

INDUSTRIAL WASTEWATER SLUDGE AS POTENTIAL FILLER MATERIALS FOR FABRICATION OF LIGHTWEIGHT CONCRETE BLOCKS

Khotamy Saphongxay^{1,2}, Chakrapan Tuakta³ and Oratai Jongprateep^{1,2,*}

Received: January 16, 2021; Revised: March 14, 2021; Accepted: April 06, 2021

Abstract

Management of sewage sludge, a residual product from the treatment of industrial wastewater, has remained challenging for decades. Attributed to the high content of heavy metal, organic compounds or micro-organisms and limited available landfill capacity, disposal of sludge through landfilling severely creates environmental pollution. This study, hence, aimed at examining potential utilization of industrial sludge in fabrication of lightweight concrete blocks. While Ordinary Portland Cement and sand were used as main constituents, industrial wastewater sludge and rice husk ash were used as fillers in the concrete block production. Chemical composition of dried sludge and rice husk ash were examined through x-ray fluorescence (XRF). The XRF results revealed high content of silica in rice husk ash, whereas hazardous elements, specifically Pb, Hg, Cd and As, were not detected in the sludge. To assess properties of the concrete blocks for practical use, compressive strength and density were evaluated. The concrete blocks containing wastewater sludge lower than 20 wt% could exhibit compressive strength exceeding 5 MPa, while maintaining density lower than 1.6 g/cm³. It was evident that the concrete blocks demonstrated compressive strengths and density values within the acceptable range defined by the Thai Industrial Standards Institute (TISI 2601-2556) Type C16.

Keywords: Lightweight concrete block, Industrial waste, Hazardous, Residual waste, Wastewater sludge, Rice husk ash

Introduction

Sludge is a byproduct of wastewater treatment process. According to (Mateo-Sagasta *et al.*, 2015), the production of wastewater in around the world exceeded 260 km³. More than 25.2 million tons of sewage sludge are produced by many industrial countries such as EU, USA, China, etc. With large quantities of wastewater sludge, effective and environmentally friendly management of sludge remains a challenge. In addition, high cost of sludge

management is one of the critical concerns. It is estimated that costs of sludge disposal and treatment process was 20% to 60% of operational of treatment process (Foladori *et al.*, 2010). The most common method for sludge disposal is landfill or land spreading, which cause risk from heavy metal leaching. Since wastewater sludge contained organic compounds and heavy metals such as Pb, Mn, Cu, Cr and Zn, leaching can lead to natural

¹ Department of Materials Engineering, Faculty of Engineering, Kasetsart University, 50 Ngamwongwan Road, Lat Yao, Chatuchak, Bangkok, Thailand

² ICE-Matter Consortium, ASEAN University Network/Southeast Asia Engineering Education Development Network (AUN/SEED-Net)

³ Department of Civil Engineering, Faculty of Engineering, Kasetsart University, 50 Ngamwongwan Road, Lat Yao, Chatuchak, Bangkok, Thailand

* Corresponding author

water contamination (Rabie *et al.*, 2019). According to (Świerk *et al.*, 2007) leaching of Cu and Ni from electroplating sludge resulted in formation of high content of H₂O, HNO₃, NaOH solutions, which could be released into environment.

With the increasing demand of construction materials, wastewater management through utilization of the sludge in construction materials can be effective (Valls *et al.*, 2004; Yagüe *et al.*, 2005). It has been reported that 10 and 20 wt% of dry sludge could be used in concrete block production as a replacement of OPC (Habeeb and Mahmud, 2010). Sludge has also been reported to be a component of concrete mixture. With the content of less than of 15% dry sewage sludge, compressive strength of the concrete was not significantly diminished (Rabie, 2016).

Rice production results in generation of more than 700 million tons of paddy, 40% of rice husk convert to rice husk ash (RHA) (FAO, 2016; Singh, 2018). Byproduct from rice production was commonly eliminated by landfilling. It should be addressed that RHA cannot degraded in nature due to high siliceous content (80 to 98% after heat treatment) (Hossain, 2003; Rashid *et al.*, 2010; Zerbino *et al.*, 2011; Yuvakkumar *et al.*, 2014; Barkar *et al.*, 2016; França *et al.*, 2017; Chandeng *et al.*, 2020). Replacement of Ordinary Portland cement (OPC) by RHA has been reported. The decrease of compressive strength, flexural strength, and tensile strength was observed at the RHA content of 20% (Ahsan and Hossain, 2018).

