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การใช้ประโยชน์กากตะกอนจากระบบตะกอนเร่งเป็นวัสดุทดแทนในการผลิตอิฐมอญ

Utilization of Waste-Activated Sludge as A Substitute in Fired Clay Brick Production

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บทคัดย่อ

ปัจจุบันค่าใช้จ่ายจากภาคอุตสาหกรรมสูงขึ้นเป็นอย่างมากสำหรับการกำจัดกากตะกอนจากระบบตะกอนเร่งในประเทศไทย โดยเฉพาะในกระบวนการผลิตแป้งมันสำปะหลัง กากตะกอนน้ำเสียจากระบบตะกอนเร่งกลายเป็นปัญหาสำคัญของโรงบำบัดน้ำเสียต่างๆ โดยวิธีการกำจัดแบบเดิมที่นิยมใช้ คือ การฝังกลบและเผา ซึ่งเป็นวิธีที่ไม่ยั่งยืนและไม่เหมาะสมเนื่องจากมีข้อจำกัดด้านสิ่งแวดล้อม ดังนั้นงานวิจัยนี้จึงสนใจใช้กากตะกอนจากระบบตะกอนเร่งทดแทนดินในการทำอิฐมอญ โดยอัตราส่วนที่ใช้มี 7 อัตราส่วนถูกใช้ในงานวิจัยนี้ ได้ทำการผสมระหว่างดินเหนียวปกติกับกากตะกอนจากระบบตะกอนเร่งเท่ากับ 1:0 (ชุดควบคุม), 0.9:0.1, 0.8:0.2, 0.7:0.3, 0.6:0.4 และ 0.5:0.5 โดยน้ำหนักแห้ง มีสามพารามิเตอร์ถูกพิจารณานำมาใช้ในการทดสอบคุณสมบัติของอิฐมอญที่ผลิตได้ คือ ความหนาแน่น ความสามารถในการดูดซึมน้ำ และความสามารถในการรับแรงอัด พบว่าอิฐที่เติมกากตะกอนจากระบบตะกอนเร่งเท่ากับ 10 เปอร์เซ็นต์ (ที่อัตราส่วนเท่ากับ 0.9:0.1) มีความเหมาะสมสำหรับงานก่อสร้าง เนื่องจากอิฐที่ผลิตได้มีน้ำหนักเบาและมีความสามารถในการรับแรงอัดได้สูงสอดคล้องกับมาตรฐานผลิตภัณฑ์ชุมชนของประเทศไทย อย่างไรก็ตามมีข้อจำกัดในการนำอิฐที่ผลิตได้ไปใช้ประโยชน์ ซึ่งพบว่ามีความสามารถในการดูดซึมน้ำสูง อิฐควรถูกนำไปแช่ในน้ำก่อนนำไปใช้ประโยชน์ ดังนั้นกากตะกอนน้ำเสียจากระบบตะกอนเร่งจึงมีความเป็นไปได้ในการนำไปใช้เป็นวัสดุทดแทนดินโดยรีไซเคิลในกระบวนการผลิตอิฐมอญ ซึ่งผลที่ตามมาคือเป็นประโยชน์ด้านการเงินและสิ่งแวดล้อมเมื่อเปรียบเทียบกับวิธีการกำจัดแบบเดิม มากไปกว่านี้งานวิจัยนี้สามามารถใช้เป็นแนวทางสำหรับจัดการกากตะกอนน้ำเสียจากระบบตะกอนเร่งจากแหล่งอื่น

คำสำคัญ : กากตะกอนจากระบบตะกอนเร่ง ; อิฐมอญ ; แป้งมันสำปะหลัง ; ความสามารถในการดูดซึมน้ำ ; ความสามารถในการรับแรงอัด

Abstract

Currently, Thai industrial spending is high for waste-activated sludge (WAS) disposal in Thailand, particularly in tapioca starch production that uses an activated sludge wastewater process. WAS is a significant problem in several wastewater treatment plants. Previous disposal methods, such as landfills and incineration, are not sustainable and proper due to limitations of environmental concerns. Therefore, this research was interested in using WAS as a soil substitute in fired clay brick production. Seven mixing ratios between normal clay soil (NS) and WAS (1:0 (control), 0.9:0.1, 0.8:0.2, 0.7:0.3, 0.6:0.4, and 0.5:0.5 by dry weight) were established in this research. Three parameters were considered for testing the properties of the finished fired clay brick as follows: density (D), water absorption (WA), and compressive strength (CS). It was found that the bricks with the addition of 10% WAS (at a mixing NS:WAS ratio of 0.9:0.1) were suitable for construction work due to the produced lightweight bricks and the high compressive strength according to the Thai community product standard (TCPS). However, there was a limitation on the use of produced brick, which has high-water absorption. The bricks should be soaked in water before using. Thus, WAS is a promising soil substitute for recycling in fired clay brick production, resulting in many financial benefits and environmental advantages as compared to the traditional WAS disposal. In addition, this research can be used as a guideline for WAS application from other sources.

