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Ground Granulated Blast-furnace Slag Geopolymer Incorporating Municipal Solid Waste Incineration Fly Ash

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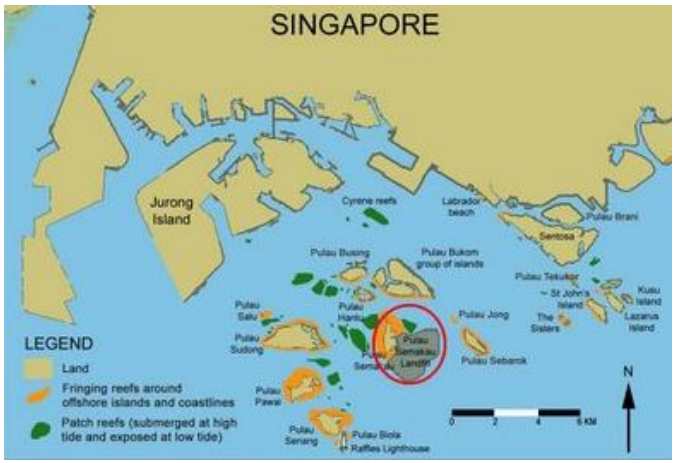
Singapore solid waste management

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%)
Total waste landfilled[3]	Mil tonnes/yr (%)	0.15 (2%)	0.17 (2%)	0.20 (3%)

Though recycle rate increases, incinerated MSW still increases year by year due to more and more MSW generated.

MSWIA landfill

- After incineration, the residue ash is disposed of by landfill.
- Now Singapore has only one landfill space Semakau, with about 40 years lifespan left



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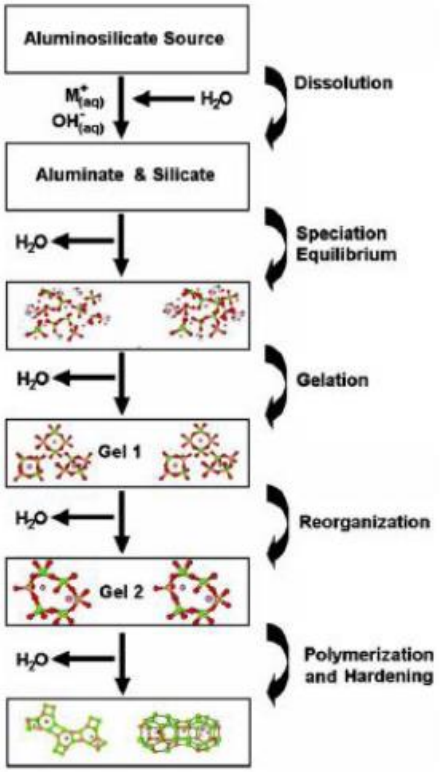
IFA & IBA

- Incineration Fly Ash (IFA)
  - High heavy metal content
  - Leaching concern
  - Hazardous waste

- Incineration Bottom Ash (IBA)
  - Lower heavy metal content and more stable
  - (Non-)hazardous waste?

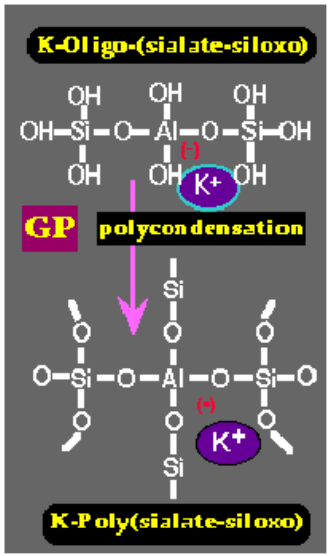
IFA has more environmental concern than IBA

Geopolymer



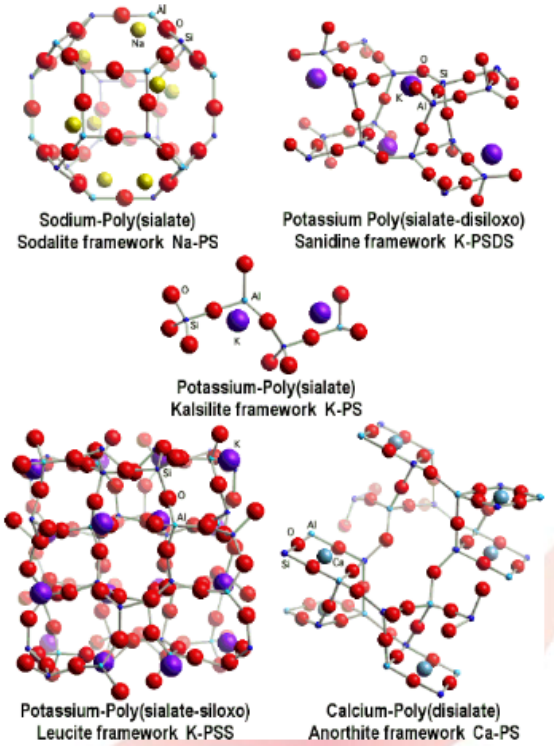
Duxson et al, 2007

- A class of synthetic **AluminoSilicate** materials



Poly(sialate): [-Si-O-Al-O-]
Poly(sialate-siloxo):[-Si-O-Al-O-Si-O-]
Poly(sialate-disiloxo): [-Si-O-Al-O-Si-O-Si-O-]

