

PREPARATION OF LIGHTWEIGHT CONCRETE AND LIGHTWEIGHT AGGREGATE FROM BAGASSE ASH AND COCONUT SHELL ASH

Ornpiya Aungaticchart^{1,2}, Nithiwach Nawaukkaratharnant^{3,4}, and Thanakorn Wasanapiarnpong^{1,2,4,*}

Received: January 27, 2021; Revised: March 27, 2021; Accepted: March 28, 2021

Abstract

Biomass ash is a waste by-product of biomass power plants which use biomass as fuel to produce electricity. Bagasse and coconut shell ashes are two of the main biomass ashes in Thailand. Ash disposal requires large area of land and could have a negative impact on the environment. One method to manage biomass ash sustainably is to use it as raw material in lightweight aggregate production. Cold bonded pelletization (CBP) process is a forming method in which artificial aggregate is produced from waste powder via addition of bonding agent such as Portland cement on an angled rotary pan. This technique has several advantages over sintering method including lower production cost and energy consumption. This study investigates the utilization of bagasse ash and coconut shell ash to produce artificial lightweight aggregate and reports the properties of the artificial lightweight aggregate and compare them to those of expanded clay aggregate, a commercially available lightweight aggregate. Artificial lightweight aggregates with bulk density of 858 and 1,104 kg/m³ were produced successfully from bagasse ash and coconut shell ash respectively, using 10 wt% Portland cement as binder. The test results indicate that it is possible to produce cold-bonded lightweight aggregates from bagasse ash and coconut shell ash that have comparable compressive strength to that of commercial expanded clay aggregate. Additionally, the compressive strength of lightweight concrete containing cold-bonded lightweight aggregate produced from bagasse ash and coconut shell ash were found to be 21.70 MPa and 28.34 MPa, respectively.

Keywords: Biomass power plant ash, bagasse ash, coconut shell ash, cold bonded pelletization, lightweight aggregate

¹ Department of Materials Science, Faculty of Science, Chulalongkorn University, Phayathai Road, Pathumwan, Bangkok 10330, Thailand.

² Center of Excellence on Petrochemical and Materials Technology, 7th floor, Chulalongkorn University Research Building, Soi Chula 12, Phayathai Road, Pathumwan, Bangkok 10330, Thailand.

³ Metallurgy and Materials Science Research Institute, Chulalongkorn University, Bangkok, Thailand.

⁴ Water Resilient City Unit (WRCU), Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok, Thailand; E-mail: thanakorn.w@chula.ac.th, 6072890723@student.chula.ac.th

* Corresponding author

Introduction

In recent years, renewable energy sources such as biomass have gradually been replacing conventional fossil fuels for electricity production (Wang *et al.*, 2017). In 2017, around 7 billion tons of biomass worldwide was reported to have the potential to be converted to energy (Vassilev *et al.*, 2017). Nevertheless, the process of thermochemistry required to convert biomass fuel to energy does create a waste by-product namely biomass ash that could lead to environmental issues if not disposed of properly. Thailand is a developing country which relies heavily on its agricultural sector. As a result, agricultural waste such as bagasse and coconut shell are converted into biomass fuels, which consequently produce bagasse ash and coconut shell ash as waste by-products. Currently, considerable amount of biomass fly ash has to be disposed of in landfills and it is known that waste disposal by landfill can negatively impact the environment, economy, and society in the long term (Cheah and Ramli, 2011). Therefore, appropriate management of bagasse fly ash and coconut shell fly ash is of a particular concern. In addition, recent environmental legislations and high cost of landfill disposal have led to increased interest in the feasibility of utilizing these ashes in other industries (Tang *et al.*, 2017).

Attempts have been made to use bagasse ash as chemical fertilizers and soil amendment because this type of ash is alkaline and contains lime which can be used to counteract acidity in the soil (Thind *et al.*, 2012; Seleiman and Kheir, 2018). On the other hand, this may not be a sustainable application for bagasse fly ash and even coconut shell fly ash when the huge amount of ash generated each year is taken into account because there is insufficient demand for ash in fertilizer. Another way to manage these two types of biomass ash is to use them in construction industry. In Thailand, 34 million tons of Portland cement is used in concrete annually (Bank of Thailand, 2019). These numbers indicate a potential for bagasse fly ash and coconut shell fly ash to be managed sustainably via utilization as raw materials in construction industry.