Nevertheless, replacement of OPC by 10% of RHA could result in higher compressive strength (Habeeb and Mahmud, 2018).

This research, therefore, aims at utilizing waste products, specifically wastewater sludge and rice husk ash, in fabrication of lightweight concrete blocks. Assessment of density, compressive strength, along with potential toxicity of the cement blocks were conducted to ensure reliability and safety usage.

Materials and Methods

Raw materials preparation and characterization

Wet sludge from wastewater treatment was collected from Okuno-Auromex (Thailand) Co., Ltd, an electroplating plant. To remove the moisture, the sludge was ground by hand grinding technique and screened through the no.200 sieve. To obtained particles with sizes less than 45 µm, rice husk was also ground for 2 h and screened through the no.345 sieve.

The morphology of the raw materials was examined by scanning electron microscopy, SEM (FEI, Quanta 450). Particle size analysis was conducted using ImageJ software. The chemical composition of dried sludge and rice husk ash were determined by energy dispersive x-ray spectroscopy, EDS and x-ray fluorescence, XRF (Bruker, S8 Tiger AXSX).

Table 1. Composition of lightweight concrete block mixtures.

No.	Material	Quantity (wt%)	Aluminum (wt%)	W/C
1	Cement	35	1	1.3
	Sand	20		
	Sludge	10		
	Rice husk ash	35		
2	Cement	35	1	1.3
	Sand	20		
	Sludge	10		
	Rice husk ash	35		
3	Cement	35	1	1.3
	Sand	20		
	Sludge	15		
	Rice husk ash	30		
4	Cement	35	1	1.3
	Sand	20		
	Sludge	20		
	Rice husk ash	25		
5	Cement	35	1	1.3
	Sand	20		
	Sludge	25		
	Rice husk ash	20		
6	Cement	35	1	1.3
	Sand	20		
	Sludge	30		
	Rice husk ash	15		

Fabrication of lightweight concrete blocks

Lightweight concrete blocks with dimension of $2.5 \times 2.5 \times 2.5 \text{ cm}^3$ were prepared by casting pastes mainly containing ordinary Portland cement, sand, sludge, and rice husk ash. Aluminum (1 wt%) was also added in the paste to produce porous structure in the lightweight concrete blocks. Water to cement ratio of 1.3 was used throughout the experiments. The cast specimens were cured in water for 3 days and 7 days, and subsequently autoclaved for 6 h. Compositions of lightweight concrete mixture were shown in the Table 1.

Characterization of lightweight concrete block

A universal testing machine, UTM (Hounsfield, H50KS) was employed in determination of compressive strength of the lightweight concrete blocks after curing and autoclaving. The bulk density was also calculated. Scanning electron microscope, SEM (FEI, Quanta 450) was used in examination of microstructure of raw materials and concrete blocks. Chemical composition, specifically organic content and hazardous elements, in lightweight concrete blocks were evaluated by energy dispersive x-ray spectroscopy, EDS.

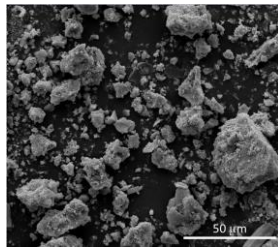


Figure 1. Scanning electron micrographs showing morphology of dry wastewater sludge.

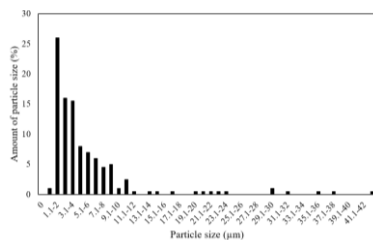


Figure 2. Size distribution of wastewater sludge particles.

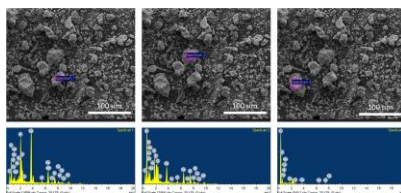


Figure 3. EDS spectrum of the wastewater sludge.

