Workshop

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Delta Electricity, Sydney, NSW

Managing Coal-fired Power Station Solid By-products

Centre for Sustainable Resource Processing

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Geopolymer Alliance

The Proposal

- The proposal is for Australian black coal-fired power stations (and perhaps the coal industry itself) to join with CSRP – to research, develop and demonstrate that **<u>all</u>** solid wastes can be converted to useful by-products, with simply the application of existing technology.

The Beneficiaries

- If such a project was successful, then the beneficiaries would be:
  - coal industry
  - power stations
  - cement industry
  - geopolymer industry
  - Australia (and potentially the world) as a whole

By-products of Power Generation

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- Coal-fired power stations generate the following by-products during the energy production cycle:
  - fly ash
  - bottom ash
  - heat

Current Production Rates

- In Australia, rough order of magnitude production figures are:
  - Portland Cement = 10 million tonnes per annum
  - Class F ROS Ash = 10 million tonnes per annum
  - Class F Ash used in concrete = 1 million tonnes per annum

Current Uses of Ash

- Typical this small proportion of fly ash is used as a supplementary cementitious material (SCM) in the retailing of Ordinary Portland Cement (OPC) blends.
  - A blended cement = OPC + SCMs + fillers

- The remainder of the ash is used for fill applications (road base for example) or stored in dams and dry stacks.

By-products from Wastes

- In theory it is possible to convert all solid wastes to commercially viable by-products for the construction industry, as:
  - Aggregates
    - sintered and treated as per Granulated Blast Furnace slag
    - geopolymer pellets
  - Binders
    - OPC or geopolymer binder fractions
  - Zeolites
    - ash + water + waste alkali + mild heat

Binder Components

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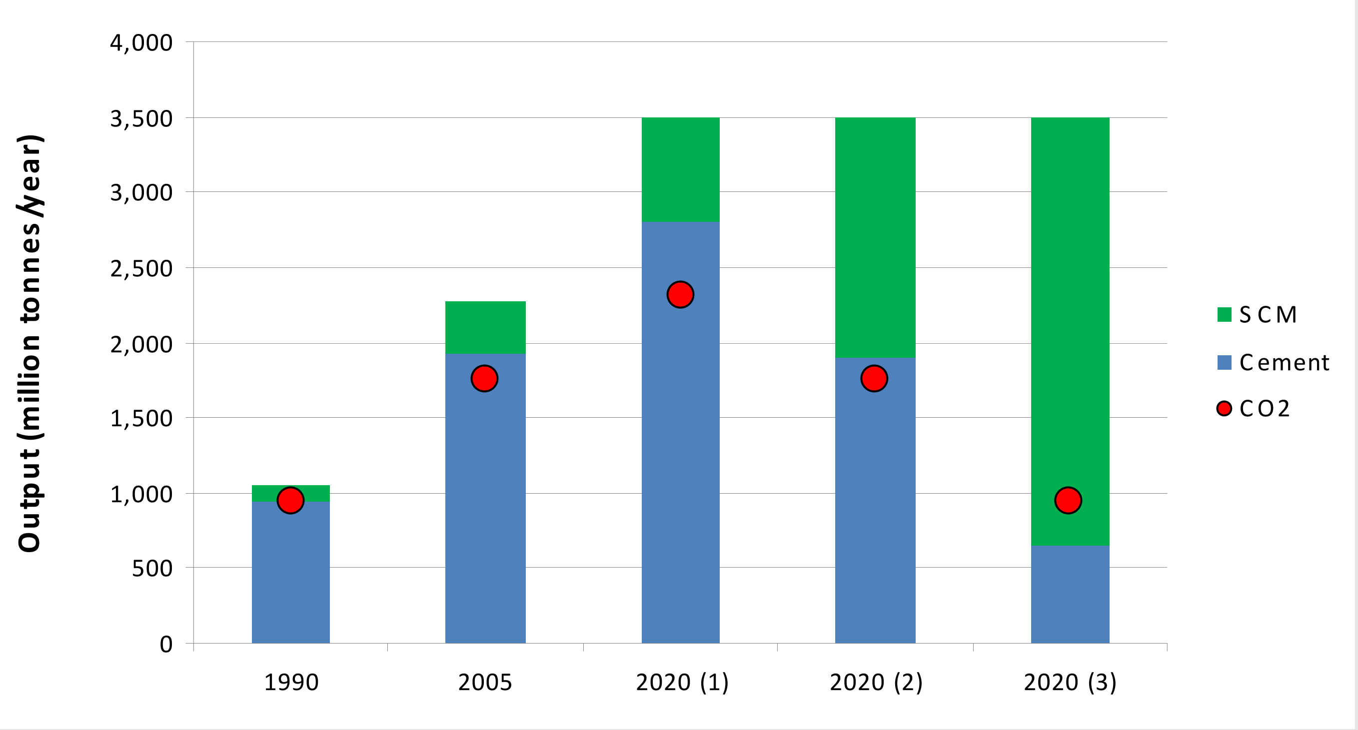
Potential ash-based products include:

