural resources and reducing waste accumulation. The majority of researchers are concentrating on physical and mechanical properties of incorporating waste. However, less attention is given to the durability properties. The importance of durability properties is to evaluate the bricks for their long-term durability when used in brick masonry and exposed to nature [6]. The major goal of this study is to investigate the durability properties and leaching behaviour of fired clay brick incorporated with gypsum waste. The scope of the research includes preparation of a sample fired clay brick manufacturing and wetting-drying test of different percentages of gypsum waste (5%, 10%, 15%, 20%,25% and 30%). The leachability test was conducted according to the United States Environmental Protection Agency (USEPA) and the Environmental Protection Agency Victoria (EPAV). Overall, this research will significantly become an indicator as the advantages of brick incorporated with waste terms of its durability and environmental impact. The objective of this research is to investigate the durability properties of fired clay brick incorporated with gypsum waste and to determine the leaching behaviour of gypsum fired clay brick.

2. Literature Review

In order to ensure that the strength and performance of fired clay brick is maintained, water absorption is the main aspect of the observation to determine the durability. Aim of the wetting drying cycle test is to influence of moisture absorption and this test would be to see how long the bricks would last and what effect soaking might have on their strength [7]. The dry season lasts two-thirds of the year, with an average maximum temperature of 500°C, and the rainy season lasts one-third of the year. The bricks were exposed to an accelerated temperature of 500°C for nearly 48 hours and immersed in water for approximately 24 hours in order to conduct an accelerated durability test of alternate wetting and drying cycles (12 total cycles). Each cylinder was subjected to accelerated temperatures of 500 °C for nearly 48 hours, then immersed in a pool of water for more than 24 hours, and finally dried at a temperature of 500°C [8].

In construction, the properties of the building are determined based on its strength. The compressive strength of a brick is determined by testing a sample of bricks. Brick compressive strength is influenced by pore size, crystallization type and pore size [8] The maximum load is divided by the original cross-sectional area of the brick to measure compressive strength. Based on Malaysian Standard MS 76:1972 [9] compressive strength of brick will be determined. For class A engineering brick the maximum value should be $70N/mm^2$ meanwhile for class B its should be $50N/mm^2$. For non loading application its should be over $5N/mm^2$.

The increasing levels of trace and heavy metals in building materials have a negative impact on the residents of the building. In this study gypsum waste contains chemicals that are toxic to the environment. This study traced heavy metal in gypsum leachate in the brick. According to the Toxicity Characteristic Leaching Procedure (TCLP) test method 1311[10], leachability is indeed the natural or artificial process of removing minerals or heavy metals from a substance by dissolving in fluid. Material extraction from the sample toxicity will refer based on EPAV and USEPA standard [11-12]. Table 1 shows standard for heavy metal concentration.

Table 1: Standard of heavy metal concentration [11-12]

Heavy Metals	USEPA (1996) (mg/L)	EPAV (2005) (mg/L)
Copper, Cu	100	800
Lead, Pb	5	4
Zinc, Zn	500	1200
Nickel, Ni	1.3	8
Barium, Ba	100	280
Chromium, Cr	5	20
Arsenic, As	5	2.8
Beyllium, Be	-	0.1
Aluminium, Al	-	5
Cadmium, Cd	1	0.8

3.0 Materials and Methods

3.1 Material preparation

There are three materials that were used in this research, clay soil, gypsum waste and distilled water. Clay soil was collected from Yong Peng and gypsum waste were collected from Premier Bleaching Earth, Pasir Gudang, Johor. These two materials have been collected and kept in the oven to dry it up to decrease the moisture content and avoid microorganism's growth. To obtain the uniform size the clay soil and gypsum waste had been grinded. There are two types of brick that have been manufactured for this study, which are control bricks and brick incorporated with gypsum waste. Controls bricks (0%) and gypsum brick (5%, 10, 15%, 20%, 25% and 30%). Ratio mixture as shown in Table 2.