Weibull distribution

Weibull distribution analysis was performed to determine the probability of survival after compression or the reliability of the concrete blocks. Values of the compressive strength of ten lightweight concrete blocks subjected to curing in water for 7 days were used in the analysis.

Weibull plot generally represents the relationship between $\ln(x)$ and $\ln(-\ln(1-F(x)))$, with $F(x)$ denotes the cumulative probability density of failure, according to the following Equation (1):

$$F(x) = \frac{i-0.3}{i-0.4} \quad (1)$$

where i is rank of ascending order (smallest to largest) of compressive strength value, and n is total number of data points. From the Weibull plot, scale (α) can be calculated from exponential of intercept divided by slope (β), as shown in Equation (2):

$$\text{Scale } (\alpha) = e^{\left(\frac{\text{Intercept}}{\text{Slope}}\right)} \quad (2)$$

The reliability or probability of survival can be calculated using the following Equation (3):

$$R = e^{-\left(\frac{x}{\alpha}\right)^\beta} \quad (3)$$

where R is probability of survival, x is the compressive strength, β is slope of Weibull plot (Weibull modulus), and α is scale parameter.

Results and Discussion

Characteristics of wastewater sludge

1. Microstructure of sludge

Functioning as a filler, wastewater sludge was added to the concrete blocks to partially fill the voids between sands and cement matrix, which may consequently diminish problems related to disintegration among concrete components. The morphology and size of the filler generally affect the filler function. Therefore, dry wastewater sludge was examined using SEM. The scanning electron micrograph, shown in Figure 1, revealed irregular-shaped particles with average particle size of $5.5 \pm 6.5 \mu\text{m}$. A wide distribution of particle sizes was observed, with the majority of the particle sizes in the range $1.1-9 \mu\text{m}$ was also observed, as shown in Figure 2.

2. Chemical composition of sludge

The chemical composition of the dry wastewater sludge was analyzed using EDS, as shown in Figure 3. The results indicated a high content of organic matter, with average carbon (C)

Table 2. Chemical composition of wastewater sludge.

Chemical elements	Content of chemical element in sludge (mass%)			
	Point 1	Point 2	Point 3	Average
Organic matter				
C	25.24	22.39	79.59	42.41±32.2
O	33.31	45.17	18.13	32.20±136
Heavy metals				
As	-	-	-	-
Cd	-	-	-	-
Cr	0.67	0.77	-	0.72±0.4
Cu	2.52	2.12	0.47	1.70±1.1
Hg	-	-	-	-
Ni	5.01	6.59	0.43	4.01±3.2
Pb	-	-	-	-
Zn	2.12	1.19	-	1.66±1.1
Other elements	31.14	21.79	1.39	20.76±15.2

and oxygen (O) content of 42.41 and 32.20 mass% of total sludge, respectively. As organic compounds constitute the main composition of sewage sludge, similar observations regarding high organic matter in sludge have been reported (Tao *et al.*, 2012; Werle and Dudziak, 2014).

Examination of the hazardous element content in wastewater sludge was conducted, with the presence of heavy metals, specifically As, Cd, Cr, Cu, Hg, Ni, Pb and Zn, being examined using EDS. The results revealed the contents of Cr, Ni, Cu, and Zn were 0.72, 4.01, 1.70, and 1.66 mass%, respectively. However, As, Cd, Hg and Pb were not detected in this study, as shown in Table 2.

Characteristics of rice husk ash

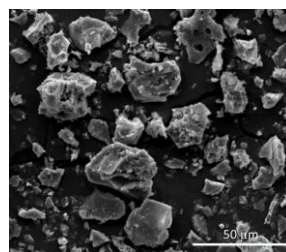
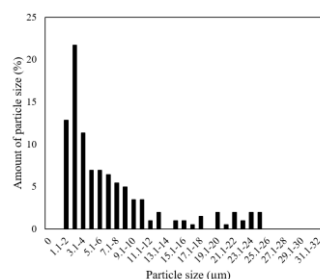
1. Microstructure of rice husk ash

It has been extensively reported that rice husk ash (RHA) contains a high content of silica that has been attributed to high pozzolanic activity between calcium hydroxide and the RHA in the concrete that potentially contributes to strength enhancement, as a fine particle size of the RHA is generally desired (Rêgo *et al.*, 2014; Aulakh *et al.*, 2017). The microstructural examination of RHA was conducted using SEM. Figure 4 shown the morphology of RHA was a porous irregular-shaped structure after ball milling for 2 hours. The particles size analysis of RHA indicates wide distribution of particle size, with the averages size of $7.1 \pm 6.4 \mu\text{m}$, as shown in Figure 5.

