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Geopolymer pervious concrete with recycled coal bottom ash (CBA) and ground granulated blast furnace (GGBF) slag in urban flooding solution

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KEYWORDS

Pervious concrete
Geopolymer
Coal bottom ash
Ground Granulated Blast furnace slag
Permeability
Porosity

ABSTRACT

Pervious concrete is known as a high content formation of open void to allow for fast drainage of water. The main compositions of pervious concrete are coarse aggregate and binder to obtain a high volume of hollow area. In this research, the coal bottom ash (CBA) is used as coarse aggregate in mix proportion. Ground Granulated Blast furnace (GBBF) slag is used geopolymer binder to replace cement in geopolymer pervious concrete (GPC). They are known as waste industrial materials from thermal power plant and steel factory. The characteristics of geopolymer pervious concrete in compressive strength, porosity and permeability are considered. The reaction between GGBF slag and CBA is investigated. The results are shown that compressive strength GPC is about 2 MPa to 8 MPa with CBA 5 mm to 10mm and can be higher about 30% to 40% with CBA 10 mm to 20 mm. The water permeability is about 0.7 cm/s to 1.8 cm/s to belong to CBA type.

1. Introduction

Climate change is more rapid than previously anticipated, causing cities to sink, and the current infrastructure of the city makes citizens even more vulnerable to severe flooding. Ho Chi Minh City (HCMC) is known as a big city in Vietnam and is vulnerable to flooding due to river overflow from high tides, heavy rains during the rainy season, and storm surges from extreme weather events. It causes increased localized flooding, and storm surges along the coastal areas of HCMC. Regular floods throughout the city cause traffic congestion, disruptions to daily business activities, and the chronic displacement of residents. Urban flooding mainly caused by rainfall overwhelming the capacity of drainage systems, such as storm sewers, affects HCMC in the environment, public health, economy, and traffic aspects. [1-4]

Pervious concrete (PC) is a sustainable solution for improving infrastructure in urban areas. The goal use of pervious concrete is to facilitate infiltration and make pavement drainage faster and easier. Pervious concrete is a new solution for sustainable urban street construction to significantly reduce rain, stormwater run-off, and flooding and has the benefit of being less energy-intensive. [5, 6]

Geopolymer pervious concrete (GPC) is an environmentally friendly concrete to mainly comprises alkali solution and geopolymer binder which has a large amount of aluminosilicates which is classified as non-toxic porous crystals. Coal bottom ash (CBA) is a component waste material that has been produced during the coal combustion produced by coal-generated power plants. The consumption of energy from coal-fired thermal power, which has also been revised to mitigate the effects of greenhouse gas emissions on climate change in the world. CBA is known as porous particle, angular and irregular in shape, which some of the particles are spherical and semi-spherical. [7-9].

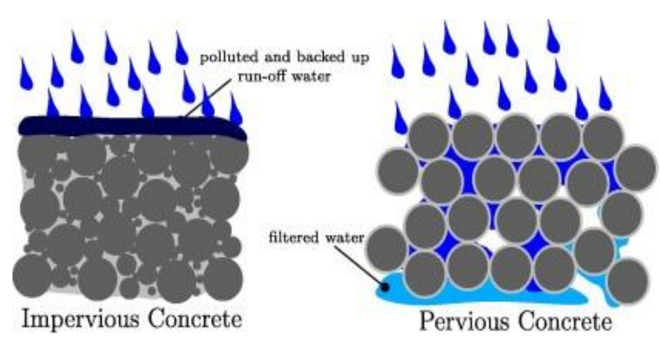

Figure 1. Comparison between pervious and impervious concrete on run-off water.

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Ground Granulated Blast furnace (GGBF) slag is known as waste materials which are high content of aluminosilicates. CBA and GGBF slag can be recycled for reuse and to produce new, innovative materials in the geopolymer materials.

In this research, CBA is used as aggregate in mix proportion of pervious concrete. The mixing between fly ash and GGBF slag is used as activated binder in geopolymerization. Hence, the relationship between strength and permeability of pervious concrete is considered.

