Compressive strength and thermal conductivity of concrete containing biochar and porous aggregate

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Abstract

This research aims to study the compressive strength and thermal conductivity of concrete containing rice husk biochar (RB), expanded clay aggregate (CA), and a combination of both RB and CA. The effect of the replacement percentage of biochar in the binder and porous aggregate in the coarse aggregate was investigated. Biochar was prepared by pyrolyzing in a furnace with a temperature of 550°C in steady-state for 8 hours. Water to cement binder was 0.50. The replacement percentage of biochar were 1%, 3%, and 5% by weight of the binder. The replacement of expanded clay aggregates was 50% by volume of coarse aggregate. The test results illustrated that the specimen containing 1% of biochar replacement showed the highest compressive strength as well as the optimum amount of biochar replacement with the binder. However, the compressive strength of the concrete decreased with the presence of expanded clay aggregate. The concrete containing biochar and expanded clay aggregate improved the thermal properties when compared with controlled concrete.

Keywords: biochar, expanded clay aggregate, porous aggregate, thermal conductivity, concrete

1. Introduction

Global warming is a massive problem that affects everyone around the world. One of the main factors is the greenhouse effect in which the rising of the daytime temperature can be observed even inside residential buildings. This increase in temperature also increases the demand for energy consumption. Such a consequence increases the amount of carbon dioxide generated during the production of electrical power accordingly. However, the amount of carbon dioxide employed by energy production is not the only problem causing the greenhouse effect; carbon dioxide released from the cement production industries is another problem. Therefore, the study on cement replacement as well as reducing cement consumption should be conducted with any suitable materials which can also reduce the thermal conductivity of concrete and energy consumption as well [1].

Biochar is chosen as a material to replace in binder according to its ability to improve concrete properties by having the nucleation effect from the negative charge of biochar particle that attracts the positively charged hydrated cement. This effect strengthens the compressive strength of concrete. Moreover, its tiny particle can fill the void between cement and sand grains to densify the concrete, in which higher compressive strength can be achieved. Some studies reported that there is a pore structure inside biochar particles that can absorb and retain water which is released gradually to allow further hydration reaction when needed (internal curing) [2, 3]. In addition, expanded clay aggregate was chosen in this study due to its lightweight which can reduce the dead load of the concrete structure and their disconnected and uniform pore structure inside its granules which improve the thermal properties of the concrete by decreasing the thermal conductivity of the concrete accordingly [4]. Therefore, this paper aims to investigate the compressive strength and thermal conductivity of concrete containing rice husk biochar, expanded clay aggregate, and a combination of both materials.

2. Experimental program

2.1 Material and mix proportion

Hydraulic cement type GU and biochar were used as a binder in this study. The chemical composition and physical properties of hydraulic cement type GU and biochar are shown in Table 1. The particle shape of biochar is shown in Fig. 1.

Table 1 Chemical compositions and physical properties of hydraulic cement type GU and biochar

Chemical composition, %	Cement type GU	Biochar
SiO_2	13.63	35.21
Al_2O_3	2.67	0.09
Fe_2O_3	3.31	0.22
CaO	66.21	0.46
MgO	1.12	0.33
Na_2O	0.31	0.04
K_2O	0.35	1.90
SO_3	1.91	0.19
Other oxides	3.7	1.30
Loss on ignition (LOI)	6.78	60.2
Physical properties		
Specific gravity	3.14	1.66
Specific surface area (m^2/kg)	2543	573.3

Biochar was prepared by the pyrolysis process at an elevated temperature of 550 °C in steady-state for 8 hours. Expanded clay aggregate was from Siamese Ecolite, as shown in Fig. 2.

The replacement percentages of biochar were 1%, 3%, and 5% by weight of the binder. The replacement percentage of expanded clay aggregate was 50% by volume of coarse aggregate. The water to binder ratio was 0.50. The tested mix proportions are shown in Table 2.

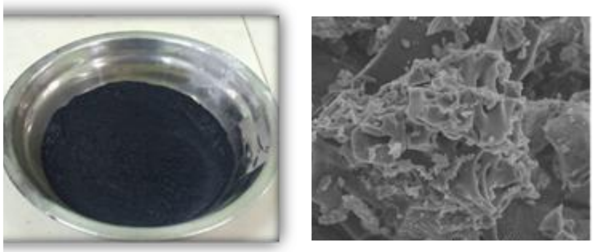
2.2 Test Methods

2.2.1 Compressive strength

Cubic specimens with the sizes of 100 mm were used. Compressive strength was measured at 7, 14 and 28 days of the age of concrete in accordance with the BS EN 12390-3 [5].

2.2.2 Thermal conductivity

The cubic sample was cut into 100 mm x 100 mm with a thickness of approximately 30 mm. Thermal conductivity was carried out using a hot disk thermal constant analyzer TPS 2500S instrument following the Transient Plane Source Method.