2. Chemical composition of rice husk ash

Rice husk ash (RHA) is a well-known pozzolanic material, having a high content of silica. Thus, determination of chemical composition of RHA is essential. Based on XRF, the RHA used in this study had a silica (SiO_2) content as high as 95.17%, as shown in Table 3. This result was in a comparable range with numerous studies, which reported that RHA contains silica in range 80-98%

(Hossain, 2003; Rashid *et al.*, 2010; Yuvakkumar *et al.*, 2014; Barkar *et al.*, 2016; França *et al.*, 2017; Chandeng *et al.*, 2020).

**Figure 4. Morphology of rice husk ash (RHA).****Figure 5. Size distribution of rice husk ash (RHA) particles.****Table 3. Chemical composition of wastewater sludge.**

Chemical elements	Chemical composition (mass%)
SiO_2	95.17
K_2O	2.32
CaO	0.90
P_2O_5	0.47
MgO	0.41
Al_2O_3	0.15
Na_2O	0.14
MnO	0.13
SO_3	0.12
Cl	0.10
Fe_2O_3	0.08
TiO_2	0.02

Effects of sludge and rice husk ash contents on physical and mechanical property of lightweight concrete blocks

1. Microstructure of lightweight concrete blocks

The microstructural examination of lightweight concrete block containing sand, ordinary Portland cement, sludge and RHA was conducted using SEM. In general, hardened cement mainly consists of mineral phase such as Portlandite ($\text{Ca}(\text{OH})_2$), calcium aluminate hydrate, and calcium silicate hydrate (C-S-H) (Scrivener *et al.*, 2016), which play a role in enhancing the compressive strength in cement.

The C-S-H phase can be evident as flock-like and fibrous-like agglomerates (Cizer *et al.*, 2020). SEM micrographs, as shown in Figure 6, demonstrate presence of fibrous-like agglomerates C-S-H. Figure 6(a) indicates that the lightweight concrete block without any sludge content had the greatest amount of the C-S-H phase, whereas a decrease in the C-S-H phase was evident in the concrete blocks with higher contents of sludge, as shown in Figure 6(f).

With a higher content of sludge, the RHA component in the concrete blocks was minimal. RHA is the initial reagent for the pozzolanic reaction, which promotes the formation of the

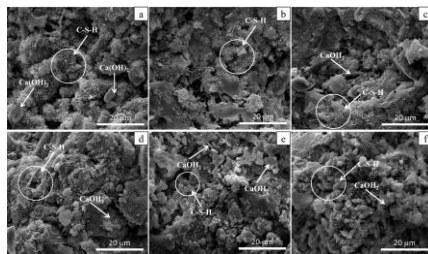


Figure 6. Microstructure of lightweight concrete blocks with sludge containing a) no wastewater sludge, b) 10 wt% of sludge, c) 15 wt% of sludge, d) 20 wt% of sludge, e) 25 wt% of sludge, and f) 30 wt% of sludge.

strengthening phase in the cement matrix (Wang *et al.*, 2019). With a low content of the RHA and the C-S-H phase, the addition of a high sludge content may have an adverse effect on the strength of the concrete blocks. The effects of sludge content on compressive strength of the concrete blocks are discussed in a subsequent section.

2. Evaluation of hazardous elements in lightweight concrete block containing sludge

As shown in Table 2, dry wastewater sludge contained some heavy metal elements which might be toxic to human health and vital organs such as lung, liver, kidney, and brain (Bandow *et al.*, 2018). In addition, heavy metals can be environmental pollutants. To ensure safety in utilization, hazardous elements in the concrete blocks containing various contents of sludge were evaluated using EDS.

