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The Feasibility of Fired Clay Bricks Production From Industrial Waste: Overview on Properties and Potential Environmental Impact

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Abstract: The ever-increasing number of industries and factories development had produced industrial wastes. In consequence, the waste products are potentially a hazard to the surrounding. Therefore, to solve this problem, a new alternative method to recover the industrial waste such as gypsum waste, electroplating sludge and mosaic sludge into new product was highlighted by incorporating into fired clay brick. This study was conducted to review the properties and the potential environmental impacts of fired clay brick production by utilizing industrial waste based on literatures from previous studies. Previously, the physical and mechanical properties showed that shrinkage was found to be effective in achieving a result of less than 8%. The increasing addition of industrial waste, the lower of compressive strength and density able to make the size of brick's pore are larger. In addition, the potential environmental impacts were analyzed using life cycle assessment. The previous data showed that traditional brick and industrial waste has a big impact on acidification, global warming and ozone layer depletion. The LCA analysis could provide insight view on the production of fired clay brick incorporated with industrial waste hence could benefit both the industrial and environmental privileges.

Keywords: Hazardous Waste, Environmental Impacts, Fired Clay Brick, Industrisl Waste

1. Introduction

Malaysia is one of the world's fastest developing economies. Malaysia's economy was ranked 24th in the 2013 global competitive index and is now placed 18th in the 2015 global competitive index rating [1]. The ever-increasing number of industries and factories development had produced industrial wastes. Malaysia's ongoing growth in waste output has been linked to the country's expanding

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population and economy [1]. In consequence, those waste produced are potentially hazardous to the surrounding. Thus, to solve these problems, a new alternative method to recover the industrial wastes such as gypsum waste, electroplating sludge, mosaic sludge and other waste into new products was highlighted by incorporating into fired clay bricks. As an alternative to immediately disposing of garbage in landfills, the 3R model technique is utilized to manage waste that has been created [2]. Furthermore, incorporating industrial waste into the fired clay brick would be able to contribute to the environmental protection, human health enhancement and lower operational costs for industry by minimizing the waste disposal cost [3].

Bricks is the oldest mansion that has been manufactured as important building materials that are used by mankind in the world. Brick making has changed from a craft industry to a mechanized industry. Depending on the materials and methods of production used it comes in different shapes, color, texture, intensity and consistency. Fired clay bricks are commonly use in the building and construction. Fired clay bricks tend to be more highly durable and highly strength when in the cooling process. The manufacture process of fired clay brick can be highly cost, challenging and produce many environmental impacts. Nevertheless, in industry areas, they are more concerned about the availability of raw resources. Therefore, many researchers are trying to find an alternative material to be incorporated into fired clay brick.

Recently, many researchers applied the Life Cycle Assessment (LCA) toward assessing the production of sustainable development in order to overcome resource depletion and to address environmental concerns. LCA is the indicator to assess the potential environmental impact, input and outputs of the brick in their whole life cycle [4]. Moreover, LCA covers the sources of the raw materials, production and transport methods, the use and maintenance of the product, process waste and the reuse, recycling, recovery of energy and disposal of the product [5]. LCA measures the resources that are being used and emissions produced in the entire product's life cycle and also evaluate the impact of this specific environmental aspects such as global warming, ozone layer depletion, eutrophication, acidification and human toxicity. Therefore, this study highlighted the properties and potential environmental impact of fired clay brick incorporated with industrial waste by reviewing the previous researches findings.

This study was conducted by reviewing previous literature reviews on incorporation of industrial waste into fired clay bricks. Firstly, properties such as shrinkage, density, water absorption and compressive strength were reviewed based on the findings from previous studies conducted. Secondly, the environmental impacts such as global warming, ozone layer depletion, acidification, ecotoxicity and others of the fired clay brick production with utilization of industrial waste, were reviewed distinctly on the Life Cycle Assessment (LCA) approach. The data collected were used to emphasize on the importance of LCA analysis throughout the production process of recycling gypsum waste, electroplating sludge and mosaic sludge into fired clay bricks. Literature reviews from different researchers discussing on the recycling of industrial waste into fired clay brick were studied in terms of properties and environmental impacts.

2. Materials and Methods

This study reviewed the experimental work conducted from the previous studies to examine the physical and mechanical properties and potential environmental impacts of industrial waste incorporated into fired clay brick using life a cycle assessment. The testing procedures, equipment and materials were reviewed accordingly. The physical and mechanical properties including shrinkage, density, water absorption and compressive strength were reviewed based on literatures. On the other hand, potential environmental impacts from brick production that was conducted using a life cycle assessment approach based on previous studies were reviewed.