(a) (b)

Fig. 1 Biochar; (a) Powder and (b) SEM (x5000)

Fig. 2 Expanded clay aggregate

Table 2 Mix proportions of concrete

Mix id.	Mix proportion of concrete (kg/m^3)					
	Cement	Biochar	Water	Sand (SSD)	Rock (SSD)	CA (SSD)
NC	381	0	196.6	775.6	1025	0
CA50	381	0	196.6	775.6	512.6	171
NCRB1	376	3.8	189.9	775.6	1025	0
NCRB3	366	11.3	188.6	775.6	1025	0
NCRB5	356	18.7	187.3	775.6	1025	0
CA50RB1	376	3.8	189.9	775.6	512.6	171
CA50RB3	366	11.3	188.6	775.6	512.5	171
CA50RB5	356	18.7	187.3	775.6	512.6	171

Note: SSD is saturated surface dry, NC is normal concrete, NCRB1 is 1% by weight of biochar replacement in the binder of normal concrete, CA50RB1 is 1% by weight of biochar replacement in binder incorporate with 50% by volume of expanded clay aggregate replacement.

3. Results and discussion

3.1 Compressive strength

The result of a compressive strength test of the concrete sample containing biochar illustrates in Fig. 3. The replacement of biochar by weight of binder resulted in an improvement of the compressive strength when compared to that of biochar-free ones. In addition, 1% by weight of biochar replacement also resulted in the highest compressive strength which can be considered the optimum amount of the biochar replacement in the binder. This increase in compressive strength is because biochar is known to enhance the nucleation and growth of hydrates on their surface [2]. Fine particle of biochar densifies the voids between cement and sand grains, and their surface negative charges attract positive charges of hydrated cement around them. This generates a nucleation effect that enhanced hydration reaction in which the precipitation of hydration product