- **Activated carbon or char** (typically 5% of ROS ash) – could be sold as an activated carbon or as a char in the iron and steel industry
- **Coarse fly ash** – could be used as a Portland cement binder component
- **Cenospheres**
- **Classified fly ash** – as currently used, as a Portland cement "extender"
- **Coarsely milled Run-Of-Station (ROS) ash** – as a Portland cement replacement
- **Finely milled ROS ash** – as an engineered binder component
- **Very finely milled Classified ash** – as a silica fume substitute
- **Bottom ash** – as a sand in geopolymer concrete

Predicted World Cement Production



The Need for Supplementary Cementitious Materials (SCMs)

- Just pulling emissions back to 1990 levels will require an estimated

3000 million tonnes of SCM per annum throughout the world

- NB: The Australian Government's target is a 50% reduction on 1990 levels

Scenarios for 2020

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- S1: Business as usual
  - even with the best efforts of the world cement industry, CO_2 emissions will **rise** by 130% over 1990 values
- S2: cut CO_2 emissions to 2005 levels
  - means using **4** times the 2005 amount of SCM
- S3: cut CO_2 emissions to 1990 levels
  - means using **8** times the 2005 amounts of SCM
- S4: cut CO_2 emissions to 50% of 1990 levels
  - means basically **not** using Portland cement at all

Future Needs

- To satisfy future needs, particularly when ash is going to be needed to form aggregates, it is likely that demand will outstrip supply.
- To supply such a demand, it will be necessary to recover ash from repositories (ash dams and dry stacks).
- This is perfectly feasible on site, as waste heat can be used to dry the wet ash; and with the addition of coarser mills, the feed can be passed on to the existing dry attritor mill setup.
- The stored ash will not have changed chemically, and milling will enhance physical reactivity.