Keywords : waste-activated sludge ; fired clay brick ; tapioca starch ; water absorption ; compressive strength

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Introduction

An abundance of waste-activated sludge (WAS) is generated as a large volume from the wastewater treatment process (WWTP). Approximately 47,600 tons of WAS are discarded annually from the tapioca starch industry in Thailand (Chavalparit & Ongwandee, 2009). WAS is a significant issue for WWTP, with an expensive disposal cost of up to 50% of the operation cost (Zahan *et al*., 2016). Additionally, landfill and incineration are not sustainable disposal options because of environmental drawbacks such as leachate problems (Dong *et al*., 2015) and greenhouse gas (GHG) emissions (Liu *et al*., 2013).

Many works studied about wastewater sludge (WS) and water treatment sludge used as raw substitutes for fired clay brick making. For example, the textile WS was applied as a brick material. It was found that the usage of 15% WS could be practical and comply with the Indian brick standard (Shathika *et al*., 2013). Shrutakirti & Husain (2016) used the automobile WS. They found that brick compressive strength decreased with the increasing WS concentration. The percentage of WS added was lower than 10% to obtain the proper bricks. Lissy P N & Sreeja (2014) stated that the bricks mixed with a textile WS content of about 6.66% met the relevant technical standards. Aeslina & Ahmad (2014) indicated that many sludge applications were also practical in fired clay brick production. Unfortunately, there is a lack of studies on WS from tapioca starch industry on brick production. Therefore, its use is interesting because it can help reduce pollutions from conventional WS disposal methods. Moreover, this can solve the problem of proper brick-making soil deficiency. As of 2018, more than 700 manufacturing plants in Thailand produce a lot of bricks for construction annually (Joyklad *et al*., 2018). Brick making process requires up to 20,086 m^3 of topsoil per million bricks. Topsoil loss can cause severe domino effects, such as crop yield loss, unproductive soil, overfertilizing in the area, and soil erosion.

This research was interested in applying the WAS from the tapioca starch plant as a potential substitute for soil in fired clay brick production. The optimal mixing ratios between WAS and normal clay soil (NS) were investigated by comparing the finished bricks with the standards and ordinary fired clay bricks. The results can contribute directly to develop further about its application. Moreover, it can be used as a model for WAS from other sources.

Methods

WAS collection and analysis

The WAS was obtained from the WWTP of a modified tapioca starch plant in Rayong province, Thailand. The NS was acquired from the community enterprises of fired clay brick production in Uttaradit province. Both were dried in natural air for 7 days and then dried in an oven at 103–105 °C for 24 hours. The dried WAS was ground and sieved with 3/8 inch mesh by hand. The size of the obtained sludge was equal to or less than 9.5 mm. Then, it was burned out to remove organic matter at 150 °C for 1 hour. After that, it was preserved appropriately in a desiccator before using and analysis (Figure 1). The total concentration (TC) for heavy metals for analysis was analyzed according to the United States Environmental Protection Agency (USEPA) methods. They evaluated whether the WAS was hazardous waste by comparing it with the Total Threshold Limit Concentration (TTLC) and Soluble Threshold Limit Concentration (STLC) in the Notification of Ministry of Industry, Industrial Waste Disposal 2005, Thailand.

Figure 1 WAS feature

<u>*Brick making process*</u>

Raw material preparation

The seven mixing ratios of NS to WAS (1:0 (control), 0.9:0.1, 0.8:0.2, 0.7:0.3, 0.6:0.4 and 0.5:0.5 by dry weight) were prepared in each batch. Each batch was prepared around 100 kg and filled with 20 kg of tap water before mixing. After that, the samples were left for 5 hours to saturate the water.

