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UTILIZATION OF SLUDGE FROM WATER TREATMENT PLANT AS FIRED CLAY BRICK

This study aims to establish the optimal percentage of water treatment sludge (WTS) for incorporation into fired clay bricks, assessing both physical and mechanical properties as well as heavy metal leachability. Fired bricks were produced with varying proportions of WTS (0%, 5%, 10%, 20%, and 30%). Compressive strength, density, shrinkage, and water absorption were examined to evaluate physical and mechanical properties. Toxicity Characteristic Leaching Procedure was employed to investigate heavy metal concentrations, focusing on inorganic constituents. Results indicated that the optimal ratio for WTS in fired clay bricks is 5%, aligning with industry standards (BS 3921:1985). The 5% sludge incorporation yielded bricks with impressive attributes: a peak compressive strength of 25.40 MPa, density within standard limits, water absorption below 20%, and firing shrinkage under 8%. Notably, aluminum content, predominant in the sludge, decreased significantly from 74.17 ppm to 4.97 ppm. These findings suggest that WTS, when integrated into fired bricks, emerges as a viable, cost-effective, and environmentally friendly alternative. The study underscores the potential of utilizing up to 5% WTS in fired clay bricks, presenting a promising avenue for sustainable construction practices.
Keyword: Fired clay brick; Water treatment sludge; Environmental impact; Waste recycling; Sustainable construction

1. Introduction

Nowadays, waste generation has increased due to population growth [1]. Malaysia's population generates a huge amount of solid waste, estimated at 38,427 tons per day (1.17 kg/capita/day) in 2021. 82.5 percent of this is disposed of in landfills. The waste generated includes WTS, industrial sludge, and sewage sludge. Most water treatment plants generate large amounts of sludge by removing impurities from raw water and various water treatment chemicals used in the related water treatment processes. Therefore, uncontrolled disposal of WTS can seriously damage the ecosystem and landfill. Due to increasing environmental awareness, water authorities are under considerable pressure to ensure safe treatment and disposal of sewage sludge [2]. In addition, WTS contains different concentrations of heavy metals. The best-known heavy metals are lead (Pb), zinc (Zn), mercury (Hg), nickel (Ni), cadmium (Cd), copper (Cu), chromium (Cr), and arsenic (As) [3]. Although heavy metals are essential for living and are found in the environment naturally, when they accumulate within organisms., they can become hazardous. Pb, Hg, As, Cd, Ni, Cu, and Cr are among the most commonly occurring heavy metals that contribute to environmental contamination [4]. Unmonitored WTS can cause health problems due to harmful bacteria and pathogens still present in the sludge. Some approaches to using WTS, such as using it in fired bricks, as has been done by researchers from different types of sludge, could be beneficial to use the sludge instead of disposing of it, creating an environmentally friendly method. This method could also improve the quality of the bricks when recycled with the WTS.

Currently, many researchers have successfully tried to use sludge for fired brick, such as WTS [5], lime sludge [6], steel mill sludge [7], sewage sludge ash [8], textile sludge [9], textile company sludge [10], and tannery sludge [11]. The use of waste sludge in fired clay bricks can lead to an excellent result in terms of strength, shrinkage, and water absorption, as well as improved thermal properties. The lightweight bricks were preferred because they cost less in transportation and handling. In addition, the addition of waste to bricks reduces the amount of clay in the burnt clay brick, which lowers production costs.

Therefore, the objective of this study is to investigated the most suitable percentage of WTS for incorporated fired clay

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brick based on its physical and mechanical characteristics and evaluated the leachability of heavy metals from sewage sludge after incorporation into fired bricks.