Table 2: Shows ratio mixture

Mixture	Percentage (%)	Clay (kg)	Gypsum (kg)	Water (mL)
Control Brick	0	2.984	0.000	450
Gypsum Brick	5	2.830	0.110	470
Gypsum Brick	10	2.686	0.220	510
Gypsum Brick	15	2.536	0.330	520
Gypsum Brick	20	2.387	0.440	550
Gypsum Brick	25	2.238	0.551	580
Gypsum Brick	30	2.089	0.661	625

3.2 Brick manufacturing process

Process of fired clay brick manufacturing were done in the Research Centre for Soft Soil laboratories. Control bricks are constructed using clay rather than gypsum waste (0%). The purpose of the control brick is to compare the results to those of other bricks containing gypsum waste. Control brick was made by combining soil and distilled water in a specific ratio in a mechanical mixer. Procedure of manufacturing of gypsum bricks are same process as control brick. Clay soil was mixed with different percentages of gypsum waste. Necessary amount of water was added to achieve desired consistency of samples. After the mixing, then allowed it to homogenize in order to eliminate any lumps that may have formed. After homogenous, the sample was pressed into the moulds according to dimensions and compacted layer by layer to ensure uniform compaction. The moulding brick was dried for 24 hours at room temperature before being dried for another 24 hours in oven at 105ºC. After drying, the brick was fired in the furnace at a rate 1ºC/min for another 17 hour and 30 minutes until it reached 1050ºC.

3.3 Wetting and drying cycle test

Procedure of this test started with determine moisture content of sample with Test Method that based on D2216 Test Methods for Laboratory Determination of Water Moisture Content of Soil and Rock by Mass [13] use a temperature of 60±3^{o} C. The dry weight of bricks was obtained before soaked in water container at 25^{o}C temperature for 24 hours. After that, bricks were removed and cleaned up. The bricks were placed in an oven to enable the drying process for 72 hours at temperature 60^{o}C. The specimens of mass loss solid content in beakers by evaporating water at 60± 3^{o}C in drying oven. This was preceded by another soaking, completing one cycle of wetting and drying. The procedure was repeated until no more moisture could be absorbed by the bricks, which took another 5 cycles. The brick was removed and weighed again after the process was completed. Compressive strength tests were conducted on the soaked bricks.

3.4 Compressive strength

This test was done to determine the durability and effects of soaking on the strengths of the bricks. Compressive strength is the strength capacity of the brick to withstand the load. Compressive strength test was carried out to determine the capacity of brick in carrying the load under compression by using compression testing machine. According to Malaysia Standard MS 76:1972 [9] and British Standard 3921:1985 [14], the minimum average of compressive strength for load-bearing brick is between 7.0 MN/m^2 to 103.5MN/m^2. The clay bricks were measured the area for all the bricks. Compressive strengths test on clay bricks on their bed face (length × width) because of its largest area compared to the stretcher face (length × height) or the header face (width × height). The sample were test for their compressive strength by imposing the brick to compression load until failure.

3.5 Toxicity Characteristic Leaching Behaviour

Toxicity Characteristic Leaching Procedure (TCLP) is a short-term analysis for leachability testing. This testing was conducted according to USEPA Method 1311 [10]. TCLP Method 1311 is intended to measure both compound, organic and inorganic mobility, which also occurs in solid and liquid in multiphasic waste.

Firstly, the samples of bricks were divided into six sections as in Figure 1. The sample were crushed and sieved through a 9.5mm sieve (50 g) were filled in screw capped polyethylene bottles. As required by method the 1:20 solid-to liquid the sample and 5.7mL of glacial acetic acid was added to the leaching the sample were agitated in a rotatory end-to-end at 30rpm in 18 hours. The sample was then filtered through 0,7µm glass fiber filter. All traces of water were separate by continuing suction after the filtration is done. Filtered is to indicate the portion of small particles remain in sample. For indicates that fluids are made up accurately, the pH value should be checked prior to use. The sample from the TCLP test were dilute with reagent water and mixed together in 100ml volumetric flask. Dilution adjustment is to maintain the signals in the linear range of instrument technique. The sample were analysis by using ICP-MS filter machine The concentration of heavy metals was determined by using Inductively Couple Plasma Mass Spectrometry (ICP-MS). After that, all results obtained from ICP-MS was compared with United State Environment Protection Agency (USEPA) [12] and Environment Protection Agency Victoria (EPAV) [11]

4.0 Results and Discussion

These results are divided into two parts according to the objectives of this study. The first is compressive strength based on the wetting drying cycle. The second parts represent the analysis of the concentration of heavy metals in and compare with USEPA and EPAV standard.