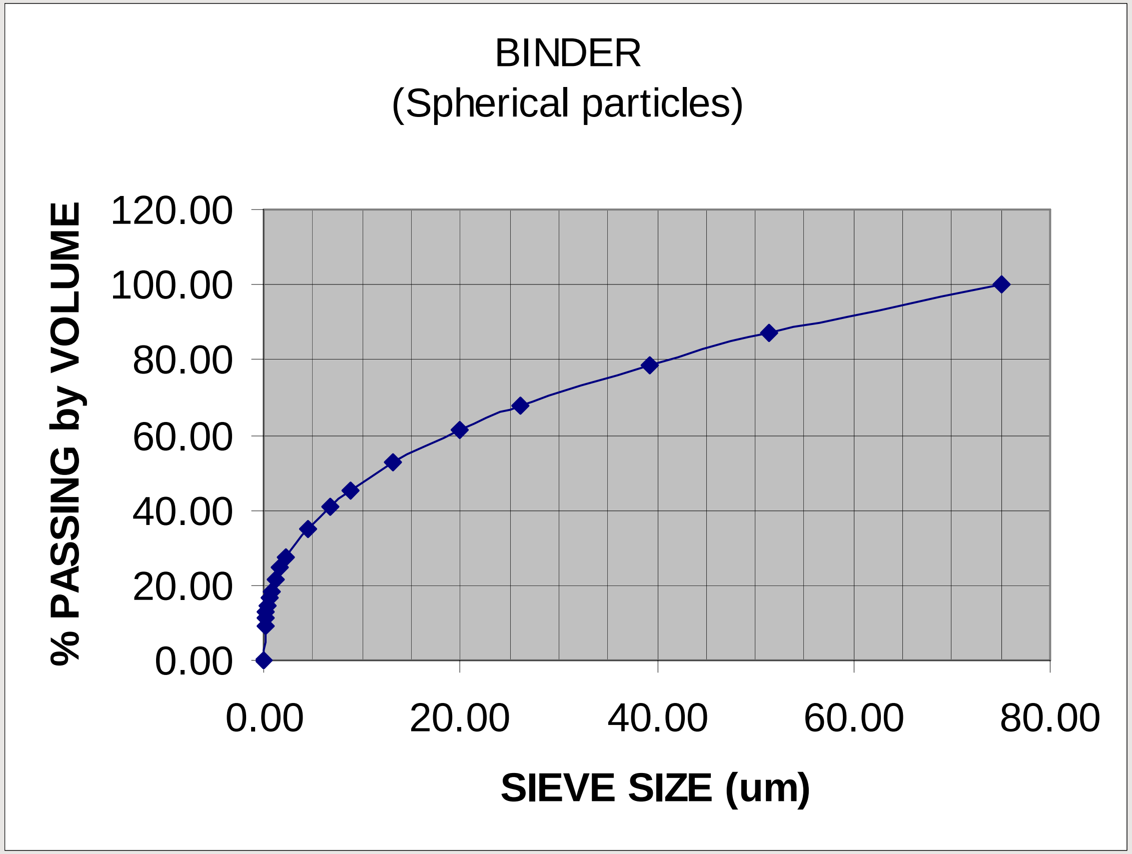
The Need for "Engineered" SCMs

- Currently most SCMs are processed to make them usable in OPC blends.
  - Fly ashes are classified in cyclones to (erroneously) chose only those particles that match the particle size distribution (PSD) of OPC, with the coarser particles (about 60% of the total ROS ash) being rejected.

    <u>To achieve the required quantities, this coarser fraction, or ROS itself will have to be milled.</u>