2. Overview of The Usage of Water Treatment Plant Sludge

The author stated in his study a new building material synthesized from WTS and fired clay brick waste. The percentage of WTS was 25%, 40%, 55%, 70%, 85%, and 100% of the total weight of the mixture. For all mixtures, the bricks were fired at 1000°C for 2 hours. The results of compressive strength ranged from 6.3 MPa to 27.4 MPa. The density of the bricks ranged from 1.7 g/cm^3 to 2.05 g/cm^3. The results of water absorption ranged from 9.87% to 23.18%. The compressive strength result showed that 100% of the specimens had the highest compressive strength of 27.4 MPa. Water absorption at 100% was the lowest at 9.87%. The highest bulk density was exhibited by the 100% samples with 2.05 g/cm^3. It can be observed that the compressive strength increases with increasing water treatment plant sludge content. It is also evident from the analytical results that higher bulk density is associated with fewer capillaries that can absorb water. On the other hand, BK 100 had an apparent porosity that was 67% lower than BK 25 [12].

Meanwhile, the author [13] studied the physical and mechanical properties of clay sludge brick. In this study, the waste from water treatment plant is used as a substitute for clay to make bricks. The brick was used to make different mixtures of sludge and clay with different water content. Before testing the physical and mechanical properties, these bricks were fired at two different temperatures (500°C and 900°C). Higher temperatures during firing would improve the physical and mechanical properties of the brick. The results show that the presence of sediments in the brick increases the water absorption capacity of the masonry. When 60% (w/w) sediment was added to the mix, water absorption increased from 5.5% to 51%. The results show that wastewater sediment has enormous potential as a clay substitute in brick manufacture.

In addition, the author [14] investigated the use of water treatment plant sludge in brick production. The bricks were mixed with proportions of 10 to 20% by weight of the sewage sludge. The brick specimens were dried and fired at 1000°C for 6 hours. The results of compressive strength ranged from 3.42 MPa to 7.6 MPa and water absorption ranged from 14% to 23%. The compressive strength result for water treatment plant sludge mix showed that 18% had a compressive strength of 3.78 MPa. However, the control brick compressive strength is better than water treatment plant sludge mixture with 7.6 MPa. The water absorption for water treatment plant sludge mixture showed that 18% of the bricks had a water absorption of 19%. However, the control bricks were better at 14%. The results show that further increase in WTS to more than 18% by weight decreases the compressive strength of the bricks, and it becomes difficult to make a mold for the bricks because cracks are observed on the surface of the bricks [14].

The results of previous research on WTS with fired clay bricks indicate a positive effect. Thus, these sludge bricks can be an alternative method for sludge disposal. Results have also shown that some of the sludge bricks in the mix are far better than conventional bricks in terms of physical and mechanical properties. In addition, previous research has shown that up to 20 percent by weight of the sludge has been successfully added. This shows that an ideal amount of sludge can be mixed into a brick. The sludge can now be disposed of in an environmentally sound manner while reducing the number of landfills required. TABLE 1 shows a summary of the physical and mechanical water treatment slurries used by previous researchers with clay bricks.

3. Materials and method

3.1. Raw material preparation

WTS was collected at the Sri Gading Water Treatment Plant. The collection of sludge in a semi-solid state at the drying lagoon, as illustrated in Fig. 1, while the clay was collected at Yong Peng, Johor [15]. Both raw materials (clay soil and WTS) were oven dried at 105°C for 24 hours. After the drying process, the materials were crushed, pulverized, and sieved with a screen diameter of 3 mm to 5 mm using a crushing machine. The entire procedure was carried out in a RECESS laboratory at Universiti Tun Husein Onn Malaysia (UTHM).