Clay fired brick forming and shaping

The prepared sample was inputted into the screw mixer and passed through the mold, as shown in Figure 2. The produced bricks were formed with dimensions of approximately 140 × 65 × 40 mm^3 (length × height × depth) by cutting with a stainless wire. Fifty bricks were produced for each mixing ratio.

Drying and burning process

The wet bricks were dried by placing them in ambient air for 24 hours. Then, they were sorted and burned in the kiln pile at temperatures between 900 and 1100°C for 24 hours by using rice husks as fuel. After leaving them for 3 days, the bricks were cooled down. The finished bricks were obtained, as shown in Figure 3.

(a) Screw mixer (b) Mould

Figure 2 Clay brick-making equipment and machine

(a) Drying process (b) Burning process

Figure 3 Drying and burning process

Test for properties of fired clay brick

The three parameters were considered for testing the properties of the ten produced fired clay bricks of each mixing ratio according to ASTM standard.

Density (D) testing method (ASTM C 373-14a)

This is the quotient of dry brick weight divided by the volume, including pores. D was calculated by using Equation 1.

$$D\ (g/cm^3) = \frac{Dry\ brick\ weight\ (g)}{Volume\ of\ the\ brick\ (cm^3)} \qquad (1)$$

Water absorption (WA) testing method (ASTM C 373-14a)

This is the quotient of the weight of water absorbed to the dry brick weight expressed as a percentage. WA was calculated by using Equation 2.

$$WA\ (\%) = \frac{[Saturated\ weight\ (g) - Dry\ weight\ (g)] \times 100}{Dry\ weight\ (g)} \qquad (2)$$

Compressive strength (CS) testing method (ASTM C 773-88)

The CS is the capacity of the brick to withstand force measured in megapascal (MPa) units, as measured with a compressive testing machine. This value is significantly influenced by the raw material's properties, burning temperature, the-production method, etc. CS was calculated by using Equation 3.

$$CS\ (MPa) = \frac{Total\ load\ on\ the\ specimen\ at\ failure\ (Newton) \times 10^{-6}}{Calculated\ area\ of\ the\ bearing\ surface\ of\ the\ specimen\ (m^2)} \qquad (3)$$

Results

WAS Characteristics

Before drying, the WAS characteristics were first considered in this work. WAS has the high moisture content with a value of 86.7%. Its pH value was 7.1, which was nearly neutral. Table 1 shows the small amount of all metals compared with the allowable TTLC and STLC standards. All metal values were remarkably lower than both standards. Therefore, the waste extraction test (WET) was not carried out in this work because the TC values in WAS did not exceed the STLC standard values.

Table 1 Comparison of TC with regulatory TTLC and STLC standards

Metal	TTLC standard (mg/g by dry weight)	TC value (mg/g by dry weight)	STLC standard (mg/l by dry weight)
Mercury (Hg)	20	ND	0.2
Cadmium (Cd)	100	ND	1
Arsenic (As)	500	ND	5
Lead (Pb)	1,000	ND	5
Copper (Cu)	2,500	9.62	25
Zinc (Zn)	5,000	26.80	250

Note : ND is a nondetectable value (Hg and As < 0.l00 mg/g; Cd < 0.600 mg/g; Pb < 3.10 mg/g)

The properties of the produced clay brick

The volume of produced brick

Figure 4 shows that the volume of bricks was likely to decrease continuously while WAS addition increased. Compared with normal bricks, the WAS bricks have a lower volume both before and after burning because the amount of adsorbed water increased with increasing WAS. According to typical WAS characteristics, a largely hydrated structure contains a high-water adsorption capability of as much as 95–98% (Liao *et al*., 2000). There was a slight difference between before and after burning of all mixing ratios.