As shown in Table 4, the results from EDS revealed that the concrete blocks consisting of wastewater sludge contained heavy metals in the amount of less than 200 ppm. The upper limit for hazardous element such as As, Cr, Cu and Pb in construction materials is a concentration lower than 1,000 ppm, while for Cd, Hg, Ni and Zn, the concentration should not exceed 2,500 ppm (Wahlström *et al.*, 2019). From the EDS results, the lightweight concrete blocks containing 10, 15, 20, 25 and 30 wt% wastewater sludge contained levels of heavy metals that were lower than the upper hazardous limit. Therefore, the results suggested that wastewater sludge in amounts not exceeding 30 wt% could be used as a filler in the fabrication of lightweight concrete blocks without creating substantial adverse effects on human health.

3. Bulk density

The results regarding bulk density of the lightweight concrete blocks containing wastewater sludge and RHA indicated that the bulk density slightly decreased from 1.6 mg/cm^3 to 1.4 mg/cm^3 as the sludge content increased, as shown in Figure 7. Notably, all concrete blocks had density values in the acceptable range defined by TISI 2601-2556 Type C16. (Alqedra *et al.*, 2011; Rabie *et al.*,

Table 4. Chemical composition of lightweight concrete blocks with various contents of sludge.

Content of sludge	0 wt%	10 wt%	15 wt%	20 wt%	25 wt%	30 wt%	Hazardous limit* (ppm)
Heavy metals	Content of heavy metal element (ppm)						-
As	-	-	-	28	25	-	<1,000
Cd	-	-	-	-	-	-	<2,500
Cr	-	9	13	-	11	14	<1,000
Cu	-	31	-	-	50	36	<1,000
Hg	-	-	-	-	-	-	<2,500
Ni	-	84	75	92	135	117	<2,500
Pb	-	-	-	-	-	-	<1,000
Zn	-	-	-	-	35	32	<2,500
Other elements (mass%)	100	98.77	99.12	98.86	97.67	98.01	-

2019) also reported that the addition of sludge in concrete resulted in a decrease in the bulk density.

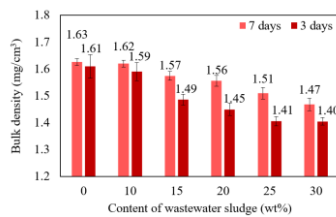


Figure 7. Effect of sludge content on bulk density of lightweight concrete block after curing in water for 3 and 7 days and autoclaving 6 h.

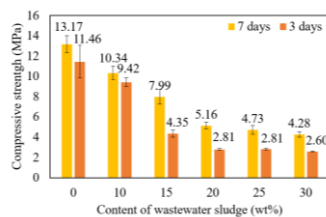


Figure 8. Effect of sludge content on compressive strength of lightweight concrete block after curing in water for 3 and 7 days and autoclaving 6 h.

4. Compressive strength

The compressive strength of lightweight concrete specimens was examined after curing in water for 3 and 7 days, and autoclaving for 6 h. The results indicated that compressive strength of lightweight concrete blocks decreased as a result of increasing the sludge content, as shown in Figure 8. Similar observations were also reported in several studies (Alqedra *et al.*, 2011; Nagar and Bhargava, 2016; Jamshidi *et al.*, 2012). Effects of prolong curing period on compressive strength was

also evident. Lightweight concrete blocks curing for 7 days exhibited the greater compressive strength than those subjected to curing for 3 days.

Weibull distribution analysis

Weibull analysis was used to assess the reliability of the concrete blocks containing various contents of wastewater sludge when subjected to compressive strength. The compressive strength data, shown in Table 5, were analyzed using a two-parameter Weibull distribution.

Figure 9 presents the Weibull plots of the compressive strength of the concrete's blocks with different contents of wastewater sludge. The plots representing $\ln(x)$ and $\ln(-\ln(1-F(x)))$ indicated good linearity, with high R^2 coefficient values (0.91-0.99). A summary of important Weibull parameters is shown in Table 6.