3.2. Brick manufacturing

The control bricks (0%) and sludge brick with different percentages (5%, 10%, 20% and 30%) were prepared in the laboratory. The sieve samples were mixed with water in a specific ratio (see TABLE 2) using a mechanical mixer. Then, the mixed samples were compacted using a compaction machine with

TABLE 1

Summary of physical and mechanical water treatment sludge utilized with clay bricks

Researcher	Mixing Percentage (%)	Firing Temperature (°C)	Characteristics			
			Compressive Strength (MPa)	Density (g/cm^3)	Water Absorption (%)	Shrinkage (%)
Erdogmus et al., 2021	25, 40, 55, 70, 85, 100	1000	6.3 to 27.4	1.7 to 2.05	9.87 to 23.18	—
Ibrahim et al, 2021	0, 40, 60, 80, 100	500 and 900	—	1.04 to 1.29	6 to 51	—
Hodage et al., 2019	10, 12, 15, 18, 20	1000	3.42 to 7.6	—	14 to 23	—

Fig. 1. Raw water treatment sludge

a 102.5 mm × 65 mm × m × 215 mm mold at 2500 psi. The compacted bricks were then dried at room temperature for 24 hours before being dried for an additional 24 hours in an oven heated to 105°C. The dried bricks were fired in the furnace for 19 hours and 30 minutes at a temperature of 0.7°C/min to 1050°C [16]. Fig. 2 shows the final products of WTS bricks.

TABLE 2

Summary of physical and mechanical water treatment sludge utilized with clay bricks

Mixture	Percentage (%)	Clay (g)	Sludge (g)	Water (mL)
Water Treatment Sludge Brick	0	2800	0	450
	5	2660	140	450
	10	2520	280	480
	20	2240	560	500
	30	1960	840	550

Fig. 2. Water treatment sludge bricks

3.3. Physical and mechanical properties

Physical and mechanical properties were tested using density, shrinkage, water absorption, and compressive strength. The test procedures were carried out following the standard (BS 3921:1985). The density of the bricks was calculated using Eq. (1). The mass of the brick was determined by weighing the brick, while the volume of the brick was determined by measuring the size of the brick after each process of manufacture.

$$p = \frac{m}{v} \tag{1}$$

Firing shrinkage is a process where the loss of water in clay bricks occurred during firing process. The result was obtained by using Eq. (2) to calculate the shrinkage.

$$Ls = \frac{Lwet - Ldry}{L} \times 100\% \tag{2}$$

Water absorption determine the amount of water of a brick can absorb as shown in Fig. 3(a). Using Eq. (3), the brick‘s water absorption was calculated.

$$Wa = \frac{Ww - Wd}{Wd} \times 100\% \tag{3}$$

The brick‘s maximum stress or ability to sustain compression on a compressive testing equipment is known as its compressive strength as shown in Fig. 3(b). Compressive strength is estimated by dividing the maximum load by the brick‘s initial cross-sectional area as shown in Eq. (4).

$$C = \frac{F}{A} \tag{4}$$

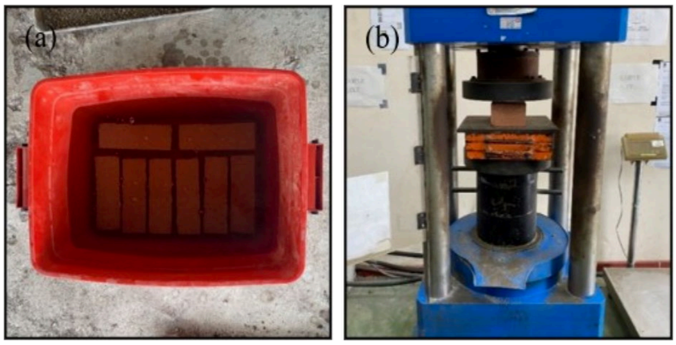

Fig. 3. (a) Water absorption test; (b) Compressive strength test

3.4. Leachability

The Toxicity Characteristic Leaching Procedure (TCLP) is used to evaluate the mobility of organic and inorganic substances in liquid, solid and multiphase sample forms. The TCLP test was used in this study to determine the concentration of heavy metals leached into fired clay bricks after waste incorporation. The brick samples are crushed and sieved with a 9.5-mm sieve. A 1-liter high-density polyethylene bottle contained the 50 g solid samples. For 1 L of extraction fluid, 5.7 mL of glacial acetic acid was mixed with water. The bottles were placed in a rotary extractor set at 30 rpm and heated for 18 ± 2 hours see

Fig. 4(a). Then, the samples were filtered using a 0.7 m size glass microfiber filter as shown in Fig. 4(b). The filtrate samples were analyzed by inductively coupled plasma mass spectrometry (ICP-MS) to measure the concentration of heavy metals.