Generally, there are two types of ash utilization in concrete: pozzolan for cement substitution and artificial aggregate for gravel or stone substitution. In the literature, there have been considerable amount of research done on the former with various types of ash and varying degree of success. Regarding the utilization of bagasse fly ash as pozzolanic material in concrete, it was that the pozzolanic activity depends greatly on particle size and chemical composition of the ash itself, meaning that the ash would need an additional step of

crushing for size reduction prior to actual application (Cordeiro *et al.*, 2008). Additionally, the cement paste was observed to require higher water content, potentially leading to reduction in concrete strength (Chusilp *et al.*, 2009). As for coconut shell fly ash, it was reported that around 20% reduction in compressive strength of concrete occurred when 25 wt% of cement was replaced with the fly ash (Joshua *et al.*, 2018). Typically, the substitution of cement with biomass ash beyond 20 wt% would result in reduction of mortar strength (Tangchirapat *et al.*, 2007).

On the other hand, it has previously been shown that as much as 95 wt% of ash could be used as raw materials for the preparation of artificial lightweight aggregate for gravel or stone substitution in concrete (Tang *et al.*, 2017; Narattha and Chaipanich, 2018). Another advantage of ash valorization in this manner is that size reduction of waste powder is not required. Preparation of artificial aggregate can be done either by heat treatment which is the sintering method (Lyra *et al.*, 2019), or by a room-temperature forming process called cold-bonded pelletization (Narattha and Chaipanich, 2018). Although the former has been proven to result in aggregates with low density and high strength, the latter does have several appealing benefits such as lower energy requirement and lower overall production costs (Gesoglu *et al.*, 2012a).

Cold-bonded pelletization is a forming method used to produce artificial lightweight aggregate in which waste powder is agglomerated into aggregate on a tilted rotating pan through addition of binder such as cement and water (Güneyisi *et al.*, 2012). Previous research in the literature showed that cold-bonded aggregate can be successfully prepared from various types of waste powder such as coal fly ash (Gesoglu *et al.*, 2007; Narattha and Chaipanich, 2018), coal bottom ash (Kim *et al.*, 2016), and municipal waste ash (Colangelo *et al.*, 2015; Tang *et al.*, 2017). However, despite extensive research done on cold-bonded pelletization of other types of waste powder, research on cold-bonded pelletized biomass ash is not yet explored nor well established.

Hence, the main purpose of this work was to investigate the recycling of bagasse fly ash and coconut shell fly ash as raw materials for production of artificial lightweight aggregates through cold-bonded pelletization process. Properties of the artificial aggregates such as bulk density, single pellet crushing strength, and water absorption were measured and compared to those of commercially available expanded clay aggregate, which is the aggregate used as reinforcement in lightweight

concrete wall panel. Application of the prepared aggregates as stone replacement in lightweight concrete was also evaluated.

Materials and Methods

Raw Materials and Characterization

Two types of biomass fly ash were collected from different sources. Bagasse fly ash (B-FA) was obtained from a sugar cane mill owned by Mitr Phol Group located in Kanchanaburi, Thailand. Coconut shell fly ash (C-FA) was obtained from a biomass power plant owned by Mahachai Green Power Co., Ltd. located in Samut Sakhon, Thailand. The collected fly ashes were screened through a 100-mesh sieve prior to application in this study. Portland cement type I (PC) was used as a binder.

The chemical composition and crystalline phases of the raw materials were determined by X-ray Fluorescence (XRF) and X-ray Diffraction (XRD, Cu-K α source, 10-80 2 θ °, 0.02 step size, 0.5 sec step time) respectively. Microstructure of B-FA and C-FA was investigated using Scanning Electron Microscopy (SEM). Particle size distribution (PSD) was determined using laser diffraction (Mastersizer 2000, Malvern). Loose bulk density of the fly ashes was measured according to ASTM D7481. Strength Activity Index (SAI), which is the ratio of the strength of FA-containing cement mortar to the strength of control cement mortar of the same curing time, was measured according to ASTM C331 to determine the pozzolanic activity of the ashes.

Table 1 shows the chemical composition of B-FA, C-FA, and PC. The main components of B-FA were found to be silica (56.56%), and alumina (11.52%), while loss on ignition (LOI) is 17.27%. The main components of C-FA were calcium oxide (26.86%), and silica (23.56%), while LOI was higher than the former at 31.34%. Similarly, PC was mainly composed of calcium oxide (62.06%), and silica (15.42%) with lower LOI value of 7.62%. Figure 1 presents the main crystalline phases of B-FA which were quartz, calcite, and calcium silicate oxide. The main crystalline phases of C-FA were quartz, cristobalite, calcite, calcium silicate oxide, and akermanite. Particle size distribution of the raw materials is shown in Figure 2. As can be seen from Figure 2(a), both B-FA and C-FA appeared to have a monodisperse particle size distribution with d_{50} of 36.26 μm and 28.77 μm respectively. Cumulative particle size distribution of the raw materials is provided in Figure 2(b). SEM micrographs in Figure 3 also supported the result. Irregular particle shape with rough surface and porous structure could also be observed for both

types of biomass ash from the SEM micrographs. Loose bulk density of B-FA was found to be 255 kg/m³, while that of C-FA was almost double at 486 kg/m³. SAI of B-FA and C-FA were found to be comparable at 45.38% and 43.29% respectively.

