4th International Conference on Rehabilitation and Maintenance in Civil Engineering
July 11th-12th, 2018, Solo Baru, Indonesia

Microstructure and Mechanical Properties of FA/GGBS-based Geopolymer

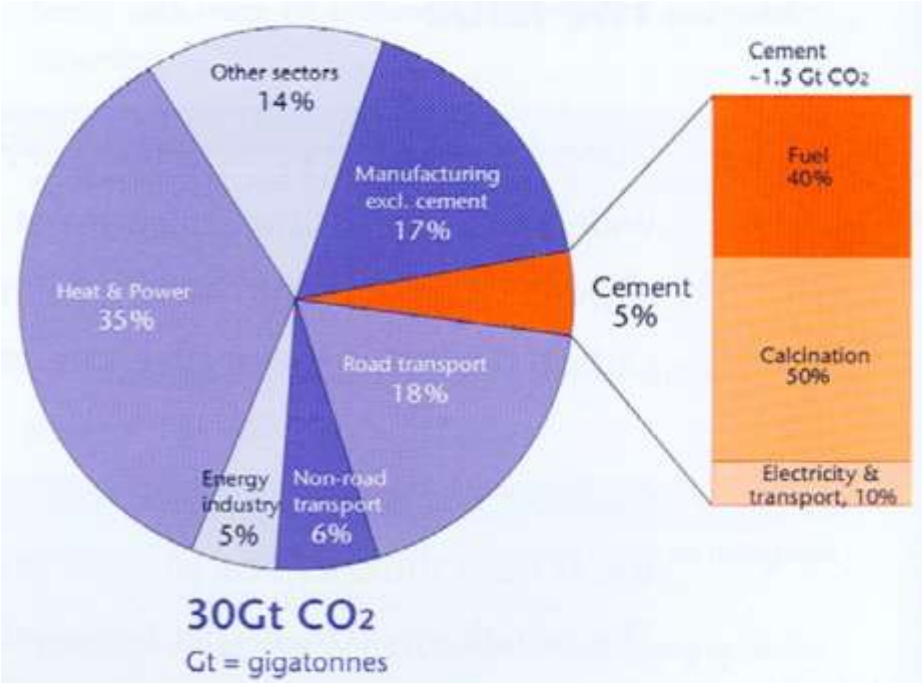
Apriany SALUDUNG, Yuko OGAWA, Kenji KAWAI

Department of Civil and Environmental Engineering
Graduate School of Engineering
Hiroshima University
2018

HIROSHIMA UNIVERSITY

Background

HIROSHIMA UNIVERSITY



Cement industry emits high amount of carbon dioxide (CO_2) that accounts for about 5% of global CO_2 emission.

Environmental degradation

can be reduced by

- Partially replace the cement in concrete (E.g. High amount of fly ash used in concrete).
- Develop alternative material (E.g. Geopolymer concrete)

Geopolymer cements can be obtained through inexpensive and eco-friendly synthetic procedures.

Background

HIROSHIMA UNIVERSITY

Fly ash-based geopolymer can cut down about 60% CO_2 emission, compared to OPC (Li *et al.*, 2004)

However…

It has very long setting time and low compressive strength.

Fly ash + ground granulated blast-furnace slag (GGBS)

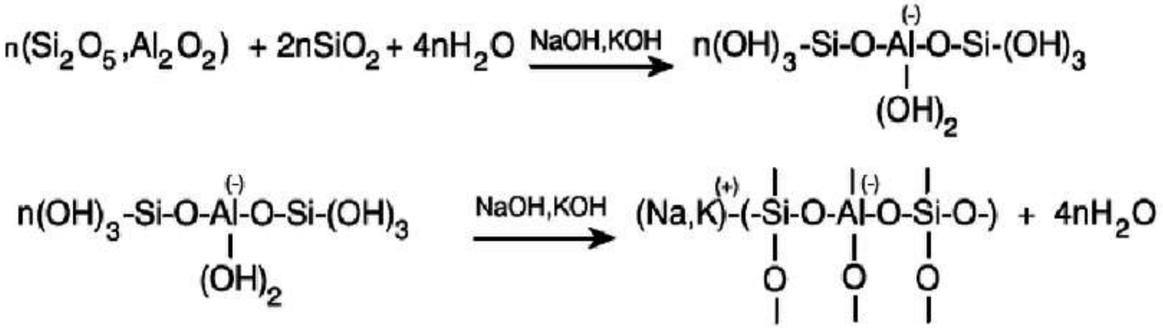
Objective

To investigate effect of GGBS on the microstructure and mechanical properties of fly ash-based geopolymer.