4.1 Compressive Strength

The purpose of the compressive strength test was to establish the maximum load that a brick could sustain. According to BS3921: British Specification for Clay Brick [14] the brick's minimum compressive strength test specification should not be below 7.0 MPa. Figure 1 illustrates the result of the compressive strength for control brick and six different percentages of gypsum brick. The highest compressive strength for gypsum brick was obtained at GB 5% with 25.8MPa followed by 10%, 15%, 20%, and 25% of GB with 22.0MPa, 13.3MPa, 11.5 MPa, and 9.1 MPa respectively. However, the compressive strength test for GB 30% did not comply with the standard as the result was below 7.0 MPa.

The porosity is crucial properties, which influences the durability of the gypsum brick. The compressive strength of the brick becomes lower because the brick's contents high porosity. These resistances are related to the specimens' high percentage of porosity, as these results similar to those presented by the previous researcher [15]. As previously stated, the pressure concentration caused by open pores can result in structural compaction loss and a decrease in brick compressive strength. Furthermore, according to a previous study, the crystal formation and, in particular, the water gypsum ratio has an impact on the strength properties of gypsum materials. Gypsum can expand into pores by forming a crystal framework. [16]. This also could happen due to the capability of GB bricks to absorb water. Bricks with lower density and poor durability properties are produced when an excessive amount of water is used during the production of brick [17]

The results as shown in Figure 5 demonstrate that GB 5% and GB 10% can be classified as moderate-weather-resistant bricks (≥17.2MPa) and for GB15%, GB 20% and GB 25% can be categorized as loading bearing walls 1 and 2 (≥7 and ≥14MPa). Meanwhile, GB 30% with the value of 6.2MPa fulfilled non-loading bearing partitions (≥ 1.4MPa) and load-bearing internal walls (≥ 5.2MPa) [13] From the result, 10% of gypsum waste is the optimum amount of waste that can be used to be incorporated into fired clay bricks.

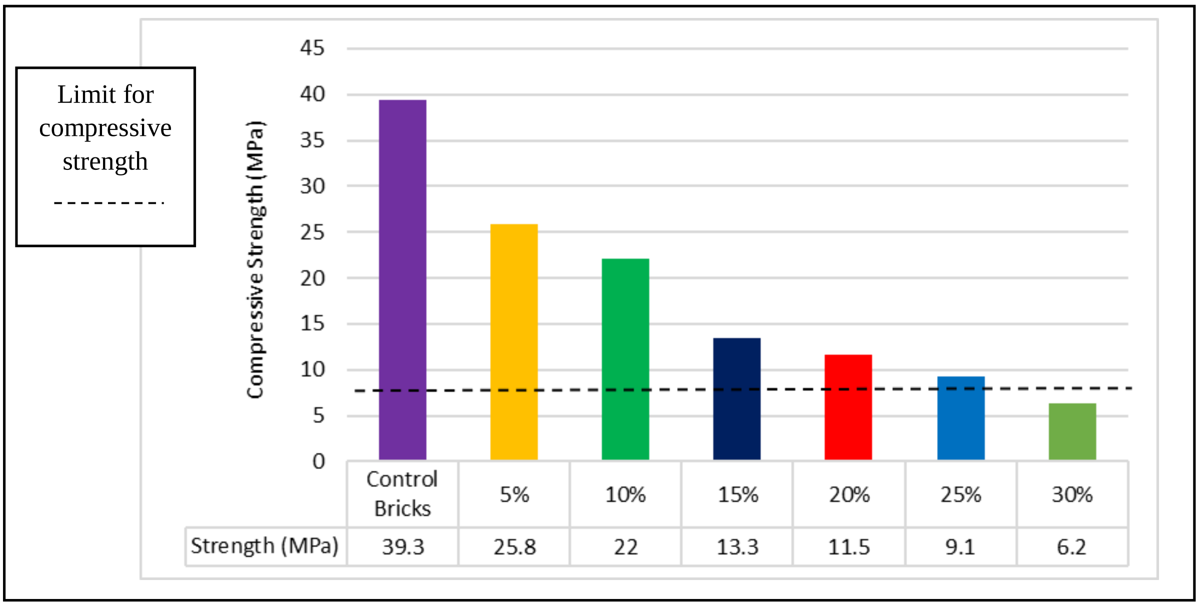

Figure 1: Compressive strength between different percentages of gypsum waste

The relation between standard deviation and mean compressive strength. A low standard deviation indicates that the data points tend to be close to the mean. A high standard deviation indicates that the data points are spread out over a large range of values. From table 2 shows the high standard deviations is control brick with 13.011MPa that followed by GB10%, 15%, 5%, 20%, 30% and 25% with 2.554MPa, 2.285MPa, 1.650MPa, 0.493MPa, 0.493MPa and 0.306MPa respectively.