Davidovits, 2005



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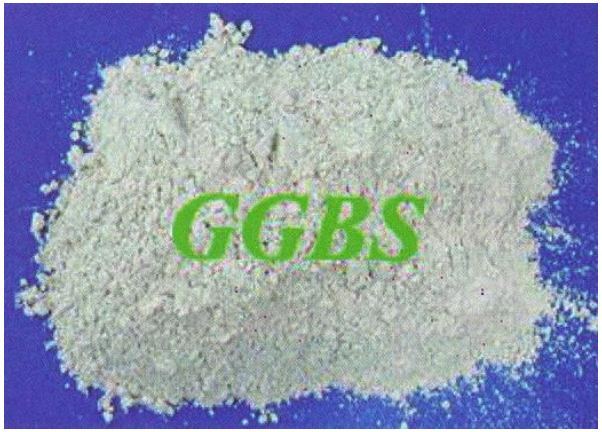
Ground Granulated Blast-furnace Slag (GGBS)

- By-product of iron manufacture industry
- Commercial product available in Singapore
- High silicate and aluminium content
- Amorphous structure, high reactivity



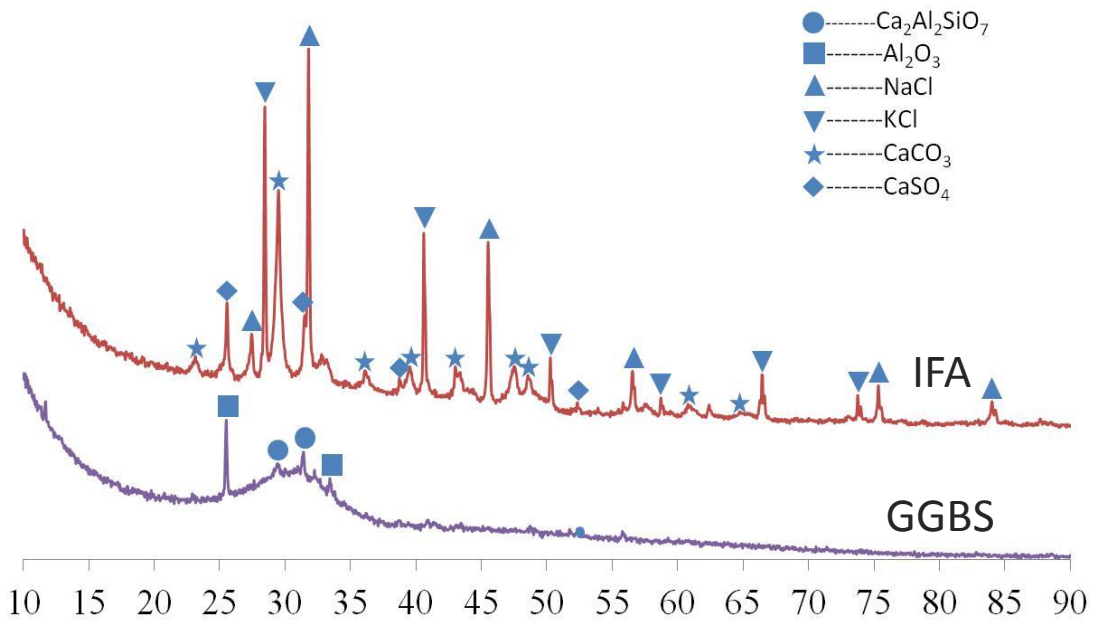
Research motivation & topic

✓Recycle IFA as construction material to prolong landfill lifespan
✓Simultaneously immobilize heavy metal in IFA to decrease environmental impact

GGBS geopolymer incorporating IFA

- Material microanalysis
- Experimental program
- Mechanical strength effect
- Leaching results

