Use of coal bottom ash as a fine aggregate in coal fly ash-based geopolymer

Ji Hoi Heo, Eun A Ko, Soo An Kim, Woo Yeong Jeon, Hyo Kim

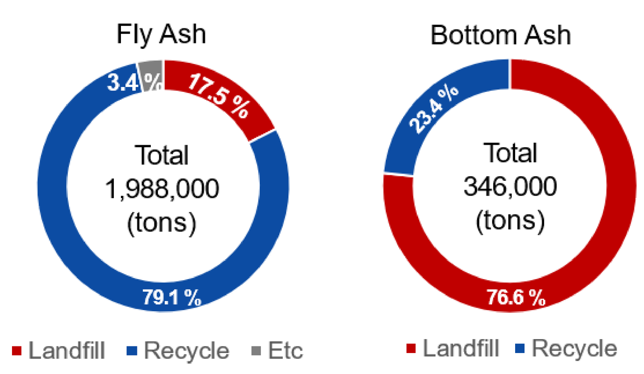
Department of Chemical Engineering, University of Seoul, Seoul, 02504

Corresponding author: hkim@uos.ac.kr

Introduction

❑ Coal Combustion Products (CCPs)

- CCPs are by-products from thermal power plant.
- CCPs can be used as a source material of geopolymer because of its high silica and alumina contents.
- Fly ash almost recycled, but bottom ash usually disposed by landfill.



❑ Geopolymer

- Geopolymer is a type of alkali-activated materials that can be synthesized by the reaction of aluminosilicate source materials with alkali activator.
- Geopolymer emits less CO_2 than Ordinary Portland cement (OPC).

Experimental design

When particles of different sizes are packed, packing state of the particles affect properties of bulk specimen. The state depends on **coarse/fine particle ratio** and **liquid to solid ratio (L/S ratio)**. The packing state can be expressed as solid concentration [1].

$$\varphi = \frac{V_s}{V}$$

where, φ : solid concentration, V_s : solid volume, V : bulk volume

$$packing\ density\ \Pi = Max(\varphi)$$

Table 1. Mix proportions of coal bottom ash, coal fly ash, and liquid to solid ratio.

Name	CBA : CFA(by mass)	L/S ratio
BA0	0:1	From dry pellet to gel (empirical)
BA1	1:1	
BA2	2:1	
BA3	3:1	

Materials

❑ Aluminosilicate source materials

- Coal fly ash (CFA)
  Classified as class F fly ash ($SiO_2 + Al_2O_3 + Fe_2O_3 \geq 70\ wt.\%$)

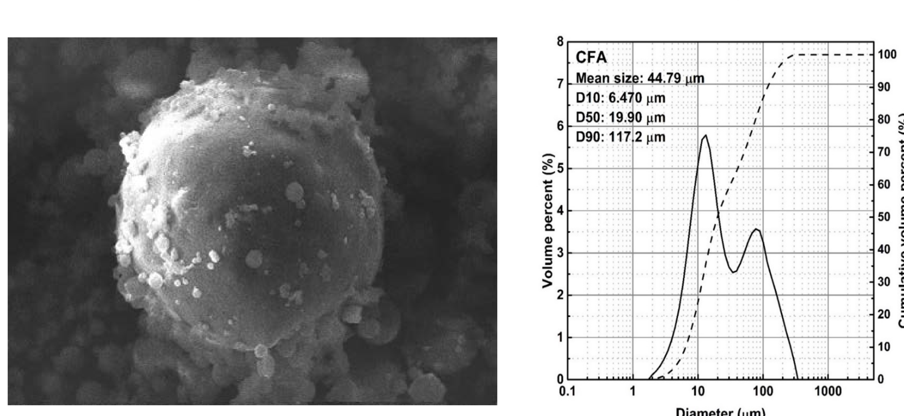


Fig. 1. SEM image (left) and particle size distribution (right) of fly ash.

