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GGBS Geopolymer Incorporating Municipal Solid Waste Incineration Fly Ash

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The potential of reutilizing incineration fly ash (IFA) as raw materials for construction applications is evaluated. The IFA is incorporated into a *ground granulated blast-furnace slag* (GGBS) geopolymer to evaluate its effect on mechanical strength and heavy metal leaching. The results show that the IFA studied in this paper is a filler material and it does not participate in the geopolymer reaction in the GGBS-IFA geopolymer system. The compressive strength of GGBS-IFA geopolymer reduces with increase of IFA replacement. However, the compressive strength of 60% IFA replacement GGBS geopolymer can still reach above 15 MPa. GGBS geopolymer can effectively immobilize heavy metal in IFA. It is plausible the long term performance of heavy metal leaching of GGBS-IFA geopolymer can be satisfactory. It is concluded IFA may be incorporated into the GGBS geopolymer matrix and re-utilized as a construction material.

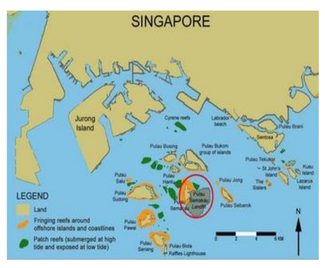
1. Background & Introduction

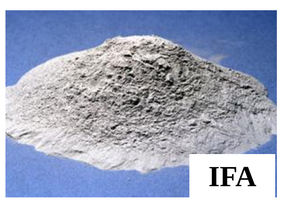
With economic development and population increase in Singapore, municipal solid waste (MSW) generation in the nation has increased tremendously over the years. As of 2010, more than 6.5 million tons of MSW was produced annually. Around 40% of the MSW is disposed of through incineration. Nearly 500,000 tons of incineration ash are produced annually and are disposed of by landfilling.

Solid Waste Generation in Singapore

Solid Waste Management	Unit	2009	2010	2011
Total waste generated[1]	Mil tonnes/yr	6.11	6.52	6.90
Total waste recycled[2]	Mil tonnes/yr (%)	3.49 (57%)	3.76 (58%)	4.04 (59%)
Total waste incinerated	Mil tonnes/yr (%)	2.48 (41%)	2.59 (40%)	2.66 (38%)

It is currently estimated that the Semakau landfill, the only remaining landfill in Singapore which began operations in 1999, will last till 2035-2045 [1]. To prolong the lifespan of the Semakau landfill, a viable solution is to reutilize this waste material for civil engineering applications



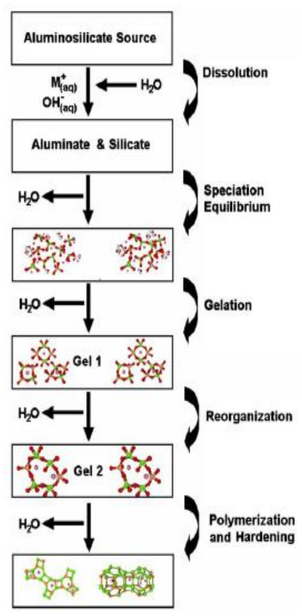


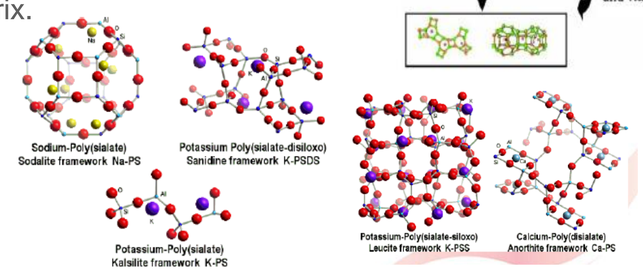
- Incineration Fly Ash (IFA)
  - High heavy metal content
  - Leaching concern
- Incineration Bottom Ash (IBA)
  - Lower heavy metal content
  - More stable

IFA has more environmental concern than IBA, and is regarded as hazardous waste worldwide

Ground granulated blast-furnace slag (GGBS) is a by-product of iron manufacture industry. Now GGBS is commercially available in Singapore.

Geopolymer is an alkali-activated aluminosilicate binder and is first named by Davidovits in 1970s. Geopolymers are commonly produced by alkali activation of industrial aluminosilicate waste materials. Geopolymer matrix could have far superior heavy metal immobilization capability compared to those of Portland cement-based system due to a combination of physical encapsulation and chemical bonding into the amorphous phase of the geopolymeric matrix.





2. Objectives

- Immobilization of heavy metal in IFA by GGBS geopolymer binder
  - Non-hazardous landfill
- GGBS-IFA geopolymer as construction materials
  - Non-structure concrete application
  - Prolong lifespan of Semakau landfil

3. Experimental program

GGBS-IFA Geopolymer Mix Design

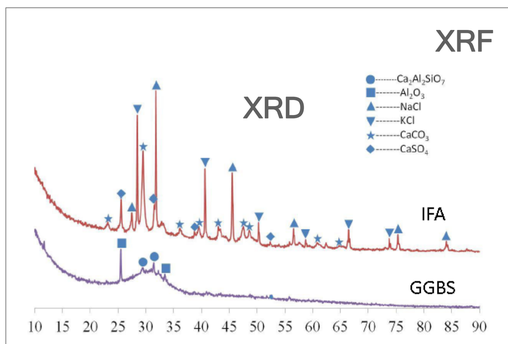
Mix	GGBS (g)	IFA (g)	NaOH (g)	Sodium silicate (g)	Water (g)	Water to binder ratio	Liquid to solid ratio
A	100	0	20	40	90	0.9	0.56
B	97	3					
C	95	5					
D	80	20					
E	60	40					
F	40	60					
G	0	100					

GGBS & IFA Dry mix → Alkaline solution added → Cast 50mm cubic samples → Curing at 75ºC for some days

4. Results & Discussion

A. Materials Microanalysis

- GGBS: High amount of Al2O3 and SiO2 (XRF), mainly amorphous calcium aluminum silicate, in a metastable state (XRD), highly reactive to engage the geopolymerization reaction
- IFA: Low aluminum and silica content (XRF), much more crystalline phases including metal chloride, calcium carbonate and calcium sulphate (XRD), a low reactivity material, unfavourable for the geopolymerization reaction as compared to the GGBS.



