

# Physico – mechanical properties of water treatment sludge – clay bricks

Do Thi Phuong<sup>1\*</sup>, Nguyen Van Quang<sup>1</sup>, Nguyen Thi Ngoc Yen<sup>1</sup>, Ha Van Phuc<sup>1</sup>, Ho Anh Tuan<sup>1</sup>, Vo Duy Vu<sup>1</sup>

<sup>1</sup> Faculty of Road and Bridge Engineering, The University of Da Nang – University of Science and Technology

## KEYWORDS

Sludge  
Water treatment sludge  
Clay brick  
Waste  
Physico-mechanical properties

## ABSTRACT

This paper presents an experimental investigation on the utilization of drinking water treatment sludge (WTS) as a partial replacement for clay in clay brick manufacturing. Clay bricks were produced by substituting natural clay with WTS at replacement levels ranging from 0 to 60%, and firing at temperatures between 850 and 1050°C. The effects of WTS content and firing temperature on the physical and mechanical properties of the bricks were systematically evaluated. The results indicate that increasing WTS content leads to a reduction in bulk density and firing shrinkage, while water absorption and compressive strength of the clay bricks increase. At the optimal firing temperature of 1050°C, the brick sample containing 50% WTS exhibited the highest compressive strength of 23.1 MPa, which is approximately 2.3 times higher than that of the control sample. In addition, this composition showed a firing shrinkage of 3.05%, bulk density of 1.75 g/cm<sup>3</sup>, and water absorption of 13.2%, meeting the requirements for solid clay bricks according to TCVN 1451:1998. These findings demonstrate the significant potential of recycling water treatment sludge as a sustainable raw material in eco-friendly building materials and clay brick production.

## 1. Introduction

One of the typical urban solid wastes requiring proper management and disposal is water treatment sludge (WTS) generated from drinking water treatment plants. Traditionally, landfilling has been the primary method adopted in most cities for sludge management. However, this practice leads to increasing costs due to the scarcity of urban land and poses significant environmental risks. Therefore, exploring alternative solutions for sludge minimization through recovery and reuse is of critical importance. At the same time, the construction materials industry is facing major challenges related to the conservation of natural resources, the valorization of industrial by-products and wastes, and the reduction of environmental emissions. In this context, the utilization of WTS in building materials has emerged as an effective and sustainable approach. Its chemical composition and physical characteristics make it particularly suitable for applications in brick manufacturing and other ceramic-based materials. Numerous studies have reported the reuse of WTS in the production of clay bricks, roofing tiles, lightweight aggregates, cement, concrete, and geopolymer materials [1-3].

The incorporation of WTS in clay brick and ceramic production has been proposed as a sustainable solution [4]. Limami et al. [5] reported that partial replacement of clay with WTS can produce fired bricks with compressive strength up to 3.95 MPa, porosity of approximately 17 %, and bulk density not exceeding 1.75 g/cm<sup>3</sup>. Several studies have indicated that iron-based sludge can enhance the mechanical performance of clay bricks and reduce the required firing temperature [1, 6]. At low replacement levels (below 10 %), WTS has been shown to improve the compressive and flexural strength of

ceramic products by 7 ÷ 97 % compared to control samples [7, 8]. Specifically, Hassan et al. [8] successfully produced clay bricks with a compressive strength of 15.1 MPa using raw materials containing 6 % arsenic-iron sludge.

In contrast, other studies have reported that aluminium-based sludge may lead to a reduction in the mechanical strength of ceramic products as the WTS content increases. Substitution levels below 10 % generally do not significantly affect the mechanical properties, whereas higher replacement levels may reduce flexural strength by 24.6 ÷ 45.45 % [1, 9, 10]. Benlalla et al. [11] investigated the influence of WTS rich in Al<sub>2</sub>O<sub>3</sub> on the physical, mechanical, and mineralogical properties of fired ceramics at temperatures between 800 and 1000 °C, showing that a 30 % WTS content resulted in higher strength than the control sample when fired at 1000 °C, with good correlations among the evaluated properties. Similarly, Liew et al. [12] produced bricks meeting local standards using up to 40 % WTS. Mohammed et al. [13] examined high replacement levels (50 ÷ 80 %) and firing temperatures ranging from 950 to 1100 °C, obtaining products with superior performance compared to commercially available bricks.