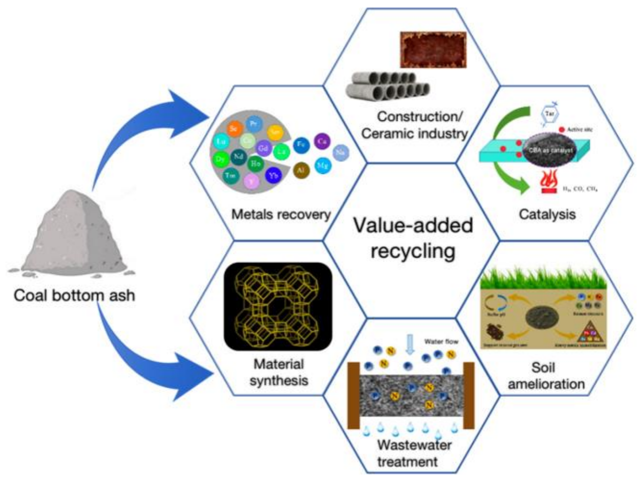

Figure 2. Coal bottom ash in recycled application [10].

2. Material and mix proportion

Coal Bottom Ash (CBA) in thermal power plant is used as coarse aggregate with 2 types such as 5 mm to 10 mm or 10 mm to 20 mm, respectively.

Ground Granulated Blast Furnace (GGBF) slag has specific gravity is 2.9 g/cm^3 to mix as geopolymer binder. The chemical composition is shown in Table 1.

The alkaline liquid is a combination of sodium silicate and sodium hydroxide in solution. The sodium silicate solution included Na_2O and SiO_2 about 36% to 38% is mixed to sodium hydroxide 10 Molar.

In the mix proportion of geopolymer pervious concrete, the ratio of alkaline liquid - GGBF slag in range from 0.3 to 0.7 by weight is used. The ratio of coarse aggregate – geopolymer binder is 1 to 5 by weight. Moreover, the coarse aggregates are used by CBA with size in range of 5 mm to10 mm and 10 mm to 20 mm, respectively. The mix proportions of geopolymer pervious concrete are shown in Table 2.

Table 1. Chemical compositions of GGBF Slag.

Oxide (%)	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	SO_3	$K_2O + Na_2O$	LOI
GGBF slag	30	12	40.9	7.4	0.21	1.98	1.17	6.34

LOI: Loss of Ignition

Table 2. Mix proportion of geopolymer pervious concrete.

Mix	CBA/B	AL/B	GGBF (kg)	CBA (kg)		AL (kg)	Porosity (%)	k (cm/s)	Strength (MPa)		
				5-10	10-20				60^{0}C	90^{0}C	120^{0}C
Mix 1A	5	0.3	300	1500	0	90	31.2	1.82	2.7	3.2	5.1
Mix 1B		0.4				120	29.1	1.61	3.2	3.8	7.2
Mix 1C		0.5				150	26.8	1.47	3.8	5.9	9.8
Mix 1D		0.6				180	22.5	1.25	5.1	7.2	11.3
Mix 1E		0.7				210	19.3	1.12	7.1	9.3	12.5
Mix 2A	5	0.3	300	0	1500	90	28.5	1.49	4.2	4.7	5.9
Mix 2B		0.4				120	25.6	1.21	5.1	5.6	7.8
Mix 2C		0.5				150	22.7	0.95	5.8	6.5	10.3
Mix 2D		0.6				180	19.8	0.82	6.3	8.3	11.8
Mix 2E		0.7				210	17.2	0.69	7.9	10.4	12.9

B: geopolymer binder; GGBS: Ground Granulated Blast Furnace Slag; CBA: coal bottom ash; AL: alkaline liquid, k: coefficients of water permeability.

The samples of GPC can be prepared for compressive strength of cylindrical concrete specimens in accordance with ASTM C109. The geopolymer concrete is cured in temperature in range from 60^0C to 120^0C for 8 hours. The compressive strength is tested at 28 days. The water permeability coefficient of pervious geopolymer concrete was tested by using the constant head method and carried out when a steady state flow was reached [11]. The coefficients of water permeability (k) were calculated by following Darcy's law as shown in the following:

$$q = K.\frac{h_1 - h_2}{L}.A \quad (1)$$

where k is the coefficient of water permeability (cm/s), q is the quantity of water collected (cm^3) over time t (s), L is the thickness of specimen (cm), H is the water head (h2–h1) (cm), and A is the cross-sectional area of the specimen (cm^2).

