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An Overview of Sludge Utilization into Fired Clay Brick

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Abstract**—**Brick is one of the most common masonry units used as building material. Due to the demand, different types of waste have been investigated to be incorporated into the bricks. Many types of sludge have been incorporated in fired clay brick for example marble sludge, stone sludge, water sludge, sewage sludge, and ceramic sludge. The utilization of these waste materials in fired clay bricks usually has positive effects on the properties such as lightweight bricks with improved shrinkage, porosity, and strength. This paper reviews on utilization of different types of sludge wastes into fired clay bricks. Previous investigations have demonstrated positive effects on the physical and mechanical properties as well as less impact towards the environment. Thus, the utilizations of sludge waste could produce a good quality of brick and could be one of alternative disposal methods for the sludge wastes.

Keywords**—**Fired Clay Brick, Sludge waste, Compressive strength, Shrinkage, Water absorption.

I. Introduction

NOWADAYS, many of researches has been carried out to find an environmental friendly material and method, as well as alternative low cost material for building purposes [1]. Recycling of waste generated from industrial or agricultural activities as building materials appear to be a solution for economic design of the building as well as in environment pollution problem [2]. The incorporation of various industrial wastes as additives in the manufacture has been attracting interest from researchers and becoming a common practice [3], [4]. One of the most common wastes incorporated in building materials is sludge. Sludge often associated with human waste from residential sludge; however sludge is also the accumulated solid which consists of industrial waste, hospital waste, wastewater treatment, runoff from the street, farmland and some cases from landfill leachate. Generally sludge from residential areas is in organic condition. Human waste cause less harmful and impact to the environment compared to industrial waste. Industrial sludge could be in organic or inorganic form. Inorganic content of industrial sludge such as heavy metals should get the specific treatment to prevent environmental pollution. Furthermore, sludge from industrial also becomes a critical issue due to public concern and limited availability of land [5]. Due to high demand and flexibility of brick, different types of waste have been successfully incorporated into fired clay brick especially sludge waste for example marble sludge, stone sludge, water treatment sludge, sewage sludge, desalination sludge, textile laundry sludge and ceramic sludge. The utilization of these wastes in clay bricks usually has positive effects on the properties such as lightweight bricks with improved shrinkage, porosity, thermal properties, and strength [6]. The lightweight bricks will reduce the transportation and manufactured cost. Moreover, with this waste incorporation it will reduce clay content in the fired clay brick, and then reduce the manufacturing cost [7]. This motivates many researches to investigate more potential of different sludge to be incorporated into the brick.

Brick is one of the most widely used as conventional building materials around the world since ancient times [8], [9]. Bricks are manufactured from variety of materials such as clay, lime, sand/flint, concrete and natural stone. Brick basically builds for masonry structure bonded with mortar or grout. Fired clay brick is manufactured by shaping suitable clay to units of standard size [10]. The manufacturer minimizes variations in chemical composition and physical properties by mixing the clays from different sources and different locations. Fired clay brick from the same manufacturer will have slightly different properties in subsequent production runs. Further, brick from different manufacturers that have the same appearance may differ in other properties [11].

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II. Overview of Sludge Waste Incorporated in Fired Clay Brick

A. Textile Sludge

Jahagirdar et al. [12] discussed the reuse of textile mill sludge in fired clay bricks. The textile mill sludge was mixed together with different proportion (5% to 35%) as the raw material in this study. The brick was fired at 600ºC to 800ºC and for 8, 16 and 24 hours. Based on the results, textile sludge can be added up to 15% as it gives compressive strength above 3.5MPa and the water absorption ratio is also less than 20%.

According to Herek et al. [13] the investigation on the incorporation of textile laundry sludge into a brick showed that sludge can be incorporated up to 20% in terms of the mechanical properties. The compressive strength of the control brick was 3.73MPa and 4.62MPa for the sludge brick. On the other hand, the water absorption result obtained has shown that 15.73% and 10.10% for control brick and sludge brick respectively. Besides, the produces brick is safe according to applied leaching and do not exceed the standard limits.

Baskar et al. [14] also discussed about characterization and reuse of textile effluent treatment plant waste sludge in clay bricks. In his study, the sludge composition was from 3% to 30% and the firing temperature is about 200ºC to 800°C. The compressive strength was between 4.24MPa to 3.54MPa which satisfies the Bureau of Indian Standard (BIS). The maximum amount range of sludge that can be added is from 6% to 9%.