❑ Fine aggregate

- Coal bottom ash (CBA)
- Silica sand (SA)
  Fineness modulus 2.33 according to ASTM C 33

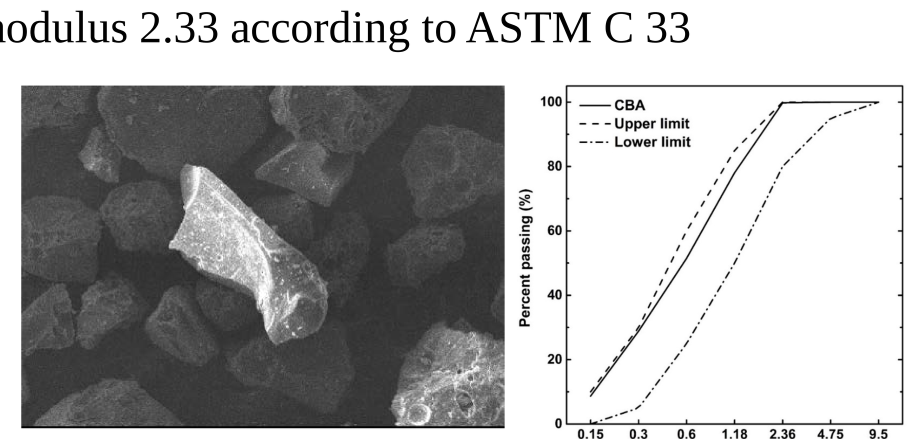


Fig. 2. SEM image (left) and particle size distribution (right) of CBA

Table 2. Chemical compositions of CFA, CBA, and SA by XRF analysis.

wt.%	SiO_2	Al_2O_3	Fe_2O_3	CaO	TiO_2	Others	Moisture	LOI
CFA	52.2	26.3	8.16	5.32	1.88	6.12	0.528	2.98
CBA	52.0	19.3	14.1	7.31	1.25	6.08	0.482	0.303
SA	78.3	13.6	1.78	0.81	0.229	5.01	0.447	0.724

❑ Alkali activator

14 M(mole/L) sodium hydroxide aqueous solution

Methods

1. Coal fly ash and coal bottom ash was mixed by hand in dry condition.
2. NaOH solution was added into the ash mixture and blended by Hobart mixer for 5 minutes.
3. Mixed geopolymer mortar was casted into triplicate 5 cm cubic mold.
4. The casted mortar was sealed with plastic bag and cured in a 90°C dry oven for 24 hours.
5. After curing, specimens were demolded and cooled down naturally.
6. The specimens were cured for 28 days at room temperature and investigated.

Results & Discussion

❑ Solid concentration

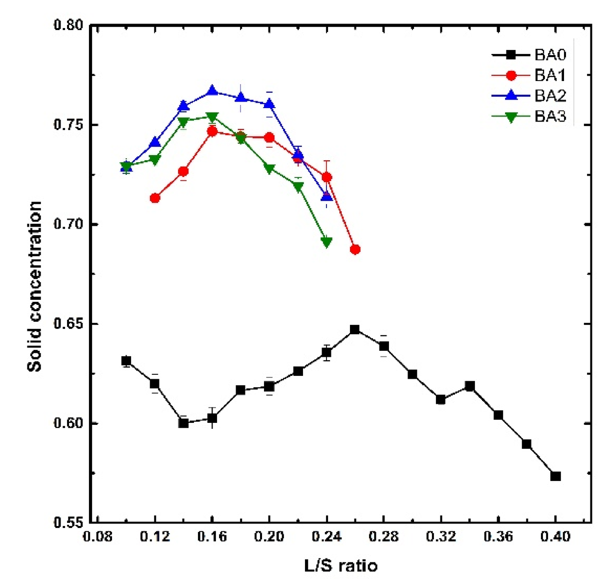


Fig. 3. Solid concentration with various BA content and L/S ratio.

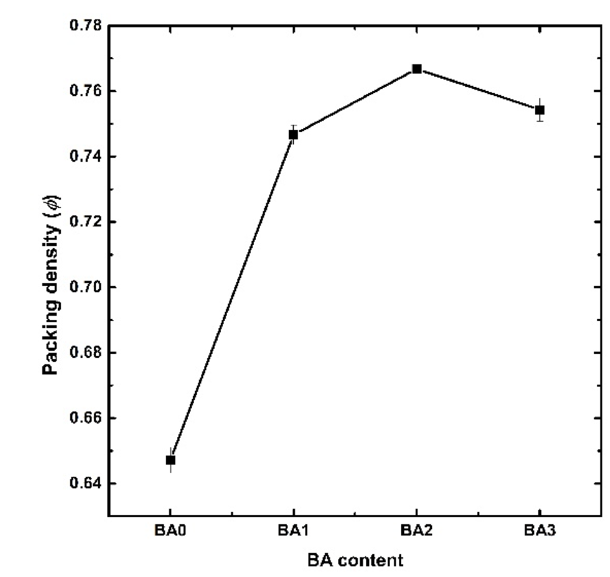
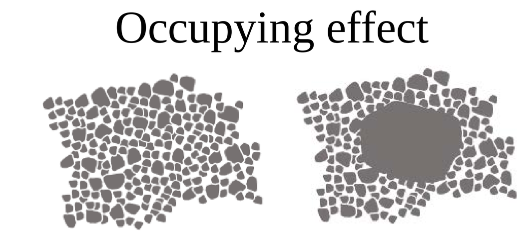


Fig. 4. Packing density with various BA content.