Table 3: Standard deviation of compressive strength for different percentages of brick

Mixture Identification (%)	Standard Deviations (MPa)
Control Bricks	13.011
5%	1.650

10%	2.554
15%	2.285
20%	0.493
25%	0.306
30%	0.493

4.2 Leachability of Fired Clay Brick

The leachability testing can help to limit the possibility of leaching from waste samples when they are disposed of in a sanitary landfill. Gypsum brick could lower the risk of heavy metal leaching. The utilization of gypsum waste into brick can be regarded as an option to maintain the environment from the effect of hazardous waste.

The results represent the maximum allowable TCLP limit of different heavy metals. Figure 2 until Figure 8 summarizes the ICP-MS results for heavy metals by using the TCLP method for different percentages of control brick and gypsum waste were compared against the concentration limits for heavy metals set by the TCLP Regulatory Levels.

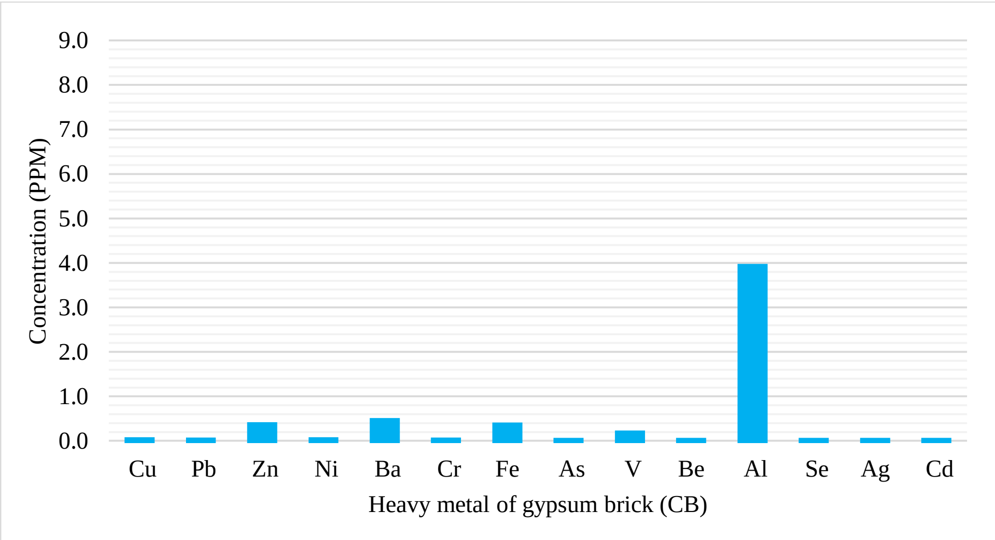

Figure 2: Heavy metal concentration of control brick

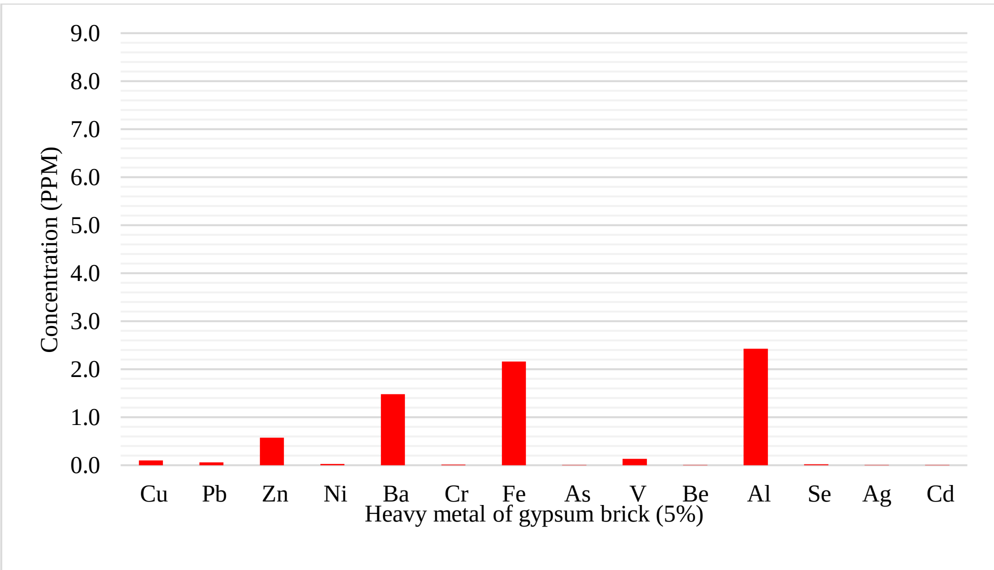

Figure 3: Heavy metal concentration of gypsum brick (5%)

