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FABRICATION OF UNFIRED BRICKS FROM INDUSTRIAL SCHEDULED WASTE (WWTS)

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Graphical abstract

	Ni (mg/L)	Cu (mg/L)	Pb (mg/L)	Zn (mg/L)
Sludge	<0.79	<0.18	<0.11	<0.53
30% PC	<0.61	<0.03	<0.09	-
30% G-PC (50:50)	<0.51	<0.01	<0.06	-
Limits	0.20	0.20	0.10	2.0

Abstract

Manufacturing industries produce wastes or secondary products, in which it has a direct impact to the environment. The storage of such wastes remains at the disposal would pollute the air, water resource and agricultural fields. There is a huge opportunity for recycling and it uses large quantities of wastes to minimize the environmental impact. This paper investigates the effect of utilization Wastewater Treatment sludge (WWTs) blended with Laterite Clay (LC) at 50:50 ratio to produce unfired bricks. These target materials were stabilized using Hydrated Lime (HL), Portland cement (PC) on its own and combination of Ground Granulated Blast-furnace Slag (GGBS), HL:GGBS and PC:GGBS both (50:50 and 70:30 ratio) at 10%, 20% and 30% stabilizer dosage. Compressive strength, flexural strength, thermal conductivity and toxicity characteristic leaching procedure (TCLP) test were conducted and compared with the relevant standards. It was found that it is feasible to utilize WWTs as unfired bricks from the economical and environmental point of view as it will conserve natural resource, protect the environment from waste disposal, and produce a low cost, low carbon construction components.

Keywords: Industrial waste, unfired bricks, compressive strength, thermal, leaching

1.0 INTRODUCTION

A large number of waste materials generated in industrialization and urbanization country. The high increasing of these materials is not only give a burden to the industry, but also has adverse effects on the environment. Thus, the new technologies need to be introduced to recycle and convert waste into materials that can be reused because it is crucial for the environmental protection and sustainable development [1]. The solution for the pollution problem can be solve by recycling an industrial waste into the construction components. The use of the industrial waste as a target material for the construction components (brick) is a practical solution to the management of wastewater sludge and to environment [2].

In order to reduce the use of non-renewable materials and conserve the natural resources, the use of industrial sludge as a sustainable construction components were currently implemented. Huge quantities of sludge are produced through conventional process of coagulation, flocculation and sedimentation from Wastewater Treatment Plant (WWTP).

Usually, the amount of sludge produced could reach as high as 2% of the total treated water [3]. In Malaysia, an estimated quantity of 52, 723 tonnes of sludge produced every year [4]. The management of WWTs should be economically feasible and it should be environmentally friendly. Recently, considerable attention has been received due to the reusing of WWTs. This is cause by the type of material which does not contain contaminants that can pose a threat to humans or the environment except alum and ferric sludge [5].

The reuses of sludge in the construction materials have been comprehensively studied. [6] investigated the mixing of clay with textile laundry wastewater sludge to produce bricks for construction components. [7] study the mechanical properties of the clay brick made with natural fibers like oil palm fruit and pineapple leaves to clay-water mixture with conditions that are baked and non baked. Although there are many previous researches investigate the use of WWTs in the construction industry, however research on WWTs from oil based industry has not been given as much attention. Thus, the following objective was designed to this research which is (i) to investigate the potential of using WWTs from oil based industry as a target material for sustainable construction components and (ii) to formulate the environmental profile of the WWTs bricks.

2.0 EXPERIMENTAL PROCEDURE

2.1 Materials Used

The materials used for the experimental investigation consisted of Laterite Clay (LC), Wastewater Treatment sludge (WWTs), Hydrated Lime (HL), Portland Cement (PC) and Ground Granulated Blast-furnace Slag (GGBS). The fundamental characteristic of these materials has been carried out in accordance with the British Standards.

2.1.1 Laterite Clay (LC)

The soil used in this study was obtained from the construction site located in Puchong, Kuala Lumpur. LC is a soil type which rich in iron and aluminium. It was air dried in a laboratory in the Faculty of Architecture, Planning and Surveying, UiTM Shah Alam prior to experimental work.

