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Recovery of Water Treatment Residue into Clay Bricks

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Water Treatment Residue (WTR) disposal is a major issue in most parts of the world as well as in Malaysia due to its huge quantity. It is estimated that WTR weighs at 2 % of the total treated water quantity. In 2014, Malaysia produces 16,000 million L/d (MLD) of drinking water. The water treatment plants produced 320 MLD of WTR. Only 30 % of the total WTR undergoes treatment prior to discharge into river. The characteristic of the WTR depends on the quality of river water (water source) and the type of coagulants used. Common chemical coagulants used in Malaysia are alum ($AlSO_4$) and poly-aluminum chloride (PAC). These chemical coagulants produce huge amount of aluminium containing WTR. In Malaysia, WTR is categorised as Schedule Waste 204 under Environmental Quality Act 1974, Environmental Quality (Schedule Wastes) Regulation 2005. This research study focused to reuse a portion of WTR as plasticiser mix with laterite earth for clay bricks manufacturing process. The research project investigated physical and mechanical properties of WTR Bricks such as compressive strength, efflorescence effects, bulk density, water absorption, weight reduction according to BS/EN Standard, loss of ignition, toxicity and ecotoxic analysis. The results from this study indicates 40 % WTR – 60 % Laterite combination gives best value of bricks and superior to local manufactured bricks.

1. Introduction

Water treatment residue is produced as a by-product at coagulation process of water treatment. Coagulation removes dirt and other particles suspended in water. Some of the commonly used coagulants are aluminum sulphate (Alum), poly-aluminum chloride (PAC) and ferric chloride. Coagulants are added into water to form tiny, sticky particles called flocs. Flocs are a lump of suspended particles and alum mixture. Flocs are heavy enough to sink to the bottom during sedimentation. These flocs when washed from sedimentation tank to be sent to sludge treatment plants, forms WTR. The concentration of WTR at this point is estimated below 1 %. At present, most of the water operators discharge WTR to lower streams of river. WTR contains aluminum salts that pollute the river water source and cause potential health hazard to consumers. Several studies have proven that the accumulative intake of aluminium salt can lead to Alzheimer's disease (Ndabigengesere and Narasiah, 1998). Aluminium has also been identified to be the causative agent in neurological disease (Muyibi et al., 2001).
Water treatment residue (WTR) has the potential to be recovered into some useful materials. WTR recycling is both environment friendly and economically advantageous (Zilli et al., 2015). In USA, the American Water Works Association Research Foundation (AWWARF) proved that WTR can be used as land application, cement and brick manufacturing, turf farming, composting and top soil and potting soil production (AWWARF, 2007). In Netherlands, 98 % of the WTR is recovered. WTR produced by Dutch water companies are widely used for brick making, road barriers materials, road foundation, land elevation and ballast material in construction of industrial parks (Vewin, 2013).
In Malaysia, WTR recycling and reutilisation is not a popular option (Shakir and Mohamed, 2013). WTR is classified as hazardous waste and sent to landfill (DOE, 2005).Our landfills are filling up fast due to inefficient recovery policy (Fauziah and Agamuthu, 2012). Upgrading water treatment plants with WTR recovery facility will involve billions of ringgits. Subsequently, the upgrading will directly impact production cost of every cubic meter of water. Therefore, an economic method to treat and efficiently convert WTR to a value added product is required. Several studies have been conducted on potential WTR recovery options in Malaysia. For instance, Elangovan and Subramaniam (2011) studied the potential use of WTR in ceramics. A few state level water agencies have collaborated with higher learning institutions to study on turning WTR into pallets for power

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generation, material for brick making and pottery (Too, 2011). The results of various research projects indicate that the quantity of WTR that should be added as a partial substitute for clay in brick manufacturing depends on the characteristics of the clay used in the process. In addition to that, the composition of WTR depends exclusively on the quality of the raw water source.
In this study, the WTR generated in a water treatment plant (WTP) from water source, Muda River is used. Varying proportions of WTR is substituted into laterite clay for brick manufacturing. The experiments were conducted using market size bricks. This paper presents the analyses of the physical and mechanical properties of the clay-WTR bricks and addresses its commercial and environmental significance.

