

Towards Sustainable Zero Waste in Alba

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Abstract

Spent pot lining (SPL) material is a hazardous waste generated during the process of aluminum smelting. SPL is toxic material that is contaminated with cyanide and fluorides. In many cases, landfilling is the conventional methodology of handling this waste, which is not a sustainable solution.

ALBA has taken the lead to construct and implement the first of its kind technology in the GCC region to process and detoxify the SPL and convert it to a valuable additive material for the cement industry. This paper discusses the project development and the challenges aroused during the project evolution. It will also focus on the process flow and the detoxification methodology as well as the final product and its specification. Finally, the paper will discuss the marketing of the final product and its benefits and impact on cement industry.

Keywords: Aluminium smelting, Spent pot lining (SPL), Solid waste, Clinker, Zero-waste.

1. Introduction

Solid waste generation and management has become a serious issue of concern, especially in aluminum smelters where it represents one of the intractable environmental challenges. Aluminum smelters are in the heart of industries where different types of solid waste are being generated part of which are being hazardous waste. Typical solid waste generated by aluminum smelters are Carbon Dust, Cast Iron Slag, General Waste, Refractory Waste, Construction Waste, Spent pot lining (SPL) and others. SPL represents around 50% of the total solid waste generated in the aluminum smelting process.

SPL material is comprised of carbon and refractories and has been categorized as hazardous waste by many regulators as it exhibits several characteristics that make it toxic. Carbon cathode gets contaminated with fluorides and cyanides during the operation of the reduction cells, and these contaminants have the potential to leach into the ground water if the material disposal is not managed well. Additionally, SPL reacts with water to generate a strong basic solution that is highly corrosive and also emits flammable and explosive gasses in the process such as methane and hydrogen and toxic gasses such as ammonia. Figure 1, SPL removed from the reduction cell.



Figure 1. SPL removed from the reduction cell.

Disposal of SPL has been carried out conventionally through either landfilling direct, or washing in sea water before taking the material to a landfill. It requires the material to be landfilled in specifically engineered landfills that are fully insulated and designed to prevent contamination of soil and ground water. These methods have become unfavorable by many environmental regulators and more sustainable methods are sought that encourages sustainable solutions and the full recovery and conversion of the material to useful end products with zero-waste output and very low environmental footprint.

SPL mainly contains carbon (40-50 %), fluoride at around (10-18 %), aluminium (10-13 %), and cyanide (0.7- 4.5 %). Such material can be useful in certain processes like cement and steel industries that is both economical and environmentally sound [1]. The most valuable constituent in this case is the fluoride which serves to lower the temperature of clinker in the cement industry and improves the formation of complexes inside the clinker [2] so that a higher yield of Portland cement is obtained.

2. Exploring the Optimum Process for ALBA's SPL Treatment

The journey to reach and identify the most suitable SPL treatment process for ALBA has taken almost a decade where a common effort with the GAC smelters was started in 2008. In 2009 ALBA sent a team to evaluate many different processes/approaches by which SPL was being handled. The team concluded that the processes/approaches evaluated then were neither mature nor complete. Nevertheless, ALBA management didn't stop the effort and started again to look into the possibility of collaborating with a small cement plant available in Bahrain. Unfortunately, this collaboration didn't grant the aimed result due to the small size and other limitation with the cement plant. ALBA's efforts continued into 2017 where some potential processes were identified again and an evaluation process started.

2.1 Technology Selection

After shortlisting the potential treatment processes and associated technology suppliers, it was decided to approach three suppliers to evaluate their offerings and to short list a recommended supplier. Based on the thorough analysis, technology benchmarking and due diligence, REGAIN technology was selected. REGAIN technology has been handling Tomago smelters SPL since 2003.

3. The Treatment Process

3.1 PL Cyanide and Flammable Gas Hazards

Over the life of the pot, the lining is progressively penetrated by aluminium metal, sodium metal and the sodium aluminium fluoride/sodium fluoride electrolyte. Chemical reactions in the lining result in the formation of various carbides, nitrides and cyanides within the pot lining. Indicative examples of the chemical reactions are:

1. Reaction of cryolite with nitrogen and sodium to form nitrides, e.g.,

$$\text{Na}_3\text{AlF}_6 + 0.5\text{N}_2 + 3\text{Na} \rightarrow \text{AlN} + 6\text{NaF}$$
2. Metals such as aluminium react with carbon to form carbides, e.g.,

$$4\text{Al} + 3\text{C} \rightarrow \text{Al}_4\text{C}_3$$
3. Various carbon-nitrogen compounds are also produced in the forms of cyanides, e.g.,

$$1.5\text{N}_2 + 3\text{Na} + 3\text{C} \rightarrow 3\text{NaCN}.$$

Spent potlining contains these carbides, nitrides and cyanides along with un-oxidised aluminium metal and sodium metal. SPL readily absorbs atmospheric water (humidity) which reacts with a number of these components to generate flammable and toxic gases.

