

TRANSFORMING MINING RESIDUES INTO VIABLE BY-PRODUCTS

Bauxite residue can be beneficiated, using conventional mineral processing techniques, to produce a range of products suitable for use as road base, for agricultural applications and as feedstock for geopolymer cement production. CSRP researchers are currently looking at using the fly ash as a component of geopolymer cement production and have already produced a number of geopolymer products for assessment including footpaths, railway sleepers and fire-resistant coatings for steel structures.

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The CSRP is developing technological solutions to progressively eliminate unused residues in the minerals cycle, while enhancing business performance and meeting community expectations. It is all about:

"Creating a partnership of science and industry to make Australia the best and most efficient mineral and metals processor in the world"

More sustainable use of mineral resources can result from:

- Improved mining techniques to extract more ore (maximise resource utilisation).
- Improving extraction/energy efficiency of unit operations.
- Developing new processes for treating previously sub-economic ores (maximise resource utilisation).
- Recycling end-of-life manufactured products to recover valuable metals (closing the loop).
- Recovering useful by-products from mineral processing residues.

So the question we should ask is: Why not re-use a mining by-product rather than just storing it as if it were a waste?

Australia and other mineral producing countries face a challenge; the generally accepted policy for dealing with mine tailings and process residues is to place them in engineered storage facilities, sometimes requiring long-term, active management. Australia is a world class minerals producer and exporter. Large volumes of residues are currently being stored, for example:

- 40 million tonnes pa of bauxite residue from the alumina industry,
- 14 million tonnes pa of ash from coal fired power stations.

MINIMISE THE ENVIRONMENTAL IMPACT

There is an opportunity to utilise these residues for large volume applications such as civil engineering and soil amendment. Much of this material is located near population centres (e.g. alumina refineries, power stations etc). Using residues would reduce the footprint of these storage areas. Additionally, if we could decrease the need for sand and gravel quarrying by reprocessing tailings then we could minimise the environmental impacts of the bush clearing currently required to produce these construction materials.

Some of Australia's largest volume by-product streams from the minerals and power industries can be used to produce low greenhouse gas construction materials and soil amendment products that address climate change issues and land degradation. This paper discusses some examples of CSRP research for improving sustainability. One of these activities is the Bauxite Residue program for utilising the various components of this by-product derived from alumina production and the other is the Geopolymers program which is investigating alternative uses of by-products from the

mining industry and from coal fired power stations to manufacture geopolymer concretes and cements.

The objective of the CSRP is to **re-direct large volumes** of currently unused resources from the minerals and energy sectors to **beneficial uses** in the construction, agricultural and environmental sectors, thus **maximising the value** to the community, to business and to the environment.

USEFUL BY-PRODUCTS FROM BAUXITE RESIDUE

Australia produces 40 million tonnes pa of bauxite residue (40 % of world production). The fine fraction of this residue (termed red mud) contains a number of potentially valuable components in amounts dependent on the source of bauxite:

- Alumina, Al₂O₃ 10-22 %
- Iron, Fe₂O₃ 14-35 %
- Titania, TiO₂ 3-15 %
- Silica, SiO₂ 3-30 %

Bauxite residue can be used directly as a filler in plastic (India and Taiwan), as a flocculent in waste water treatment, in cement kilns (Jamaica and Germany), in brick or tile manufacture, for composting organic wastes and as a remediating additive for acid soils (Australia, Greece etc). The volumes currently utilised are low.

In a trial associated with the new Perth Bunbury Highway, a demonstration "nutrient trap" comprising bauxite red mud has been installed to improve water quality collected in a constructed wetland by the side of the road. The trap collects water run-off and removes nutrients such as phosphates and nitrates, to help prevent algal blooms in the surrounding waterways. A monitoring program will be carried out by the Department of Food and Agriculture WA (DAFWA)

VALUABLE COMPONENTS CAN BE SEPARATED

Rather than using the total bauxite residue as currently produced and stored, valuable components can be separated and made available to end users as controlled specification feedstocks which can directly replace virgin materials. This would minimise end user resistance to accepting an end-of-pipe residue product. An example of this approach is CSRP's project on the production of ReSand[®], a sand sized fraction extracted from mineral tailings.