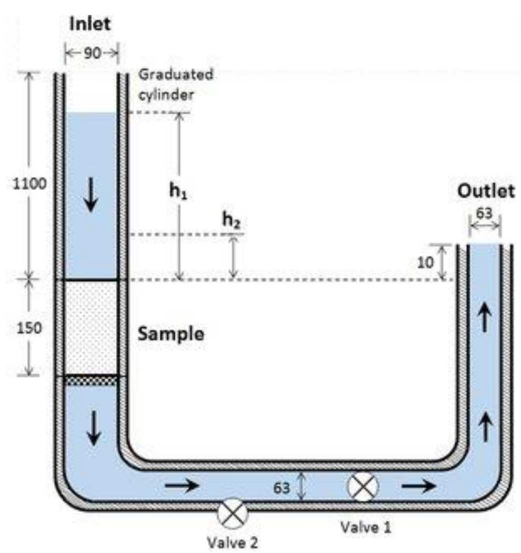

Figure 3. Water permeability coefficient testing [12].

3. Results and Discussion

3.1. Influence of alkaline solution and curing condition on strength of pervious concrete

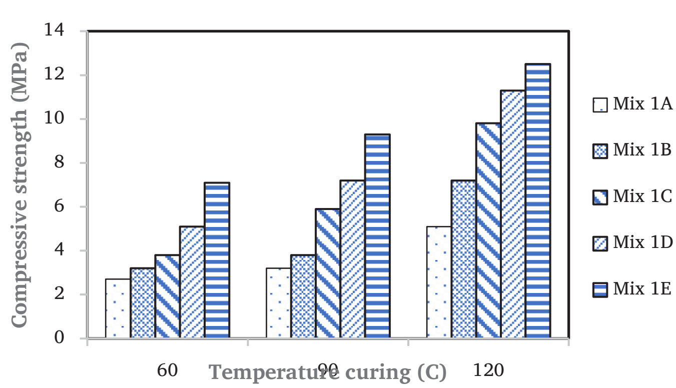

Figure 4. Strength of geopolymer concrete with CBA 5 mm to 10 mm.

The results are shown that the compressive strength of GPC can be obtained about 2.2 MPa under curing condition 60^0C for 8 hours in Mix 1A. As seen in Fig. 4, the compressive strength tends to increase by about 30% with higher curing temperature from 60^0C to 120^0C for 8 hours. It can be seen that the GGBF slag is reacted with alkaline liquid to make strength of pervious concrete. However, the strength is very low. The compressive strength of GPC tends to increase about 30% to 40% with higher in alkaline solution, as seen from Mix 1A to Mix 1E, during similar curing condition.

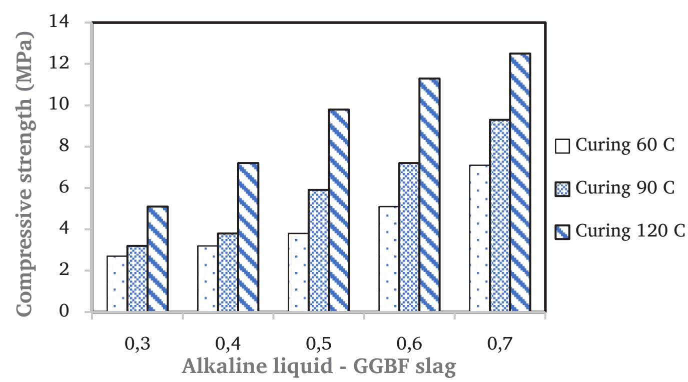

Figure 5. Behavior between alkaline liquid and curing condition on strength of GPC.

As seen in Fig. 5, the geopolymer concrete can be increased strength up to 2.5 times MPa by increasing in ratio of alkaline solution to GGBF slag from 0.3 to 0.7 by weight, respectively, with 60^0C curing condition. The strength can be up to 30% to 40% by increasing in curing temperature from 60^0C to 120^0C for 8 hours. It can be indicated that the compressive strength is significantly belonging to high alkaline liquid and high curing temperature. It can be obtained more 10 MPa in mixture with ratio alkaline to GGBF slag from 0.5 to 0.7 and curing temperature 120^0C for 8 hours.