Cold-Bonded Lightweight Aggregate Production and Characterization

Cold-bonded lightweight aggregate production Two types of artificial lightweight aggregate, one

Table 1. Chemical composition of raw materials

Chemical composition (wt%)	Bagasse fly ash (B-FA)	Coconut shell fly ash (C-FA)	Portland cement type I (PC)
CaO	2.50	26.86	62.06
SiO ₂	56.56	23.56	15.42
Fe ₂ O ₃	3.46	1.98	2.95
Al ₂ O ₃	11.52	1.89	4.34
SO ₃	0.45	0.73	4.39
MgO	1.42	3.94	1.77
K ₂ O	4.38	6.39	0.50
P ₂ O ₅	2.18	1.85	0.067
Others	1.47	0.27	0.88
LOI	17.27	31.34	7.62

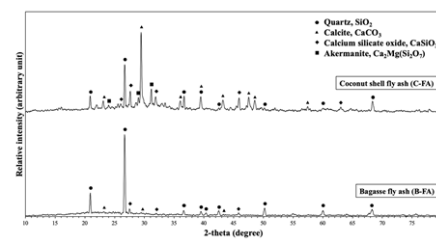


Figure 1. XRD patterns of B-FA and C-FA

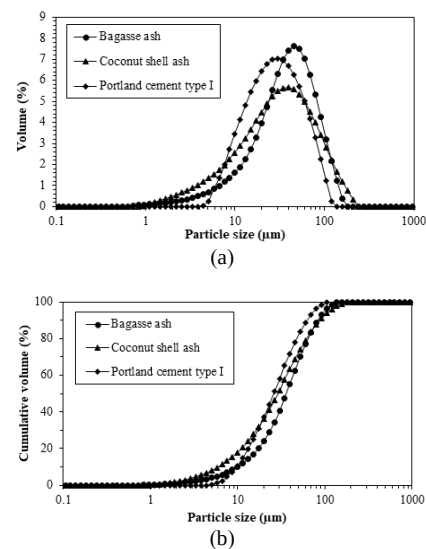


Figure 2. (a) Particle size distribution and (b) cumulative particle size distribution of raw materials

containing B-FA and the other C-FA, were produced by cold-bonded pelletization method using PC as binder. The process is shown in Figure 4. Samples were prepared with 10 wt% binder and 90 wt% biomass fly ash. The percentage of binder was optimum at 10% and was selected with reference to other literatures (Tang *et al.*, 2017; Narattha and Chaipanich, 2018). Firstly, powdered raw materials were mixed in a concrete mixer for 10 min to obtain homogeneity and then added to the disc pelletizer. Water was sprayed onto the rotating pan during the first 5 min of rotation to generate aggregate nuclei. The disc was later run for another 10 min to facilitate aggregate generation and compaction. The produced aggregates were collected and kept in a plastic container with 100% relative humidity at room temperature for 7 days and subsequently cured in water for strength development for another 21 days.

Cold-Bonded Lightweight Aggregate

B-FA and C-FA artificial aggregates aged 7 and 28 days were collected for testing. Bulk density and water absorption were measured according to ASTM C127. Single pellet crushing strength was measured according to ASTM D1479 in a set-up similar to, (Gesoglu *et al.*, 2007; Gesoglu *et al.*, 2012b; Tang *et al.*, 2017), in which 45 pellets were selected as samples and the maximum load was taken as pellet strength. The result was then compared to that of expanded clay aggregate, which is a commercially available artificial aggregate used as reinforcement in non-load-bearing lightweight concrete wall panel production. X-ray s Diffractometry was used to observe crystalline phases in the aggregate. Scanning Electron Microscopy (SEM) was also employed to study the microstructure of artificial aggregate fracture surfaces.