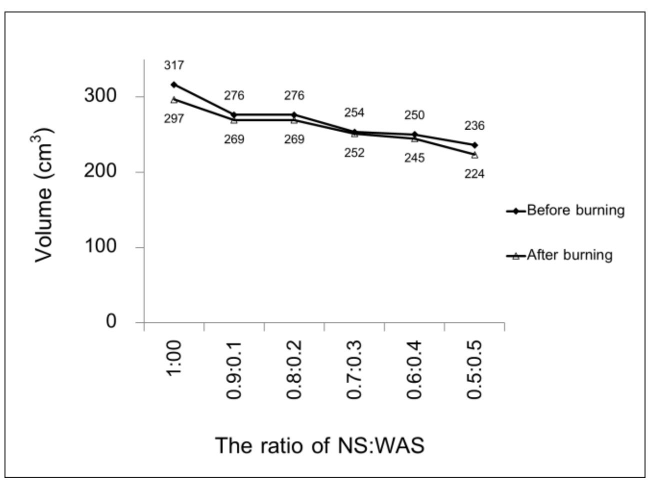

Figure 4 The volume changes of the produced bricks before and after burning

The density of the produced brick

The D of produced bricks had an extreme decrease compared to the normal bricks. However, these trends dropped slightly from 1.48 to 1.346 g/cm^3 of brick before burning and from 1.22 to 1.038 g/cm^3 of brick after burning (Figure 5). Therefore, the various WAS mixing ratios have the small effect on the D values. The burning process of WAS bricks can significantly affect the densities, which were obviously presented with the big gaps between after and before burning. The densities of all WAS ratios bricks were lower than the regular fired clay bricks with minimum densities of approximately 1.30–2.20 g/cm^3 (Fernando, 2020).

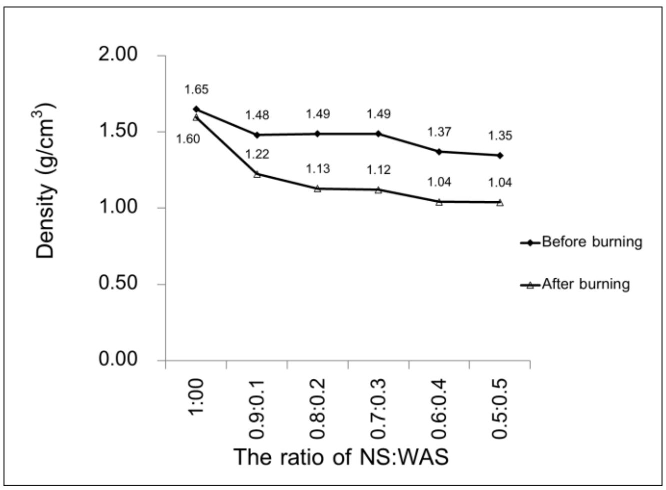

Figure 5 The D changes of the produced bricks before and after burning

The water absorption of the produced brick

The WA values (Figure 6) increased dramatically at the initial mixing ratio of 0.9:0.1. After that, the WA values slightly increased when the WAS was increased. However, all WAS mixing ratios had significantly higher WA values as compared to the Thai industrial standard (TIS)77-2545 of ordinary constructing brick type B and the Thai community products standard (TCPS) that recommended less than 25%.

The compressive strength of the produced brick

The CS of bricks were mixed with WAS by showing significant reduction in the CS value from 8.4 MPa for the ratio of 0.9:0.1 to 3.9 MPa for a ratio of 0.5:0.5 (Figure 7). The TCPS and TIS standards recommended that ordinary fired clay bricks should contain more than 7 and 9 MPa compressive strength values, respectively. Most WAS mixing ratios did not meet both standards except for the ratio of 0.9:0.1, which passed only the TCPS standard.