In addition, WTS has been combined with other industrial and agricultural wastes—such as fly ash, bottom ash, waste glass, brick debris, marble dust, dam sediments, and agricultural residues—in ceramic production, yielding promising results [9, 14-18]. The WTS from other industries, such as paper and textile plants or sludge from dredging rivers, has also been investigated as a raw material for ceramic production with encouraging outcomes [19-22]. However, sludge from industrial sources requires careful assessment due to the potential presence of heavy metals and hazardous substances.

\*Corresponding author: dtphuong@dut.udn.vn

Received 28/03/2026, revised 21/05/2026, accepted 22/05/2026

Link DOI: <https://doi.org/10.54772/jomc.v16i01.1303>

This study focuses on evaluating the physical and mechanical properties of clay bricks incorporating WTS obtained from a drinking water treatment plant in Vietnam, with varying replacement ratios and firing temperatures. The objective is to develop fired bricks from WTS that meet the technical requirements for solid clay bricks according to TCVN 1451:1998. The use of WTS-based bricks contributes to the development of eco-friendly building materials, promoting sustainable construction practices while conserving natural clay resources.

## 2. Materials and Methods

### 2.1. Clay

The clay used in this study was collected from a local brick manufacturing plant in Da Nang, Vietnam. Its chemical composition is presented in Table 1. The strength of clay bricks largely depends on the silica ( $\text{SiO}_2$ ) content in the clay. Compared to clay, the water treatment sludge (WTS) contains lower silica but higher alumina ( $\text{Al}_2\text{O}_3$ ) content. While alumina tends to increase the firing temperature, it also enhances the thermal stability of the final product. The clay contains a relatively low amount of fluxing oxides, which may pose challenges during the firing and sintering processes.

**Table 1.** Chemical composition of the clay.

Oxide	Weight content (wt.%)
$\text{SiO}_2$	58.34
$\text{Al}_2\text{O}_3$	21.16
$\text{Fe}_2\text{O}_3$	7.07
$\text{CaO}$	0.54
$\text{MgO}$	0.13
$\text{K}_2\text{O}$	2.79
$\text{Na}_2\text{O}$	0.09
$\text{SO}_3$	0.08
$\text{TiO}_2$	0.91
LOI	8.90

The raw clay was received in large lumps and then crushed and sieved to pass a 0.63 mm sieve prior to specimen preparation (Figure 1). Subsequently, it was oven-dried at 105-110 °C to a constant mass

**Table 3.** Particle size distribution of clay and WTS.

Raw materials	Particle size distribution (%)		
	Sand fraction (0.05 ÷ 0.63 mm)	Silt fraction (0.002 ÷ 0.05 mm)	Clay fraction (< 0.002 mm)
Clay	10 ÷ 30	20 ÷ 40	> 30
WTS	5 ÷ 10	65 ÷ 80	15 ÷ 25

The chemical composition of WTS is presented in Table 4, showing that it is rich in silica, alumina, and iron oxides—similar to

to ensure complete moisture removal. Selected physical properties of the clay are summarized in Table 2.

**Table 2.** Properties of the clay.

Properties	Values	Testing methods
Natural moisture content (%)	9.07	TCVN 4196:2012
Natural bulk density, $\text{g/cm}^3$	1.68	TCVN 4202:2012
Dry powder bulk density, $\text{g/cm}^3$	0.89	TCVN 4202:2012
Specific gravity, $\text{g/cm}^3$	2.70	TCVN 4915: 2012
Liquid limit, %	32.77	TCVN 4197:2012
Plastic limit, %	12.72	TCVN 4197:2012
Plasticity index	20.05	TCVN 4197:2012

### 2.2. Water Treatment Sludge (WTS)

The WTS used in this study was collected from a drinking water treatment plant in Da Nang, where the treatment process typically includes coagulation, sedimentation, and filtration. The sludge, initially with high moisture content (26.5 %), was collected from storage tanks, transported to the laboratory, air-dried (moisture content of 14.7 %, bulk density of 1.54  $\text{g/cm}^3$ ), and then oven-dried at 105-110 °C to constant mass. It was subsequently ground into fine powder passing a 0.63 mm sieve before use in brick manufacturing (Figure 1).