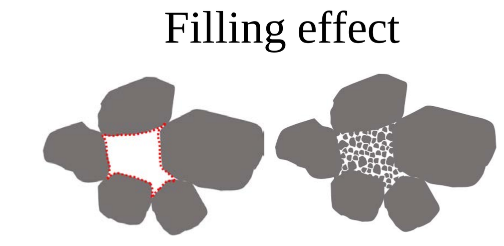
- Solid concentration of BA0 was decreased from L/S ratio of 0.10 to 0.14 due to 'Bulking' phenomenon [3]. The phenomenon is resulted from capillary stress between particles when the particles were partially saturated [3]. The capillary stress disturbs movement of the particles by compactive effort [3], which results in decrease of solid concentration.

- After L/S ratio 0.14 of BA0, the solid concentration was continuously increased with increment of liquid due to reduced capillary stress but decreased again when added excess liquid, which resists compression and disperses the particles [3], showing mound shape tendency.
- With increasing BA content, packing density was increased achieving its maximum value at BA2 due to occupying and filling effects [2].
- However, packing density of BA3 was decreased, which is the result of lack of the fly ash particles to fill the void between the bottom ash particles [2].

Occupying effect



Filling effect



❑ Compressive strength

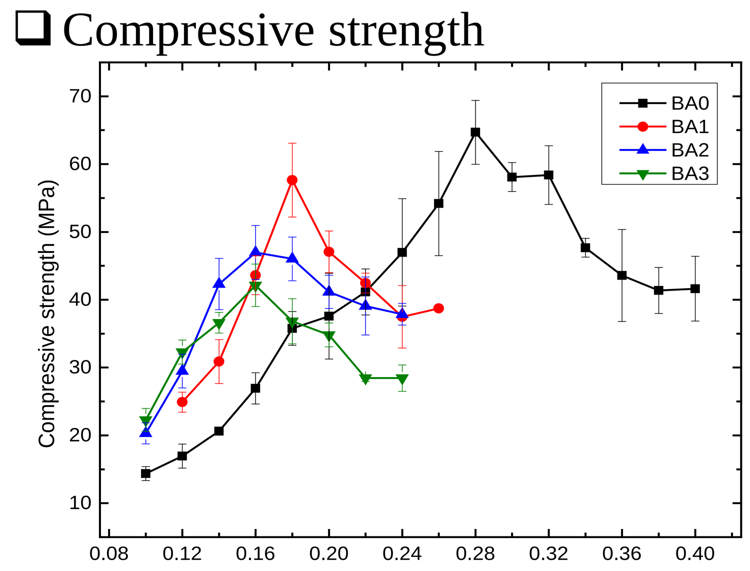


Fig. 5. Compressive strength with various BA content and L/S ratio.

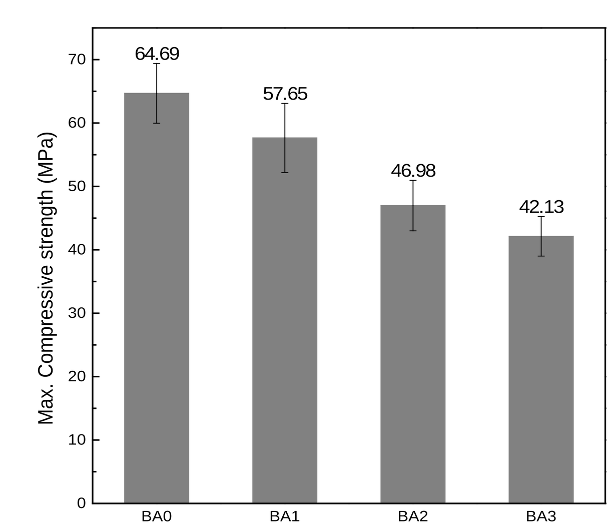


Fig. 6. Compressive strength with various BA content.