Figure 2 illustrates heavy metal concentration for control bricks, control brick had the highest levels of Al with 3.918 ppm followed by Ba with 0.453 pp. Control brick has a low concentration of heavy metals for Cu, Pb, Ni, Cr, As, Be, Se, Ag, and Cd compared to Zn, Ba, Fe, V, and Al. Meanwhile, Figure 3 illustrates the heavy metal concentration of GB 5%, Al element was higher in Al with 2.430 ppm followed by Fe with 2.160 ppm. For Figure 4 shows a heavy metal concentration of GB 10%. It shows that Aluminum (Al) elements are the highest with 7.822 ppm and passing the limit of EPAV standard which is should be less than 5,0 ppm. Nevertheless, all other heavy metals complied with USEPA and EPAV standards. The heavy metal concentration of gypsum brick (15%) was shown in Figure 5. The result obtained showed that Fe was the highest concentration of heavy metal obtained compared to other heavy metals with 2.54 ppm. The results of heavy metal concentration of gypsum brick (20%) were illustrated in Figure 6 The aluminum element is passing the limit of EPAV standard with 8.377 ppm. Figure 7 shows the gypsum brick (25%) concentration of heavy metals. The highest concentration of heavy metal was Al with 4.380 ppm. The result from Figure 8 shows the heavy metal concentration of gypsum brick (30%). Aluminum element shows the highest concentration with 7.950 ppm and not passing the limit of EPAV standard with 5 ppm.

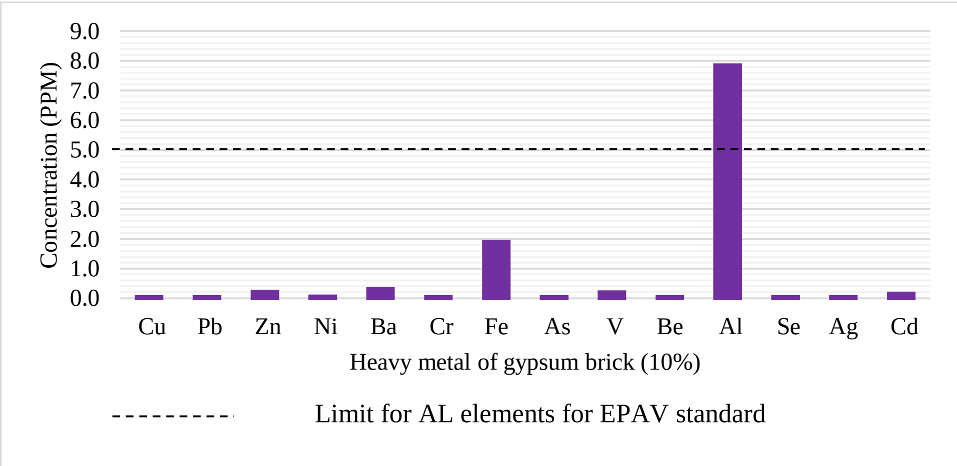

Figure 4: Heavy metal concentration of gypsum brick (10%)