The manufacture of control bricks includes raw material that is clay combined with distilled water. Nevertheless, without adding any chemicals or waste, the control brick was originally made from clay. In conjunction to compared the result of clay brick and industrial waste-clay brick, control brick was produced. The sample was then mixed with distilled water. After that, sample materials were compacted by layer into brick mould according to the dimension of brick. Based on previous study, the brick dimension is 50 mm x 35 mm x 10 mm for length: width: height [6]. Then the bricks were place into a drying process at room temperature for 24 hours. In another 24 hours, the samples were transferred into an oven with set up for temperature 105ºC or 110ºC. For the next 24 hours, the bricks were placed into the firing process. Based on previous study, firing of brick at 1050 °C [7], at 1000ºC [8], at 800ºC to 1100ºC [9], 500ºC and 900ºC [10], at 950ºC, 1000ºC and 1050ºC [11] and at 1000ºC to 1300ºC [12]. After the firing process, the brick was tested for shrinkage, density, water absorption, and compressive strength based on the standard stated on the research previously.

Different proportion of additional industrial waste into fired clay brick during the mixing process. However, the process is still the same as the control brick manufacturing in the drying and firing process. The percentage mixing of industrial waste into fired clay bricks based on previous study are shown in Table 1. Life Cycle Assessment (LCA) is an indicator to assess the potential environmental impact, input and outputs of the brick in their whole life cycle. There were 4 steps in analysis of LCA which is goal and scope definition, life cycle inventory analysis (LCI), life-cycle impact assessment (LCIA), and interpretation.

Table 1: Percentage of industrial waste incorporation into brick from previous studies

No.	References	Percentage of industrial waste (%)	Type of Industrial waste
1.	(Mao et al., 2019) [13]	0, 5, 10	Electroplating sludge
2.	(Pérez-Villarejo et al., 2015) [7]	0, 1, 2, 3, 4, 5	Galvanic sludge
3.	(Durante Ingunza et al., 2011) [8]	5, 10, 15, 20, 25,30, 35 and 40	Sewage sludge
4.	(Emrullahoglu Abi, 2014) [9]	0, 2.5, 5, 7.5, 10, 12.5 and 15	Borogypsum
5.	(Dhanapandian & Gnanavel, 2010) [10]	0, 10 ,20, 30, 40, and 50 by weight	Granite waste and Marble waste
6.	(Rouf, 2003) [11]	5, 15, 25 and 50	Arsenic and iron sludge
7.	(Bygness, 2015) [12]	100	Fly ash

3. Results and Discussion

3.1 X-ray fluorescence (XRF) of gypsum waste, electroplating sludge and mosaic sludge

The dresults of characteristic of gypsum waste, electroplating sludge and mosaic sludge from the previous studies were reviewed. From data analysis, the results for the properties of different percentages of clay-industrial waste brick and control brick (CB) with a certain amount of heating rate were obtained. The characteristics of gypsum waste, electroplating sludge and mosaic sludge was determined by using X-Ray Fluorescence (XRF). From previous research, gypsum waste consists of a high amount of calcium oxide (CaO) with 50.29% as reported by Pedreño-Rojas et al., (2019). Meanwhile for electroplating sludge, the highest chemical composition contained in raw material from previous studies were iron oxide (FeO3) with 28.25% [6]. As for mosaic sludge, the highest heavy metal compound was silicon oxide (SiO2) which with 65.77% [15].

3.2 Physical and Mechanical Properties of gypsum waste, electroplating sludge and mosaic sludge incorporating with fired clay bricks

The properties of gypsum waste, electroplating sludge and mosaic sludge incorporating with fired clay bricks such as shrinkage, dry density and compressive strength were reviewed as following**.**

3.2.1 Shrinkage

Shrinkage of gypsum waste showed the expansion behaviour of unfired bricks during firing was investigated using dilatometric analysis. In the drying stage for bricks, dilatometric charts demonstrate that less shrinkage occurs at 100°C. Because of quartz transformation, significant expansion occurs about 500–585 °C for bricks at a rate of 0.4%. Furthermore, the softening temperature of the reference brick was approximately 1025°C, whereas the temperature of the brick containing 15% concrete waste was approximately 1075 °C. The addition of concrete debris raises the fire temperature to 50^{o}C. However, both samples obtained a same similar expansion behaviour of 0.2% after cooling process [16].

Besides that, electroplating sludge showed that based on Zhang et al., (2018) study, the shrinkage of the bricks increases as the addition of electroplating sludge increases. The results show that the shrinkage for 0%, 2%, 4%, 6%, 8% of electroplating sludge proportion and 10% was 0.14%, 0.64%, 0.71%, 0.85%, 0.98%, and 1.12% respectively. The quality of brick was acceptable because it does not exceed 8% of shrinkage limit.