Theory and Application

HIROSHIMA UNIVERSITY

The term ‘geopolymer’ was coined in the 1970s by the French scientist and engineer Prof. Joseph Davidovits, and applied to a class of solid materials synthesized by the reaction of an aluminosilicate powder with an alkaline solution.



(Geopolymer precursor)

(Geopolymer backbone)

Brisbane West Wellcamp Airport, Queensland, Australia is the world’s largest geopolymer concrete project.

Experimental Method (1)

HIROSHIMA UNIVERSITY

Materials

1. Precursors:

- Fly ash (fineness : 3.550 cm/g^2, density : 2.24 g/cm^3)
- GGBS (fineness : 4.170 cm/g^2, density : 2.91 g/cm^3)

2. Alkaline liquids

- Combination of sodium hydroxide (NaOH) 14 M and sodium silicate (Na_2SiO_3).

Table 1. Chemical compositions of raw materials by EDS analysis.

Composition	Fly ash (mass%)	GGBS (mass%)
SiO_2	68.44	34.45
Al_2O_3	20.65	14.06
Fe_2O_3	4.18	0.27
CaO	2.25	43.78
K_2O	1.53	0.23
TiO_2	1.19	0.56
MgO	0.58	5.84
Na_2O	-	0.24
LOI	2.9	0.05

Experimental Method (2)

HIROSHIMA UNIVERSITY

Fly Ash + GGBS + Alkaline solution (14 M $NaOH+Na_2SiO_3$)

→ Fresh Geopolymer paste

GGBS/FA : 0.15, 0.30, 0.45, 0.60 (By mass)
Solution/Binder : 0.45 (By mass)
Na_2SiO_3/NaOH : 2 (By mass)

→ Casted in cylindrical plastic mold (50mmx100mm) and cured at 70ºC for 24 hours

→ Demould and kept in controlled room (20ºC and 60% RH) for 7, 14, and 28 days

→ Characterization and measurement

Results and Discussion

- Compressive strength test
- Scanning Electron Microscopy (SEM)
- X-Ray Diffraction (XRD)
- Thermo-gravimetric analysis

Compressive strength

Table 2. Compressive strength of geopolymer paste specimens.

Specimen	Compressive strength (MPa)		
	7 days	14 days	28 days
FAS0	24.21 (1.17)	24.7 (1.23)	24.36 (1.43)
FAS15	43.51 (5.74)	44.06 (1.89)	44.38 (3.01)
FAS30	62.92 (5.43)	61.15 (0.83)	56.46 (1.79)
FAS45	77.19 (1.69)	80.39 (6.78)	84.17 (1.79)
FAS60	105.54 (5.55)	100.84 (3.10)	93.36 (7.54)

