Developing a Parallel-to-Aluminium Value Chain for Scandium and Al-Sc Alloy Production. Pilot Scale Results under the SCALE Project

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Abstract

Bauxite residue produced from the Bayer process from alumina production has been identified as a potential source for scandium extraction. Scandium found in the initial bauxite ore is concentrated in the bauxite residue (BR). In the case of the Greek BR, scandium concentration varied between 80-120 mg/kg over the past seven years. With an annual production of 850 kt BR at MYTILINEOS alumina refinery, 70-80 t of Sc dissipate each year in the BR by-product stream. Under the 4-year collaborative H2020 SCALE research project, a novel process to extract Sc from BR was developed and evaluated in an industrial pilot scale. Over 10 t of BR was leached with sulfuric acid solution to produce a low impurity Sc pregnant leach solution (PLS) suitable for ion-exchange extraction, utilizing the novel proprietary "Selective Ion Recovery (SIR)" process, developed by II-VI. A crude concentrate was produced using the SIR technology to upgrade scandium by more than 2500 times into an intermediate concentrate having 22 % Sc, 15 % Ti and minor impurities. The crude concentrate at this Sc level would be a suitable feed material for pure Sc_2O_3 / ScF_3 production using existing technologies. The leached BR was neutralized and depleted in soda, making this material more attractive for BR reuse options such as cement and iron production. The end goal of Sc recovery from BR is the production of Al-Sc alloys, the use of which is expected to rapidly increase in the next decade, given their impressive properties in strength, weldability, corrosive resistance, and application in 3D printing. Lab-scale electrolysis trials at SINTEF in a cryolite melt with Al_2O_3 and Sc_2O_3 as feed material, successfully led to the production of Al metal with ~2 % Sc at current efficiencies ranging from 85 to 90 %. Thus, a new parallel-to-aluminium value chain for Sc production can be established.

Keywords: Scandium, bauxite residue, leaching, ion-exchange, Al-Sc alloys.

1. Introduction

'Bauxite residue' (BR) refers to the insoluble solid material, generated during the extraction of alumina (Al_2O_3) from bauxite ore using the Bayer process. When bauxite ore is treated with caustic soda, the aluminum hydroxides/oxides contained within, are solubilized, with approximately 50% of the bauxite mass being transferred to the liquid phase, while the remaining solid fraction constitutes the bauxite residue. It is estimated that for each ton of alumina produced, 0.9-1.5 tons of solid residue (on a dry basis) are generated depending on the initial bauxite ore

grade and alumina extraction efficiency [1]. Bauxite residue contains various major (g/kg) oxides of Fe, Al, Ti, Ca, Si, Na, as well as minor (mg/kg) oxides like V, Ga, REE/Sc and others (depending on the initial chemical composition of the bauxite ore) along with inclusions of unwashed sodium aluminate solution.

The worldwide typical concentration of REE in BR is 800-2500 mg/kg and is related to the initial bauxite ore and the operation conditions of the Bayer process [2]. Typically, REE are hosted in alumina bearing minerals of the bauxite ore, which are dissolved during the Bayer process; the contained REE are incorporated into secondary precipitation phases known as "desilication products - DSP", a mineral matrix that contains a mixture of Fe, Ti, Si, Al, Ca and Na ions [3]. Scandium often differs from the other REE in its mineral behavior; especially in lateritic bauxites and their corresponding BR, it is often correlated with iron, titanium and zircon minerals [3-5], which for the most part are unaffected through the Bayer process. This is also confirmed by the laterite deposits in Australia and the Greek BR [6] where the main mineral, with high concentration of Sc, is goethite [7]. However, there are cases of BR, where scandium is related to larger extent to the soluble Al-bearing minerals [8]. It has been estimated that 70% of the world's Sc resources might be found in bauxite minerals and bauxite residue [9].

The present work, under the H2020-SCALE project, focuses on developing a novel value chain from BR to Al-Sc master alloy, that runs parallel to that of the primary aluminium. The process starts with BR as the Sc source, from which Sc is selectively leached into solution with sulfuric acid [10-13]; followed with the II-VI Selective-Ion Recovery (SIR) technology [14-15] to extract Sc from the leach solution and produce a crude Sc concentrate, suitable for Sc_2O_3 oxide production based on established technologies; and concludes with Al-Sc metal production through co-electrolysis of Al_2O_3 and Sc_2O_3 in the Hall-Heroult cell [16]. Following small pilot leaching scale tests coupled with lab scale SIR testing, the optimum leaching conditions to maximize loading of Sc while maintaining steady operation of SIR were established [13]. A year-long pilot campaign followed at MYTILINEOS, in which more than 10 t of Bauxite Residue were leached producing 14 m^3 of Pregnant Liquid Solution (PLS), 10 m^3 of which were processed with SIR to produce a 22%wt crude Sc concentrate. In parallel, lab scale and bench scale tests were conducted to achieve and validate the modified Hall-Heroult at SINTEF.

2. Experimental

The MYTILINEOS acid leaching pilot plant consist of a series of PP (Polypropylene) reactor tanks, at 800 L capacity, with mechanical steering and heating/cooling through immerged coils for circulating steam and cooling water, respectively. Filter pressed BR produced at MYTILINEOS alumina refinery is mixed with industrial water in the first reactor (100-TK-10) to produce a pulp of specific density measured through an inline Coriolis Mass Flow Meter. The pulp is pumped to the second reactor (100-TK-30) where it is heated and contacted with concentrated sulfuric acid. The leaching takes place at 85 ºC with a retention time of 30 minutes. The pulp exiting the 100-TK-30 is driven to the cooling tank (200-TK-40) where it is cooled to 60 ºC and is subsequently passed to the filter press circuit. The Filter press separates the solids from the liquids, generating the final PLS to be used for the SIR process. Filter press used consists of 25 frames 470x470 mm having 11 chambers plates and 12 membranes plates and a filter area of 6,6 m^2. Inlet slurry pump is a diaphragm pump with a maximum working pressure at 15 bar. In the filter press the cake washing is conducted directly, as fresh water is pumped through the cake and collected at a separate tank. Cake squeezing, and cake air blowing are also applied in the filter press, before the cake discharge.

aluminum smelters (Figure 8). The BR leaching process can be integrated in the alumina refinery at the final stage of BR washing, just before filter pressing (or pulp disposal). Based on the achieved results, in the case of MYTILINEOS SA, which consumes annually 1.8 million tons of bauxite ore to produce 835,000 t of alumina and 850,000 t of BR, a total of 62 t of 22 % Sc concentrate can be produced, which in turn are refined to 22 t of Sc_2O_3. The latter can be returned to the aluminium smelter to produce the 733 t of Al-Sc 2% master alloy.

The new flowsheet can achieve sustainable co-extraction of Sc from bauxite ore, adding value to the final product of the aluminium smelter. Furthermore, the neutralized BR cake, produced in the process, is depleted of alkalinity, and has an increased amount of calcium sulfates, which makes it more attractive for reuse in Ordinary Portland Cement (OPC) production.

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