2. Materials and Methods

2.1 Raw materials and sample preparation

Raw materials used in this study were laterite and water treatment residue (WTR). A compositional analysis was conducted on WTR to evaluate the metal and mineral contents in accordance to SW 846 6010C using ICP-OES, SW 846 Method 7473 and SW 846 3060A. WTR was incorporated in proportion into laterite. A proportion of 20 %, 30 % 40 %, 50 % and 60 % was added into laterite base. The water was kept at 30 % for every mixture. The samples with 80 % and above cannot be formed. Laterite earth was collected from a local brick producer. Laterites are rich in iron and aluminum, rendering a rusty red colour in appearance. Laterite was grinded and sieved to mesh size of 10 and below to have good mixing ratio. WTR was collected from washing of sedimentation tank in a drinking water treatment plant. The concentration of WTR is below 1 percent. Natural drying bed was used to dry the WTR. The sludge was dried to achieve a concentration of suspended solids not less than 50 percent. WTR at moisture content of 45 % - 50 % was chosen to cater mixing with laterite without adding any additional water. Laterite was mixed into wet WTR till the water content becomes 30 % in weight. The 30 % in weight water content is needed to facilitate smooth mixture movement during mixing and molding process. Extrusion mixing using extruder was adopted to ensure homogeneous mixing. The mixture was pounded into a metal mold. The metal mold was made in accordance to market brick dimension, which is 10 cm (W) × 25 cm (L) × 8 cm (H). The molded bricks were dried naturally, under the sun, for 5 - 6 days till complete volumetric shrinkage occurs (Ramadan et al., 2008). The green bricks were preheated at 100 °C to further remove water prior to firing. Final shrinkage and weight loss was recorded. The green samples were subjected to three firing temperatures, which are 950 °C, 1,000 °C and 1,050 °C (Jewaratnam, 2007). The temperature profile used in this work is presented in the Table 1 below. The samples were gradually heated from 100 ˚C to desired final temperature in stages to prevent cracking in samples.

Table 1: WTR bricks firing profile

Firing Profile	950 °C	1,000 °C	1,050 °C	Time (min)
1	100	100	100	30
2	300	300	300	30
3	500	500	500	60
4	700	800	800	90
5	950	1,000	1,050	510

2.2 WTR bricks testing

Water treatment residue (WTR) bricks, made in this study, were tested according to Malaysian Standard (MS 76) and British Standard (BS EN). The most important test for a brick is compressive strength (tested as per BS EN 772-1 :2000 - Clause 5.3.4), water absorption (tested as per BS EN 771-1 : 2003, Annex C) and efflorescence (tested as per MS 76: 1972 - Clause 42). The compressive strength and water absorption reflect the load bearing quality of the bricks. From this information, the possible application can be determined. Efflorescence is calcium salt deposits that occur on the surface of bricks. It is a whitish powder, usually present in samples using groundwater. Efflorescence affects the aesthetics property of the bricks. There should be no efflorescence found on the bricks surface to pass marketable quality. In addition to that, toxicity characteristics leaching procedure (TCLP) was conducted on the brick samples. This test is a must to ensure the toxic metals or minerals does not leachate out when exposed to adverse conditions. The methods used are SW846 Method 1,311, SW 846 6,010C and SW 846 7,473. ICP-OES was used to detect the metals and minerals.

3. Results and Discussion

3.1 Chemical Composition of WTR

The chemical composition of WTR is given in Table 2. The composition analysis clearly shows significant presence of silicon, aluminum, and iron oxides, which are primary components present in commercial clay brick production.

Table 2: Chemical composition of water treatment residue

Components	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	MnO	Cl
%	58.40	5.465	17.44	0.074	0.308	< 0.1	0.04	1.013	0.029	0.039

3.2 Compressive Strength of WTR Bricks

Strength test is the most important test for assuring the engineering quality of a building material. Strength of the sample is dependent on the amount of sludge in the brick and the firing temperature.