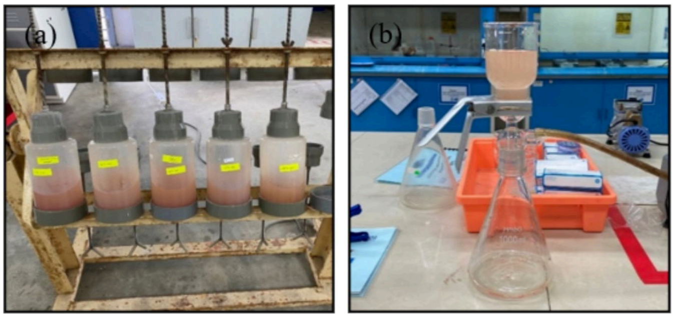

Fig. 4. Rotate using rotary extractor set to 30 rpm; (b) Sample filtration with 0.7 μm og glass microfiber

4. Results and discussion

4.1. Density

Fig. 5 shows the density of the WTS brick. The density of the brick is increasing, starting with 30% WTS brick at 1481 kg/m^3, then it increases slightly with 20%, 10%, 5% and 0% at 1567 kg/m^3, 1723 kg/m^3, 1765 kg/m^3 and 1787 kg/m^3, respectively. Based on the sample results, it was found that 5% WTS brick has the highest density at 1765 kg/m^3, while 30% WTS brick has the lowest density at 1481 kg/m^3. Overall, the WTS brick does not exceed the density of a control brick (0%). The bulk density of the bricks was affected by the amount of WTS in the mix [4]. Consequently, the density of the brick decreases when the percentage of sewage sludge increases. In addition, the presence of WTS resulted in more pores and thus lower density of the brick [4].

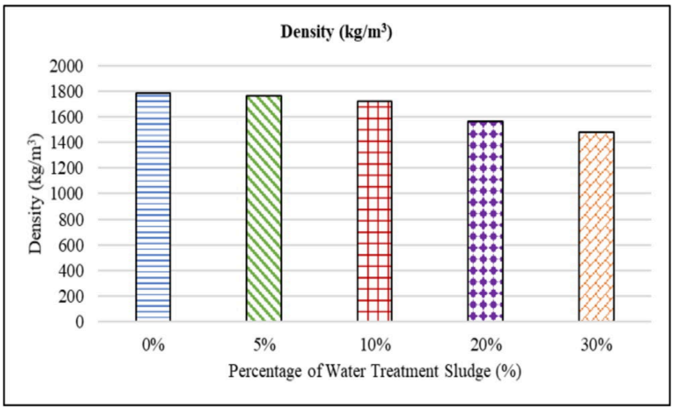

Fig. 5. Density between different ratio of WTS brick

4.2. Shrinkage

As shown in Fig. 6, the result shows the shrinkage of the WTS brick. Based on the result, it was found that 30% WTS brick has the highest shrinkage with 3.01%, while 5% WTS brick has the lowest shrinkage with 1.62%. In general, good quality fired clay bricks have shrinkage below 8% [11]. With a lower volume shrinkage of the brick mixture, deformation and fractures of the bricks can also be prevented [17]. Shrinkage is the phenomenon of decreasing in length that takes place in samples due to decreasing moisture content which happens during drying and firing processes [15].