In addition, for mosaic sludge showed that from (Kadir, Rahim, & Hassan., 2016) study, it shows that the 5% addition of mosaic sludge to the brick obtained the least shrinkage with 0.31% followed by 1%, 10%, 20% and 30% addition of mosaic sludge brick with 0.46%, 0.56%, 0.52% and 0.67% respectively. Nevertheless, no addition of mosaic sludge proportion showed the highest values with 0.69%. However, all manufactured bricks do not exceed 1% of shrinkage and far from the good quality requirement by previous researcher that should less than 8% [17].

3.2.2 Density

For gypsum waste, previous study showed that density stands up as the most crucial aspect related to the reason because it can alter so many physical, mechanical and thermal properties of composites. The average of density of brick when 20% of gypsum waste was added was 0.26 g/cm^3 [18].

Furthermore, density of electroplating sludge showed that different amount of electroplating sludge has been used with the percentage between 1% to 10%. From research study by Zhang et al., (2018), there is dropped from 2.07 g/cm^3 (control brick), 2.05 g/cm^3 (2%), 2.04 g/cm^3 (4%), 2.03 g/cm^3 (6%), 2.0 g/cm^3 (8%) and 1.96 g/cm^3 (10%).

Nevertheless, mosaic sludge based on Kadir et al., (2016) study, the lowest density of bricks was 1.66524 g/cm^3 with mosaic sludge 30%. While the others, there is slightly increasing value from 20%, 10%, 5%, 1% and 0% with density 1.67743 g/cm^3, 1.67989 g/cm^3, 1.68328 g/cm^3, 1.68806 g/cm^3 and 1.69824 g/cm^3 respectively.

3.2.3 Compressive strength

Compressive strength for gypsum waste showed different amount of gypsum waste has been used such as in between of 0% to 99.5%. Based on the researcher study by Geraldo et al., (2017), the brick strength was 11.5 MPa at 20% of gypsum waste. From research study by Gencel et al., (2016), there is decreased in compressive strength as the gypsum waste increasing. Compressive strength for control brick at 79.5% of gypsum waste was 1.9 MPa and dropped to 1.6 MPa at 89.5% of gypsum waste. Then, the compressive strength dropped to 1.1 MPa as the gypsum waste at 99.5%. In Gencel et al., (2020) study, it stated that the higher compressive strength was recorded at 23.4 MPa with gypsum waste 2.5%.

In addition**,** from research study by Zhang et al., (2018), there is decreased in compressive strength as the electroplating sludge addition increasing. Compressive strength for control brick at 0% of electroplating sludge was 24 MPa and dropped to 22 MPa at 2% of electroplating sludge. Then, the compressive strength dropped to 19.3 MPa as the electroplating sludge at 4%. During addition of electroplating sludge by 6%, 8% and 10%, the compressive strength continues to dropped which is 18.1 MPa, 17.8 MPa and 15 MPa respectively.

Moreover, for mosaic sludge, the result of compressive strength dropped from 23 MPa at 0% mosaic sludge to 19.5 MPa when 3% of mosaic sludge was added [19]. Then, at the 5% addition of mosaic sludge, the compressive strength was 18 MPa. Lastly, the compressive strength was dropped to 16.5 MPa at 10% of mosaic sludge.

3.3 Life Cycle Assessment (LCA)

Recently, many researchers applied the Life Cycle Assessment (LCA) toward assessing the production of sustainable development in order to overcome resource depletion and to address environmental concerns. LCA is the indicator to assess the potential environmental impact, input and outputs of the brick in their whole life cycle [4]. LCA was started by Coca-Cola Company in 1969 which cradle to grave study to quantify the environmental effects of packaging. LCA monitors and tracks the environmental impacts of a product, service or operation [5]. Moreover, LCA covers the sources of the raw materials, production and transport methods, the use and maintenance of the product, process waste and the reuse, recycling, recovery of energy and disposal of the product [5]. LCA will measures the resources that being used and emissions produced in entire of product's life cycle and also evaluate the impact of this specific environmental aspects such as human health climate change and damage to ecosystems. Therefore, the environmental impacts such as global warming, ozone layer depletion, acidification, ecotoxicity and others of the fired clay brick production with utilization of industrial waste, were reviewed distinctly on the Life Cycle Assessment (LCA) approach by reviewing the previous researches findings.