SPL is hazardous due to:

1. Presence of leachable cyanide,
2. Presence of leachable fluorides,
3. Propensity to react with water and produce flammable gases.

3.2 SPL Treatment Plant Layout

ALBA started building the SPL treatment plant in the beginning of 2020. Despite the challenges and restrictions due to COVID-19 regulations, ALBA managed to start the plant in July 2021 without delay on project schedule. SPL treatment plant consist of SPL preparation at the storage area, primary crushing, metal recovery, mill crushing and finally thermal treatment plant. Figure 2 shows the ALBA SPL plant layout.

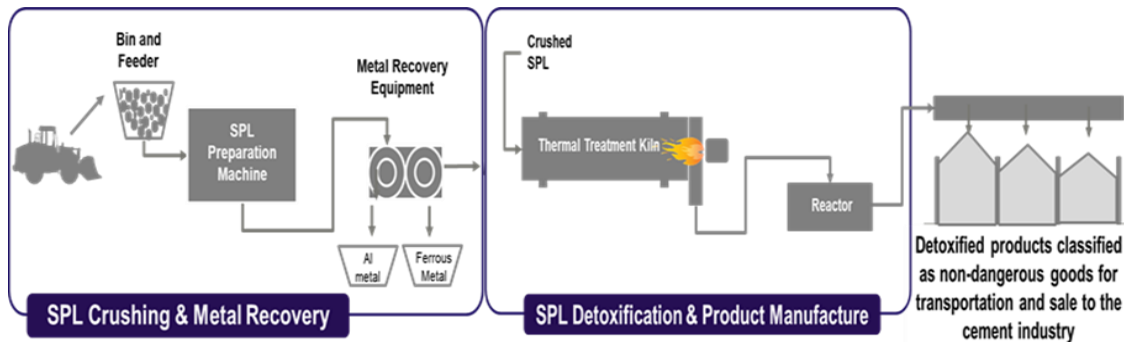


Figure 2. SPL plant layout.

3.3 ALBA SPL Material Preparation

SPL materials is delivered by trucks from the smelter. The material is stored in the SPL plant storage shown in Figure 3. The storage has been designed and built exclusively to handle preparation process of SPL in ALBA

SPL Preparation involves (a) recovery of material from storage; (b) segregation and removal of metals (aluminum and iron), pulverizing the carbon materials and refractory materials to the required feed size; (c) sorting into alike material streams, and (d) crushing and size classification.



Figure 3. ALBA SPL warehouse.

3.4 ALBA Primary Crushing Plant

The SPL material is then conveyed through several transfer conveyors and feeder, which, in turn, discharged to the primary crusher. The primary crusher crushes the SPL material to the nominal size of 200 mm.

3.5 Mill Crushing and Metal Recovery

The objective of the ALBA SPL crushing and metal recovery plant (C&MRP) is to crush the receiving SPL from the primary crushing plant to minus 12 mm in size and to separate and recover aluminium and ferrous metals prior feeding the material to the thermal treatment plant.

3.6 Thermal Treatment Process

The cyanide and explosion hazards in SPL are eliminated through the SPL treatment process. Neutralization of the reactive compounds is achieved by bringing on the reactions that generate the explosive gases in a controlled environment such that no more gas can be generated after treatment.

The Treatment Process is self-sustaining by re-using the gases generated to destroy Cyanide by thermal oxidation i.e., heating the material in the presence of oxygen. No residual materials are produced because there of no other chemical processes or additives.

4. Processing ALBA SPL in REGAIN Plant in Tomago Smelter

For ALBA to qualify its SPL processing and to prove that SPL can be processed using REGAIN SPL processing technology, ALBA has considered options for recycling its spent pot lining using the existing REGAIN facility in Tomago, Australia for which 343 tonnes of SPL was exported in sealed containers from Bahrain to REGAINs' SPL Processing Facility. Exporting of SPL from Bahrain to Australia was done following the requirements of the "Basel Convention for the Transboundary Movement of Hazardous Waste". The regulatory formalities for the export took almost one year. This was meant for characterization of ALBA SPL properties and for recycling as shown in Figure 4.