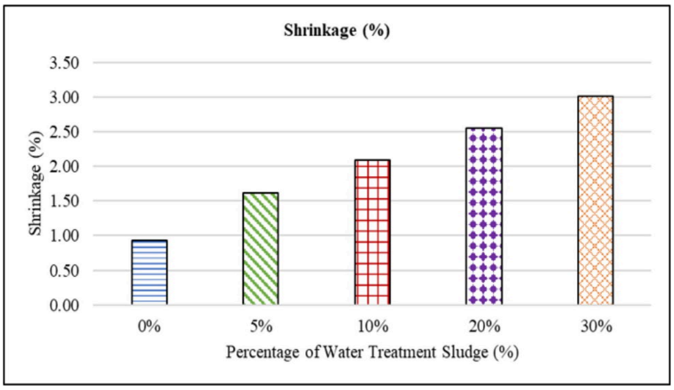

Fig. 6. Shrinkage between different ratio of WTS brick

4.3. Water absorption

Fig. 7 shows the result of water absorption for WTS brick. The ability of the brick to absorb water increases with the addition of sludge starting with the control brick (0%), followed by 5%, 10%, 20%, and 30% WTS bricks with 15.77%, 18.20%, 19.84%, 24.43%, and 28.21%, respectively. The results show that 5% WTS bricks have the lowest water absorption at 18.20%, while 30% WTS bricks have the highest water absorption at 28.21%. Overall, the control bricks perform better than the WTS bricks in terms of water absorption. The trend shows that bricks with higher sludge content absorb more water [4]. Due to the obvious porosity in the bricks, an increase in water treatment sludge leads to an increase in water absorption. The brick with a high proportion of WTS will have more internal porosity and decrease composition. This process leads to an increased capacity for absorbing water [18].

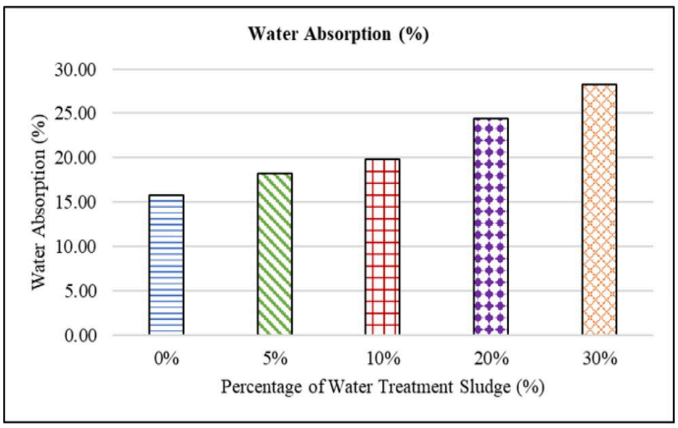

Fig. 7. Water absorption between different ratio of WTS brick

4.4. Compressive strength

The strength of WTS bricks is shown in Fig. 8. When 30% sewage sludge is used in the brick, the compressive strength is 5.3 MPa, and the compressive strength of the brick gradually increases to 20%, 10%, 5% and 0% at 8.25 MPa, 18.85 MPa, 25.40 MPa and 26.25 MPa, respectively. Based on the result of compressive strength, it was found that 5% WTS brick has the highest compressive strength at 25.40 MPa, while 30% WTS brick has the lowest compressive strength at 5.25 MPa. Consequently, the strength of the brick decreases as the percentage of WTS increases. The results of this study show a similar result to the study of [12], which claimed that WTP sludge with a content of more than 18% in bricks significantly reduces the compressive strength of bricks. The author [19-20] stated that, the minimum compressive strength for good quality bricks typically falls within the range of 3.5-7 N/mm^2.