Application of the Produced Cold-Bonded Lightweight Aggregate in Concrete

The prepared artificial lightweight aggregates were used in concrete as 100% substitution for expanded clay aggregate. 5×5×5 cm³ concrete cubes were casted with the formulations presented in

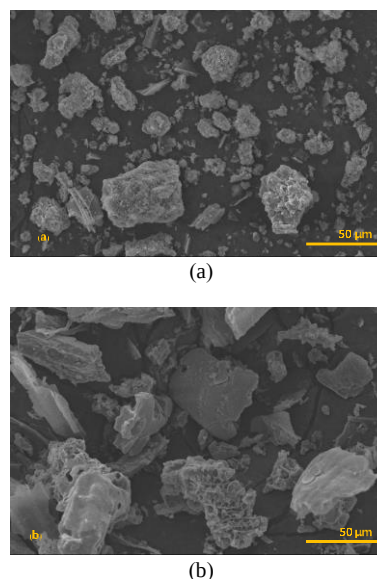


Figure 3. SEM micrographs of (a) B-FA and (b) C-FA

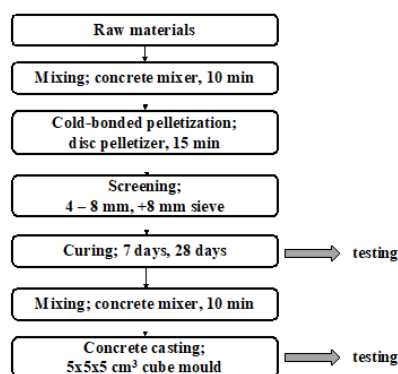


Figure 4. Artificial aggregate forming and concrete casting procedure

Table 2. Control samples were prepared with the formulation used for production of lightweight concrete wall panel. As for concrete samples containing B-FA aggregate and C-FA aggregate, the volume of aggregate substitution was kept constant at 0.467 m³ per cubic meter of concrete. The water/cement ratio implemented was 0.5. After

Table 2. Lightweight concrete formulations per cubic meter of concrete

[illegible]

Aggregate volume kept constant at 0.467 m³, w/c = 0.5

7 and 28 days, concrete samples were tested for bulk density and compressive strength according to ASTM C127 and ASTM C109, respectively.

Results and Discussion

Cold-Bonded Lightweight Aggregate Characterization

The prepared bagasse fly ash and coconut shell fly ash aggregates are shown in Figures 5(a) and 5(b). The diameter of the artificial aggregate produced ranged from 4.0 mm to 16.0 mm, which was comparable to that of other cold-bonded aggregates reported in the literature (Gesoglu *et al.*, 2007, 2012b; Tang *et al.*, 2017; Narattha and Chaipanich, 2018). The bulk density of 4-8 mm B-FA aggregate was found to be 858 kg/m³, while that of +8 mm aggregate was lower at 653 kg/m³. C-FA aggregate was found to be heavier with the density of 1,104 kg/m³ for 4-8 mm aggregate and 832 kg/m³ for +8 mm aggregate. It is possible that the enhanced density of C-FA aggregate when compared to B-FA aggregate was due to its smaller ash particle size, resulting in higher compaction during the pelletizing process. Having loose bulk densities lower than 1,200 kg/m³, the cold-bonded aggregates produced in this study could be classified as lightweight aggregate according to EN 13055-1.

The prepared B-FA and C-FA artificial cold-bonded aggregate were 24.5% and 60.2% heavier when compared to the control sample shown in Figure 5(c), which had the bulk density of 689 kg/m³. This is to be expected since the volume of expanded clay aggregate mostly consists of void and pores. In addition, B-FA artificial aggregate prepared in this study was lighter than most cold-bonded aggregates produced in a similar manner, which are 1,765 kg/m³ (Narattha and Chaipanich, 2018), 980 kg/m³ (Tang *et al.*, 2017), 835-927 kg/m³ (Tang and Brouwers, 2017), etc. The observed lower aggregate bulk density could be attributed to the physical properties of biomass ashes, which had lower loose bulk density when compared to other types of fly ashes as well as the irregular particle shape and porous microstructure.

The water absorption of B-FA aggregate after having been cured for 28 days was 26.89%, while that of C-FA aggregate was significantly lower at 17.87%. The different water absorption values of these two types of aggregate could be traced back to their bulk densities. As water absorption is inversely related to the porosity in the aggregate matrix, the higher compacity and density of C-FA resulted in its possessing lower water absorption value than B-FA aggregate. Therefore, the water absorption results agreed with the bulk density values reported earlier.