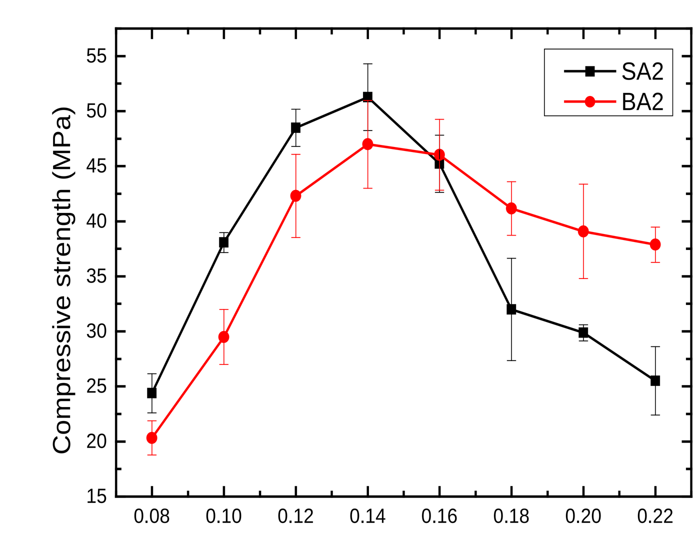


Fig. 7. Compressive strength of geopolymer added bottom ash and sand respectively.

- Maximum compressive strength in each BA content was decreased with increment of BA content.
- It was resulted from reduced amount of fly ash that contributes significantly to development of compressive strength [4].
- Sand added geopolymer had slightly higher strength than bottom ash added geopolymer.

❑ SEM analysis

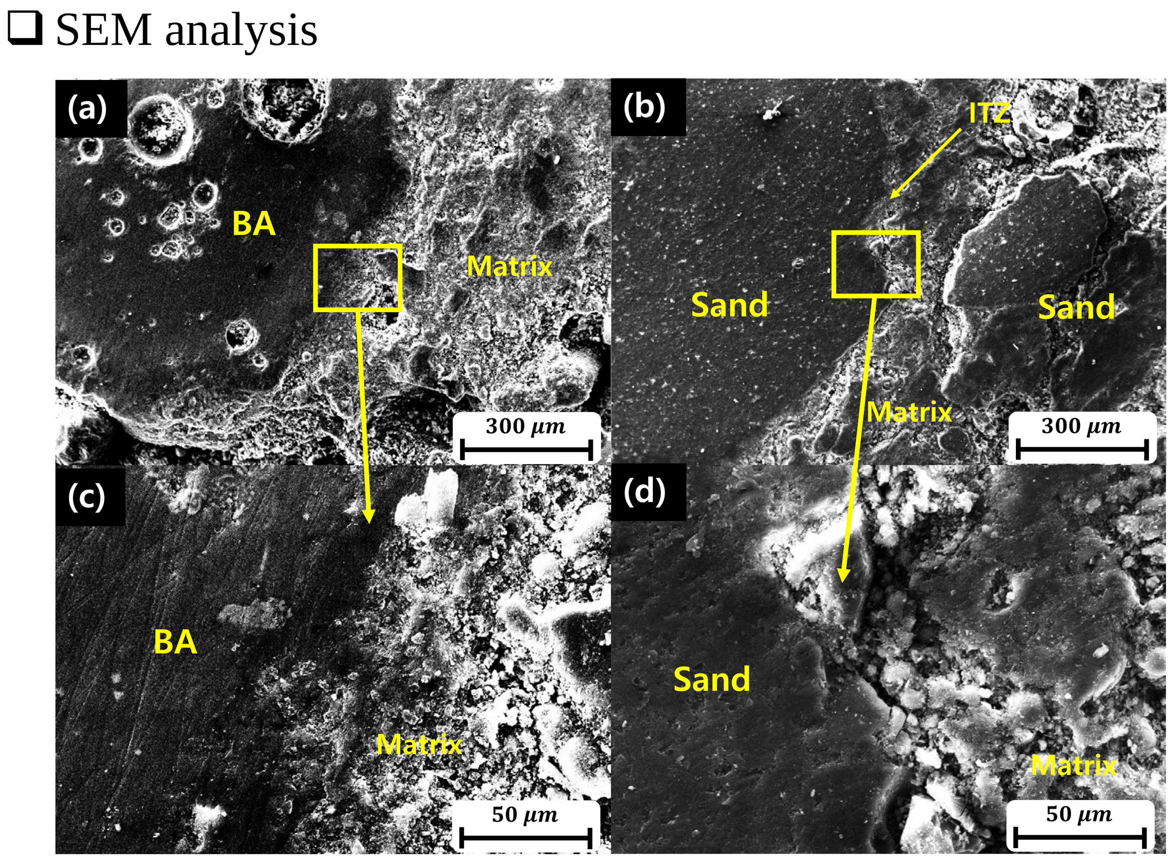


Fig. 8. SEM images of geopolymer matrix with bottom ash (a), (c) and sand (b), (d).