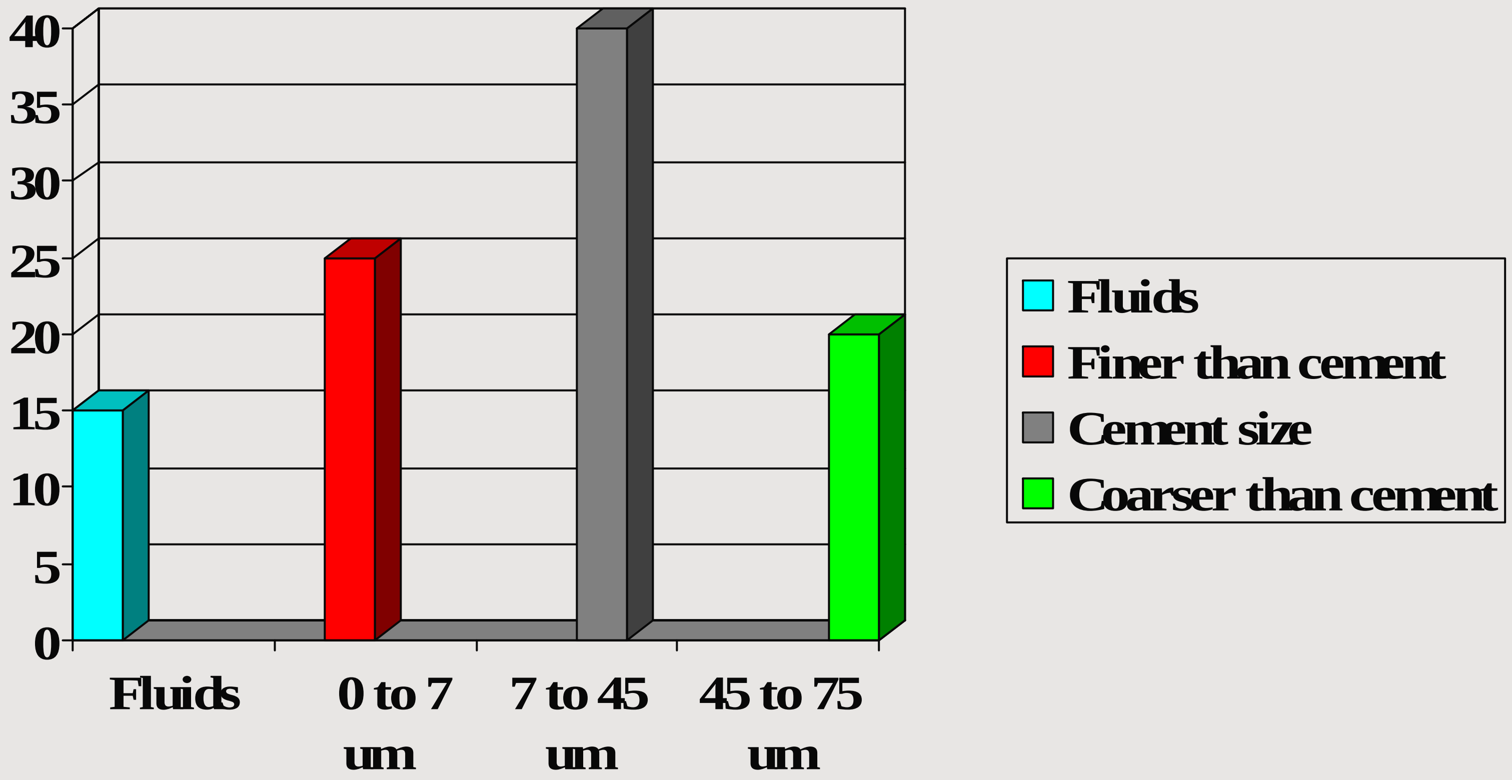
  - Granulated blast furnace slag is ground to form GGBFS.

Optimising Binder PSD:
The Optimum Packing Curve



Binders:

Ideal Particle Size Distribution (% by Volume)



Current Binder Design

- Current design methods end up with a fluids/binder ratio of about 60:40 by volume because water and air have to fill the large void space created by imperfect packing.

- This equals a fluids/binder ratio of about

  0.48 by mass

  (a typical moderately high strength concrete)