* ( ) = Standard deviation

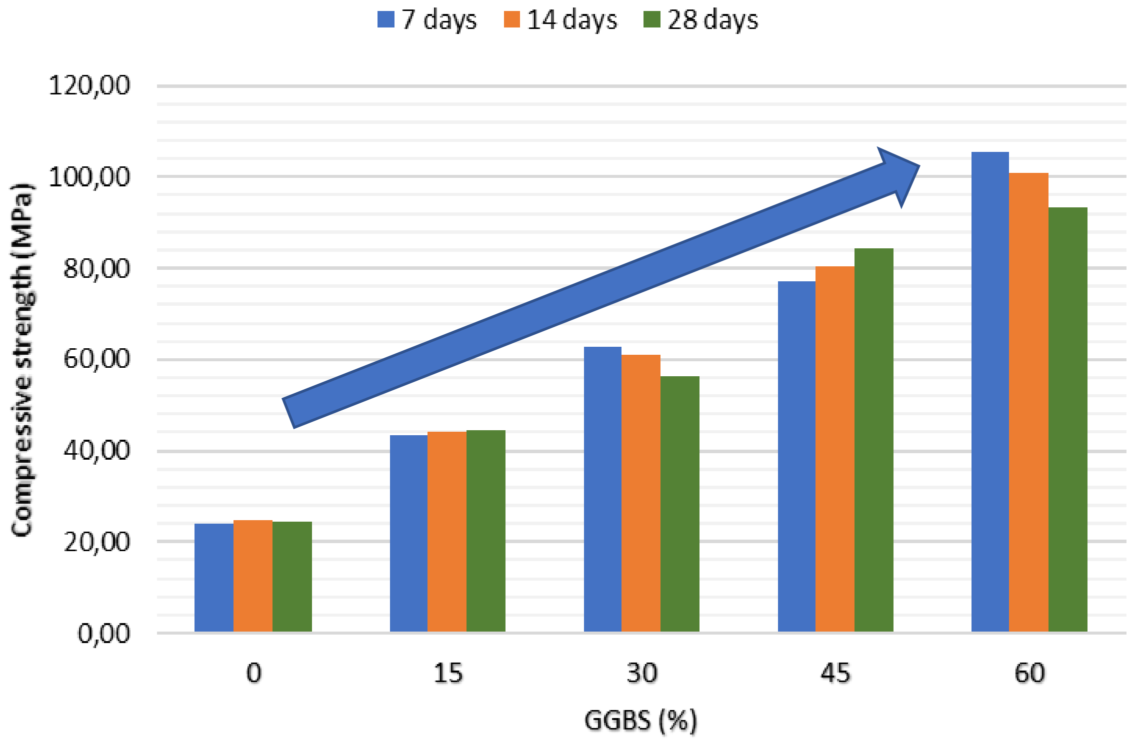
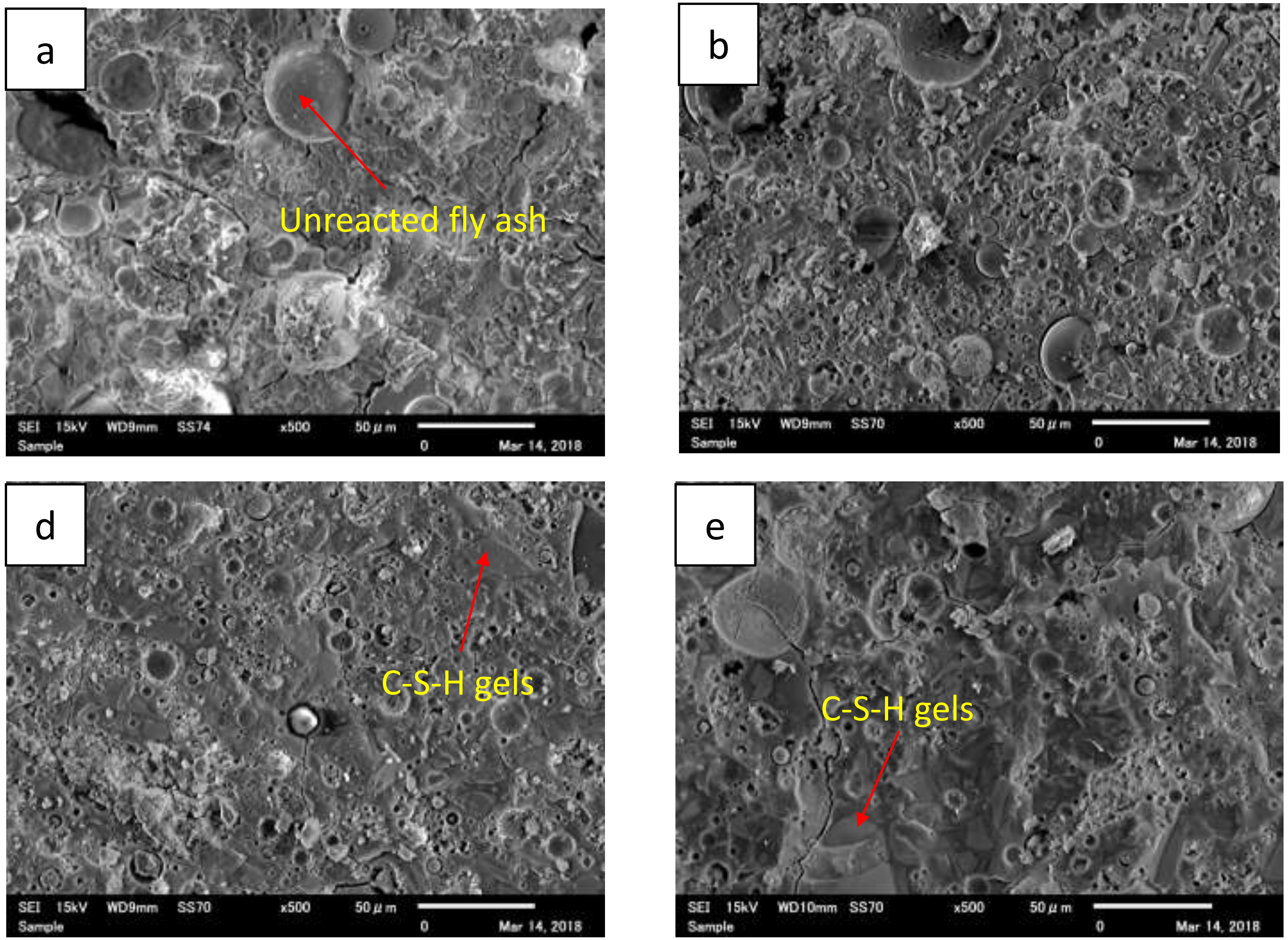