(a) Clay (b) Water Treatment Sludge (WTS)

**Figure 1.** The raw materials in this work.

The WTS has a specific gravity of 2.61  $\text{g/cm}^3$  and a bulk density of 0.83  $\text{g/cm}^3$ . Particle size distribution analysis conducted using a hydrometer (Table 3) indicates that WTS contains a higher proportion of fine particles (silt fraction) compared to clay.

typical clay used for brick production—indicating strong potential for reuse in ceramic materials [4]. The loss on ignition (LOI) of WTS is

14.9 %, reflecting a higher organic matter content than clay, which significantly affects the structure and mechanical properties of the brick during firing.

**Table 4.** Chemical composition of the WTS.

Oxide	Weight content (wt.%)
SiO <sub>2</sub>	48.42
Al <sub>2</sub> O <sub>3</sub>	24.82
Fe <sub>2</sub> O <sub>3</sub>	8.89
CaO	0.46
MgO	0.16
K <sub>2</sub> O	2.13
Na <sub>2</sub> O	0.10
SO <sub>3</sub>	0.10
Cl <sup>-</sup>	0.02
LOI	14.9

### 2.3. Preparation of Specimens

Brick specimens were prepared using mix proportions detailed in Table 5, with WTS replacing clay at levels of 10 %, 20 %, 30 %, 40 %, 50 %, and 60 %. The properties of WTS-incorporated bricks were compared with a control sample (G0) consisting of 100 % clay.

**Table 5.** Mix proportions and forming moisture content of brick specimens.

Samples	Weight content (Wt.%)		Forming moisture content, (%)
	WTS	Clay	
G0	0	100	24.2
G1	10	90	25.4
G2	20	80	25.9
G3	30	70	26.0
G4	40	60	26.6
G5	50	50	27.1
G6	60	40	27.8

The raw materials were first dry-mixed according to the specified proportions and then mixed with water to achieve suitable molding moisture content. In this study, the plastic forming method was employed, typically requiring a moisture content of 18 ÷ 25 %. However, due to the fine particle size and high LOI of WTS, its water absorption and retention capacity increased, leading to higher molding moisture content. The appropriate moisture content was determined based on the Vicat needle penetration depth of 3 ÷ 4 cm into the plastic mixture, following a procedure similar to the determination of standard consistency of cement paste (TCVN 6017:2015).

After mixing, the material was aged for at least 48 hours before molding. Specimens were formed into cubic molds of 50 × 50 × 50

mm. The molded samples were air-dried for 2 ÷ 3 days and then oven-dried at 105-110 °C until constant mass. Subsequently, dried bricks were fired at temperatures of 850 °C, 950 °C, and 1050 °C, with a heating rate not exceeding 120 °C/h and a soaking time of 3 hours (Figure 2).



(a) Green bricks



(b) Fired bricks

**Figure 2.** Images of specimens.

### 2.4. Testing methods

After firing, the specimens were visually inspected for shape, dimensions, defects, color, and soundness. The main physical and mechanical properties evaluated included bulk density, firing shrinkage, water absorption, and compressive strength. Bulk density, water absorption, and compressive strength were determined in accordance with TCVN 6355:2009.

#### a. Firing shrinkage

The volumetric shrinkage (%) of the fired bricks was determined based on the reduction in specimen volume after firing. The dimensions of the specimens were measured using a caliper, and shrinkage was calculated according to Equation (1).

$$C_v = \frac{V_1 - V_2}{V_1} \cdot 100 \quad (1)$$

where  $V_1$  is the volume of the specimen before firing (mm<sup>3</sup>),  $V_2$  is the volume of the specimen after firing (mm<sup>3</sup>).