To meet the standard requirement of construction material (TISI standard) Type C16 for

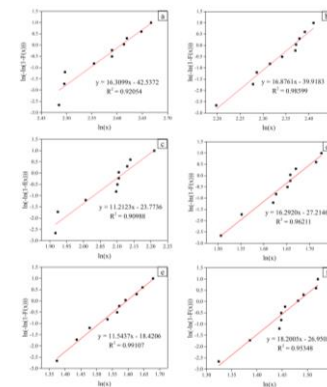


Figure 9. Weibull distribution plots for compressive strength of lightweight concrete blocks with sludge contains at a) 0 wt% b) 10 wt%, c) 15 wt%, d) 20 wt%, e) 25 wt%, and f) 30 wt%

Table 5. Compressive strength results of lightweight concrete blocks with various content of sludge at 7 curing in water.

Specimen No.	Compressive strength (MPa)					
	0 wt%	10 wt%	15 wt%	20 wt%	25 wt%	30 wt%
1	12.00	9.01	6.80	4.51	3.95	3.76
2	12.13	9.76	6.85	4.72	4.21	4.00
3	12.14	9.84	7.44	5.06	4.38	4.24
4	12.86	10.13	8.14	5.09	4.64	4.26
5	13.33	10.40	8.18	5.22	4.78	4.26
6	13.33	10.70	8.21	5.25	4.82	4.29
7	13.65	10.72	8.21	5.25	4.91	4.40
8	13.73	10.80	8.42	5.31	5.09	4.45
9	14.13	10.93	8.50	5.55	5.18	4.56
10	14.40	11.14	9.12	5.62	5.36	4.58
Average	13.17	10.34	7.99	5.16	4.73	4.28
Standard deviation	0.86	0.66	0.74	0.34	0.44	0.25
TISI (Type C16)	13.17>5 MPa	10.34>5 MPa	7.99>5 MPa	5.16>5 MPa	4.73<5 MPa	4.28<5 MPa
Compressive strength>5 MPa						

Table 6. Weibull distribution analysis of lightweight concrete block with content of sludge.

Content of sludge	Identical data analysis of Weibull distribution			
	Slope (β)	Intercept	Linear coefficient (R^2)	Scale (α)
0 wt%	16.30990	42.53720	0.92054	13.5727
10 wt%	16.87610	39.91830	0.98599	10.64803
15 wt%	11.21230	23.77360	0.90988	8.333756
20 wt%	16.29200	27.21460	0.96211	5.314438
25 wt%	11.54370	18.42060	0.99107	4.931916
30 wt%	18.20050	26.95020	0.95348	4.396196

Table 7. Reliability analysis of lightweight concrete block with content of sludge.

Compressive strength	Reliability of compressive strength					
	Content of sludge					
	Control	10 wt%	15 wt%	20 wt%	25 wt%	30 wt%
1	1.00	1.00	1.00	1.00	1.00	1.00
2	1.00	1.00	1.00	1.00	1.00	1.00
3	1.00	1.00	1.00	1.00	1.00	1.00
4	1.00	1.00	1.00	0.99	0.91	0.84
5	1.00	1.00	1.00	0.69	0.31	0.00
6	1.00	1.00	0.98	0.00	0.00	0.00
7	1.00	1.00	0.87	0.00	0.00	0.00
8	1.00	0.99	0.53	0.00	0.00	0.00
9	1.00	0.94	0.09	0.00	0.00	0.00
10	0.99	0.71	0.00	0.00	0.00	0.00

Table 8. Compressive strength of lightweight concrete block of commercialized product and standard requirement in Thailand.

	Commercialized product (Quality Construction Products Public Co., LTD, 2021)	TISI standard Type C 16 (TISI 2601-2556, 2013)	This study
Compressive strength (MPa)	6	> 5	5-13

commercial applications, compressive strength of the concrete block must not be lower than 5 MPa, Reliability analysis of the concrete blocks was conducted, as shown in Table 7. The results indicated that probability of survival of all concrete blocks remained 1.00 when subjected to compressive test at 1-3 MPa.

For the compressive test at 5 MPa (according to the TISI standard), the concrete blocks containing sludge between 0-15 wt% had 100% survival rate. At the sludge content of 20 wt%, only 69% survived the test. The results confirmed that the increasing of sludge contents in lightweight concrete block led to decreasing in compressive strength and lower the survival probability. Therefore, in order to fabricate the lightweight concrete blocks which can pass the requirement for the industrial applications, the content of wastewater sludge in the concrete blocks should not exceed 15 wt%. The compressive strength obtained in this study was in an acceptable range when compared to those obtained from commercialized products and industrial standard, as summarized in Table 8. These results suggested that the lightweight concretes containing wastewater sludge could potentially be used as construction materials.