Table 3: Compressive strength of WTR bricks

Temperature	Compressive strength (N/mm^2) for varying WTR (%)				
	20	30	40	50	60
950 °C	6.01	8.58	9.14	6.97	5.13
1,000 °C	6.35	8.91	10.13	7.46	5.35
1,050 °C	6.66	9.74	11.98	8.04	6.32

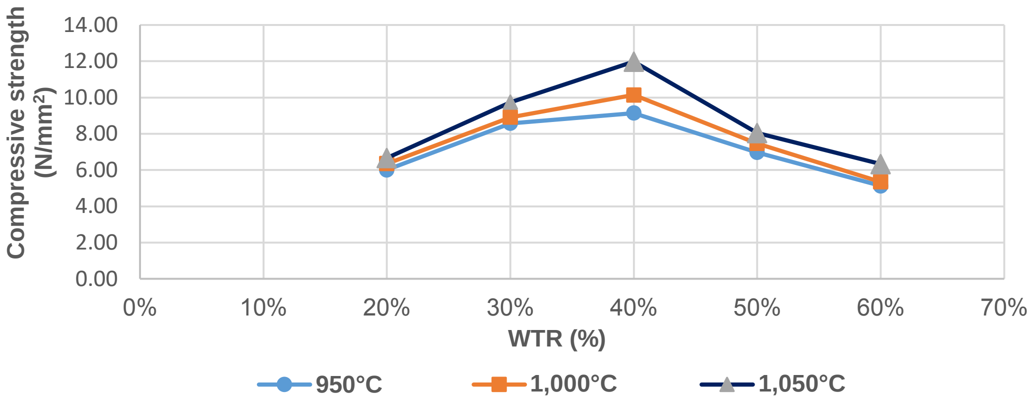

Figure 1: Compressive strength of WTR bricks

Figure 1 and Table 3 indicate that strength of the samples increases with increasing firing temperature. The strength increases with increasing WTR composition between 20 % to 40 % and then decreases with further WTR increment. The best strength is observed for 40 % WTR incorporation into laterite and fired at 1,050 ˚C.

3.3 Water absorption of WTR bricks

Durability of the bricks is measured by water absorption of the bricks. It indicates the ability of bricks to withstand humid environment. Water absorption of WTR bricks are presented in Table 4 and Figure 2. Water absorption increases with increasing WTR percentage for each firing temperature setting. Increasing moisture absorption indicates that the bricks have more pores. Increment in WTR into laterite increases the porosity of the brick sample. Literatures suggest that higher water absorption will affect the strength of brick samples. In our observation, as the WTR percentages increases from 20 to 40 within the same temperature, the strength is not affected. It increases with the composition. However, for WTR above 40 %, the strength is decreases. The percentage of water absorption reduced with increasing firing temperature in all samples. At higher firing temperature, the aluminium component in the brick mixture melts and closes the pores in the brick structure. This renders a compact and solid bricks with higher density.

Table 4: Water absorption of WTR bricks

Temperature	Water absorption (%) for varying WTR (%)				
	20	30	40	50	60
950 °C	18.28	17.94	24.64	27.74	31.28
1,000 °C	15.86	15.28	20.72	21.53	24.65
1,050 °C	15.18	15.98	17.88	18.20	19.51

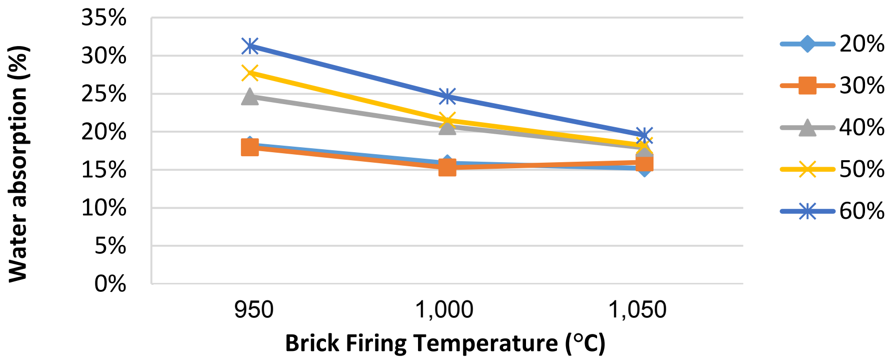

Figure 2: Water absorption of WTR bricks

3.4 Efflorescence on WTR bricks

From the observation, no efflorescence effects were detected on all the bricks. This is because the bricks were completely dried before firing. Therefore, the minerals stay in the laterite clay matrix and bonded due to effect of high temperature curing.