The linear shrinkage of the specimens ( $C_l$ , %) was determined based on the volumetric shrinkage (Equation 2).

$$C_l = \left[ 1 - \left( 1 - \frac{C_v}{100} \right)^{1/3} \right] \cdot 100 \quad (2)$$

### b. Bulk density

After cooling to room temperature, the mass ( $m$ , g) and dimensions of the specimens were measured to determine the volume ( $V$ ,  $\text{cm}^3$ ). The bulk density ( $\text{g}/\text{cm}^3$ ) was calculated according to Equation (3).

$$\gamma_o = \frac{m}{V} \quad (3)$$

### c. Water absorption

The fired specimens were first cooled to room temperature and weighed (dry mass). They were then fully immersed in water for 24 hours. After saturation, surface water was removed using a damp cloth before weighing (saturated mass). Water absorption (%) was calculated according to Equation (4).

$$H_p = \frac{m_2 - m_1}{m_1} \cdot 100 \quad (4)$$

### d. Compressive strength

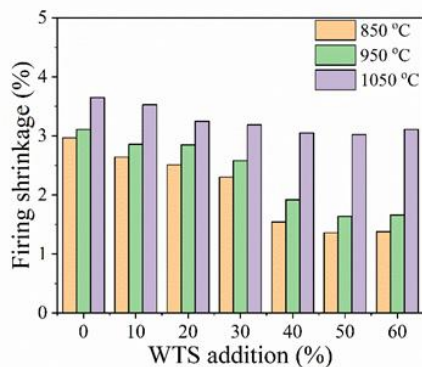
The compressive strength (MPa) was determined using a Shimadzu testing machine with a capacity of 500 kN after the specimens were cooled to room temperature. The compressive strength was calculated according to Equation (5), where  $F$  is the failure load (N) and  $A$  is the average loaded area of the specimen ( $\text{mm}^2$ ).

$$R_n = \frac{F}{A} \quad (5)$$

## 3. Results and Discussion

### 3.1. Linear shrinkage upon firing

Firing shrinkage is closely associated with the sintering behavior of ceramic materials. This parameter reflects the effects of temperature on physical and chemical transformations within the matrix, leading to dimensional reduction during firing [23].



**Figure 3.** Firing shrinkage of brick specimens at different firing temperatures.

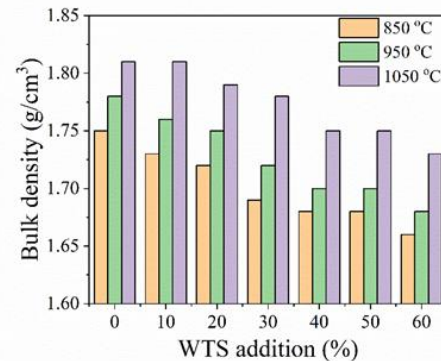
As shown in Figure 3, increasing the WTS content results in a decrease in firing shrinkage at all temperature levels. This reduction is particularly pronounced when the WTS content exceeds 30 %, while a slight increase is observed at 60 % WTS. The decrease in shrinkage

with higher WTS content can be attributed to the combustion of organic matter during firing, which generates pores within the ceramic matrix. Although porosity increases, the rigid ceramic skeleton exhibits lower shrinkage. These findings are consistent with several studies reporting reduced shrinkage with the addition of 10 ÷ 50 % WTS [12, 24, 25] although some authors have observed the opposite trend [23].

An increase in firing temperature from 850 to 1050 °C leads to higher shrinkage values due to dehydroxylation, phase transformations, and closer packing of structural units, resulting in densification. The shrinkage values of WTS-containing bricks range from 1.38 ÷ 2.64 % at 850 °C, 1.66 ÷ 2.86 % at 950 °C, and 3.11 ÷ 3.53 % at 1050 °C, compared to 2.97 ÷ 3.65 % for the control samples. Maintaining shrinkage within an acceptable range is essential to avoid cracking during thermal processing. In this study, all values fall within the recommended limits for brick production [26].