Figure 4. Left bulk batch, middle pulverizing, right crushed SPL.

The shipment consisted of different types of SPL material from both Hydro/Montecatini and Pechiney AP30 technology generated from delined cells from line 1-3 and line 4&5, respectively. Moreover, it was categorized in both 1st and 2nd cut category.

The process was divided in to two stages started with the pulverizing, crushing and sampling of untreated SPL for characterization and followed by a thermal treatment process. The objectives were:

1. Destroying cyanide in the SPL
2. Eliminating the flammable gas hazard from SPL reacting with water; and
3. Proving the ALBA SPL could be processed using REGAIN SPL processing technology.

Table 3 shows the result of a representative sample of each lot of ALBA SPL before treatment.

Table 3. Analytical results of crushed ALBA SPL (untreated).

Description	Unit	Hydro/Montecatini 2nd Cut Batch - BT2774	Hydro/Montecatini 1st Cut Batch -BT2775	Pechiney AP30 1st Cut Batch - BT2776	Pechiney AP30 2nd Cut Batch - BT2777
Silicon	as SiO ₂ %	50.6	3.6	6.9	39.4
Aluminium	as Al ₂ O ₃ %	19.8	8.8	9.8	18.3
Iron	as Fe ₂ O ₃ %	2.7	0.6	0.9	3.5
Titanium	as TiO ₂ %	0.59	0.06	0.09	0.43
Potassium	as K ₂ O %	0.86	0.18	0.22	1
Magnesium	as MgO %	0.6	0.2	0.4	0.8
Sodium	as Na ₂ O %	13.3	14.6	12.2	12.7
Calcium	as CaO %	1.7	2.2	2.4	2.2
Sulphur	as SO ₃ %	<0.1	0.2	0.2	<0.1
Manganese	as MnO %	0.02	0.01	0.01	0.02
Phosphorus	as P ₂ O ₅ %	0.06	0.01	0.01	0.04
Chloride	%	0.01	0.01	0.01	0.01
Fluoride	Total as F %	6.6	11.3	9	6.4
Carbon	%	11.5	61.8	60.2	19.5
Calorific Value	MJ/kg	3.9	19.9	18.7	7.4
Cyanide	(CN) mg/kg	177, 182	198, 194	168, 156	69, 76
Chromium	Total mg/kg	70	25	25	60

To enable better determination of the SPL characteristics and to establish the composition of HiCAL of ALBA SPL, it was processed as follows:

1. The four lots of ALBA SPL were processed as a separate controlled batch including sorting, metal recovery, crushing and reduction to a size suitable for chemical treatment

2. A representative sample from each lot of ALBA SPL was taken after processing for analytical testing of properties
3. The processed SPL was used in the manufacturing of REGAIN HiCAL Products for sale and consumption in cement manufacture.

The HiCAL product results were satisfactory and were accepted by the customers and this marked the completion of the recycling of ALBA SPL characterization.

5. HiCAL Marketing

The HiCAL material has proven to be valuable to certain cement producing plants that are geographically located close to the equator. Due to the heavy tropical rain, the queries used by these plants are usually deprived of the minerals usefully needed in the clinker manufacturing process. Therefore, the addition of HiCAL elevates the concentration of the minerals and improves the production of clinker and increases the output of Portland cement in a cost-effective manner.

In order to ensure the sustainability of the project, a key factor is to gain the regulator confidence on the product and ensure their acceptance in the proper classification of the product for the shipping purpose. To date, the importation and use of HiCAL products in cement making have already been accepted by regulatory authorities in eight countries. Consequently, A set of meetings were held with the national environmental regulator, as well as the Bahrain ministry of industry and commerce to agree and confirm that the produced material can be classified as raw material with the proper international harmonized code for exportation.

A plant visit and management meeting was held with a major Asian cement producer as part of the due diligence assessment of the project to verify off take products usage and need for the material. It has been confirmed that there is high demand for HiCAL products, and that the product is fully consumed and, moreover, that its toxicity is eliminated in the chemically irreversible cement clinking process. In addition, the cement industries realize significant benefits through energy saving, greenhouse gas (GHG) emission reduction and cost-effective production increases.

6. HiCAL Benefits for the Cement Industry

SPL has specific elements that work like mineralizers and fluxes for the clinking process in the cement manufacturing. A flux can be defined as an element that decreases the liquids temperature for a solid substance and/or generates a higher liquid quantity at a certain temperature. Similarly, mineralizer can be defined as the element that help faster reaction rates where the creation of the required material in the liquid phase for the cement clinker or any similar material is generated. The outcome of such process is a higher quality product and lower energy usage due to lower kiln resistance time and hence, less GHG emissions for a process like manufacturing of cement. As far as cement industry is concerned, sodium as flux and fluorides as minerals are of specific importance coming from SPL [3].