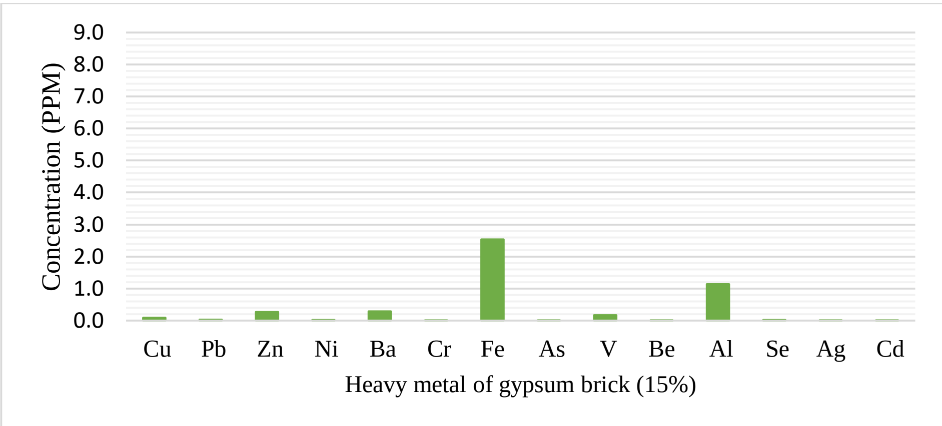

Figure 5: Heavy metal concentration of gypsum brick (15%)

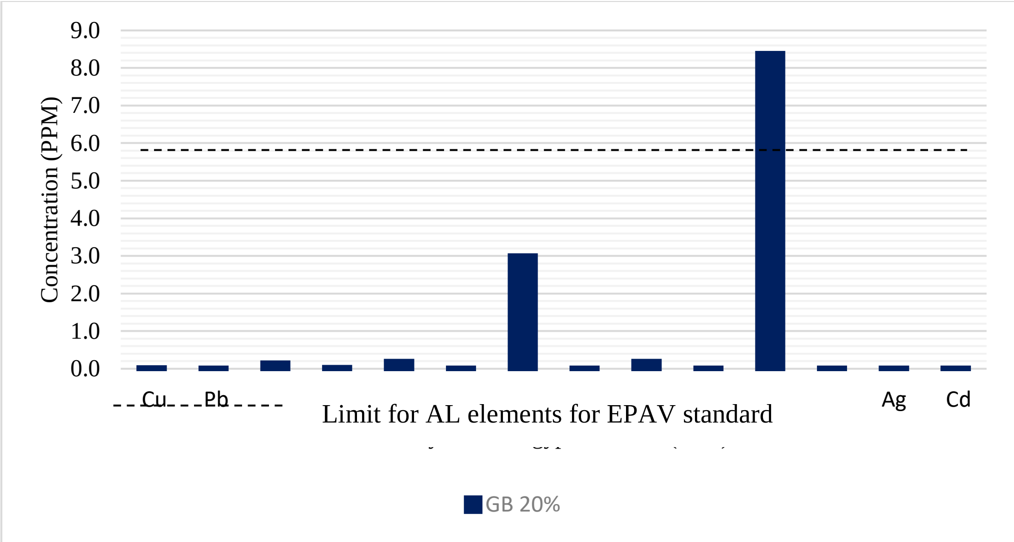

Figure 6: Heavy metal concentration of gypsum brick (20%)