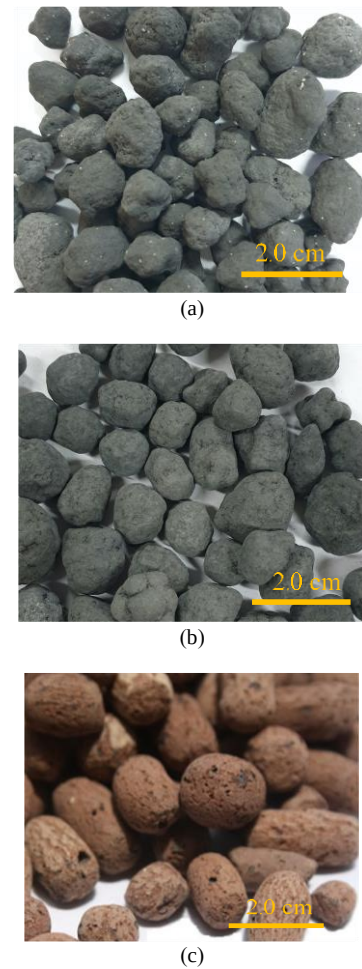


Figure 5. (a) Cold-bonded bagasse fly ash aggregate (b) cold-bonded coconut shell fly ash aggregate and (c) expanded clay aggregate

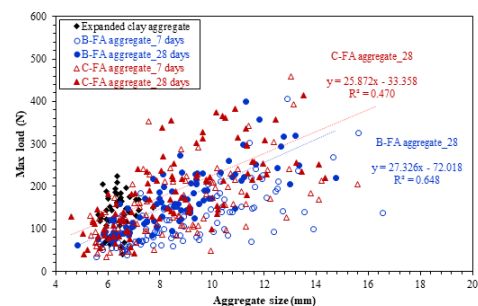


Figure 6. Individual pellet strength of produced aggregates

B-FA had higher water absorption while C-FA had lower water absorption when compared to other cold-bonded artificial aggregates in the literature, which are 21.2% (Güneyisi *et al.*, 2015) and 18.7-21.2% (Thomas and Harilal, 2015).

The strength of individual aggregates with different curing time and that of control sample expanded clay aggregate is presented in Figure 6. The strength of the produced aggregate varied with aggregate size, ranging from 61.33-399.1 N for B-FA aggregate and 40.49-414.29 N for C-FA aggregate. Overall, C-FA aggregate appeared to have slightly higher individual pellet crushing strength than B-FA aggregate did, despite having similar Strength Activity Index (SAI) values, indicating similar degree of pozzolanic activity. This result could be explained by the fact that the chemical composition of C-FA contained higher percentage of CaO. It can also be seen from the graph that aggregate strength increases with increasing aggregate size. Additionally, there is an increase of strength with longer curing time. These two findings agree with previous research (Gesoğlu *et al.*, 2007, 2012b; Tang *et al.*, 2017). Considering the strength of 7 and 28-day-cured aggregate, it can be observed that there is only a slight increase in strength with increasing curing time. This result implies that both types of aggregate could be ready for application as soon as 7 days after having been formed. Moreover, the individual strength of both 7 and 28-day-cured aggregate was found to be comparable to that of expanded clay aggregate of the same size range. This indicates feasibility of fully replacing expanded clay aggregate which has higher production cost than the produced cold-bonded lightweight aggregate.

In other studies, it has been reported that the amount of binder plays significant role on the strength of aggregate and that the strength of the pellet comes from binder (Gesoğlu *et al.*, 2012b; Tang *et al.*, 2017). In the present study, despite having added the same amount of cement binder, the maximum strength of lightweight aggregate was found to be higher than some others produced with different ashes such as 310 N, thermal power plant ash (Gesoğlu *et al.*, 2007), 127 N, class F fly ash (Güneyisi *et al.*, 2013), etc. Nevertheless, there have been aggregates produced with other types of ashes that reported higher individual pellet strength such

as 650 N, municipal waste bottom ash (Tang *et al.*, 2017), and 820 N, Class F fly ash (Gesoğlu *et al.*, 2012b). An implication of this is the possibility that the types of ash did play a role in strength development of aggregate. Considering the fact that the fly ashes utilized in this study had considerably low SAI values, it could be assumed that there had been little pozzolanic activity that occurred due to the presence of fly ash in the aggregate matrix. This suggests that an increase of SAI value of ashes could increase the product of pozzolanic activity which are calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H) and could possibly help strengthen the lightweight aggregate.

The results obtained from XRD analysis of the aggregates produced in this study are provided in Figure 7. As can be seen from the XRD pattern, similar crystalline phases were found in B-FA and C-FA artificial aggregates with varying degree of peak intensities. The aggregates contained quartz (SiO_2) and calcite (CaCO_3) from the fly ashes. Calcium silicate phases, which were CS, C_2S , and C_3S , resulting from the hydration reaction of Portland cement type 1 added as binder were also detected.