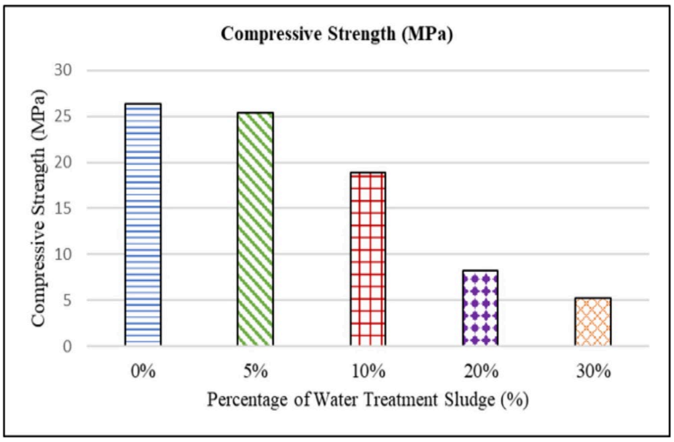

Fig. 8. Compressive strength between different ratio of WTS brick

4.5. Leachability of WTS brick

The results of leachability of WTS bricks are shown in TABLE 3. The element aluminum (Al) exhibited the highest value of 74.17 mg/L for the raw WTS. In addition, the clay soil had the highest Al content of 3.64 mg/L compared to the other elements. This shows the compatibility of the WTS in manufacturing brick with replacement of bricks by replacing clay soil. In addition, the element aluminum (Al) has the highest value among the other heavy metals in WTS bricks. Due to the immobilization of the heavy metal during the high firing process lead that Al content decreased significantly from 74.17 ppm to 4.97 ppm after its incorporation into brick. as illustrated in the TABLE 3. Therefore, it can be concluded that the Al content in fired bricks can be reduced. Apart from this, most of the heavy metal contents were within the acceptable limits in very few cases.

4. Conclusion

In conclusion, the optimum percentage of WTS was determined based on its physical and mechanical properties, as well as the leachability of heavy metals from the WTS after its incorporation into fired clay bricks. Based on the physical and mechanical properties of the WTP sludge, the suggested percentage of WTS up to 5% was used to obtain the optimum percentage of sludge in fired bricks. The results were also in accordance with the standards (BS 3921:1985) for fired clay bricks. The 5% WTS brick could achieve the highest compressive strength exceeding the average of load-bearing brick class 3, i.e., more than 20.5 MPa, and the brick exhibits lower apparent porosity and better brick strength. The results show that all heavy metals, including Cu, Zn, Ni, Cr, As, Cd, Pb, Al, Fe and Mn, found in the WTS bricks were within the allowable limits. The element Al has the highest heavy metal concentration compared to the other elements. The Al content in the sludge can positively influence the formation of sludge bricks by improving the coagulation, curing and drying rate of the sludge. However, the exact influence of Al on the formation of sludge bricks depends on various factors such as the type of mud, the amount of Al, and the processing conditions. In view of the promising results, sludge from water treatment may be a more cost-effective and environmentally friendly alternative.

TABLE 3

Heavy metals leachability concentration by using TCLP

TCLP	Raw Materials		Control	WTS Brick				USEPA (mg/L)	EPAV (mg/L)
Heavy Metals	Clay Soil	WTS	0%	5%	10%	20%	30%		
	Concentrations (mg/L)								
Cu	0.04	0.03	0.01	0.02	0.02	0.01	0.01	100	800
Zn	0.13	0.21	0.06	0.08	0.06	0.05	0.05	500	1200
Ni	0.04	0.01	0.01	<0.01	0.01	<0.01	0.00	1.3	8
Cr	0.02	0.04	0.04	0.01	0.01	0.01	0.01	5	20
As	<0.01	0.01	0.01	<0.01	0.01	0.01	0.02	5	2.8
Cd	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.00	1	0.8
Pb	0.02	0.02	0.02	0.01	0.01	0.01	0.01	5	4
Al	3.64	74.17	30.16	4.97	4.99	4.90	5.53	—	—
Fe	0.48	2.34	19.84	0.39	0.19	0.24	0.15	—	—
Mn	2.84	3.26	0.17	0.12	0.10	0.09	0.09	—	—

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