B. Water Treatment Sludge

Babu and Ramana [15] in their research investigated on bricks durability of cast brick with industrial sludge. The results show that the earth brick can be replaced with sludge up to 40% by weight with satisfactory value in strength. The compressive strength of brick without sludge and 5% of sludge were 11.7MPa and 17.6MPa respectively. The compressive strength was decreasing with addition of sludge beyond 5% from 17.6MPa to 10.5MPa. For water absorption result, when the sludge added more than 10% by weight, the water absorption was gradually increased. In this study, addition of sludge into brick gives dual benefits of safe disposal of sludge from industry and also conservation of brick making.

As for Hegazy et al. [16], they discussed the incorporation of water treatment sludge and rice husk ash in clay bricks. In this study, 25%, 50% and 75% by weight of water treatment sludge was added to produce clay bricks. Each brick series was fired at 900ºC, 1000ºC, 1100ºC, and 1200ºC. The compressive strength of brick value were 5.7MPa to 6.8MPa for the control brick and 2.82MPa to 7.84MPa for Sludge-RHA brick. Meanwhile, for the water absorption test, the results were 9.94% to 11.18% of control brick and 17.41% to 73.33% for Sludge-RHA brick respectively. From the obtained results, it was concluded that by common temperature, 75% addition was the optimum sludge to produce the bricks. On the other hand, Hegazy et al. [17] also discussed the incorporation of water sludge, silica fume (SF) and rice husk ash (RHA) in brick making. Three different series of sludge to SF and RHA proportion which were (25:50:25%), (50:25:25%) and (25:25:50) were incorporated. Each brick was fired at 900ºC, 1000ºC, 1100ºC and 1200°C. For the compressive strength and water absorption the results obtained 5.03MPa to 8.12MPa and 16.24% to 52.11% respectively. The operating at the temperature commonly practiced in brick klin could be concluded that mixture consists of 50% of sludge, 25% of SF and 25% of RHA was the optimum materials proportions that demonstrated obvious superior properties to the 100% clay control-brick.

Victoria et al. [18] developed bricks from water works sludge with five different mixing ratio of sludge at 0%, 5%, 10%, 15% and 20% of the total weight of sludge-clay. Each brick has been moulded by hand and been fired into furnace at elevated temperature of 850°C, 900°C, 950°C, 1000°C and 1050°C. The result of compressive strength of sludge clay brick are between 0.97MPa to 12.98MPa. Increasing the sludge content result in decreased compressive strength decreased density and increased water absorption. Results for density and water absorption are 1g/cm2 to 2g/cm2 and 14.07% to 31 % respectively. Toxicity characteristic leaching procedure (TCLP) result showed that the metal leaching level is within the acceptable limits of NESREA and USEPA limits.

According to Saijun et al. [19] in their investigation, the incorporation of three sludge percentages which are 6%, 8% and 10% shows that the compressive strength was decreased to 20.22% but the flexural strength increased. The compressive strength of 10% of sewage sludge obtained 21.8MPa and flexural strength of 4.6MPa. Autoclaved sludge fly ash was incorporated in brick when pH 6.9 was obtained which is close to normal pH. The heavy metals were solidified during the curing process and it will not pollute the environment.

In the year 2008, Ramadan et al. [20] discussed the reuse of sludge from water treatment plant. The results of water absorption ranged between 4.84% and 17.34% which comply with the requirement of the Egyptian standard specification. There were five brick types that exhibited water absorption less than 7% and met the requirement for the British standard to be classified as Engineering Brick B. According to Ramadan et al. [20] compressive strength is usually affected by the porosity, pore size and type of crystallization. The results show compressive strength values between 2.3MPa and 11.66MPa. Compressive strength values more than 7.35MPa met the requirement of British standard for engineering brick. A. Ramadan et al. [20] also concluded that all bricks tested in this investigation are superior compared to the commercial clay brick types available in the Egyptian market.