❑ ATR-FTIR

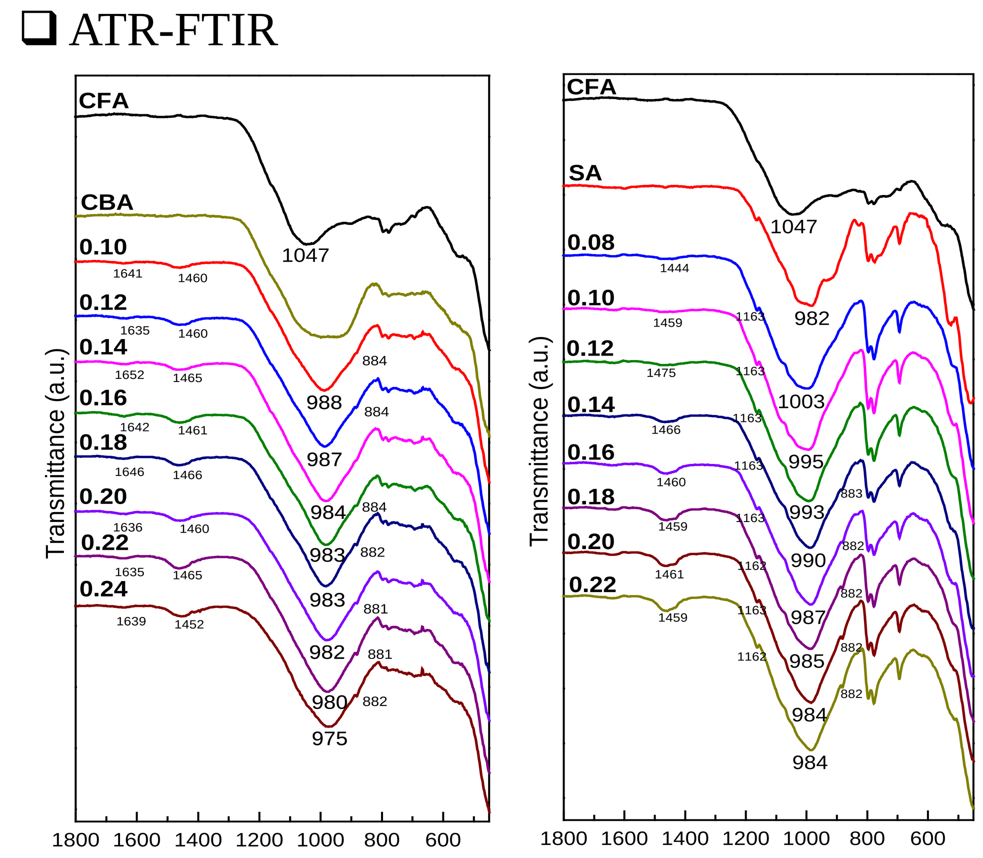


Fig. 9. FTIR spectra of raw materials and geopolymer samples.

Conclusions

- Compressive strength was influenced by packing state, degree of geopolymerization, and its structural characteristics. Optimum L/S ratio existed where the maximum compressive strength could be achieved at each BA content. At low or high L/S ratio, compressive strength was decreased due to poor packing state and modified geopolymer structure as shown in solid concentration and ATR-FTIR results.
- Geopolymer mortar had maximum packing density when BA was added with ratio of CBA/CFA=2 (BA2). Also, the cured geopolymer samples achieved excellent compressive strength, more than 40 MPa, at low L/S ratio thanks to its good packing state.
- BA added geopolymer(BA2) had slightly lower compressive strength than sand added geopolymer(SA2) although the latter geopolymer developed interfacial transition zone. In conclusion, coal bottom ash is good substitutes of sand aggregate in terms of excellent compressive strength of BA added geopolymer and use of industrial by-products.

References

[1] Wong, H.H. and A.K. Kwan, *Packing density of cementitious materials: part 1—measurement using a wet packing method*. Materials and structures, 2008. 41(4): p. 689-701..

[2] Wong, V., K. Wai Chan, and A. Kwok Hung Kwan, *Applying theories of particle packing and rheology to concrete for sustainable development*. Organization, technology & management in construction: an international journal, 2013. 5(2): p. 844-851

[3] Kim, B., et al., *Determination of ash mixture properties and construction of test embankment-part A*. Joint Transportation Research Program, 2006: p. 262.

[4] Li, X., et al., *Mechanical properties and microstructure of class C fly ash-based geopolymer paste and mortar*. Materials, 2013. 6(4): p. 1485-1495