2.1.2 Wastewater Treatment sludge (WWTs)

The WWTs used for this study were collected from Wastewater Treatment Plant (WWTP) in Lam Soon Edible Oils Sdn Bhd, located in Telok Panglima Garang, Klang. This factory produces the WWTs with approximately 52, 723 tonnes per annum. The WWTs undergone pH coagulation and flocculation tank before clarifier. Once this process was done, the sludge undergone the anaerobic reactor and bio tank before the filter press to remove the water.

2.1.3 Hydrated Lime (HL) and Portland Cement (PC)

The HL used in this study is obtained from MCB Industry Sdn Bhd. The cement used in this study complies with the Ordinary Portland Cement (OPC) according to Malaysian Standard MS 522: Part 1: 1989 [8], marketed under the trade name of YTL was used throughout.

2.1.4 Ground Granulated Blast-furnace Slag (GGBS)

GGBS used in this study is from YTL Cement Berhad, located in Pelabuhan Klang. GGBS is a by-product obtained by quenching molten iron slag from a blast-furnace that is then dried and ground into a fine powder. The manufacturer of GGBS is accordance with the Malaysian Standard MS 522: Part 2: 2005 [9]. The oxide composition of materials is presented in Table 1. The mix design compositions for brick specimens are shown in Table 2.

2.2 Specimen Preparations

The bricks specimen with dimensions 215×102.5×65 mm were manufactured in industrial scale by using conventional mixer and mechanical press at Majpadu Bricks Sdn Bhd, Klang, Selangor. All of the materials were weighed and mixed thoroughly for 5 minutes to ensure that all materials have been evenly mixed then it was poured into the brick moulds and pressed by using a pressing machine with 9kN/in². After pressing, the bricks were left on wooden pallets and then it was stored in an open area and air cured. The brick specimens were tested after 7 and 28 days of curing according to BS 1377-2:1990 [10] to determine the compressive and flexural strength.

Table 1 Oxide Compostion Materials

Oxides	LC	WWTs	Lime	PC	GGBS
Co	0.13	2.75	51.75	34.32	20.80
CO_2	17.87	69.35	25.09	30.50	18.82
MgO	3.45	0.84	2.94	5.37	15.44
Al_2O_3	25	15.38	0.38	3.27	14.10
SiO_2	38.73	1.34	0.22	6.72	17.14
Fe_2O_3	12.19	4.24	19.32	17.58	10.54
SO_3	0.04	11.63	0.04	2.13	2.60
TiO_2	0.64	1.10	0.08	0.17	0.41
K_2O	2.13	0.07	0.03	0.36	0.25
P_2O_5	0.04	0.41	0.02	0.06	0.01
Na_2O	0.35	0.93	0.23	0.50	0.63

Table 2 Mix design composition for brick fabrication

Target Material (%)	Stabiliser	Ratio (%)	Dosage (%)	OMC (%)
LC (100%)	HL	100	30	25
	PC	100	30	20
	GGBS:HL	70:30	30	25
	GGBS:HL	50:50	30	25
	GGBS:PC	70:30	30	20
	GGBS:PC	50:50	30	20
LC:WWTs (50:50)	HL	100	10	15
	PC	100	30	15
	GGBS:HL	70:30	20	15
	GGBS:HL	50:50	30	15
	GGBS:PC	70:30	30	15
	GGBS:PC	50:50	30	15

Thermal conductivity and TCLP were conducted after 28 days of curing. Each result was compared to the properties of the control brick specimens and Department of Environment (DOE) standards. Figure 1 (a) shows the appearance of the brick samples and Figure 1(b) shows the compressive strength test of bricks.

2.3 Test Procedures

A several tests were carried out in accordance to the British Standard (BS) to determine the compressive and flexural strength, thermal conductivity and toxicity characteristics leachate procedure (TCLP) tested on the brick specimens. The details about the test procedures are given below.

2.3.1 Compressive Strength

All mixes for compressive strength test were performed in accordance with BS EN 772-1:2011 [11]. The compression test machines with a maximum capacity of 2000kN were using to determine the brick samples of compressive strength test. The test was conducted at Majpadu Bricks Sdn Bhd with a specified loading rate of 35N/mm²/min (12.4 kN/s) and 15N/mm²/min (5.3kN/s).

