HIGH VOLUME RESOURCES FROM BAUXITE RESIDUE

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Abstract

Alcoa World Alumina (Alcoa) has been investigating opportunities to produce products from bauxite residue for many years. While many products have been produced, their economics are generally unfavourable due to the high volumes of materials that are required to be processed. A new approach has been taken to investigate high volume products in an attempt to improve economics and utilisation of the bauxite residue resource. Three of these potential products are described here, being Red Sand, Alkaloam®, and Red Lime™.

Red Sand has a nominal particle size of +100 micron and is physically little different to crushed bauxite. In Alcoa's Western Australian refineries, Red Sand constitutes up to half of the bauxite residue going to impoundment areas. Trials indicate that this sand can be processed to provide various industrial raw materials. Such materials include: a sand suitable for concrete, a material that is acceptable as general landfill or in road base construction, and a material containing high iron content.

Alkaloam® is the fine-grained residue often referred to as red mud. Intensive research has shown the benefits of adding this material to sandy soils, common in coastal regions of Western Australia (WA). Alkaloam® has properties that can elevate the pH of the acidic soils and also retain phosphorus, reducing overall fertiliser use and protecting sensitive waterways. This work is being expanded in the USA and Brazil.

Red mud has many potential uses within the construction industry. Due to the high content of aluminium and iron in the bauxite residue, there is a potential for red mud to be used as cement feedstock. Preliminary analysis indicated that both brown mud and red mud could be used, limited by the proportion of iron and salt content. Other uses include tile, brick, block and concrete manufacture.

Red Lime™ is a by-product of the refining process. This material has a high acid neutralising value and could be more effective at pH control than most available products, due to the fine particle size and entrained sodium carbonate. Testing indicates this product has potential use as an agricultural lime, a general neutralising agent and as a feedstock for cement manufacture.

1 Introduction

Bauxite residue is a high volume material resulting from alumina refining, and is stored in large secure impoundments close to the refining operations. Approximately 20,000 tonnes of mud and a similar tonnage of sand are produced daily across Alcoa's three Western Australian refineries. A similar level of mud is produced in Alcoa World Alumina Atlantic refineries.

Alcoa has been working toward more sustainable residue management practices for many years. This work has seen a transition from a traditional wet disposal practice to a dry stacking process. This has increased the volume of residue that can be stored within a given footprint and significantly reduced the potential for impacts on the surrounding environment. Research is continuing to look for ways to modify the residue through neutralisation, further lessening the potential for environmental impacts from residue storage activities. However, the ultimate aim in terms of the sustainability of residue management is to identify beneficial uses for the residue.

The move to dry stacking was a critical step along the pathway toward re-use, as it produced a readily accessible deposit of material at a relatively low cost. Neutralisation of the residue is seen as a similar step along this same pathway, as the major hazard associated with the residue (the high pH of the residual liquor) will be removed.

Alcoa continues to support a large amount of research into potential beneficial uses of residue. Potential uses that have been identified and continue to be investigated include:

- Use as a soil amendment to help retain nutrients and adjust soil pH.
- Use as a neutralising agent for treatment of acid mine drainage and amendment of acid producing soils.
- Use as a filtration medium to remove phosphorus and nitrogen from sewage effluent in domestic and industrial septic systems.
- Use as an additive to fertiliser to improve phosphorus retention in soils.
- Use in brick and tile manufacture, both fired and non-fired.
- Use as a filler for plastics, to impart strength, resistance to UV, heat and chemicals, and colour.
- Use as road base, either using the sand fraction directly, or the mud as a component of a composite with gypsum or fly ash.
- Use as a raw material for the production of cement alternatives, such as mineral polymers and ceramics.
- Use of the residue as cement feed stock
- Use as a pigment for a range of applications in coatings and materials manufacture.

The following discussion focuses on three of the more promising re-use opportunities that Alcoa believes hold the greatest potential for large volume re-use of the residue. These include use of the coarse residue fraction (Red Sand) within a variety of construction materials, use of the solar dried fine mud fraction (Alkaloam®) as a soil amendment and also within construction, and use of lime residue (Red Lime™) as an agricultural liming agent.

Table 1. Composition of generic red sand and three potential products (values in %).

SAMPLE NAME	Al_2O_3	Fe_2O_3	SiO_2	CaO	Na_2O
Generic Red Sand	10	26	56	0.6	0.4
Typical Mineralogy following Magnetic Separation of the Generic Sand					
High Iron Red Sand	26	62	5	0.2	0.2
Middle Fraction	7	19	68	0.4	0.2
High Silica Red Sand	2	2	93	0.3	0.1

2 Red Sand

The residue from processed West Australia's Darling Range bauxite is characterised by a high coarse fraction (nominal particle size >100 micron). This fraction can reach 50% of residue volume compared to ca 5% for other typical bauxite deposits from around the world.

As part of the assessment of the potential for use of Red Sand in construction, consideration has been given to potential environmental constraints on the use of this material. Total composition and leachate testing has been carried out, with further work planned to ensure the final product sand meets Department of Environment requirements as an inert fill material. To meet these requirements the following process treatments are likely to be required.