Mineralizing clinker using fluorides increases the clinker reactivity and reduces the clinker quantity required for each tonne of cement [4]. The Alite level increases in the clinker due to mineralization that correspond to less clinker proportion needed to produce a certain strength cement (i.e. improved clinker factor). The clinker factor is improved in the magnitude of 10 % or more at the optimum fluoride mineralization. Clinker amount in cement can be reduced by 15 to 20 % maintaining the same performance because of fluoride mineralization [5]. Thus, fluoride mineralization provides significant economic and environmental gains when the right market, raw materials and clinking process conditions are achieved.

Concerning the fuel used to make clinker, according to Chun Man Chow [6], around 3.8 % of coal consumption was reduced in the cement manufacturing plant with the use of 0.6 % of SPL in the raw meal. The reduced fuel consumption was equivalent to the energy input provided by the SPL carbon and the flux impact on lowering the needed kiln temperature. At the same time CO₂ was lower by 1% due to these two factors. Yet, the total CO₂ emission reduction was only 0.6 5% as part of the CO₂ emission comes from the usage of SPL itself. Chun also anticipated that NO_x will be reduced by 3.8 % due to lower Nitrogen generation associated with lower coal burning and the impact of the flux resulting reduced fuel and thermal NO_x generation Figure 5.

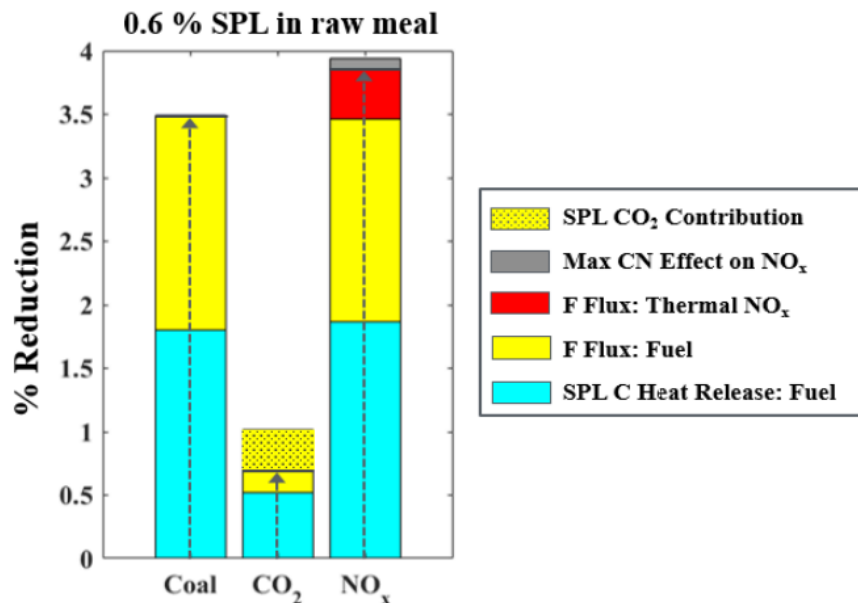


Figure 5. SPL addition's effect on cement production on fuel consumption, CO₂ and NO_x emissions. The arrow indicates the net reduction (Source [6])

7. Commissioning and Start Up of SPL Plant

SPL plant is under commissioning process and full ramp up expected by the end of October 2021. The initial products have been promising which is matching HiCAL specifications.

8. Conclusion

SPL material is categorized as hazardous waste by many regulators. The conventional way of SPL disposal in many cases was landfilling, and this is not acceptable any more. More sustainable and environmentally friendly solutions are being sought to encourage the circular economy and zero waste recovery.

As part of its social corporate responsibility, ALBA has been seeking the most possible viable solution for the SPL issue for a long period. With very limited capacity of cement industry in Bahrain, recycling SPL directly in local cement manufacturing was not found to be feasible. Thus, after a rigorous selection procedure, ALBA selected the REGAIN technology who has been in business of SPL treatment since 2002, to ensure transforming its SPL to a non-hazardous waste, used as a feedstock (raw material) for cement industry.

The converted SPL (HiCAL) has significant benefits for cement manufacturing where it reduces the raw material inputs, decreases the required energy, and NO_x and GHG emissions.

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