Figure 1 shows the comparison of life cycle assessment that was conducted by Lozano et al., (2018), Muñoz et al., (2018), and López et al., (2016). In Lozano et al., (2018) study, life cycle assessment was conducted using 1kg of clay with a fixed thermal resistance. However, the impact assessment method used were different such as ReCiPe Endpoint and Impact 2002+ v2.12. These gives a difference value on impact category. Based on figure, it shows that terrestrial ecotoxicity have a higher impact (55%) by using ReCiPe Endpoint method than Impact 2002+ v2.12 method (38%). Both impact assessment method, obtained same value for ozone layer depletion and ionizing radiation impact category indicator with 100% respectively. According to Muñoz (2018), the acidification impact category indicator has obtained higher value among the rest which is 84% compared to ozone layer depletion (70%) and terrestrial ecotoxicity (31%). The assessment impact method used by Muñoz et al., 2018 was ReCiPe Midpoint (Europe H) v.1.13 and ReCiPe Endpoint (Europe H/H). In addition, based on Figure 4.16, it obviously that acidification impact category indicator by researcher López *et al*., (2016) obtained the highest value than the other researcher which is 93%. Nevertheless, terrestrial ecotoxicity gives impact by 55%. The impact assessment method in this study was ReCipe midpoint.

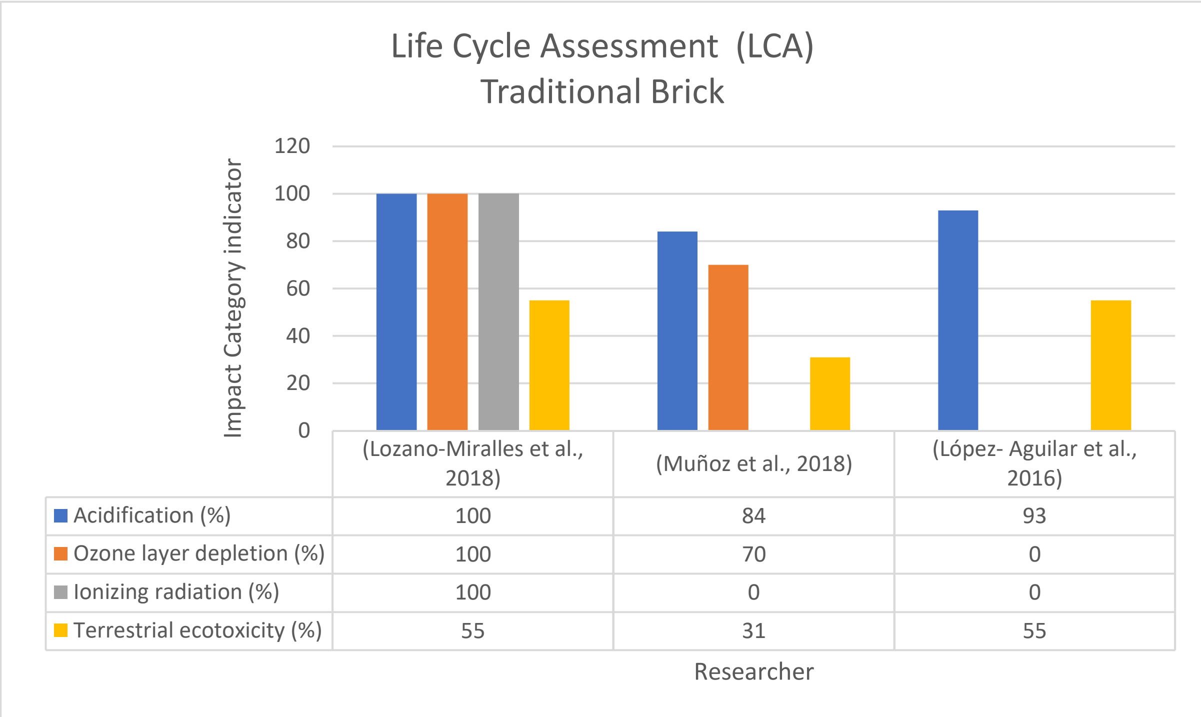

Figure 1: Life cycle assessment of traditional brick based on previous studies

4.0 Conclusion

As conclusion, the findings from earlier research indicated that electroplating sludge may be used as a raw material in the brick production. The ideal concentration of industrial waste is less than 8%. Shrinkage of less than 8% allows for sufficient brick production. Bricks that have a lower density will experience a lower heat conductivity hence, produce more lights. Porosity is reduced in bricks with lesser water absorption, which can increase compressive strength. At the same time, it will provide insight view for the industry from the cradle to gate of the advantages and also disadvantages in recycling industrial waste into fired clay bricks. In conclusion, fired clay brick with industrial waste has the potential to be utilize as low-cost building materials while also helping to reduce environmental pollution.

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