3.2. Influence of CBA type on strength of pervious concrete

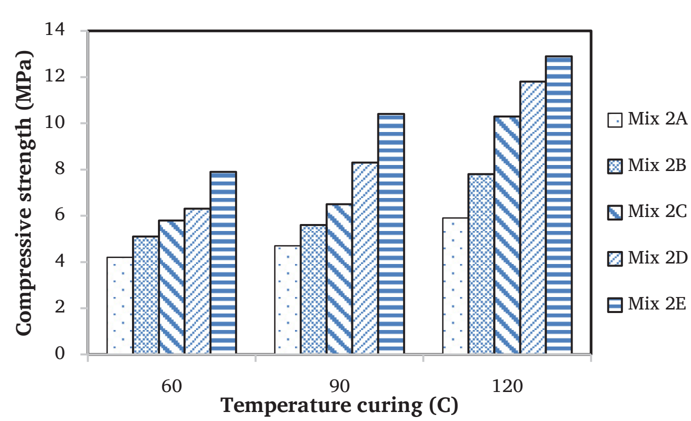

Figure 6. Strength of geopolymer concrete with CBA 10 mm to 20 mm.

As seen Fig. 6, the compressive strength of GPC can be obtained about 4 MPa and up to 6 MPa by increasing curing condition from 60^0C to 120^0C for 8 hours in Mix 1A with CBA 10 -20 mm. The GPC can be increased in strength about 25-35% with an increasing in alkaline content in mix proportion. It can be seen that the effect of GGBF slag and alkaline solution on GPC strength is similarly result above. Moreover, GPC can obtain higher strength with CBA 10 – 20 mm to compare to its with 5-10 mm.

3.3. Influence of CBA and porosity on permeability of pervious concrete

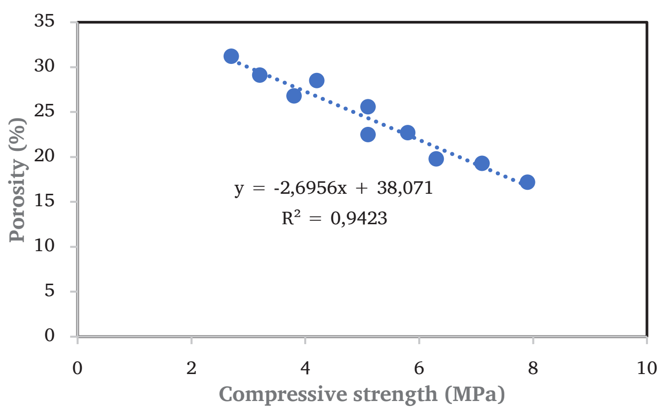

Figure 7. Behavior between porosity and compressive strength GPC.

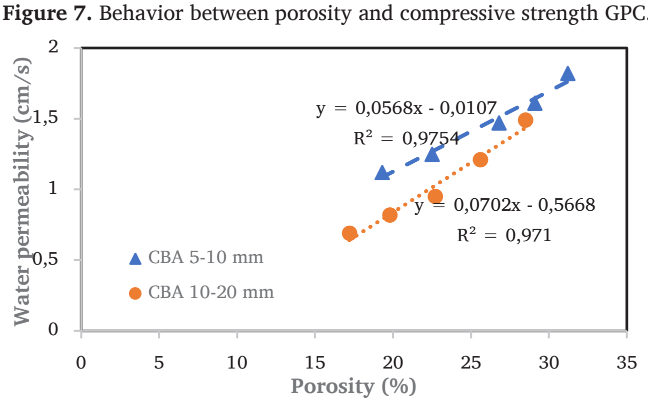

Figure 8. Behavior between water permeability and porosity of GPC with various CBA sizes

The results are shown that the porosity of GPS are about 15% to 30% in mixture between CBA aggregate and GGBF slag. The behavior between porosity and compressive strength is linear as seen in Fig. 7.

As seen Fig. 8, the behavior between porosity and permeability is linear. The water permeability of GPC is about 1.1 cm/s to 1.8 cm/s in the mixture with CBA 5 mm to 10 mm. On the other hand, the permeability is about 0.7 cm/s to 1.4 cm/s in mixture with CBA 10 mm to 20 mm.

4. Conclusion

The investigation of coal bottom ash and ground granulated blast furnace slag on permeability of geopolymer pervious concrete is shown the results:

- The compressive strength of GPC is about 2.7 MPa to 7 MPa with ratio of alkaline liquid to GGBF slag in range from 0.3 to 0.7 by weight. It can be increased up to 40% by various temperature curing from 60^0C to 120^0C on 8 hours.

- GPC can be improved about 25% to 35% in strength with CBA 10-20 mm in mixture during similar curing condition and geopolymerization.

- The porosity of GPC is about 15% to 30% to be affected on reduce compressive strength. The permeability of GPC is about 0.7 cm/s to 1.8 cm/s to be used in urban flooding solution.

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