West Australian bauxites have high quartz levels – up to 40 % w/w – which results in a high coarse fraction of the bauxite residue (particle size from 70 micron to 1 mm). Work by Curtin University and Alcoa identified a separation/beneficiation process for separating this coarse fraction for use as ReSand[®] for large scale testing. A pilot plant of 10 tonnes per hour capacity was installed by Alcoa (Figure 1) and in 2009 produced several thousand tonnes of sand suitable for road making trials.

A demonstration project with Main Roads WA resulted in this sand being used for several hundred metres of sub-base (shown in Figure 2) for one lane of a new link road from Pinjarra connecting to the recently completed Perth Bunbury Highway. ReSand[®] met all standard industry specifications for road base applications. The performance of the roadway is now being monitored by Main Roads WA, Curtin University of Technology and CSIRO.



Figure 1 Alcoa ReSand[®] pilot plant (photo courtesy of Garside Images & CSRP)



Figure 2 Road construction using ReSand[®] as sub-base. (photo courtesy of DAFWA)

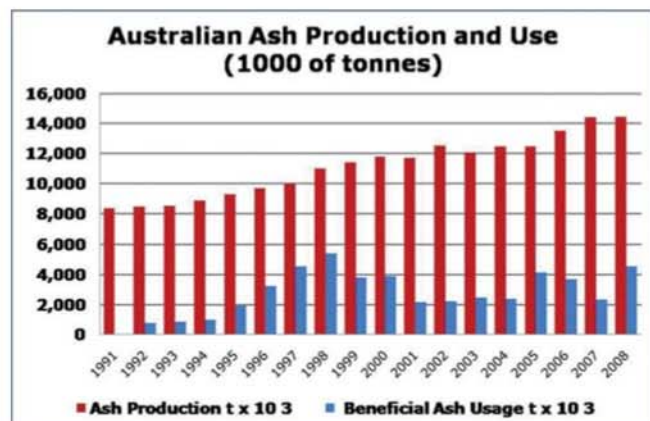


Figure 3 Production and use of fly ash in Australia (Ash Development Association of Australia website <http://www.adaa.asn.au/statistics.htm>).

ReSand[®] was also trialled as a top-dressing for a sports field at Fairbridge, an historic village and holiday camp, an hour's drive south of Perth. Excellent grass growth was observed within a few months of application of around 20 mm of sand.

GEOPOLYMER CONCRETE PRODUCTS FROM COAL FLY ASH

Coal-fired power generation produces 14 million tonnes of ash in Australia annually, most of which is fly ash captured from stack gases. According to the Ash Development Association of Australia, in 2008, 4.5 million tonnes of ash were used for beneficial purposes, amounting to about a third of all ash produced.

Of the 4.5 million tonnes taken from ash dams in 2008, only 1.8 million tonnes went into high value end products such as cement and concrete, while the remainder went into low value applications like mine-site remediation and construction of haul roads.

One of the target uses for fly ash is as a component of a class of high technology cements called 'geopolymers'. These are made from any aluminosilicate source (eg clays, fly ash, slag and other industrial by-products). Fly ash is a good source of aluminosilicates and several examples were obtained from various Australian power stations for investigation by CSRP's research teams based at Curtin and CSIRO.

Geopolymers are inorganic polymers produced by the dissolution of aluminosilicate raw materials in a highly alkaline solution. The resulting paste can be mixed with sand to make mortar or with aggregate to make concrete. Geopolymers can set and harden at ambient temperatures and can be handled like construction materials made from Ordinary Portland Cement (OPC). The CSRP Geopolymer team has investigated the properties of these geopolymer materials and how the varying composition of different fly ashes affects the performance of the final product.



Figure 4 Geopolymer sewer pipe made from fly ash (photo courtesy of Rocla).