(a) (b)

Figure 1 (a) Industrial scale brick samples (b) Compressive strength test for bricks

2.3.2 Flexural Strength

The three-point bending test with a supporting span of 180mm, a height of 75mm and a width of 105mm were used to determine a value for the flexural modulus of rupture according to the BS EN 1015-11:1999 [12]. The bending test equipment consists of two rollers. The distance between the two supporting rollers was 100 mm ± 5 mm. A third roller sitting on a specimen in the midpoint.

Then a load was applied gradually to the upper roller using a Universal Testing Machine, ensuring the failure occurred between 30-90 Sec after the load was applied. The results were calculated to the nearest 0.01 N/mm² as an average of the specimens.

2.3.3 Thermal Conductivity

Thermal conductivity is the measurement of the ability of a material to conduct heat, determine by the rate of the flow in accordance with the BS EN 1745:2012 [13]. The thermal conductivity test was conducted using KD2 Pro device with 30mm dual-needle sensors that is compatible with most solid and granular materials. The sensors were inserted into the brick specimens and the reading appeared on the device screen. Thermal conductivity test was conducted at Faculty of Applied Science, UiTM Shah Alam. Figure 2 shows the device use to measure thermal conductivity of the bricks.

Figure 2 KD 2Pro devices for Thermal conductivity test

2.3.4 Toxicity Characteristics Leaching Procedure (TCLP)

The TCLP was created to identify the movement of both organic and inorganic analytes present in liquid, solid and multi-phase wastes. The two initial samples which are 30% PC and 30% G-PC with 50:50 ratio was tested at Faculty of Civil Engineering, UiTM Shah Alam. These two samples were chosen due to the higher strength from the result of compressive strength test.

150gm of sample were immersed in 100ml of distilled water. Leachate was analyzed by atomic absorption spectrophotometers that are shown in Figure 4. The parameters tested are the nickel, copper, lead and zinc, and were compared with the 'Malaysian Guidelines for Waste Disposal' [14]. For this test, the lower detection limit is 0.001mg/L.

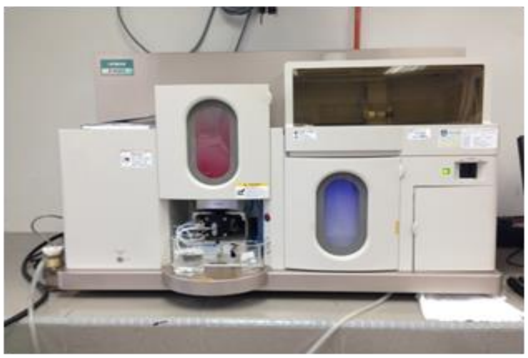

Figure 3 Atomic absorption spectrophotometer for TCLP test

3.0 RESULTS AND DISCUSSION

3.1 Compressive Strength

Figure 3 shows the results of compressive strength test for all mixes. The figure shows the compressive strength results of target material, LC mixed with WWTs (50:50) stabilized with 10%, 20% and 30% stabilizer. Time plays an important role in the development of strength and there was a continuous increase over time. The higher strength of 1.67 N/mm² at 28 days were recorded when the target material stabilized by 30% GGBS-PC at 50:50 ratio and the results followed by 1.34 N/mm² when target material mixed with 30% PC alone.

The results show that when PC act as stabilizers to LC and WWTs (either when use alone or combined with GGBS) recorded higher strength compared with lime-based stabilizer throughout 7 and 28 days.The main factor for the increasing in strength development is due to the contribution of silica oxide (SiO_2) and alumina oxides (Al_2O_3) present in WWTs when combined with PC and GGBS enhanced the pozzolanic reaction. On the other hand, when HL was used on its own as stabilizers or combined with GGBS, the strength results are lower than PC.

The results also show that the optimum percentage of using HL to stabilize WWTs is 10%. The increment of HL in the system will reduce the compressive strength. This is because the silica and alumina contents in the lime much lower than PC that act as a pozzolanic reaction. The form of lime between both silica and alumina created the pozzolanic reaction and the cementing material were produces and it consists of calcium-silicate-hydrates and calcium-alumina-hydrates [15]. [16] also stated that lime gives the improvement in workability and plasticity however, it shows the lowered strength in the short time curing period compared to PC.