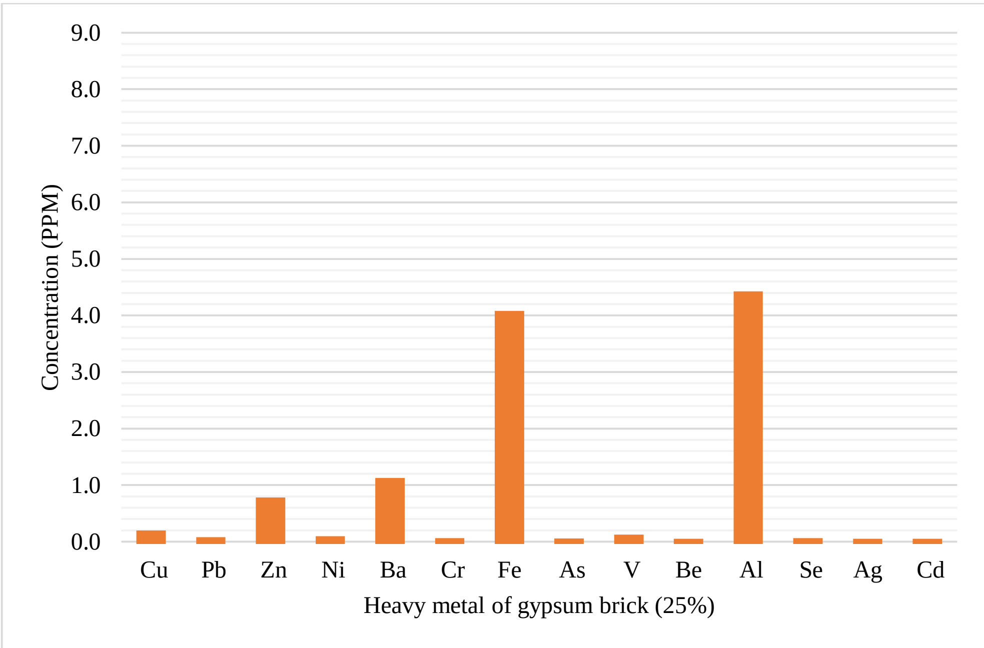

Figure 7: Heavy metal brick concentration (25%)

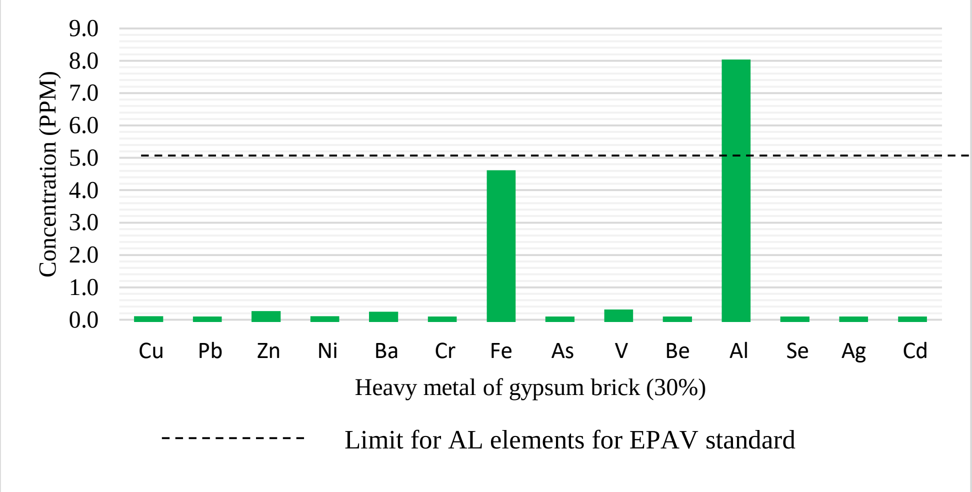

Figure 8: Concentration of heavy metal gypsum brick (30%)

The Fe concentration in the gypsum brick showed a huge difference compared to the control brick which is 1.520 ppm, this represents the brick's permeability and durability [19]. The highest concentration of aluminum (Al) was showed in the gypsum brick at 20% with 8.377 ppm. The high value of Aluminum gives an effect to humans and environments. People exposed to high levels of aluminum may develop Alzheimer's disease and also linked to inflammatory descend in wide range of disease [20]. The TCLP test used acetic acid in fluid reagent causing the heavy metals to bind leachate out was higher [21]. Consideration to repeating the leaching test to helps reduce the effects of errors and represent the better results. Moreover, most elements of heavy metal showed below the limit's concentration. Since heavy metals were oxidized during the firing process at higher temperatures, the threat of toxic element leaching was decreased. [22]. Thus, the reuse of gypsum brick to produce fired clay bricks could minimize the adverse impact of waste generation on the environment and hence, an eco-friendly cleaner way of managing industrial waste.

5.0 Conclusion

The findings of the wetting drying process revealed that the utilization of gypsum brick obtained the highest compressive strength up to 25.8 MPa. However, the result obtained was below compared to control brick. The higher amount of gypsum waste is manufactured brick, the lower the compressive strength of the brick. However, these results still fulfilled the minimum of ASTM International, (2017); MS 76, (1972). The second objective was achieved when TCLP all the percentages have complied with USEPA (1996) and EPAV (2005) except for Al element which passes the limit that is set by EPAV (2005) standard. Overall, it can be stated that gypsum brick is a prospective and suitable waste to be incorporated in fired clay brick because it can produce lightweight brick to generate new low-cost building materials while also improving the landfill's lifespan and reducing pollution to the environment. Recommendation for further research by add additives such as electroplating sludge to improve the strength of the gypsum brick. Different firing rates also could be used to find the optimum temperature for the firing process. As an outcome, the performance assessment of fired clay bricks made from gypsum waste used up to 15% of waste was demonstrated the potential utility in the construction of sustainable non-loading brick.

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