### 3.2. Bulk density

The bulk density of fired bricks incorporating WTS is presented in Figure 4. A clear decreasing trend in bulk density is observed with increasing WTS content. This is primarily due to the formation of a more porous ceramic structure, resulting from the combustion of organic matter and volatilization of certain inorganic components in WTS, as well as its lower specific gravity compared to clay.



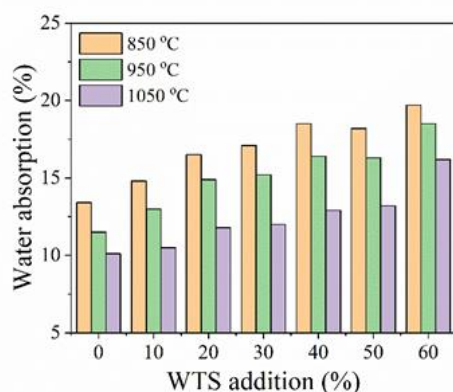
**Figure 4.** Bulk density of brick specimens at different firing temperatures.

Conversely, increasing the firing temperature from 850 to 1050 °C significantly enhances bulk density. This is attributed to phase transformations, liquid phase formation, and pore filling during sintering, which promote densification and reduce overall porosity. The control samples exhibit bulk densities of 1.75, 1.78, and 1.81  $\text{g}/\text{cm}^3$  at 850, 950, and 1050 °C, respectively. In comparison, WTS-containing bricks show bulk density ranges of 1.66 ÷ 1.73  $\text{g}/\text{cm}^3$  (850 °C), 1.68 ÷ 1.76  $\text{g}/\text{cm}^3$  (950 °C), and 1.73 ÷ 1.81  $\text{g}/\text{cm}^3$  (1050 °C). These results are comparable to previous studies. Moulato et al. [23] reported bulk densities of 1.40 ÷ 1.57  $\text{g}/\text{cm}^3$  for bricks containing

10 ÷ 60 % WTS fired at 930 °C, while Erdogmus et al. [16] observed values increasing from 1.7 to 2.05 g/cm<sup>3</sup> as WTS content increased to 100 % at 1000 °C. In the present study, all WTS-based bricks exhibit bulk densities greater than 1.65 g/cm<sup>3</sup>, satisfying the requirements for solid burnt clay bricks according to TCVN 1451:1998. These findings indicate that, despite increased porosity, the density remains within acceptable limits for structural applications.

### 3.3. Water absorption

Water absorption is directly related to the open porosity of the material and is inversely correlated with bulk density. The experimental results are presented in Figure 5.



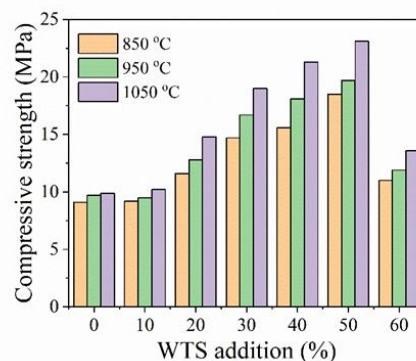
**Figure 5.** Water absorption of brick specimens at different firing temperatures.

The water absorption of WTS-containing bricks ranges from 10.5 % to 19.7 % with increasing WTS content, whereas the control samples exhibit values between 10.1 % and 13.4 %. The increase in water absorption is mainly due to the higher porosity induced by the combustion of organic matter in WTS [12, 23]. The size, distribution, and connectivity of pores significantly influence both water absorption and mechanical performance. Similar trends have been reported in the literature. Liew et al. [12] observed water absorption values of 26.7 ÷ 37 % for 10 ÷ 40 % WTS, while Areias et al. [27] reported values exceeding 22 % for WTS contents above 15 %. In contrast, the present study demonstrates relatively lower absorption values, indicating a more favorable pore structure. With increasing firing temperature, water absorption decreases due to enhanced sintering, crystallization, and reduction of open porosity [13].