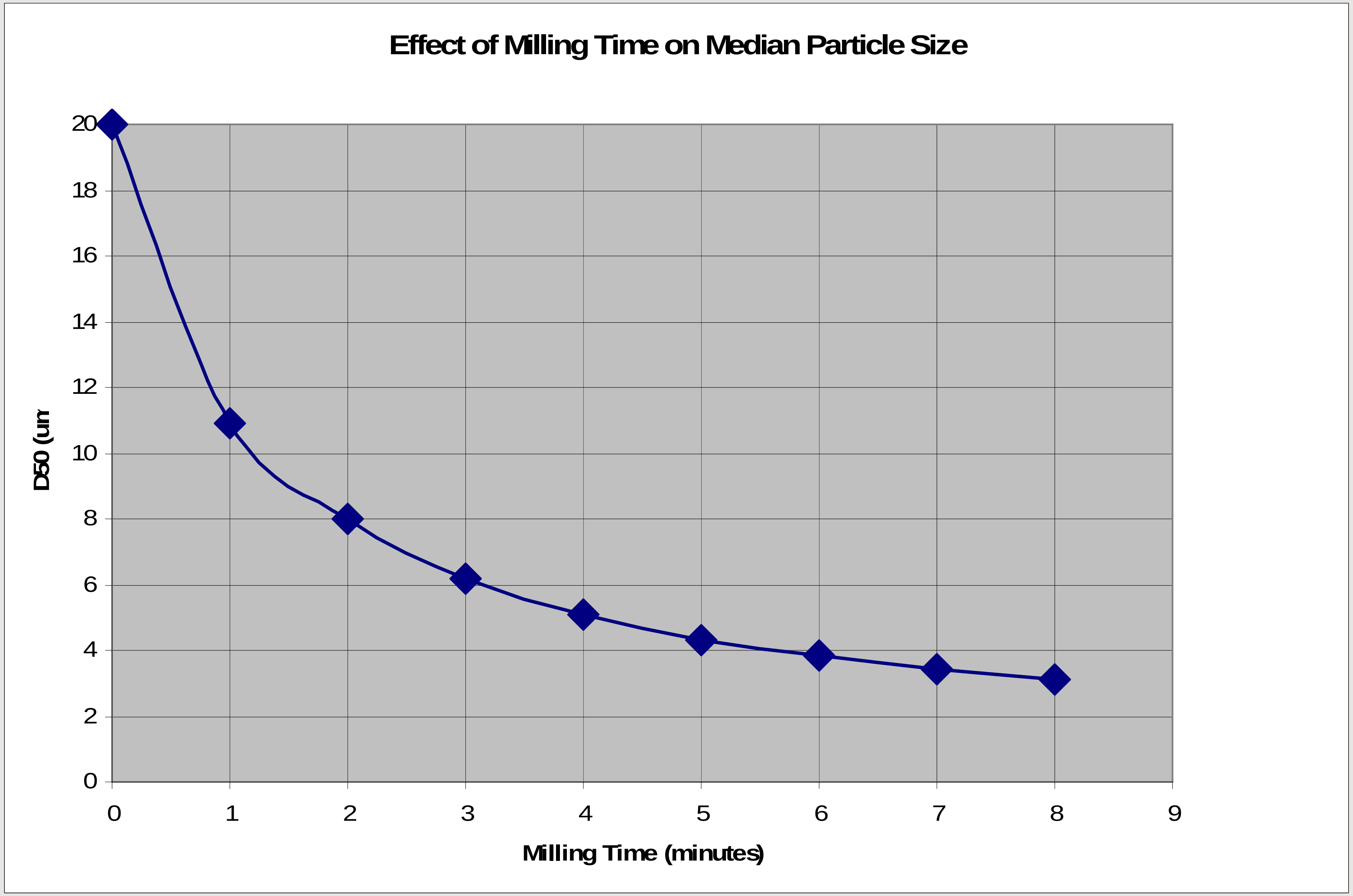
Why Engineer PSD?

- If we engineer PSD to get closer to the perfect packing distribution then:
  - There are less voids between the particles which have to be filled with fluids (water and air)
  - Less water means a stronger paste
  - Less air means a stronger paste
  - A stronger paste means we can increase the ratio of SCMs (or SCMs + fillers) to OPC (currently the ratio is typically about 10 to 25%), and still satisfy concrete performance targets
  - Increasing the ratio reduces CO2 emissions

Fly Ash vs Slag

- There are 2 commercially feasible sources of SCMs in Australia: fly ash and GGBFS.
- GGBFS is more reactive than most unprocessed fly ashes, largely because of its calcium content.
- Fly ash is much easier to mill:
  - Fly ash milling is like crushing egg shells
  - Slag milling is chipping small pieces off hard solid particles
- Milled fly ash has a better PSD than milled slag:
  - Milled fly ash has a single-mode PSD
  - Milled slag normally has a bi-modal PSD (parent particles + chips)

Effect of Milling Time on Fly Ash PSD



What is Engineered FA?