- Remove the coarse lime as a separate residue after causticisation in the refinery. Currently, this lime residue is added to the bauxite residue as a means of disposal.
- Improve the separation of the fine and coarse residue to remove the majority of the <100μm material which will include any residual fine lime and DSP.
- Add additional stages of counter current washing to reduce the level of soluble soda down to low levels.
- Carbonate this final 'washed' residue stream to reduce any remaining caustic to carbonates and bicarbonates, thus reducing the pH to below 10.
- Stockpile this material and allow it to drain down to its natural moisture content (recovering the drainage water and returning it to the liquor circuit).

Alcoa has previously reported (Cooling & Jamieson 2004) a number of tests conducted on laboratory produced samples of Red Sand. The results satisfy the market specifications for fill and road construction sub-grade sands. The fines content ranges from 5–8% < 0.075 mm, and is considered suitable for fill and for road sub grade material. Although Red Sand does not meet drainage sand specifications (1% maximum <0.075 mm), it is still likely to have very good drainage potential. California Bearing Ratio (CBR) values are around 50%. These values are significantly higher than typical sands on the Coastal Plain which have values between 12% and 18% (Golder 2003). The high values can be attributed to the angular nature of the sand. It is likely that the final product sand will be suitable for road embankment construction (including sub-grades and foundations).

3 Magnetic Separation of the Red Sand

Red Sand has proven to be easily processed by a variety of mineralogical separation techniques. Principally through Wet High Intensity Magnetic Separation (WHIMS), a highly magnetic fraction can be removed. This material is termed High Iron Red Sand. Two other products are also generated, these being High Silica Red Sand and a mid fraction.

High Iron Red Sand represents about 40% of coarse residue and has an iron content of 60% Fe_2O_3. This material represents a possible feed material for the new generation of direct smelting iron production facilities. Alumina content up to 25% may require blending with a low alumina feed, however the alumina will report to a slag which may be suitable as cement clinker. Preliminary work has shown that the alumina content can be reduced through high temperature digestion of the High Iron Sand, increasing the iron content to around 75% Fe_2O_3, and reducing the alumina content to less than 10%.

The middle fraction of the Red Sand is the material that can not be readily separated by magnetic processes and represents about 20% of the product. This fraction will likely be used for road construction and general fill. Further development will take place to enhance the separation process to minimise this fraction.

High Silica Red Sand has a SiO_2 content of about 90% and can be cleaned to near white with various attritioning and leach processes. It has been shown that this material can be upgraded further through spiral processing or tables to greater than 98% silica. Tests are under way for use as a surface coating material, for glass manufacture and for fine aggregate in concrete. This fraction represents about 40% of the coarse residue fraction.

4 Alkaloam®

The fine fraction of the residue (nominal particle size <100 micron) is silt to clay sized material and is commonly referred to as 'red mud'.

The use of red mud to improve the nutrient and water retention of the sandy soils of Western Australia was first reported by Barrow (1982). He suggested that the addition of a blend of waste gypsum and red mud to the relatively infertile, acidic sandy soils of the Swan Coastal Plain could improve the water retention, nutrient leaching and productivity of these soils. In this way, a new valuable product can be generated. Heightened awareness of the nutrient problems in the Peel-Harvey Estuary resulted in further research and trials on the use of bauxite residue as an aid in catchment management (Tacey et al. 1984; Vlahos et al. 1989, Summers 2002).

Red mud has the ability to retain nutrients such as phosphorus and to a lesser extent nitrogen, and when added to sandy soil it can substantially decrease the rate at which phosphorus leaches from the soil. Early work involved application rates of up to 2000 t/ha, which substantially modified the structure of the soil. However, transport and incorporation costs made this option impractical. Further trials conducted by the Department of Agriculture, WA, indicate that rates from 20 to 80 t/ha can reduce phosphorus leaching by more than 70 percent. Even lower rates of 5 to 20 t/ha were shown to significantly reduce soil acidity and improve crop yields. Pasture improvements of up to 25% have been attributed to elevation in soil pH and to greater availability of phosphate. (Summers et al. 1996 a, b, 2001)

The use of Alkaloam® in broad acre agriculture and horticulture for nutrient control was approved by the Environmental Protection Authority following a Public Environmental Review (Department of Agriculture 1993). This approval limited the use of Alkaloam® to the Peel-Harvey Catchment, and was conditional on the Department of Agriculture, WA, continuing with detailed catchment monitoring. Results from this monitoring program are reviewed annually by the Department of Environment and are publicly available. Following negative publicity surrounding the use of Alkaloam® in Perth and Sydney based newspapers, Alcoa decided to place the release of Alkaloam® on hold.