Increasing the firing temperature from 850 to 1050 °C significantly reduces water absorption. The values range from 14.8 ÷ 19.7 % at 850 °C, 13.0 ÷ 18.5 % at 950 °C, and 10.5 ÷ 16.2 % at 1050 °C. At 1050 °C, bricks containing 10 ÷ 50 % WTS exhibit water absorption below 16 %, meeting the requirements for solid fired clay bricks according to TCVN 1451:1998. This trend is consistent with the observed increase in bulk density and decrease in shrinkage variability.

### 3.4. Compressive strength

Compressive strength is a key parameter for evaluating the structural performance of fired bricks. High-quality bricks typically require a balance between adequate density and mechanical strength [14]. The results are presented in Figure 6.



**Figure 6.** Compressive strength of brick specimens at different firing temperatures.

Bricks incorporating WTS exhibit significantly higher compressive strength than the control samples. The strength increases markedly (11.6 ÷ 23.1 MPa) as WTS content increases from 20 % to 50 %, while the control samples show values of approximately 9.1 ÷ 9.9 MPa. Although the high organic content in WTS initially increases porosity, thereby affecting the thermal, mechanical, and acoustic properties, increasing water absorption while reducing bulk density of the final product, its combustion at elevated temperatures releases heat, contributing to energy savings and enhancing the sintering process [12, 28]. Improved sintering reduces porosity and strengthens the ceramic matrix, leading to higher compressive strength. Benlalla et al. [11] also stated that the compressive strength of sludge – clay bricks were higher than the control samples. However, when the WTS content exceeds 50 %, compressive strength decreases. Excessive WTS adversely affects pore structure, reduces bonding within the matrix, lowers density, and introduces brittleness due to gas release and organic decomposition during firing [12, 23]. While higher WTS contents may still be feasible with additional additives [16, 17]. In addition, many studies report strength reduction at high sludge contents due to increased organic matter [12, 20, 23]. The particle size distribution, chemical composition, and mineralogy of WTS play a crucial role in determining brick performance.

An increase in firing temperature from 850 to 1050 °C significantly enhances compressive strength due to improved densification and strengthening of pore walls. The compressive strength ranges from 11.0 ÷ 18.5 MPa (850 °C), 11.9 ÷ 19.7 MPa (950 °C), and 12.6 ÷ 23.1 MPa (1050 °C). At 1050 °C, the sample containing 50 % WTS achieves the highest compressive strength of 23.1 MPa, more than twice

that of the control sample. These results are consistent with previous findings. Ramadan et al. [13] identified 50 % WTS as an optimal replacement level for sludge–clay brick production at typical industrial firing temperatures. Areias et al. [27] suggested that 15 % WTS is suitable for achieving balanced shrinkage, water absorption, and mechanical strength at 850-950 °C, although higher contents up to 50 % can still be considered optimal under appropriate conditions.

Overall, the combined effects of WTS content and firing temperature demonstrate strong interdependence among shrinkage, bulk density, water absorption, and compressive strength, highlighting the importance of optimizing both parameters for the production of eco-friendly fired bricks.

#### 4. Conclusions

This study investigated the feasibility of utilizing drinking water treatment sludge (WTS) as a partial replacement for natural clay in burnt clay brick manufacturing. Based on the experimental results and discussions, the following conclusions can be drawn:

- The incorporation of WTS significantly influences the physical and mechanical properties of clay bricks. Increasing WTS content reduces bulk density and firing shrinkage, while increasing water absorption and compressive strength within a certain range.

- Firing temperature plays a crucial role in improving brick performance. Higher temperatures (up to 1050 °C) enhance sintering, leading to increased bulk density and compressive strength, and reduced water absorption due to the refinement of pore structure.

- An optimal WTS replacement level of approximately 50 % was identified. At this proportion and a firing temperature of 1050 °C, the bricks achieved the best performance, with a compressive strength of 23.1 MPa, bulk density of 1.75 g/cm<sup>3</sup>, firing shrinkage of 3.05 %, and water absorption of 13.2 %. These values satisfy the technical requirements for solid burnt clay bricks according to TCVN 1451:1998.