Conclusions

Lightweight concrete blocks consisting of wastewater sludge, RHA, sand, and OPC were successfully fabricated. The contents of hazardous elements were evaluated to evaluate the potential toxicity of the cement blocks. The results indicated that the levels of heavy metals were lower than the limit for hazardous elements in construction materials. Increasing the content of wastewater sludge decreased the compressive strength and bulk density. Nevertheless, the Weibull reliability analysis indicated that the concrete blocks containing wastewater sludge at amounts less than 20 wt% could provide excellent reliability and passed the compressive test requirements specified by TISI standard Type 16.

Acknowledgments

The ICE-Matter Consortium, AUN/SEED-Net scholarship provided financial support. Equipment support was received from the Department of Materials Engineering and the Department of Civil Engineering, Faculty of Engineering, Kasetsart

University, Bangkok, Thailand. Okuno-Auromex (Thailand) Co., Ltd and Dhebkaset Co., Ltd provided the main raw materials.

References

- Ahsan, M.B. and Hossain, Z. (2018). Use of rice husk ash (RHA) as a sustainable cementitious material for concrete construction. In: International Congress and Exhibition "Sustainable Civil Infrastructures: Innovative Infrastructure Geotechnology". Springer, Cham. p. 197-210.
- Alqedra, M., Arafa, M., Arafa, M., and Mattar, M. (2011). Influence of low and high organic wastewater sludge on physical and mechanical properties of concrete mixes. *J. Environ. Sci. Technol.*, 4(4):354-365.
- Aulakh, D.S., Singh, J. and Kumar, S., (2017). The effect of utilizing rice husk ash on some properties of concrete-a review. *Curr. World. Environ.*, 13(2):224-231
- Bakar, R.A., Yahya, R. and Gan, S.N., (2016). Production of high purity amorphous silica from rice husk. *Procedia Chem.*, 19(2016):189-195.
- Bandow, N., Gartner, S., Ilvonen, O., and Schoknecht, U. (2018). Evaluation of the impact of construction products on the environment by leaching of possibly hazardous substances. *Environ. Sci. Eur.*, 30(1):1-12.
- Chandeng, L., Meesak, T., Tuakta, C., Jirawattanasomkul, T., Ueda, T., and Jongprateep, O. (2020). Effects of water content on compressive strength of eco-friendly lightweight cement blocks using cement-like material prepared from agricultural wastes. *Chiang Mai J. Sci.*, 47(4):700-711.
- Cizer, Ö., Van Balen, K., Van Gemert, D., and Elsen, J. (2020). Carbonation and hydration of mortars with calcium hydroxide and calcium silicate binders. Taylor&Francis Group, London, UK. 11p.
- Foladori, P., Andreottola, G., and Ziglio, G. (2010). Sludge reduction technologies in wastewater treatment plants. IWA publishing. 368p.
- Food and Agriculture Organization of United Nations. (2016). Rice Market Monitor. Food and Agriculture Organization of United Nations, Rome, Italy. 19(1). 34p.
- França, A.A., Schultz, J., Borges, R., Wypych, F., and Mangrich, A.S. (2017). Rice husk ash as raw material for the synthesis of silicon and potassium slow-release fertilizer. *J. Braz. Chem. Soc.*, 28(11):2,211-2,217.
- Habeeb, G.A. and Mahmud, H.B. (2010). Study on properties of rice husk ash and its use as cement replacement material. *Mater. Res.*, 13(2):185-190.
- Habeeb, G.A. and Mahmud, H.B. (2010). Study on properties of rice husk ash and its use as cement replacement material. *Mater. Res.*, 13(2):185-190.
- Hossain, K.M.A., (2003). Blended cement using volcanic ash and pumice. *Cem Concr Res.*, 33(10):1,601-1,605.