ACID AND SULFATE RESISTANT

Advantages of geopolymers over OPC-based concretes include greater durability and a much lower greenhouse gas footprint. Geopolymer-based concrete sewer pipes have been shown to be acid and sulfate resistant which means that their service life can be significantly greater than conventional pipes. Because it is not made from calcined limestone, the geopolymer product has up to 80 % lower greenhouse gas emissions. This is globally significant because OPC contributes 5-8 % of all CO₂ output, second only to the burning of fossil fuels.

Potential applications of geopolymers are numerous:

- Sewer pipes with better acid resistance (Figure 4)
- Railway sleepers with greater flexural strength (Figure 5)
- Light weight, sound absorbing building panels
- Culverts for water drainage

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- Mine backfill using mining tailings
- Tilt-panels for construction with high fire resistance
- Marine breakwaters
- Binding radioactive residues and toxic wastes containing elements such as arsenic for long term storage

CSRP has laid two geopolymer concrete footpaths in the last two years. These were made from fly ash derived from different power stations. Due to the significant variation in composition, specific formulations had to be developed for each fly ash. As shown in Figure 6, the paths were successfully laid with the same equipment, staff and methods employed by the conventional concrete industry. Figure 7 shows the appearance of the path shortly after laying.

Another application which has been identified takes advantage of the high fire resistance of geopolymers. Instead of spalling when exposed to temperatures above 600 °C, geopolymers tend to vitrify and increase in compressive strength. Consequently, geopolymers have potential application as fire resistant panels, as protective coatings on steel frames for high rise buildings and as construction materials which can survive high temperatures while maintaining their strength (eg in road traffic tunnels).



Figure 6 Fly ash geopolymer footpath being laid at Curtin University in 2008. (photo courtesy of CSRP).



Figure 7 Completed fly ash geopolymer footpath at Curtin University in 2008. (photo courtesy of CSRP)



Figure 5 Geopolymer railway sleepers replacing some timber sleepers (photo courtesy of CSRP).

In summary, the benefits of using geopolymers include:

- Reduced greenhouse gas emissions (cement replacement)
- Reduced storage of coal-fired power generation residues in Australia
- Production of new construction materials with wide range of applications.

PROVIDE A CONSISTENT FEEDSTOCK

However, some issues still remain to be resolved. Variability of composition of fly ash is a problem and is related to the coal source and the combustion efficiency of the power station. Excessive iron content can be deleterious and there needs to be sufficient alkali active alumino-silicate present in the fly ash. Consequently, pre-treatment may be necessary as well as some blending to provide a consistent feedstock. Regulatory approval of the use of "fly ash waste" in concrete as well as its acceptance by the construction industry as a substitute for OPC-based products are needed to encourage greater utilisation of fly ash geopolymers. One of the emerging opportunities identified by the CSRP is the idea that the components of bauxite residue (i.e. alkali, sand and red mud) can be combined with fly ash to make geopolymers. In this way, two by-product materials can be combined to provide an environmentally and economically beneficial outcome for the resource industry, the construction industry and the wider community.

CONCLUSIONS

For new projects, proper selection of the processing flowsheet based on sustainability principles will minimise residue and maximise useful by-product recovery while still meeting acceptable production targets. Residue should be regarded as a potentially useful source of by-products with an identifiable market. It should be noted that, in many cases, the by-products are large volume-low value and there needs to be a local market otherwise transport costs will be excessive. Co-location of residues and markets is a feature of several of Australia's alumina refineries (particularly those situated south of Perth in WA) while many coal-fired power stations are near large population centres (eg the Hunter Valley in NSW).

For existing tailings, it is a matter of developing and encouraging viable uses for the stored by-products. The CSRP has carried out sustainability assessments on various residues which have also provided an insight into opportunities. This approach allows identification of:

- Possible useful by-products in residues
- If the by-products can be produced economically from the residue
- If there is a market for the recovered by-products (usually local)
- Any long term consequences of not doing anything with the stored residues.

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