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Bauxite Residue Handling Practice and Valorisation Research in Aluminium of Greece*

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Abstract

The Mytilineos Metallurgy Business Unit, former Aluminium of Greece (AoG), is one of the few vertically integrated alumina and aluminium plants in the world, exploiting mainly Greek bauxite ores. Since 1991, AoG has been actively pursuing new and sustainable ways not only to safely store Bauxite Residue (BR) but also to valorise it as a secondary raw material resource. In this paper, the handling practice of filter-pressing the BR for dry disposal is presented, along with the major research results for BR valorisation produced the last decades in cooperation with NTUA, KU Leuven and other universities. Aspects of policy and legal framework, as well as process economics are also presented herein in light of formulating a pragmatic strategy for achieving a zero waste alumina production process.

Introduction

Management and storage methods of bauxite residue have developed gradually over the decades.[1] Prior to 1980, most of bauxite residue (BR) was stored in lagoon-type impoundments and the practice is still carried out at some facilities. As land for lagoon storage became scarce for many plants, "dry stacking" methods were adopted. Whilst dry stacking methods were first adopted in the 1940s, dry stacking has become the prevailing industrial practice since the 1980s, aiming to reduce any leakage potential of the caustic liquor to the surrounding environment, reduce the land area required, and maximize the recoveries of soda and alumina. Filtration using drum filters and plate and frame filter-presses to recover caustic soda, produce a lower moisture and more handle-able BR is now growing in usage. In addition to helping recover more caustic, this trend provides considerable benefits in terms of reuse, as the material is normally produced as a filter-cake, with typically less than 28% moisture and lower soda, thereby substantially reducing transport issues and costs.

* Keynote paper

Current management of Bauxite residue in Greece

Mytilineos SA-Metallurgy Business Unit, Alumina and Aluminium plant (former Aluminium of Greece), is the only alumina refinery in Greece, processing each year about 1.8 Mt of bauxite ore (originating mainly from Greek bauxite mines), for the production of more than 800 kt of alumina and 750 ktons of BR. In 2006, the plant installed its first high-pressure filter press in Europe which produced a relatively dry BR. During the period 2006-2011 a total of 4 filter presses were installed and since 2012 all BR produced is filter-pressed and stored as a “dry” (moisture < 26%) by-product in an appropriate industrial landfill (Figure 1).

Figure 1. Filter press in operation and BR discharge (above); site of BR disposal in the plant (below)

Currently, dry stacking of filter-pressed BR is the best available technique worldwide for BR management since it significantly decreases the waste volume to be deposited, eliminates the risk of dam failure and allows for direct transportation and utilization of the BR in other applications, such as in the construction and cement industry.

Past activities for Greek BR utilisation

Past activities and research for Greek BR utilisation[2] involve the direct utilisation of BR in cement industry, production of bricks, soil remediation and water-permeability barrier in landfills, road base construction etc. (Figure 2). Despite the many efforts made, the only utilisation of Greek BR currently taking place is in cement production, where up to 40 kt are used each year, in two cement plants in Greece and Cyprus. In both cases, BR is transported by ship at a moisture level of about 18% (achieved through sun drying of the filter cake for one month). The factors limiting the higher utilization of the Greek BR in the cement industry are mainly the low production volumes of the Greek cement industry due to the ongoing financial crisis as well as the legislative barriers described at the end of this paper.

Figure 2. Examples of developed and tested BR utilization options since 1991

Bauxite residue as resource in Europe

Bauxite residue from the alumina industry is stockpiled at a rate of approx. 6-7 Mt on a dry basis per year in Europe:

- With an average iron oxide content of 40 wt%, it can be considered as an equivalent of 3.4 Mt of iron ore available in Europe. This could result in a 4% decrease in iron ore imports and an 18% increase in European iron ore production.