Scanning electron microscopy (SEM) was used to investigate the microstructure of the aggregate fracture surface of B-FA and C-FA. Figure 8(a). shows a 5,000x magnification micrograph of B-FA aggregate in which a multiphase microstructure could be observed. B-FA was seen scattered in the matrix and the space between

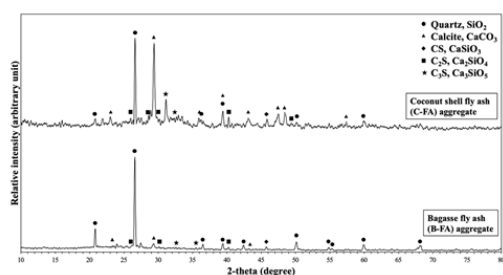


Figure 7. XRD patterns of B-FA and C-FA aggregates

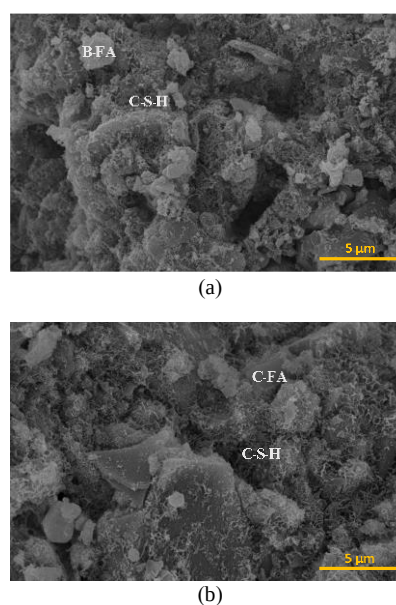


Figure 8. SEM micrographs of (a) B-FA aggregate fracture surface and (b) C-FA aggregate fracture surface

fly ash was connected mainly by C-S-H gel which was the product of cement hydration, resulting in refinement of pore and reduction of void and pore in the aggregate matrix. Similarly, in Figure 8(b). C-H-S gel phase could be observed dispersed throughout the surface, binding the C-FA particles together, reducing porosity, and giving strength to the aggregate. These micrographs were in agreement with the findings from XRD analysis and the assumption that there was some pozzolanic activity due the presence of fly ashes.

Application of the Produced Aggregate in Concrete

Concrete samples using B-FA aggregate as 100% lightweight aggregate substitution were found to have a bulk density of 1,740 kg/m³, whereas the ones with C-FA aggregate had a higher bulk density of 1,930 kg/m³. The former was 8.1% heavier while the latter was 19.9% heavier than the control concrete containing expanded clay aggregate, which had a bulk density of 1,610 kg/m³.

The compressive strength of 5×5×5 cm³ concrete cubes containing cold-bonded artificial lightweight aggregate, which is an average of three data values, is presented in Figure 9. The 7-day compressive strength of B-FA aggregate concrete was 13.15 MPa, which was 32.1% lower than that of control concrete containing expanded clay aggregate (19.87 MPa). On the other hand, the 7-day compressive strength of C-FA aggregate concrete was found to be significantly higher at 24.25 MPa, which was 22.0% higher than that of the control sample. The 28-day compressive strength of B-FA aggregate and C-FA aggregate concrete was 21.70 MPa and 28.34 MPa, respectively, which was 18.3% lower and 6.7% higher than that of the control concrete (26.56 MPa). Apart from individual pellet strength of the aggregate, another factor that could have an effect on the compressive strength of the concrete is the water absorption of the aggregate. The fact that C-FA aggregate had significantly lower water absorption than B-FA aggregate could be another reason why C-FA aggregate concrete had higher compressive strength than B-FA concrete. An increase in compressive strength after the concrete cubes had been cured was also observed for both B-FA and C-FA aggregate concretes. It can be seen from the bar chart that the concrete cubes containing cold-bonded C-FA lightweight aggregate produced in this study have both higher early and long-term strength than concrete cubes containing expanded clay aggregate.