Material microanalysis



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%	-

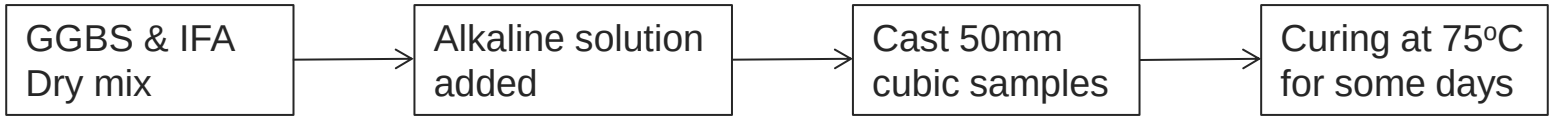
- GGBS: Mainly amorphous Ca-Al-Si content, high reactivity
- IFA: Low Si & Al content, mainly stable crystalline phase, low reactivity

Experimental program

- 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					

- Processing



- Testing

  Compressive strength, leaching test

Compressive strength results

Mix	*GGBS (g)*	*IFA (g)*	*Compressive Strength (MPa)*
A	100	0	38.8
B	97	3	38.0
C	95	5	29.8
D	80	20	20.8
E	60	40	20.9
F	40	60	16.6

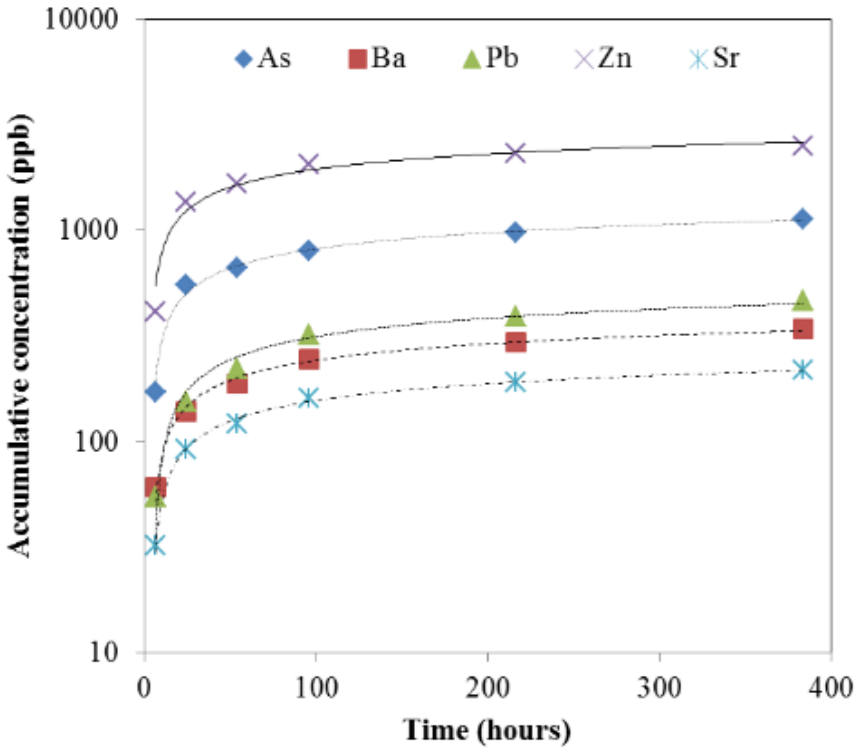
✓ Generally, compressive strength decreased with the increase of IFA content.
✓ Below 3% IFA dosage, IFA filler effect can compensate strength reduction.
✓ At higher than 3% dosage, geopolymerization account for the main reduction of strength

Leaching analysis

Element	*IFA powder 1-hr leaching (ppb)*	*GGBS-IFA geopolymer 6-hr cum. leaching (ppb)*			*GGBS-IFA geopolymer 16-day cum. leaching (ppb)*			*Non-hazardous waste landfill (ppb)*
		IFA:GGBS			*IFA:GGBS*			
		2:8	*4:6*	*6:4*	*2:8*	*4:6*	*6:4*	
As	320	59	120	171	405	776	1,128	2,000
Ba	270	77	70	61	316	331	340	100,000
Cd	10	4	6	9	19	31	50	1,000
Cr	241	2	1	0	5	17	29	10,000
Cu	684	15	19	12	88	98	87	50,000
Ni	9	0	0	0	1	1	2	10,000
Pb	77,980	52	56	55	169	403	463	10,000
Zn	12,830	141	185	411	633	1,333	2,506	50,000
Sr	5,110	18	27	32	191	234	217	5,000

✓ 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
✓ 16-day accumulative concentration of all heavy metal elements are still below the limiting values even at 60% IFA replacement

Leaching of several heavy metals



✓ Increasing rate reduced with time, and gradually tended to zero leaching
✓ Values after 16-day leaching test are still far below limitation

→ **Ensure its safety during service life of infrastructure**

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 chemical bond of heavy metals in GGBS-IFA geopolymer is needed

IFA can be incorporated into the GGBS geopolymer matrix and re-utilized as a construction material

Thanks ☺