Fig.1. Effect of GGBS on the compressive strength of geopolymer paste specimens.

The compressive strength was found to increase with the increase in amount of GGBS; however, it remained almost constant between 7 and 28 days.

SEM Images

HIROSHIMA UNIVERSITY



Ca^{2+} and silicon resulting from the dissolution of GGBS react to form a C-S-H gel.

The formation of C-S-H gel helps to form denser structure.

Fig. 2. Micrograph of geopolymer specimens with (a) 0%, (b) 15%, (c) 30%, (d) 45%, (e) 60% of replacement by GGBS.

XRD Results

HIROSHIMA UNIVERSITY

M : Mullite, Q : Quartz

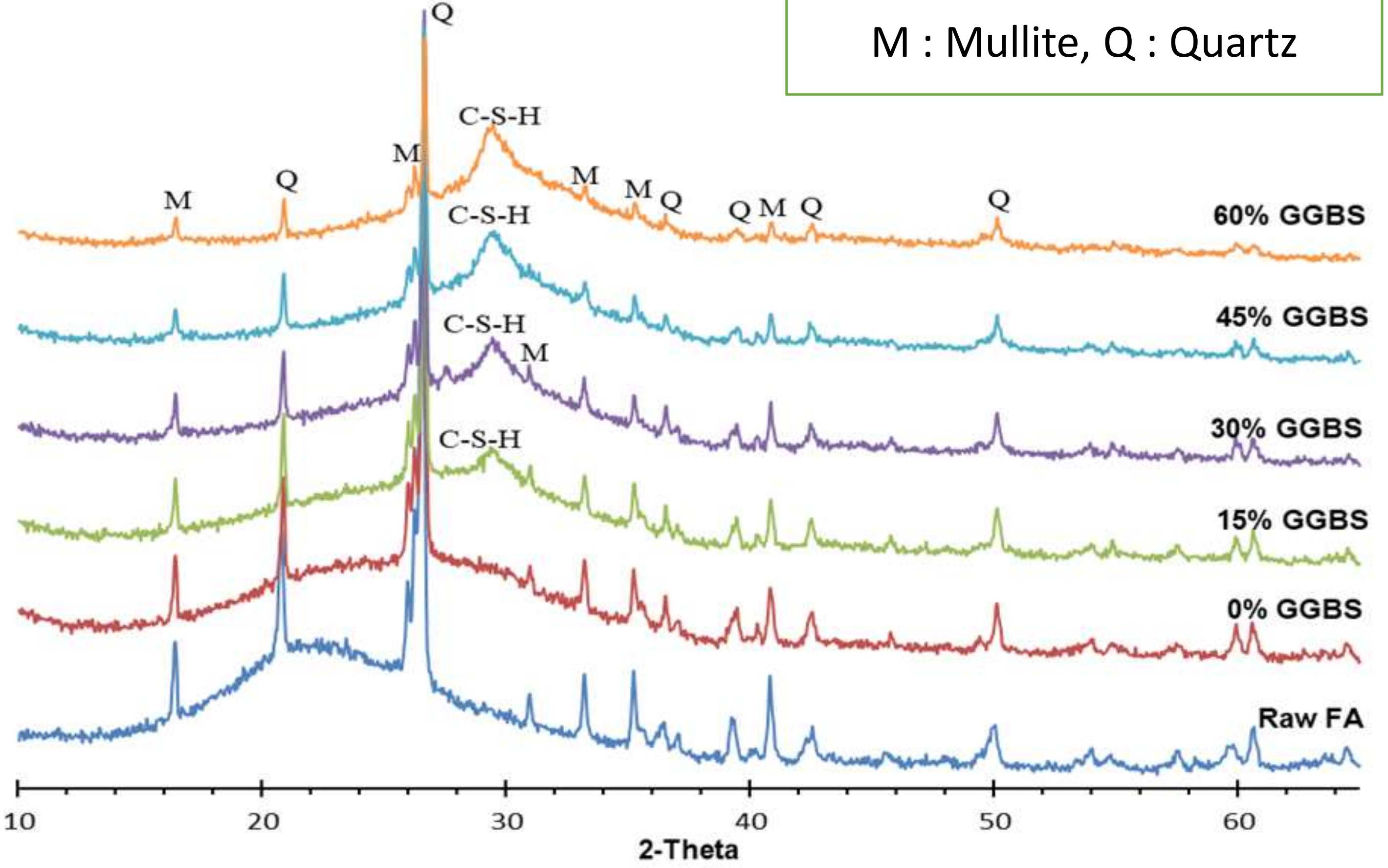


Fig.3. XRD patterns of geopolymer specimens

XRD Results

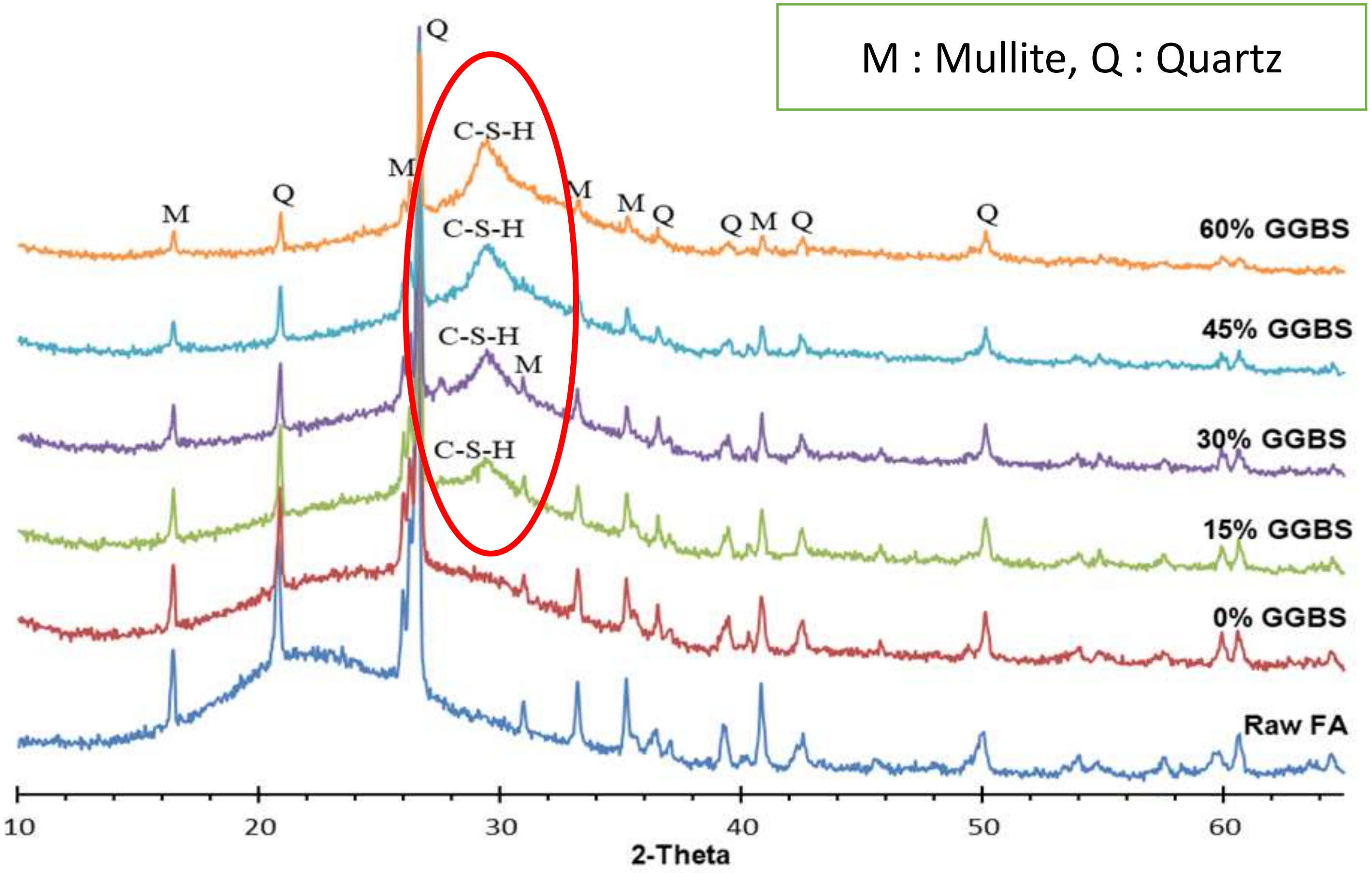


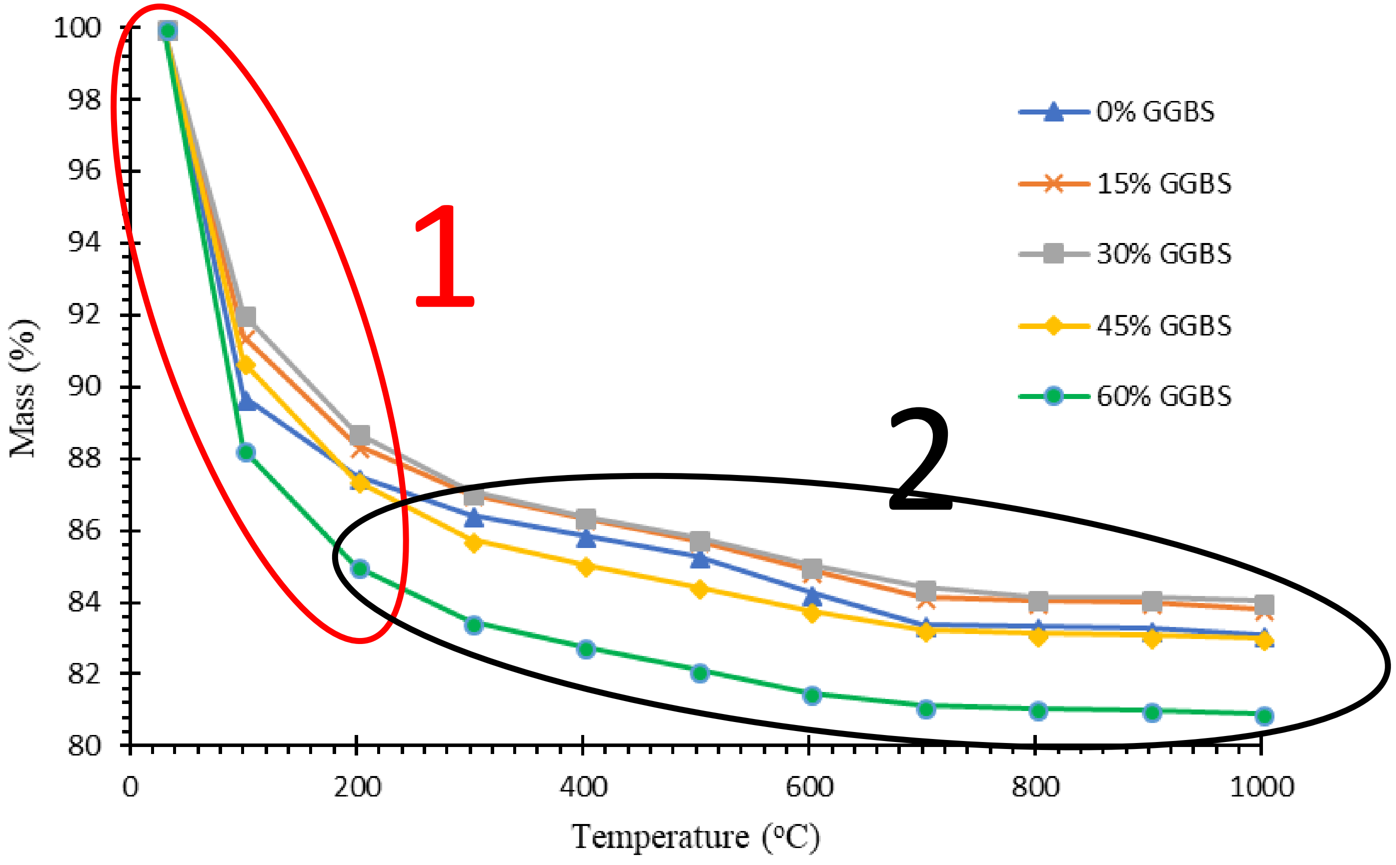
Fig.3. XRD patterns of geopolymer specimens