C. Sewage Sludge

Ingunza et al. [21] used 5%, 10%, 15%, 20%, 25% and 30% of sewage sludge incorporated into soft-mud brick with 12 specimens for each sludge percentages. From the result obtained there is no sign of alteration in color or odor. Brick with 35% sludge were very brittle and there are some of dimension reduction changes between 1mm to 7mm. Based on the result, the brick mass significantly loss according to the percentage of sludge. Weng et al. [22] also reported the same conclusion. Inagunza also claim that bricks manufactured with 20%, 25% and 30% are above the limit proposed [23]. In terms of properties the water absorption result shows there were increment for each brick compared to control brick. With 25% of sludge used, the brick absorbing capability increased to an average of 160% more than control brick. The sludge brick with 25% and 30% inclusion do not meet minimum standard required but other percentages comply with the minimum standard strength.

Liew et al. [24] study the incorporation of dry weight of sludge into brick with 10% to 40% and fired at 985°C. In this study, the utilization of sludge more than 40% still complied with the standard based on physical and chemical properties. However, the researchers concluded that the maximum percentage of sludge used should not be more than 30% by weight due to its fragility. The water absorption value increased by up to 37% compared to the control brick (23.6%) and the compressive strength decreased to 2MPa against 15.8MPa for the control brick. During the firing process, the gases included steam and CO_2 were released, also the cross section revealed black coring due to the combustion of the organic content in the sludge. The bricks were only appropriate for use as common bricks because of the entire weak and poor exterior surface.

According to Lin et al. [25] the results obtained demonstrated that the appropriate percentage of ash sludge to produced good quality bricks is in the range of 20% to 40% by weight with a 13% to 15% optimum moisture content prepared in the moulded mixture. Firing is conducted at 1000ºC for 6 hours. Utilization of 10% sludge ash exhibited higher compressive strength than normal brick.

Dondi et al. [26] discussed in their review on recycling of industrial and urban waste in brick production shows that waste characteristic highly with organic content, for example, on the incinerator solid waste urban content range from 10% to 20% (mass) organic content [27] and some cases is range from 30% to 60% organic content. Furthermore, the organic content mostly high for sewage sludge [28]. In some cases, the waste is often too dried at temperature 450°C [27], [29]. Furthermore, according to Dondi et al. [26] basically, inorganic chemical composition was silicate, meanwhile for the heavy metals content such as Pb, Zn, Cr, Cu and others [28]-[30]. Dondi et al. [26] also mention because of several of the characteristics of the products were tested; the approximate value for 10000kJ/kg of dry fraction could save fuel from 10% [28] up to 40% [30]. The best percentage of sludge to be incorporated into clay is within a range of 2% by mass [27] up to 25% to 30% by mass [31], [32]. This utilization could save the raw material consumption as well as disposing a potential waste that could pollute the environment [33], [34]. In process terms of properties some cases reported that, the shrinkage was increased significantly during the drying process by formation of cracks [28], [31]. Dondi et al. [26] also mention 30% of sewage sludge reduces 15% of dry density after the firing [35]. The strength properties due to variation effect were decreased from 4% to 30% with sludge addition more than 50% [35]. During the firing process, there was negative impact including unpleasant odors [29], [32], efflorescence [29] and black core phenomena.

Sidrak [36] research on the Biofly brick is by reuse of fly ash and sewage sludge. The results show the brick incorporated with 50% to 70% indicated that the average of compressive strength ranged between 21.4MPa to 49.7MPa for Biofly brick and 39.1MPa for ordinary brick. This research used firing temperature of 200°C, 400°C, 600°C, 800°C and 1100°C. The water absorption result shows averaged of cold and hot water absorption values of 15% and 15.3% for Biofly brick and 3.9% and 4.9% for clay/shale brick. As for the leachate studies there were three different size fractions were undertaken for all the bricks made. All leachate samples were analyzed for copper, iron, manganese, nickel, lead, zinc, cadmium, chromium and aluminium concentration. All metals were tested by using Atomic Absorption Spectrophotometry. The results shown the concentration of heavy metals was within the limits standard by Victoria EPA and US Code of Federal Regulation (CFR). Nevertheless, the heavy metals were detected still inside the brick even in the low concentration. The gas consumption and gas emission study indicated that the brick process uses less energy and produced a smaller amount of air pollution compared to standard brick. Biofly brick also saves energy up to 44%, produces 20% to 24% lighter brick and 10% to 30% stronger compared to the conventional bricks.

D.Other Sludge

Stone sludge was another sludge that studied by Rajgor et al. [37] to be used in clay bricks. Varying percentages of stone sludge 10%, 20%, 30%, 40%, 50% and 60% were incorporated in the clay bricks. All samples were fired at 1050ºC. The results for compressive strength are 2.11MPa to 4.2MPa and water absorption ratio is from 8% to 12%.