Currently the Department of Agriculture, WA, are developing Best Management Practices (BMPs) for improved water quality in the Peel-Harvey Catchment as a part of a federal government funded project under the Coastal Catchments Initiative. As a part of this process, they have reviewed available tools for reducing phosphorus in runoff, and this has included a review of the use of Alkaloam®. Modelling the costs and benefits of the various alternatives has shown that the use of Alkaloam® is the cheapest and most effective management practice available and has the potential for the greatest improvement in water quality from a single management practice. Most other management practices have both a capital cost and an on-going cost. However, Alkaloam® has long term improvements in productivity continuing to generate profit for many years after application. The detailed research by Alcoa and the Department of Agriculture, Western Australia, into the use of Alkaloam® has also made it one of the best studied materials for the improvement in water quality from farmland into the fragile estuarine system of the Peel Inlet and Harvey Estuary.

Further work on the use of Alkaloam® is under way in the US through Alcoa's Technical Centre and in Brazil through the Brazilian Agricultural Agency, Empresa Brasileira de Pesquisa Agropecuaria (EMBRPA). This work is an extension of the testing done in Western Australia, evaluating the potential of using bauxite residue for controlling nutrient and trace metals in agriculture and concentrated animal farming practices. In addition to the stabilisation of soluble nutrients, it is hoped that combining bauxite residue and composting materials could also be used to increase the carbon content in soils (proving an effective means of sequestering CO_2) and reducing the movement of pesticides and herbicides applied to land as part of current agricultural practices.

5 Red Mud as a Feedstock to Cement

Portland cement is manufactured by crushing, milling and proportioning the following materials:

- Lime or calcium oxide, CaO: from limestone, chalk, shells, shale or calcareous rock
- Silica, SiO_2: from sand, old bottles, clay or argillaceous rock
- Alumina, Al_2O_3: from bauxite, recycled aluminum, clay
- Iron, Fe_2O_3: from clay, iron ore, scrap iron and fly ash
- Gypsum, $CaSO_4.2H_20$: found together with limestone

The materials, without the gypsum, are proportioned to produce a mixture with the desired chemical composition and then ground and blended by either a dry process or wet process. The materials are then fed through a kiln at 2,600ºF to produce greyish-black pellets known as clinker. The alumina and iron act as fluxing agents which lower the melting point of silica from 3,000 to 2600ºF. After this stage, the clinker is cooled, pulverized and gypsum added to regulate setting time. It is then ground extremely fine to produce cement.

A preliminary analysis indicated that bauxite residue could be a viable alternate material for the aluminium and iron content in the cement manufacturing process. The high calcium and silica content in the brown mud (brown mud comes from bauxite that is sintered prior to leach process) is especially attractive as alternate cement feed stock.

6 Red Lime™

Lime is used in the Bayer process, primarily to convert sodium carbonate to sodium hydroxide via a process step termed causticisation. The residual lime from this process is a combination of calcium carbonate, mono-carbonate and tri-calcium aluminate. This residual lime is added to the bauxite residue stream as a means of disposal. Pilot trials have investigated the feasibility of retaining the solid residue from this causticisation process as a separate residue stream and producing an agricultural lime from this material to be traded as Red Lime™. Field trials aimed at evaluating the efficacy of Red LimeTM have commenced through the Cooperative Research Centre for Sustainable Resource Processing with the field trials being coordinated by Department of Agriculture WA.

Table 2 Composition of a potential Red Lime™ product.

Mono Carbonate	Tri-calcium aluminate	$CaCO_3$	Moisture
10%	35%	21%	20%

The neutralising value (NV – expressed as a percentage of calcium carbonate equivalent) for typical agricultural liming agents range from 50–80% (Department of Agriculture 2002). Agricultural limes with a NV above 60% are considered of higher grade. Red Lime™ has a NV greater than 75%. The material is fine grained so release of the alkalinity is relatively fast. It also has a level of soluble alkalinity that will be flushed into the soil with the first rains, providing an immediate soil pH adjustment. The product will be of a consistent quality, overcoming variability associated with some natural sources of agricultural lime.

Table 3 Particle size and neutralisation value for Red Lime™.

Sieve Range mm	% wt	N V %
0-0.125	23.7	84.6
0.125-0.25	26.7	77
0.25-0.5	28.1	79.1
0.5-1	7.4	79.8
>1.00	14.1	82.5

Red Lime™ is also being investigated for use as a reagent for flue gas scrubbing, for treatment of acid mine tailings, for remediation of Acid Sulphate Soils and as a feedstock for the manufacture of cement.

7 Conclusions

Development of alternative uses for bauxite residue has been one of the major objectives of Alcoa's residue development program since 1978. Research and development activities in this area have continued, as Alcoa believes that it is important to demonstrate that the residue is a potentially useful material rather than a waste. Alcoa also recognises that if significant re-use can be achieved, the rate of expansion of the residue storage areas can be slowed, and the potential for long term impacts related to residue storage can be reduced.

Re-use of residue should be from multi-application approaches with the deployment focusing on local uses. Opportunities such as Red Sand, Alkaloam®, cement feedstock, and Red Lime™ if realised, will represent a significant reduction in the volume of residue currently being placed in storage areas, and provide a valuable resource to a range of users.

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