As GGBS was presented in the mixes, the formation of C-S-H gel was generated.

The increase amount of GGBS resulting in the increase of C-S-H peak indicates that the higher the amount of GGBS, the higher the formation of C-S-H.

Thermo-gravimetric analysis

HIROSHIMA UNIVERSITY



1. A sharp decrease in mass before 200°C was due to the evaporation of free water.
2. Above 200°C, the mass loss is attributed to dehydroxylation of chemically bound water.

Fig.4. Thermal stability of geopolymer paste under different dosage of GGBS

Thermo-gravimetric analysis

HIROSHIMA UNIVERSITY

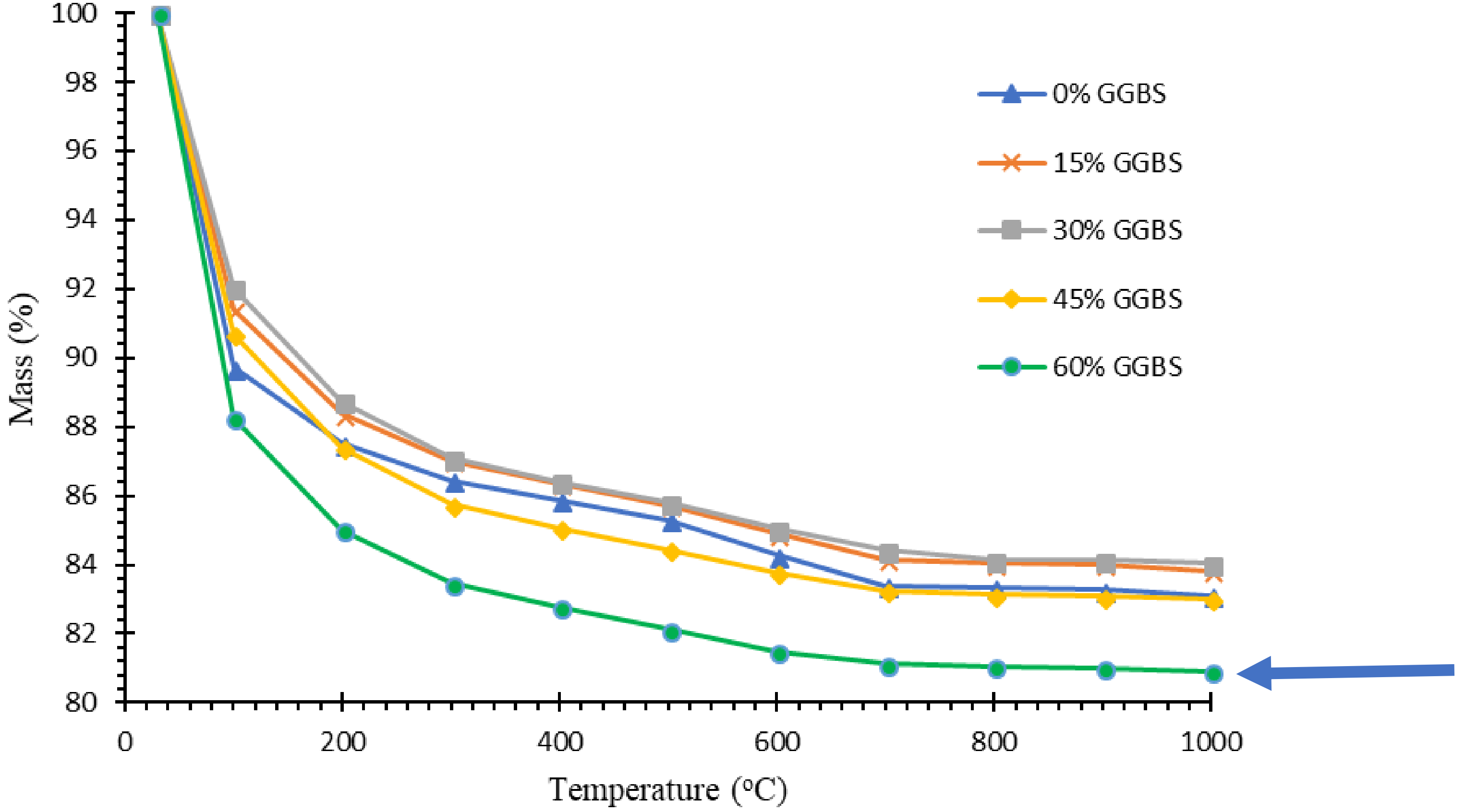


Fig.4. Thermal stability of geopolymer paste under different dosage of GGBS

1. A sharp decrease in mass before 200°C was due to the evaporation of free water.
2. Above 200°C, the mass loss is attributed to dehydroxylation of chemically bound water.

60% replacement by GGBS may cause durability problem when using it in the field.

Conclusions

HIROSHIMA UNIVERSITY

1. The addition of GGBS in the mixes significantly increased the compressive strength of geopolymer paste specimens. The highest strength was found at 60% of replacement of fly ash by GGBS.
2. The SEM micrographs show that in the specimens containing GGBS, the geopolymeric gels were found to be co-existed with calcium silicate hydrate (C-S-H) gels, and thus contributed to the strength development of geopolymer specimens.