- With an average alumina content of 20 wt% and some properties resembling clay-like behaviour, BR is a valuable raw material for various building applications.
- The Bayer process for alumina production cannot achieve more than 90% alumina leaching efficiency. The remaining alumina of the bauxite is lost in the bauxite residue where it is present at levels of 15-20wt%. Recycling this alumina content to the alumina refinery or valorising it into other application (i.e. cement production) would mark 100% extraction efficiency of alumina from the initial bauxite ore.
- BR is a considerable resource for REE/Sc. Extracting the REE from Aluminium of Greece's annual BR production can meet the needs of approximately 10% of the European REE demand.
- Gallium is found in bauxite ores at levels of 30-80 g/t and is dissipated in the alumina and BR streams; extracting gallium from both the BR and Bayer liquor from a single European alumina refinery would amount to global levels of gallium production (annual world production 284 t in 2012).

Recent and new efforts in Greece and Europe

In the past decade, AoG in cooperation with universities like NTUA, KU Leuven and RWTH, as well as with several other partners, has developed the Mud2Metal concept which proposes to solve the BR disposal problem through technological innovations and co-generation of products.[2] Using this approach, a sustainable flow sheet can be developed which transforms BR from a waste into a multitude of high added-value products, as shown in Figure 3. Adopting this scheme would lead to a multitude of products that would secure both the economic viability of the flow sheet as well as the complete utilization (near zero-waste) of the BR produced by the alumina industry. Iron alloy and cement are two products with huge market applications which can absorb the majority of the BR volume. In addition, niche applications like REE compounds, Al-Sc master alloy, mineral fibre products, and specialty cements with more limited markets in term of product volumes but significantly higher product values, strengthen the financial viability of the overall process.

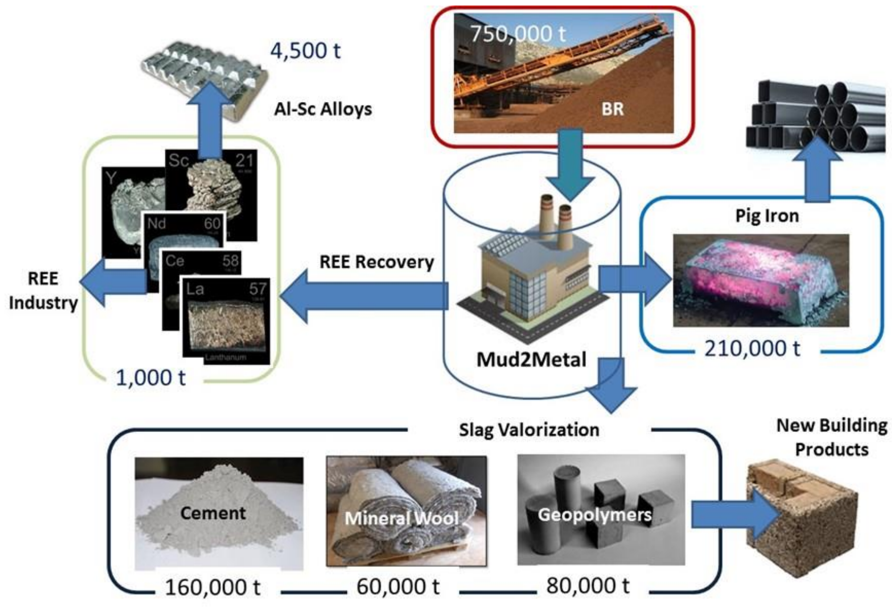

Figure 3. The Mud2Metal concept of BR utilisation

Towards this direction the plant participates in and/or coordinates several collaborative R&D projects described briefly below:

ENEXAL (energy-exergy of Aluminium industry) [2010-2014]

Under the ENEXAL project,[3] the first near zero-waste solution for BR was demonstrated in pilot scale at AoG. More than 35 t of BR where processed in a 1MVA Electric Arc Furnace to produce pig iron suitable for the secondary steel industry and slag suitable for mineral wool production.[4] While the project resulted in a techno-economically successful process, it could only be applied to a small fraction of the annual BR production, as the mineral wool market is limited in volume and rather local, considering it uneconomical to transport mineral wool over large distances.

EURARE (European Rare earth resources) [2013-2017]

Under the EURARE project,[5] the first REE concentrate from BR was produced, through a novel Ionic Liquid leaching process where a selective leaching was developed to extract REE against the major metals found in BR (Fe, Ti, Al, Si).[6] Despite the extremely low REE concentration in BR, the process could be feasible by employing innovative and selective extractive techniques.