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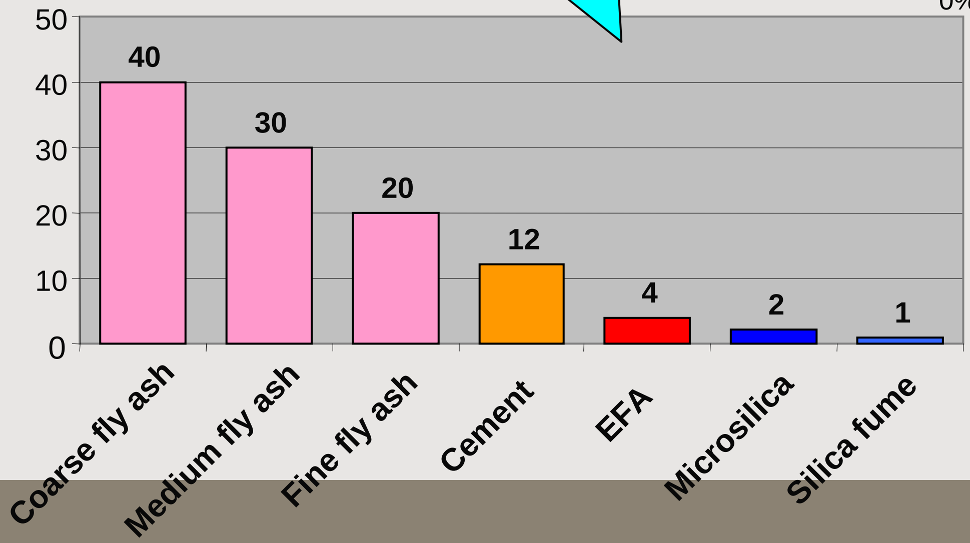
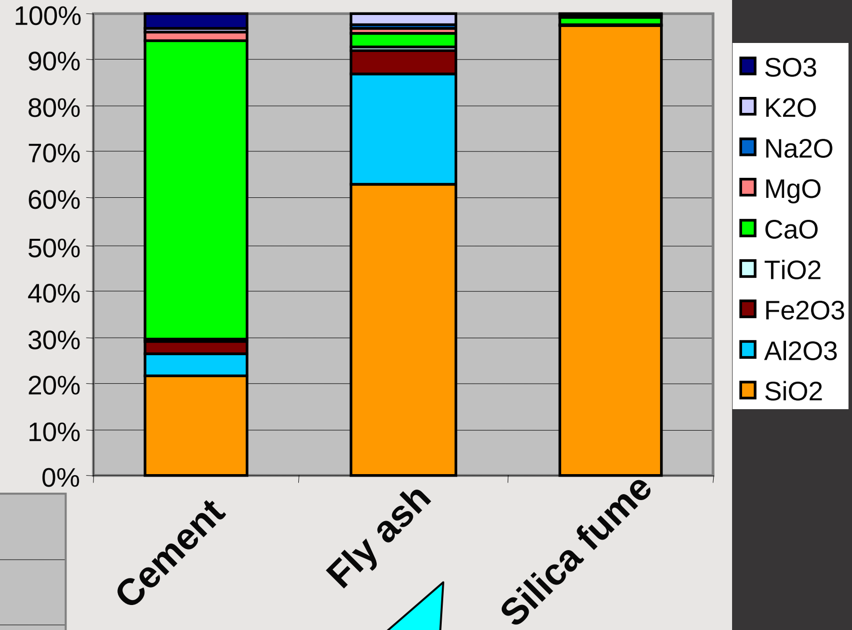
EFA consists of particles about one third the size of cement and one quarter the size of fine grade fly ash.

Median particle size (microns)



Chemical composition



EFA is made by mechano-chemically processing fly ash.

The Synergies of Power Station Ash and Geopolymers

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- Geopolymer binders are composed of only SCMs (no OPC needed).
- The geopolymer industry needs a high volume, more controlled, more uniform feedstock.
  - Currently fly ashes vary considerably because:
    - Coal sources change
    - energy demand changes creating changing burning conditions
    - Amorphous contents and elemental proportions vary with particle size
  - Milling ROS ash removes the latter variable and enhances the activity of the ash.

The Unrecognised Advantage

- Geopolymer concretes can use alkali reactive aggregates.
- Conventional OPC concretes can not, because of the danger of later age ASR cracking.
- Hence GPC can use:
  - sintered or pelletized fly ash aggregate or granulated slag aggregate
  - bottom ash as a sand
  - recycled glass
  - rounded alkali reactive aggregate (there is now both chemical and physical bonding to the matrix)

Geopolymer Concrete Ash Usage

* % by mass

Concrete Type	Aggregate:	Aggregate:	Sand:	Sand:	Binder fraction	Binder fraction	Total % SCM
	Normal	Fly ash pellets or GBFS	Normal	Bottom ash or fine GBFS	OPC	SCM	
A typical OPC concrete	55*		30		12	3	3
A possible geopolymer concrete		55		30		15	100