3. This study revealed that the geopolymer cement made from fly ash and GGBS has a potential use as an alternative binder to replace Portland cement due to high compressive strength and good thermal stability. However, using too high amount of GGBS (over 45%) may cause durability problem at high temperature due to the C-S-H decomposition.

References

HIROSHIMA UNIVERSITY

1. F. Fan, Z. Liu, G. Xu, H. Peng, C. Cai, Cons. & Buil. Mat., **160**, 66-81 (2018)
2. M. Kaur, J. Singh and M. Kaur, Cer. Int., **44**, 1534-1537 (2018)
3. F. N. Okoye, *Mat. Today : Proc.,* 4, 5599-5604 (2017)
4. L. Yun Ming, H. Chen Yong, M. M. Al Bakri, K. Hussin, Prog. in Mat. Sci., **83**, 595-629, (2016)
5. A. Autef, E. Joussein, G. Gasgnier, S. Rossignol, J. of Non-Crystalline Solids, **366**, 13-21, (2013)
6. Z. Li, S. Li, Cons. & Buil. Mat., **163**, 668-680, (2018)
7. P. Nath, P. Sarker, Proc. Eng, **14**, 1149-1156 (2011)
8. A. K. Saha, Sus. Env. Res., **28**, 25-31, (2018)
9. R. A. Hawileh, J. A. Abdalla, F. Fardmanesh, P. Shahsana, A. Khalili, Arc. of Civ. & Mec. Eng., **17**, 511-519 (2017)
10. S. Saha, C. Rajasekaran, Cons. & Buil. Mat, **146**, 615-620 (2017)
11. C. D. Budh and N. R. Warhade, Int. J. of Civ. Eng. Res, **5**, 83-86 (2014)
12. J. L. Provis, J. S. J. van Deventer, *Geopolymers : Structure, processing, properties, and industrial application*, Woodhead Publishing Limited (2009)
13. P. Behera, V. Baheti, J. Militky, S. Naeem, Cons. & Buil. Mat., **160**, 733-743 (2018)

Thank you for your attention