MSCA-ETN: RED MUD [2014-2018]

Under the RED MUD European Training Network, 15 early stage researchers perform their doctorate studies across 7 European Universities (including NTUA, KU Leuven, and RWTH). All these explore different, yet complementary processes, aiming to recover valuable elements and reuse the BR in an industrial process. The BR from AoG was used as the test material in all studies, while 2 of the PhD students conducted their research at the AoG plant.

SCALE (Scandium –Aluminium in Europe) [2016- 2020]

In the ongoing SCALE project,[7] Figure 4, a pilot plant is being set up to demonstrate scandium extraction from BR, through the use of a sulfuric acid based process developed by NTUA and a novel Sc-specific separation process developed by the company II-VI.

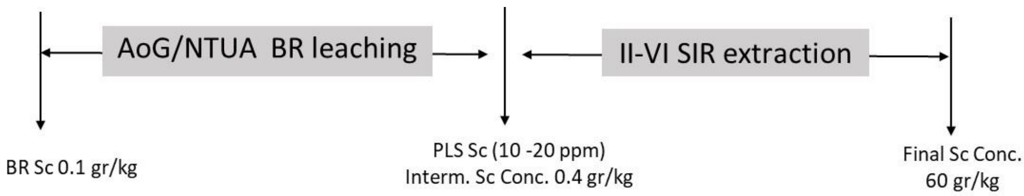

Figure 4. Planned flowsheet for Sc extraction at the SCALE project

ENSUREAL (Ensuring sustainable alumina production) [2017- 2021]

In the ENSUREAL project,[8] the Pedersen process for the co-production of iron and alumina through a combination of Electric Arc Smelting and Sodium Carbonate leaching will be tested on BR. The goal is to recover both Fe and Al from the BR.

SIDEREWIN (Sustainable Electro-wining of Iron) [2017- 2022]

The SIDERWIN project,[9] coordinated by ArcelorMittal, aims to further develop the alkaline electrolysis process for iron production in pilot scale. Under the same project, AoG and NTUA aim to adapt the process to BR, targeting the electrorecovery of iron form the alkaline pulp produced in the Bayer process.

REMOVAL [2018- 2022]

The RemovAl project, Figure 5, is scheduled to begin in May 2018. It is coordinated by AoG and the strong consortium of 29 members includes the majority of alumina producers in Europe. Its premise and mission are that BR reuse solutions do exist as stand-alone but pooling them together in an integrated manner is the only way to render BR reuse viable from an economic point of view and acceptable for the industry. The RemovAl project will combine, optimize and scale-up developed processing technologies for extracting base and critical metals from selected industrial residues (BR predominantly) and valorise the remaining processing residues in the construction sector. The technologies and pilots plants to be used, in most cases, have already been developed in previous or ongoing projects and through RemovAl they will be pooled together and utilized in a European industrial symbiosis network.