Additionally, the compressive strength of C-FA aggregate concrete was found to be higher than those with similar percentage of aggregate replacement, but more cement content reported in

the literatures; 27.7 MPa (Tang *et al.*, 2017), 20-28 MPa (Ferone *et al.*, 2013), 21 MPa (Güneyisi *et al.*, 2015), etc. It has been reported that the application of cold-bonded lightweight aggregate as aggregate replacement in concrete is feasible (Gesoglu *et al.*, 2006; Güneyisi *et al.*, 2015) but with drawbacks such as decreased strength (Colangelo *et al.*, 2015; Thomas and Harilal, 2015). Nevertheless, it is shown in this study that concrete containing cold-bonded lightweight aggregate has superior strength than the concrete mixture containing expanded clay aggregate which is used for production of lightweight concrete wall panel. Hence, it could conceivably be concluded that the cold-bonded lightweight aggregate prepared in the present study performed better than other artificial aggregates and is suitable for application as reinforcement in lightweight concrete wall panel.

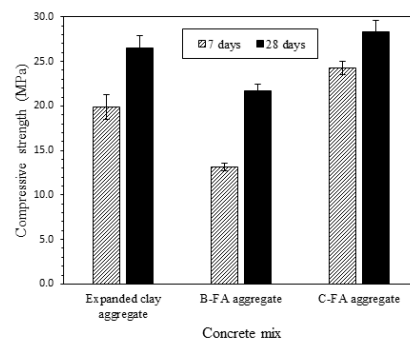


Figure 9. Compressive strength of lightweight concrete containing artificial aggregate

Conclusions

This paper investigated the utilization of bagasse fly ash and coconut shell fly ash to produce artificial lightweight aggregate through cold-bonded pelletization process. The following conclusions can be drawn from the results obtained in this study:

Bagasse fly ash and coconut shell fly ash are potential raw materials for artificial lightweight aggregate production by cold-bonded palletization process. 4-8 mm lightweight aggregates according to EN 13055-1 with loose bulk density of 858 kg/m³ and 1,104 kg/m³ were successfully prepared through recycling of bagasse fly ash and coconut shell fly ash.

The properties of coconut shell fly ash aggregate produced in this study was comparable to expanded clay aggregate, which is commercially used as reinforcement in lightweight concrete wall panel. The results suggest that it is possible to fully replace expanded clay aggregate with coconut shell fly ash aggregate, which has the benefits of lower

production cost and higher environmental sustainability.

Lightweight concrete containing coconut fly ash aggregate had the 28-day compressive strength of 28.34 MPa, which was higher than others with the same percentage of aggregate replacement, but more cement content reported in the literatures. It also had both higher early and long-term strength than lightweight concrete containing expanded clay aggregate.

Acknowledgments

The authors wish to gratefully thank the Center of Excellence on Petrochemical and Materials Technology for providing the scholarship and research funding of this work. The authors would like to also acknowledge the following companies for their sponsorship of materials: Mitr Phol Group, and Mahachai Green Power Co., Ltd.