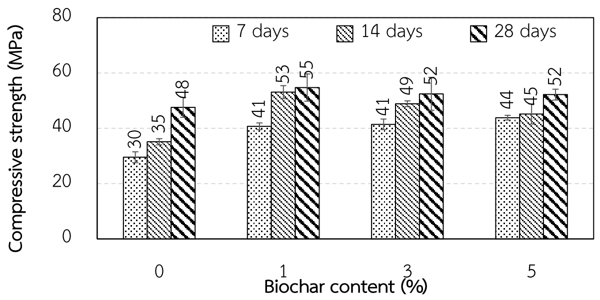


Fig. 3 Effect of biochar content on compressive strength

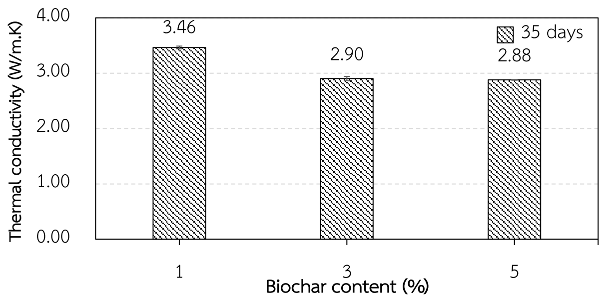


Fig. 6 Effect of biochar content on thermal conductivity

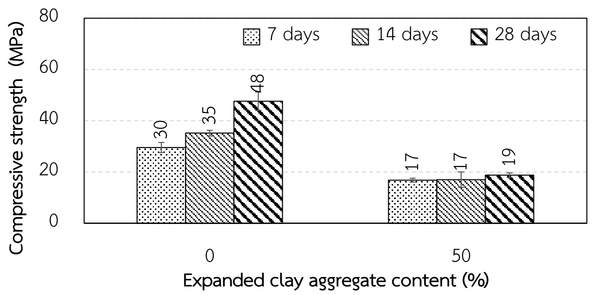


Fig. 4 Effect of expanded clay aggregate content on compressive strength

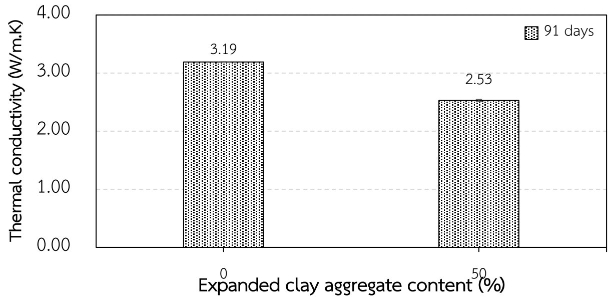


Fig.7 Effect of expanded clay aggregate content on thermal conductivity

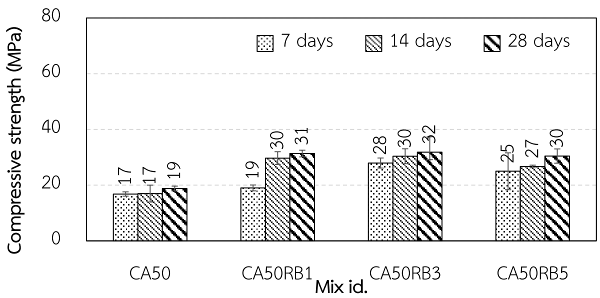


Fig. 5 Effect of biochar content with 50% of expanded clay aggregate replacement

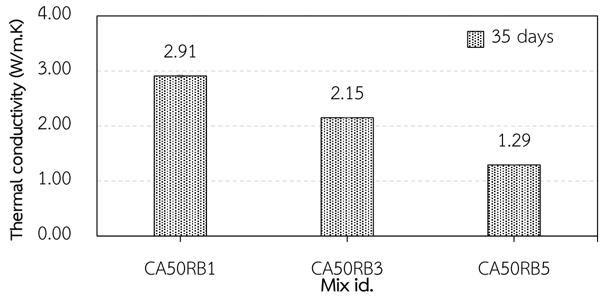


Fig. 8 Effect of biochar content with 50% of expanded clay aggregate on thermal conductivity

is in a cluster form. In terms of expanded clay aggregate, the compressive strength of the concrete decreased with the presence of expanded clay aggregate because of the pore structure inside the expanded clay aggregate granules. Moreover, with the combination of biochar and expanded clay aggregate, it shows that the nucleation effect of biochar influenced improving the compressive strength of concrete as shown in Fig.

3.2 Thermal conductivity

Thermal insulation plays an important role in decreasing the energy consumption of residences and therefore lesser greenhouse gases are released in the buildings with good thermal properties. The thermal conductivity of any material is a quantity of heat that can pass by a unit thickness in the direction perpendicular to the unit surface area because of the temperature gradient under the given condition [6]. As shown in Fig. 6, the thermal conductivity of concrete containing biochar decreases with a higher amount of biochar content. This indicates that the biochar has a positive effect on the insulating properties of the concrete. This decrease in thermal conductivity is due to the increased porosity of material as a result of using biochar in concrete, as well as the low thermal conductivity of biochar [7]. The effect of expanded clay aggregate content on thermal conductivity is shown in Fig. 7. It illustrates that the thermal conductivity of concrete decrease with the presence of expanded clay aggregate. This decrease in thermal conductivity can be from the increase of pore structure inside the expanded clay aggregate itself. Saygili and Baykal [8] also reported that an increase in the void ratio decreased the density of concrete which in turn lowered the thermal conductivity of the concrete. As air is the poorest conductor in comparison with the liquid and solids, it will contribute to the decrease in thermal conductivity of the concrete containing porous aggregate [9]. It follows that with the combination of biochar and expanded clay aggregate, the thermal conductivity decreases with a higher amount of biochar which is used in a combination with expanded clay aggregate as shown in Fig. 8. This decrease in thermal conductivity from the combination of both materials is because of the increase in the void inside the concrete as a result of the use of both porous materials such as biochar and expanded clay aggregate.

4. Conclusions

This study focuses on compressive strength and thermal conductivity to decrease the energy consumption from the residence and promote the use of green materials such as hydraulic cement type GU. The biochar, expanded clay aggregate, and the combination of both materials were used in this study. The following conclusions can be drawn from the experiment.

1. Compressive strength of concrete containing different levels of biochar content resulted in a higher compressive strength when compared to the controlled concrete. Moreover, 1% by weight of biochar replacement resulted in a higher compressive strength which can be considered as the optimum amount of biochar replacement in the binder.
2. Biochar has a positive effect on thermal conductivity in which a higher amount of biochar decreases the thermal conductivity of concrete.
3. The presence of the expanded clay aggregate reduced the thermal conductivity of the concrete as well as the compressive strength. However, the combination of biochar and expanded clay aggregate improved the compressive strength as well as decreased the thermal conductivity.
4. A concrete with the combination of both biochar and expanded clay aggregate, 1-5% of biochar replacement in the binder and 50% by volume of expanded clay aggregate replacement in coarse aggregate is applicable for the use of constructing basic concrete structures such as wall and roof deck slab due to its low thermal conductivity and normally compressive strength, in which are approximately 30MPa.
5. Biochar and expanded clay aggregate can be used as ingredients for concrete mixtures which require low thermal conductivity.

Acknowledgments

This work was financially supported by Burapha University and Thailand Science Research and Innovation (TSRI) (Grant no. 27/2565). The authors also thank the support from the Burapha Construction and Maintenance Technology Research Unit (BCONTEC) and the Construction Technology and Traffic Management (CONTRA), Burapha University, THAILAND.

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