3.2 Flexural Strength

The flexural strength test of unfired brick specimens were carried out on the samples that had cured after 28 days. The results shown in Figure 5. The flexural strength of the mixture containing 10% L shows the higher load which is 1.74 kN compared to the other samples of unfired brick which is 30% G-PC at 50:50 ratio, 30% PC and 30% G-PC at 70:30 ratio shows the comparable load were about 1.58kN, 1.53kN and 1.52kN. By comparing the flexural strength of unfired clay bricks containing lime and PC it can be found that PC showed the highest strength while lime showed the lowest strength when mixed with GGBS. It is suggested that the chemical properties in lime and GGBS not suitable to be mixed with WWTs due to the weakness in strength thus bond each particle.

3.3 Thermal Conductivity

As seen in Figure 6, the thermal conductivity of unfired brick samples 10% L and 20% G-L with a ratio of 50:50 exhibited lower thermal conductivity compared with the rest. The reduction conductivity values were about 0.29 W/m.K and 0.32 W/m.K. [17] reported that the increase of void ratio that decreased the unit weight of bricks is one of the factor responsible for the decrease in thermal conductivity.

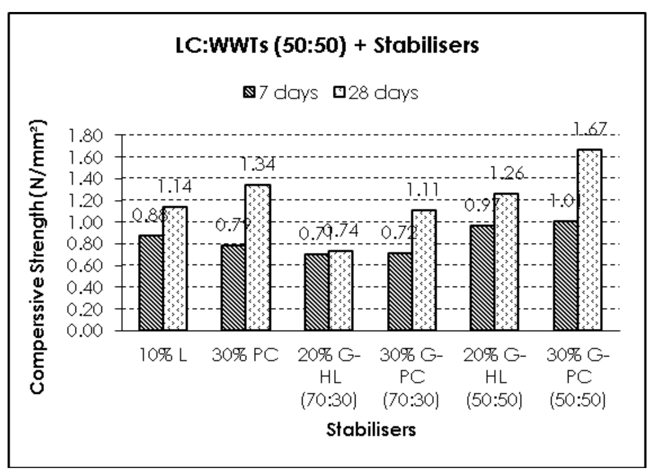

Figure 4 The compressive strength development of the LC: WWTs (50:50) mixed with stabilizers at 7 and 28 day curing period

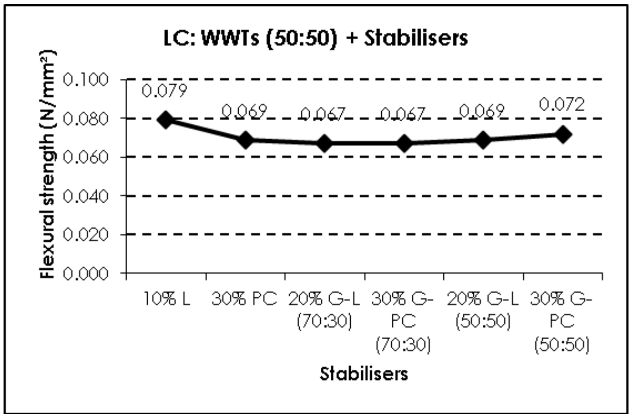

Figure 5 Effect of LC: WWTs (50:50) on the flexural strength of bricks

3.3 Thermal Conductivity

As seen in Figure 6, the thermal conductivity of unfired brick samples 10% L and 20% G-L with a ratio of 50:50 exhibited lower thermal conductivity compared with the rest. The reduction conductivity values were about 0.29 W/m.K and 0.32 W/m.K. [17] reported that the increase of void ratio that decreased the unit weight of bricks is one of the factor responsible for the decrease in thermal conductivity. However, higher thermal conductivity was found for brick samples containing PC and 30% GGBS-PC with 50:50 ratios which is 0.38W/m.K and 0.36W/m.K compared with the samples containing lime. [18] noted that the decreasing on the conductivity of brick is due to the addition of cement content. The low on thermal conductivity value would give the benefits in energy efficiency, economical and an effective building sustainable. The previous research also has investigated that the thermal conductivity of unfired clay bricks give a better value compare to the conventional once (fired clay bricks). The acceptable standards of K-value for building brick is 0.6-1.0W/m.K and insulating brick is 0.15W/m.K. Based on the thermal conductivity results of this study, it showed that all brick specimens recorded lower K-value than the acceptable standards. All of the unfired clay bricks which utilize by WWTs are suitable to be used as insulating bricks.