References

- Cheah, C.B. and Ramli, M. (2011). The implementation of wood waste ash as a partial cement replacement material in the production of structural grade concrete and mortar: An overview. *Res. Conserv. Recy.*, 55(7):669-685.
- Chusilp, N., Jaturapitakkul, C., and Kiattikomol, K. (2009). Utilization of bagasse ash as a pozzolanic material in concrete. *Construc. Build. Mat.*, 23(11):3,352-3,358.
- Colangelo, F., Messina, F., and Cioffi, R. (2015). Recycling of MSWI fly ash by means of cementitious double step cold bonding pelletization: Technological assessment for the production of lightweight artificial aggregates. *J. Hazard. Mat.*, 299:181-191.
- Cordeiro, G.C., Toledo Filho, R.D., Tavares, L.M., and Fairbairn, E.M.R. (2008). Pozzolanic activity and filler effect of sugar cane bagasse ash in Portland cement and lime mortars. *Cement Concrete Comp.*, 30(5):410-418.
- Ferone, C., Colangelo, F., Messina, F., Iucolano, F., Liguori, B., and Cioffi, R. (2013). Coal combustion wastes reuse in low energy artificial aggregates manufacturing. *Mater.*, 6(11):5,000-5,015.
- Gesoğlu, M., Özturan, T., and Güneyisi, E. (2006). Effects of cold-bonded fly ash aggregate properties on the shrinkage cracking of lightweight concretes. *Cement Concrete Compos.*, 28(7):598-605.
- Gesoğlu, M., Özturan, T., and Güneyisi, E. (2007). Effects of fly ash properties on characteristics of cold-bonded fly ash lightweight aggregates. *Construc. Build. Mat.*, 21(9): 1,869-1,878.
- Gesoğlu, M., Güneyisi, E., and Öz, H. Ö. (2012a). Properties of lightweight aggregates produced with cold-bonding pelletization of fly ash and ground granulated blast furnace slag. *Mat. Struct.*, 45(10):1,535-1,546.
- Gesoğlu, M., Güneyisi, E., Mahmood, S.F., Öz, H.Ö., and Mermerdaş, K. (2012b). Recycling ground granulated blast furnace slag as cold bonded artificial aggregate partially used in self-compacting concrete. *J. Hazard. Mat.*, 235-236:352-358.
- Güneyisi, E., Gesoğlu, M., and Booya, E. (2012). Fresh properties of self-compacting cold bonded fly ash lightweight aggregate concrete with different mineral admixtures. *Mat. Struct.*, 45(12):1,849-1,859.
- Güneyisi, E., Gesoğlu, M., Pürsünlü, Ö., and Mermerdaş, K. (2013). Durability aspect of concretes composed of cold bonded and sintered fly ash lightweight aggregates. *Compos. B: Eng.*, 53:258-266.
- Güneyisi, E., Gesoğlu, M., Altan, İ., and Öz, H.Ö. (2015). Utilization of cold bonded fly ash lightweight fine aggregates as a partial substitution of natural fine aggregate in self-compacting mortars. *Construc. Build. Mat.*, 74:9-16.
- Joshua, O., Olusola, K.O., Busari, A.A., Omuh, I.O., Ogunde, A. O., Amusan, L.M., and Ezenduka, C.J. (2018). Data on the pozzolanic activity in coconut shell ash (CSA) for use in sustainable construction. *Data Brief.*, 18:1,142-1,145.
- Kim, H.K., Ha, K.A., and Lee, H.K. (2016). Internal-curing efficiency of cold-bonded coal bottom ash aggregate for high-strength mortar. *Construc. Build. Mat.*, 126:1-8.
- Lyra, G.P., dos Santos, V., De Santis, B.C., Rivaben, R.R., Fischer, C., Pallone, E.M.d.J.A., and Rossignolo, J.A. (2019). Reuse of sugarcane bagasse ash to produce a lightweight aggregate using microwave oven sintering. *Construc. Build. Mat.*, 222:222-228.
- Narattha, C. and Chaipanich, A. (2018). Phase characterizations, physical properties and strength of environment-friendly cold-bonded fly ash lightweight aggregates. *J. Clean. Produc.*, 171:1,094-1,100.
- Seleiman, M.F. and Kheir, A.M.S. (2018). Saline soil properties, quality and productivity of wheat grown with bagasse ash and thiourea in different climatic zones. *Chemosp.*, 193:538-546.
- Tang, P. and Brouwers, H.J.H. (2017). Integral recycling of municipal solid waste incineration (MSWI) bottom ash fines (0-2 mm) and industrial powder wastes by cold-bonding pelletization. *Waste Manage.*, 62:125-138.
- Tang, P., Florea, M.V.A., and Brouwers, H.J.H. (2017). Employing cold bonded pelletization to produce lightweight aggregates from incineration fine bottom ash. *J. Clean. Produc.*, 165:1,371-1,384.
- Tangchirapat, W., Saeting, T., Jaturapitakkul, C., Kiattikomol, K., and Siripanichgorn, A. (2007). Use of waste ash from palm oil industry in concrete. *Waste Manag.*, 27(1):81-88.
- Bank of Thailand. (2019). Bank of Thailand (Statistical Data) EC_EL_016_S2 Private Investment Indicators. Bangkok, Thailand.: Bank of Thailand. Available from: https://www.bot.or.th/App/BTWS_STAT/statistics/ReportPage.aspx?reportID=857&language=eng. Accessed date: 30 October 2019.
- Thind, H.S., Yadvinder, S., Bijay, S., Varinderpal, S., Sharma, S., Vashistha, M., and Singh, G. (2012). Land application of rice husk ash, bagasse ash and coal fly ash: Effects on crop productivity and nutrient uptake in rice-wheat system on an alkaline loamy sand. *Field Crops Res.*, 135:137-144.
- Thomas, J. and Harilal, B. (2015). Properties of cold bonded quarry dust coarse aggregates and its use in concrete. *Cement Concrete Compos.*, 62:67-75.
- Vassilev, S.V., Vassileva, C.G., Song, Y.-C., Li, W.-Y., and Feng, J. (2017). Ash contents and ash-forming elements of biomass and their significance for solid biofuel combustion. *Fuel.*, 208:377-409.
- Wang, P., Guo, Y., Zhao, C., Yan, J., and Lu, P. (2017). Biomass derived wood ash with amine modification for post-combustion CO₂ capture. *Appl. Ener.*, 201:34-44.