- Excessive WTS content (above 50 %) adversely affects the brick structure, leading to increased porosity, reduced density, and a decline in compressive strength.

- Further research is recommended to investigate the combined effects of WTS with other industrial and agricultural wastes on the microstructure and performance of clay bricks, aiming to optimize material design and expand the application of sustainable brick manufacturing.

The results confirm that WTS, particularly with suitable chemical composition and fine particle size, is a promising alternative raw material for eco-friendly building materials, contributing to waste valorization, conservation of natural clay resources, and reduction of environmental impacts.

#### References

- [1]. De Carvalho Gomes, S., Zhou, J.L., Li, W., Long, G. "Progress in manufacture and properties of construction materials incorporating water treatment sludge: a review," *Resour Conserv Recycl*, vol. 145, pp. 148–159, 2019.
- [2]. Dahhou, M., El Hamidi, A., El Moussaoui, M., "Reusing drinking water sludge: physicochemical features, environmental impact and applications in building materials: a mini review," *Chem. Afr.*, vol. 6, pp. 1145–1161, 2023.
- [3]. Gomes, S.D.C., Zhou, J.L., Li, W., Qu, F., "Recycling of raw water treatment sludge in cementitious composites: effects on heat evolution, compressive strength and microstructure," *Resour Conserv Recycl*, vol. 161, p. 104970, 2020.
- [4]. Cremades, L.V., Cusido, J.A., Arteaga, F., "Recycling of sludge from drinking water treatment as ceramic material for the manufacture of tiles," *J Clean Prod*, vol. 201, pp. 1071–1080, 2018.
- [5]. Limami, H., Manssouri, I., Cherkaoui, K., Khaldoun, A., "Recycled wastewater treatment plant sludge as a construction material additive to ecological lightweight earth bricks," *Clean Eng Technol*, vol. 2, p. 100050, 2021.
- [6]. Anderson, M., Biggs, A., Winters, C., Use of two blended water industry by-product wastes as a composite substitute for traditional raw materials used in clay brick manufacture. In *Recycling and Reuse of Waste Materials*, Thomas Telford Publishing, 2003.
- [7]. Kizinič, O., Žurauskienė, R., Kizinič, V., Žurauskas, R., "Utilisation of sludge waste from water treatment for ceramic products," *Constr Build Mater*, vol. 41, pp. 464–473, 2013.
- [8]. Hassan, K.M., Fukushi, K., Turikuzzaman, K., Moniruzzaman, S.M., "Effects of using arsenic–iron sludge wastes in brick making," *Waste Manag.*, vol. 34, pp. 1072–1–78, 2014.
- [9]. Huang, C., Pan, J.R., Sun, K.D., Liaw, C.T., "Reuse of water treatment plant sludge and dam sediment in brick-making," *Water Sci Technol*, vol. 44 (10), pp. 273–277, 2001.
- [10]. Teixeira, S., Santos, G., Souza, A., Alessio, P., Souza, S., Souza, N., "The effect of incorporation of a Brazilian water treatment plant sludge on the properties of ceramic materials," *Appl Clay Sci*, vol. 53 (4), pp. 561–565, 2011.
- [11]. Benlalla, A., Elmoussaoui, M., Dahhou, M., Assafi, M., "Utilization of water treatment plant sludge in structural ceramics bricks," *Appl Clay Sci*, vol. 118, pp. 171–177, 2015.
- [12]. Liew, A.G., Idris, A., Wong, C.H.K., Samd, A.A., Noor, M.J.M.M, Baki, A.M., "Incorporation of sewage sludge in clay brick and its characterization," *Waste Manag. Res.*, pp. 226–233, 2004.
- [13]. Ramadan, M.A., Foad, H.A., Hassanin, A.M., "Reuse of Water Treatment Plant Sludge in Brick Manufacturing," *J. Appl. Sci. Res.*, vol. 4 (10), pp. 1223–1229, 2008.
- [14]. Li, P., Sun, F., Dong, Y., Wen, L., Lin, L., Xiao-yan LI, "Utilization of drinking water treatment sludge with coal fly ash to make permeable bricks for low impact development," *Resour. Conserv. Recycl.*, vol. 212, 2025.
- [15]. Sutcu, M., Gencel, O., Erdogmus, E., Kizinič, O., Kizinič, V., Karimipour, A., Velasco, P.M., "Low cost and eco-friendly building materials derived from wastes: combined effects of bottom ash and water treatment sludge," *Constr. Build. Mater.*, vol. 324, p. 126669, 2022.
- [16]. Erdogmus, E., Harja, M., Gencel, O., Sutcu, M., Yaras, A., "New construction materials synthesized from water treatment sludge and fired clay brick wastes," *J. Build. Eng.*, vol. 42, p. 102471, 2021.
- [17]. Gencel, O., Kazmi, S.M.S., Munir, M.J., Sutcu, M., Erdogmus, E., Yaras, A., "Feasibility of using clay-free bricks manufactured from water treatment sludge, glass, and marble wastes: An exploratory study," *Constr. Build.*