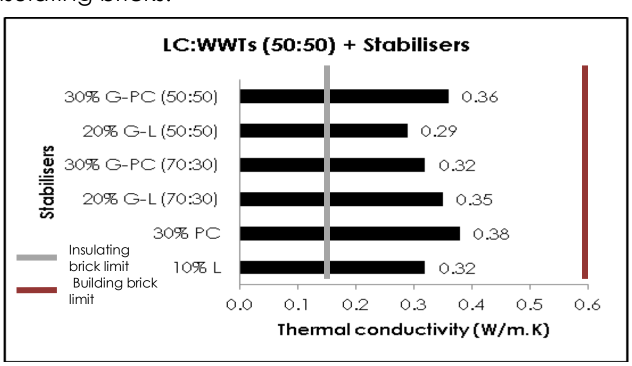

Figure 6 Thermal conductivity of bricks using LC:WWTs (50:50)

3.4 Toxicity Characteristics Leaching Procedure (TCLP)

The Toxicity Characteristics Leaching Procedure (TCLP) in Malaysia is controlled by environmental policies which are regulated by the Department of Environment (DOE). Typically, landfills need to simulate leaching of metals and organic compounds from solids under the conditions of temperature and pressure and it is one of the purposes. To evaluate the leachability of possible heavy metals from WWTs in unfired bricks, TCLP test was conducted in this study.

The raw sludge taken from industry and TCLP regulatory limits along with results of heavy metal concentrations in mg/L of the TCLP for unfired bricks with the different WWTs replacement have shown in Table 3. The results only Ni, Cu, Pb and Zn were tested for this study.

The table indicates low concentrations of metals in Cu, Pb and Zn when compared with the limits contained in the guidelines of environmental waste disposal which suggests 0.20 mg/L, 0.10 mg/L and 2.0 mg/L. Only, Ni was exceeding the permissible limits by DOE but compared with the raw sludge it shows decrease when WWTs replacement in unfired bricks.

This can be explained that the highly alkaline environment attributed to the solidification and stabilization matrix where the metals exists as metal hydrated phases, metal hydroxides and calcium-metal compounds that cause the reduction of leachate. On the other hand, cement-based matrixes were effectively solidified and stabilized the heavy metals. Hence, fabrication bricks from WWTs can release an unacceptable amount of heavy metals through leaching because the chemical stabilization has the abilities of suppressing unsuitable metals.

Table 3 The results of heavy metal contents, raw sludge and regulatory limits of TCLP in different compositions of WWTs in bricks

	Ni (mg/L)	Cu (mg/L)	Pb (mg/L)	Zn (mg/L)
Sludge	<0.79	<0.18	<0.11	<0.53
30% PC	<0.61	<0.03	<0.09	-
30% G-PC (50:50)	<0.51	<0.01	<0.06	-
Limits	0.20	0.20	0.10	2.0

4.0 CONCLUSIONS

Based on the results, it have exhibited that the used of WWTs as a supplement for laterite clay under unfiring temperatures and manufacturing methods used in this study could be successfully produced as unfired clay bricks. The amount of WWTs in the mix proportion is the key factor that affects the quality of the bricks. Hence, to produce a good quality brick, the WWTs could be used for several engineering applications in the construction within the acceptable international standards (BS 3921: 1985) [19].

This unfired bricks are comparable in strength and thermal conductivity, besides it was eventually greener and eco friendly to the society. The data from this research showed an average saturated flexural strength of unfired bricks. Besides that, the brick design thermal requirements for clay masonry and building regulations are compliance with the unfired bricks. Additionally, the potentials leachability of heavy metals from brick is under environment protection limits that acceptable in Malaysian. Thus, this research illustrates the production of unfired bricks using WWTs would have a potential in the future in terms of low-cost housing constructions and promote to sustainable construction components.

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