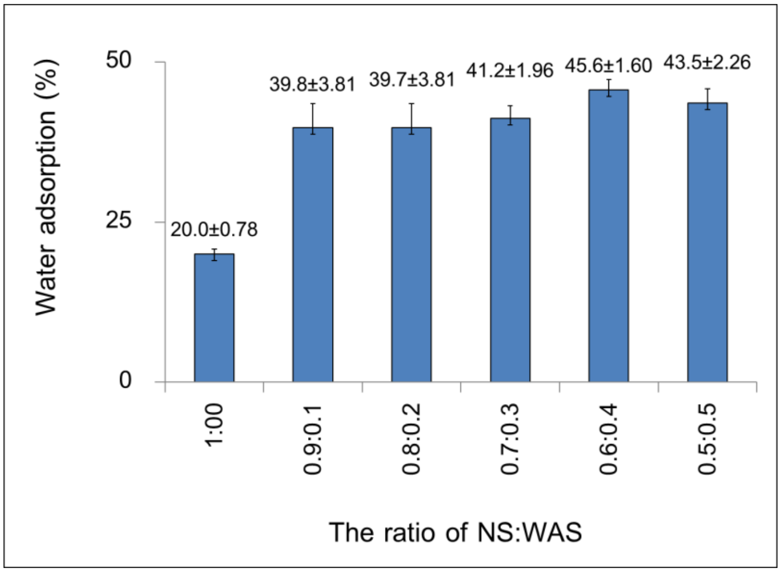

Figure 6 The WA of the produced bricks

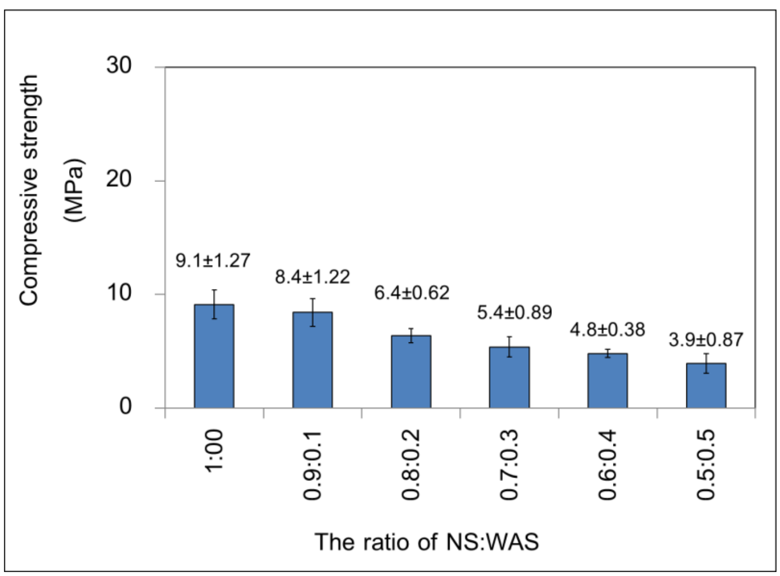

Figure 7 The CS of the produced bricks

Discussion

The results indicate that WAS is a non-hazardous waste. Therefore, it could be used as a partial material in brick due to being harmless to health. As the volume of produced brick results, the addition of WAS was found to be the main factor affecting the volume changes compared with the ratio without WAS addition. In contrast, the burning process was unimportant factor since there was minimal residual water in the brick after the drying process. The all-mixing ratios show a lower D value than their regular value because of the continued increase of WAS. On the other hand, these decreases in D were beneficial by providing the lightweight fired clay brick. These densities close to the clay bricks prepared with 10% bagasse addition were observed at 1.0-1.2 g/cm^3, and a burning temperature between 800-1,000°C (Janbuala & Wasanapiarnpong, 2016).

All WAS mixing ratios show the high WA values. Normally, the high WA is direct to the porosity of fired clay brick (Abdel Hamid *et al.,* 2023). These may result in adverse effects on mortar binding and strength. The bricks can scramble to absorb water from mortar, leading to incomplete mortar hydration (Christy et al., 2012). Therefore, they should be soaked or sprayed with water until complete saturation before applying for construction. A saturated brick retains sufficient available pore space to provide all essential water uptake, which is necessary to properly bed into mortars (The Clay Brick Association of Southern Africa, 2023).

The mixing ratio of 0.9:0.1 can be used in construction by resisting pushing forces from construction and building materials. However, water absorption should also be the main concern. The other WAS mixing ratios may be used for other purposes, such as paving, fencing, and garden decoration, which require less strict conditions. As compared with other sludges blending into fired clay brick by Kadir & Rahim (2014), there is a wide range in compressive strength value. These resulting values were close to the bricks with 20%textile laundry sludge added equal to 4.62 MPa (Luciana *et al*., 2012). Similarly, bricks mixed with 25–75 water treatment sludge and rice husks valued at 2.82–7.84 MPa (Badr El-Din, Hanan, & Ahmed, 2012), and bricks mixed with 10-20% of desalination sludge showed the CS value of 2–3 MPa (Kevin *et al*., 2013).

Conclusions

WAS from the tapioca starch industry is a potential soil substitute in fired clay brick production. However, construction applications should use an NS:WAS mixing ratio equal to 0.9:0.1. Before using it, water soaking is necessary for reducing water absorption to maintain adequate water for the complete hydration of mortar. In contrast, the other ratios can be developed for other purposes that do not require a high compressive strength. Its usage will be beneficial by reducing the WAS disposal costs of the wastewater treatment process. That was estimated for as much as fifty percent of the total operating cost of wastewater treatment plants. Furthermore, it would help mitigate adverse environmental impacts from the conventional disposal methods.

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