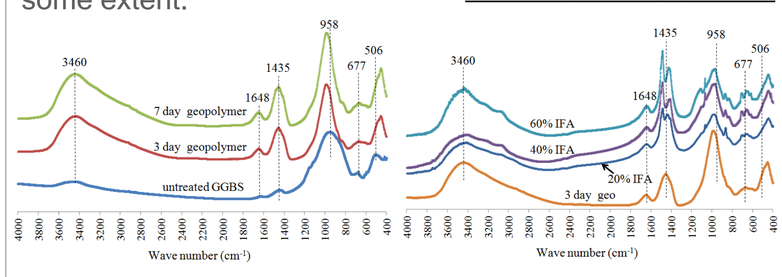
XRF

Oxide	IFA (%)	GGBS (%)
Na2O	4.89%	0.33%
MgO	1.64%	9.32%
Al2O3	1.03%	13.41%
SiO2	2.24%	31.19%
SO3	5.29%	4.25%
K2O	6.69%	0.53%
CaO	47.37%	39.43%
TiO2	0.75%	0.66%
MnO	0.06%	0.29%
Fe2O3	0.81%	0.38%
CuO	0.17%	0.03%
SrO	0.04%	0.16%
ZrO2	-	0.01%
PbO	0.48%	-
P2O5	0.72%	-
ZnO	2.49%	-
Br	0.31%	-
Cl	25.03%	-

B. FTIR Test

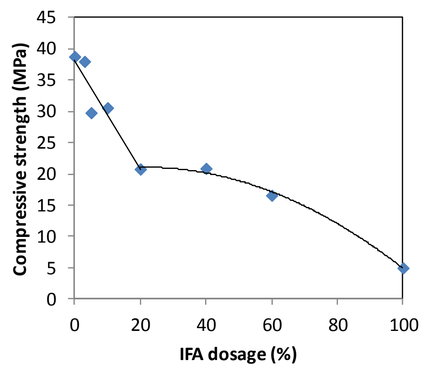
- Geopolymer reaction happened as Si(Al)-O tetrahedral peak shift and changed.
- Geopolymerization is a quick reaction as 3-day & 7-day spectrum remained similar
- Carbon dioxide absorption may happen during mixing and curing process.
- IFA incorporation destroyed GGBS geopolymer framwork to some extent.

Wave number	bond meaning
958	asymmetric stretching of Si(Al)-O-Si
506	bending vibration of O–Si–O bonds
677	symmetric stretching vibrations of the Si–O–Si(Al) bridges
1435	$[CO3]^{2-}$
1648	$[OH]^-$
3460	$[OH]^-$



C. Effect of IFA on the Compressive Strength of GGBS Geopolymer

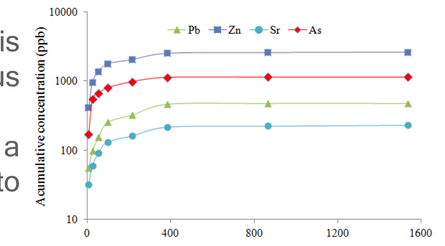
- Generally, compressive strength decreased with the increase of IFA content.
- There seems to be 2 mechanisms before and after 20% incorporation, which still need further investigation.



D. Leaching Analysis

Element	IFA powder 1-hour value (ppb)	GGBS-IFA geopolymer 6-hour value (ppb) IFA:GGBS 2:8	4:6	6:4	GGBS-IFA geopolymer 64-day accumulative value (ppb) IFA:GGBS 2:8	4:6	6:4	Limiting value for non-hazardous waste landfill (ppb)
As	320	59	120	171	408	776	1133	2000
Cd	10	4	6	9	20	32	52	1000
Cr	241	2	1	0	6	20	37	10000
Cu	684	15	19	12	88	98	87	50000
Ni	9	0	0	0	1	1	2	10000
Pb	77980	52	56	55	169	408	476	10000
Zn	12830	141	185	411	700	1415	2603	50000
Sr	5110	18	27	32	213	249	231	5000

- Untreated IFA is considered a hazardous waste.
- GGBS geopolymer is a very effective binder to immobilize heavy metal.



- Higher IFA replacement ratio results in an increase of heavy metal leaching.
- 64-day accumulative concentration of all heavy metal elements are still below the limiting values even at 60% IFA replacement
- Increasing rate reduced with time and gradually tended to zero
- Values after 64-day leaching test are still far below limitation

Conclusion

- ❑ GGBS geopolymer binder can effectively immobilize heavy metals in IFA for non-hazardous landfill.
- ❑ GGBS-IFA geopolymer with compressive strength above 15MPa (replacement ratio 60%) has a potential use as a non-structural construction material.
- ❑ Further study on compressive strength decrease mechanism and chemical bond of heavy metals in GGBS-IFA geopolymer are needed.