Mater., vol. 298, p. 123843, 2021, doi:

- [18]. Heniegal, A.M., Ramadan, M.A., Naguib, A., Agwa, I.S., "Study on properties of clay brick incorporating sludge of water treatment plant and agriculture waste," *Case Stud. Constr. Mater.*, vol. 13, p. e00397, 2020.
- [19]. Trung, N.V., Tinh, N.T., Quyen, N.T.L., Qui, D.T., "Research on using sewage sludge as a raw material for producing clay bricks," *J. Mater. Constr.*, vol. 14, no. 01, pp. 36–43, 2024. [Vietnamese].
- [20]. Wolff, E., Schwabe, W.K., Conceição, S.V., "Utilization of water treatment plant sludge in structural ceramics," *J. Clean. Prod.*, vol. 96, pp. 282–289, 2015.
- [21]. Hoa, N.N., Linh, N.C., Tiep, T.B., "Utilization of treated urban sludge to produce red brick by using the stiff-mud process," *J. Sci. Technol. Civ. Eng.*, vol. 15, no. 6V, pp. 23–34, 2021. [Vietnamese].
- [22]. Hoa, N.N., Huan, N.X., Quan, T.H., Hoan, V.K., "Utilization of nhue river's waste sludge to produce red bricks by semi-dry pressing method," *J. Sci. Technol. Civ. Eng.*, vol. 15, no. 6V, pp. 12–22, 2021. [Vietnamese].
- [23]. Cusidó, J.A.; Cremades, L.V.; González, M., "Gaseous emissions from ceramics manufactured with urban sewage sludge during firing processes," *Waste Manage.*, vol. 23(3), pp. 273–280, 2003.
- [24]. K. Moulato, M. Ammari, L. Ben Allal, "Performance of sewage sludge reuse in the manufacturing of fired bricks," *Glob. J. Environ. Sci. Manag.*, vol. 9 (3), pp. 477–496, 2023.
- [25]. Katte,V.Y., Seukep,J.F.N., Moundom,A., "The effect of partial replacement of waste water treatment sludge on the properties of burnt clay brick," *Int. J. Civ. Eng. Technol.*, vol. 8 (6), pp. 567–583, 2017.
- [26]. Ang, K.H., "Use of Sludge as a Construction Material. Undergraduate Thesis," Undergraduate Thesis, Dept. of Civil Engineering, National University of Singapore, 1982.
- [27]. International Labor Office & the United Nations Industrial and Development Organization. *Small-scale Brickmaking - Technical Memorandum*, 6, 1984.
- [28]. Areias, I.O.R., Vieira, C.M.F., Colorado, H.A., Delaqua, G.C.G, Monteiro, S.N., Azevedo, A.R.G., "Could city sewage sludge be directly used into clay bricks for building construction? A comprehensive case study from Brazil," *J. Build. Eng.*, vol. 31, p. 101374, 2020.