3.5 Toxicity Leachate Characteristics Procedure (TCLP)

Toxicity leachate test revealed insignificant leachate concentrations. Weng et al. (2003) mentioned that leaching of metals in the waste added clay tiles are always low because high firing temperature transform metals into oxide forms that is more stable. Magalhaes et al. (2005) added that silicate phases in the clay based ceramic combined with the high temperature firing are capable of dissolving considerable amount of metals in the structure.Magalhaes et al. (2005) found out that extraction level of metallic species from clay-waste mixture increases with decreasing concentration of metals in the particular waste. The reason is, during firing, decomposition in the low metal containing waste is much significant than the metal-richer waste. Severe decomposition in the low metal containing waste disconnects physical interaction between clay and waste particles. The chemical reaction that should take place is retarded. The less alteration the metal-richer waste allows, it improves the development of intimate contact and effective reaction between the silica and metal components. Metal-richer wastes are highly sinterable. It promotes highly closed packed microstructure, thus limit leachate. The TCLP for product with 40 % sludge addition is shown in Table 5 below. TCLP of the WTR bricks were compared to Malaysian Standard Leachate Limit. Clearly, the leachate concentrations are well below the desired limit except for aluminum concentration which is less than 1 mg/L.

Table 5: Malaysian Standard Leachate Limit

Elements	Cu	Al	Mn	Sn	Pb	Ni	Zn	Ti	Fe
TCLP limit (mg/L)	-	-	-	-	0.75	11	4.3	-	-
EQA 1974 limit (mg/L)	1.0	-	1.0	-	0.5	1.0	1.0	-	5.0
40 % WTR bricks (mg/L)	< 1.0	< 1.0	ND	ND	0.2	< 1.0	< 1.0	ND	ND

3.6 Feasible application of WTR bricks

Table 6 and 7 is a summary of minimum compressive strength and maximum water absorption requirement for construction materials application. The classification is as per Malaysian (MS) and American (ASTM) Standards. Matching the Tables 3, 4, 6 and 7, WTR bricks with 30 - 50 % residue incorporation and fired at 950 °C, 1,000 °C and1,050 °C complies to load bearing Class 1 (MS) as in Table 5 and load bearing clay wall tile (ASTM) classification as in Table 6.

Table 6: Classification of engineering and load bearing bricks as per MS 7.6 1972

Load bearing class	1	2	3	4	5	7
Strength (MPa)	≥ 7.0	≥ 14.0	≥ 20.5	≥ 27.5	≥ 34.5	≥ 48.5
Water absorption (%)	No specific requirement					
WTR bricks	Comply	Non-compliance				

Table 7: ASTM Classification

Bricks/tiles	Load bearing clay wall tile	Industrial floor brick
Minimum compressive strength (MPa)	3.4 - 9.6	5.2 - 13.8
Maximum water absorption (%)	19 - 28	1 - 12
WTR bricks	Comply	Non-compliance

4. Environmental benefits

Recycling waste into building material has direct environmental impact. The high firing temperature turns hazardous wastes into inert and safe for the health products. Diminishing mineral resources will be spared for longer term. The open quarry extraction of natural construction material will be reduced and it contributes to the air pollution reduction. Ultimately, landfills will be conserved.

5. Conclusions

The good mechanical properties obtained and rather quick strengthening of samples prepared suggests that it is possible to make building materials from drinking water treatment residue, where the water source came from Muda River. The toxicity characteristic leachate procedure (TCLP) test revealed that the leachability of the major metals in the WTR bricks are well below the DOE standard limits. Therefore, further pilot scale testing should be done to evaluate the feasibility of using the WTR bricks as building materials for consumer use.

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