- Jamshidi, M., Jamshidi A., and Mehrdadi, N. (2012). Application of sewage dry sludge in concrete mixtures. *Asian J. Civ. Eng.*, 13(3):369-379.
- Mateo-Sagasta, J., Raschid-Sally, L., and Thebo, A. (2015). Global wastewater and sludge production, treatment and use. In: *Wastewater Economic Asset in an Urbanizing World*. Drechsel, Pay.; Qadir, Manzoor.; Wichelns, D.; (eds.). Springer, NL, p. 15-38.
- Nagar, B., and Bhargava, V. (2016). Experimental study on effects of sludge waste in concrete. *Int. J. Eng. Sci. Res.*, 5(10):54-63.
- Quality Construction Products Public Co., LTD (Q-CON). (2021). Laboratory report. Bang Pa-In, Thailand. Available from: <https://qcon.co.th/en/lab-report>. Accessed date: March 25, 2021.
- Rabie, G.M. (2016). Using of wastewater, dry and wet sludge in the concrete mix. *J. Civil. Environ. Eng.*, 6(1):2165-784X.
- Rabie, G.M., Abd El-Halim, H., and Rozaik, E.H. (2019). Influence of using dry and wet wastewater sludge in concrete mix on its physical and mechanical properties. *Ain Shams Eng. J.*, 10(4):705-712.
- Rashid, M.H., Molla, M.K.A. and Ahmed, T.U. (2010). Durability of mortar in presence of rice husk ash. *Int. J. Environ. Eng.*, 4(7):176-179.
- Rêgo, J.H.S., Nepomuceno, A.A., Figueiredo, E.P., Hasparyk, N.P., and Borges, L.D. (2014). Effect of particle size of residual rice-husk ash in consumption of Ca(OH)₂. *J. Mater. Civ. Eng.*, 27(6):04014178.
- Scrivener, K., Snellings, R., and Lothenbach, B. (2016). A Practical Guide to Microstructural Analysis of Cementitious Materials (1st ed.). CRC Press, Taylor&Francis Group. FL, USA, 142p.
- Singh, B. (2018). 13-Rice husk ash. In: *Waste and Supplementary Cementitious Materials in Concrete*, Siddique, R. and Cachim, P. (eds.). Woodhead Publishing, MA, p. 417-460.
- Świerk, K., Bielicka, A., Bojanowska, I., and Maćkiewicz, Z., (2007). Investigation of heavy metals leaching from industrial wastewater sludge. *Pol. J. Environ. Stud.*, 16(3):447-451.
- Tao, J., Wu, S., Sun, L., Tan, X., Yu, S., and Zhang, Z. (2012). Composition of waste sludge from municipal wastewater treatment plant. *Procedia Environ. Sci.*, 12(2012):964-971.
- Thai Industrial Standards Institute 2,601-2,556. (2013). Cellular lightweight concrete blocks using preformed foam. Thai Industrial Standards Institute.
- Valls, S., Yagüe, A., Vázquez, E. and Mariscal, C. (2004). Physical and mechanical properties of concrete with added dry sludge from a sewage treatment plant. *Cem Concr Res.*, 34(12):2,203-2,208.
- Wahlström, M., Teittinen, T., Kaartinen, T. and van Cauwenberghe, L. (2019). Hazardous Substances in Construction Products and Materials: Parade. Best Practices For Pre-Demolition Audits Ensuring High Quality Raw Materials. EIT RawMaterials, 71p.
- Wang, H., Hu, L., Cao, P., Luo, B., Tang, J., Shi, F., Yu, J., Li, H., and Jin, K. (2019). The application of electrical parameters to reflect the hydration process of cement paste with rice husk ash. *Materials.*, 12(17):2,815.
- Werle, S. and Dudziak, M. (2014). Analysis of organic and inorganic contaminants in dried sewage sludge and by-products of dried sewage sludge gasification. *Energies.*, 7(1):462-476.
- Yagüe, A., Valls, S., Vázquez, E. and Albareda, F. (2005). Durability of concrete with addition of dry sludge from waste water treatment plants. *Cem Concr Res.*, 35(6):1,064-1,073.
- Yuvakkumar, R., Elango, V., Rajendran, V., and Kannan, N. (2014). High-purity nano silica powder from rice husk using a simple chemical method. *J. Exp. Nanosci.*, 9(3):272-281.
- Zerbino, R., Giaccio, G., and Isaia, G.C. (2011). Concrete incorporating rice-husk ash without processing. *Constr. Build. Mater.*, 25(1):371-378.