Hii et al. [38] discussed the reused of desalination sludge for brick. Desalination sludge has been dried and ground into fine powder before being mixed with clay with mixing ratios 0%, 10%, 20%, 30%, and 40% content by weight. The average of compressive strength was decreasing from 8MPa, 3MPa and 2MPa for 0%, 10%, and 20% sludge bricks respectively. Water absorption results showed that increasing sludge will increase the water absorption with 8.1kg/m2min for control brick to 14.6kg/m2.min for 40% of the dried desalination sludge.

Ferez et al. [39] investigated on how to manufacture ceramic bricks by using recycled brewing spent kieselguhr sludge. The result obtained demonstrated an increases value in the porosity and decreases the bulk density around 1919kg/m3 to 2090kg/m3 at 900°C to 1000°C respectively. Water absorption was increased with the increasing of the sludge and decrease with firing temperature. For the mechanical properties, strength shows 8.3MPa, 17.1MPa, 17.5MPa and 18.4MPa at 105°C, 900°C, 950°C, and 1000°C respectively. In this research, the results shown no constrain concerning mechanical properties. Furthermore, the ecotoxicity evaluation also shows the safety of the brewing spent kieselghur incorporation in ceramic product is complied with the standard.

Environmental concern encourages Khezri to explore the investigation of aluminium anodizing sludge cake utilization in brick manufacturing [40]. The sludge contains huge toxic components such as aluminium, calcium oxide, silica, nickel, sulphur and other dangerous components. From the results, it shows all brick are in standard range of usual brick, usable and have no limit in water absorption. Salt leakage test shows that by increasing the percent of sludge in bricks the salt leakage is increasing too. The bricks sludge had a low average salt leakage with sludge incorporated from 0%, 40%, 50%, and 60%. The brick incorporated with anodizing sludge had less density and the toxic leakage of aluminium and iron were in the range stated by standard of Iran DOE for 50% and 60% of the sludge. Anodizing aluminium sludge has more benefits besides decreasing harmful effect of this sludge on the ecosystems.

According to Weng et al. [22], by using dried sludge as a clay substitute to produce an engineering quality brick is a very potential alternative material. The proportion of sludge in the mixture and the firing temperature are two key factors affecting the quality of brick. In all, Weng et al. [22] recommended the optimum proportion of sludge in brick is 10% with 24% optimum moisture content, prepared mixtures and fired between 880ºC and 960ºC to produce a good quality brick.

According to Sengupta et al. [41], petroleum sludge was hazardous sludge containing high amount of hydrocarbons. The petroleum sludge contains oil, water and inorganic material [42]. The major constituents of the sludge are SiO_2, CaO, Al_2O_3 and Fe_2O_3. The result shows that, the quality of brick sludge is better than the standard bricks due to color and less fuel of firing. Compressive strength results shown the Soil: Sand: Water (SS) and Soil: Sand: Sludge (SSS) brick produced 16.45MPa and 16.02MPa respectively higher than commercial brick with 9.06MPa. All bricks complied with all requirements according Indian standard. Most of the metals (Mn, Cr, Sb, Ni, Co, and Hg) are emitted during firing. By using this sludge, it will reduce the requirement of water and fuel in brick manufacture and could be one of the disposal methods for the hazardous sludge.

Tay et al. [43] used 2% to 16% of industrial sludge in clay bricks and fired with temperature 1050ºC. The compressive strengths of sludge clay bricks with various mix proportions fall within range of 12MPa to 31MPa. The experimental study indicates that the reuse of marine clay-industrial sludge mixes as brick making material offers a technically feasible alternative for disposal of the wastes as well as resource recovery.

III. Conclusion

The utilization of different types of sludge waste into fired clay brick always obtain various advantages in terms of physical and mechanical properties such as low density, lightweight bricks, better strength and even reducing energy consumption during firing even though some drawbacks were also demonstrated. In addition, these investigations also have shown a significant lower impact towards the environment by incorporating these wastes into fired clay brick. After the incorporation, most of the chemical compositions as well as the heavy metals were emitted during firing or solidified during curing, thus the end product is comply with the standards. As a conclusion, the utilizations of sludge waste could produce a good quality brick and provide environmental friendly disposal methods for the sludge wastes.

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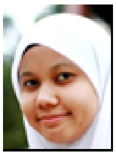

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