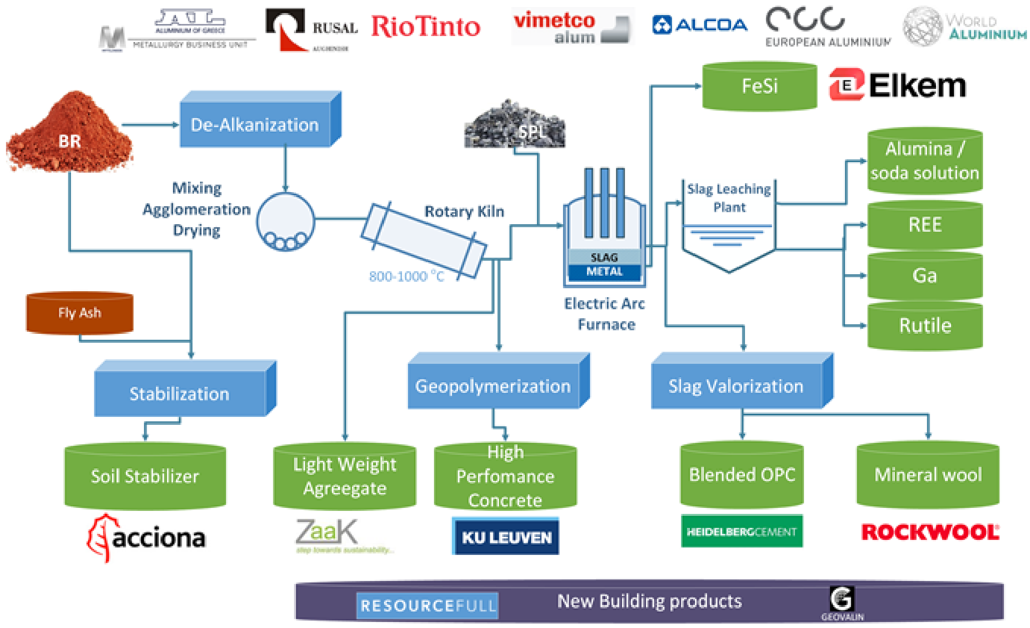

Figure 5. Visualization of combined processing to be tested at pilot scale in the RemovAL project

Main barriers in industrializing BR recycling solutions

The main barrier in applying any solution for the valorisation of BR is not necessarily the techno-economic viability of the solution but often the legislative environment for applying the solution. The simplest BR recycling option, utilization in the raw meal of cement clinker, is hindered by the European waste legislation that dictates that the cement company receiving BR should have the appropriate license which allows it to utilize/process wastes in its operations. When said company is in a different country from the alumina refinery, a specialized transfer procedure is needed. And while most cement plants have licenses to process waste materials, the same is not true for other sectors (iron industry, building materials, etc.), which could implement novel BR reuse solutions. In sending BR to another industry for valorisation, an EU alumina refinery today, must face:

- Costs for licensing the transfer and the cost of the transfer itself (particularly higher if transportation is crossing national borders)
- Potential gate fees costs at the end-user industry, a practice that is very common, effectively negating the premise of circular economy.

The alternative, to landfill BR, is often not only the most economical solution but in addition, the far less complicated one. To change that, lifting the existing barriers is critical and two main policy actions are identified:

- Simplify the de-characterization process for BR (especially when it is delivered as a material with less than 30% moisture) from waste to by-product or raw material. This would greatly simplify both the transport and the reuse of BR in other industries, driving down costs and time. The legislative framework for this already exists in EU under the The Waste Framework Directive and its amendings (2008/98/EC)* under which a non-hazardous waste can be de-characterised if appropriate conditions exist, such as: that there is use for the waste in another process, that the use of the waste does not pose a threat to human health and others. However such de-characterisation decisions are very difficult to be reached independently by national governments, as such issues are very sensitive for the public. A related EC wide directive/policy on the conditional de-characterization of BR is needed.
- Provide incentives to industries for prioritizing the use of industrial by-products over virgin raw materials. Currently, industries that could utilize BR as iron and alumina sources in their process have no incentive to do so, as virgin raw material are cheap and their use far less complicated. Companies would only use BR if it comes at a lower price or even at a negative price (gate fees). EC needs to provide economic and commercial incentives to industries that promote circular economy practices, otherwise, by-products like BR will only be utilized where and when virgin raw materials are scarce or depleted. Incentives could have the form of tax reductions, CO_2 emission allowances, green product labels, and others.

Acknowledgments

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* The Waste Framework Directive and its amendings (2008/98/EC) set the basic concepts and definitions related to waste management, such as definitions of waste, recycling, recovery. It explains when waste ceases to be waste and becomes a **secondary raw material** (so called **end-of-waste** criteria), and how to distinguish between **waste** and **by-products**. The Directive lays down some basic waste management principles: it requires that waste be managed without endangering human health and harming the environment, and in particular without risk to water, air, soil, plants or animals, without causing a nuisance through noise or odours, and without adversely affecting the countryside or places of special interest. The Waste Framework Directive also contains a list of waste and hazardous waste (marked with an asterix). The inclusion of a substance or an object in this list shall not mean that it is a waste in all circumstances (Art. 7.1 of 2008/98/EC). The subject or object is only a waste in case the holder discards or intends or is required to discard (Art. 3.1 of 2008/98/EC).

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