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Closing the Loop – Processing of Waste By-Product from Aluminum Recycling into Useful Product for the Steel Industry

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During melting of aluminum scrap a slag residue is formed. The slag residue, called black dross, has no industrial use and has to be landfilled. The work presented herein aims at developing a novel treatment process for the slag, converting it into a useful product for the steel industry and thereby replacing commercially available products made from virgin material. The concept consists of flash melting black dross and lime to form a synthetic slag former for treatment of high quality steel. Results from the modelling work indicate that the overall energy savings for an extended use of the developed product at the SSAB Europe Luleå site amounts to 31 GWh/y corresponding to 8 kt CO_2/y, in addition to the process removing the need for landfill of around 20 kt of black dross per year with subsequent risk of leakage of toxic compounds.

1. Introduction

Aluminum is an increasingly important material for the construction, packing and transportation industry, and is very well suited for recycling. The core of the recycling process is the melting of sorted aluminum scrap in either reverberatory or rotary furnaces. Salt fluxes are added during the melting to generate a slag which floats on top of the melt which reduces the oxidation of metallic aluminum in order to minimize the material losses during the process. The slag is often classified according to the metal content in terms of “white dross” (high metal content), “black dross” (medium metal content, 3 - 15 %) and “salt cake” (7 % metal content). The varying metal content provides different recycling and utilization possibilities; white dross may be recycled back to the melt in order to recover metallic aluminum and the salt cake may be possible to extract salt though black dross is landfilled, with following risk of leaching and emission of environmental hazardous compounds.
Steel production is an energy intensive industry; in Sweden, the steel industry is the second largest energy consuming industry, and accounts for 18 % of the total energy use by the industry sector. The integrated steel production chain is characterized by a number of sub processes which are interconnected with, and dependent on, each other. The overall energy- and raw material efficiency of the plant is determined by the operation of each of these processes and its function together; by improving the efficiency of one process it is possible to achieve plant wide increased efficiency.
Environmental concerns such as energy- & resource efficiency and minimizing of waste generation are ever-present topics for energy intensive industries such as steel production and aluminum recycling, and research for reducing the environmental impact is constantly ongoing work. The resource efficiency within iron ore based steel production is the focus of the RFCS project REFFIPLANT (Efficient use of resources in steel plants through process integration), and aims at optimizing the use of energy and materials (both external raw material and internally generated by-products). For the aluminum recycling, research for

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increasing the value of the generated dross through various processes has been conducted. Beheshti et al. (2012) evaluates heat treatment of black dross for reduction of salt content in preparation for using the dross in production of fluxing agents and refractories. Hwang et al. (2006) presents work for recovery of aluminum from various aluminum smelting by-products, including black dross, through grinding and Eddy Current Separators. Waste minimization is of course also a recurring theme for industries other than steel production and aluminum recycling, such as the electrical power industry; Ondova and Stevulova (2013) presents a study on the environmental impacts of using fly ash from coal fueled power industry in the cement industry, the method used in the study is Life Cycle Analysis (LCA). The study also evaluates the performance and durability of the produced cement. In a similar way LCA is also used by Margallo et al. (2013) to evaluate the environmental impacts of various treatment methods for processing of bottom ash from municipal waste incineration.

This study proposes a treatment method for recovering of black dross from aluminum recycling through production of a synthetic slag former for the steel industry. This method will completely remove the need for landfill of hazardous dross material as well as increase the recovery of salt from the dross, to be recovered back to the process. The produced slag former has good melting properties which reduce treatment time during steel production, leading to plant wide increased energy efficiency.

2. Background

2.1 Aluminum recycling and Stena Aluminium AB

Primary production of aluminum is based on mining of bauxite, which is treated and later processed into metallic aluminum through electrolytic reduction. The electrolytic reduction is a large consumer of electricity; the specific electricity consumption is around 15 kWh/kg. In comparison, the recycling and re-melting of aluminum scrap is energy efficient with energy consumption of around 5 % of that for primary production, primarily fossil based. According to the International Aluminium Institute (2015a), the annual primary production of aluminum amounts to more than 50 Mt while the recycled aluminum production is around 20 Mt/y (International Aluminium Institute, 2015b).

Stena Aluminium AB is the leading Nordic producer of recycled aluminum for foundries and steel industries, located in Älmhult, Sweden. The annual production is around 55 kt. The melting is performed batch-wise in sizes of around 30 t, each batch taking 3 - 3.5 h to melt. The melting is commonly performed in rotary furnaces. The primary use of energy at Stena Aluminium is LPG, with consumption of around 1.3 MNm^3/y. During the production roughly 16 kt/y of black dross is produced. The dross has no industrial application as is currently landfilled after treatment.

2.2 Steel production & SSAB Europe Luleå

The worldwide steel production is basically divided in two major production categories; integrated steel production and scrap based steel production. Integrated steel production is based on mining of iron ore, which goes through melting and reduction in the blast furnace. The hot metal from the blast furnace is composition adjusted in the converter and secondary metallurgy before it is casted and shipped to the rolling mill.

As the name implies, scrap based steel production uses recycled steel scrap as raw material, which is melted in an electric arc furnace, the following production steps are similar to the integrated steel production. According to OECD the integrated steel production route accounts 71 % of the annual world production, and the scrap based route accounts for 24 %.

SSAB Europe Luleå site is an integrated steel production site consisting of coking plant, blast furnace, converter, secondary metallurgy, and continuous casting, see Figure 1.

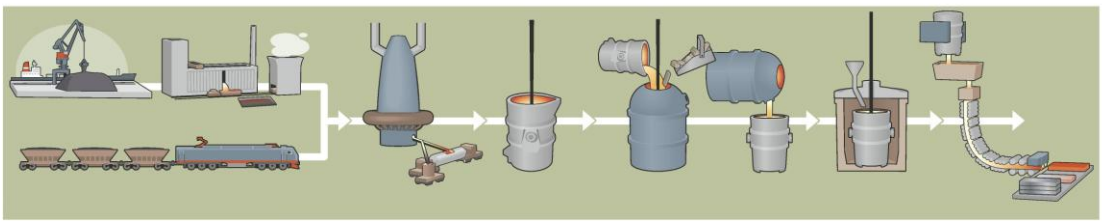

Figure 1: Production route for SSAB Europe Luleå, with the main processes included

The affected process stage in the presented study is the secondary metallurgy, where the liquid steel is further refined to remove impurities and inclusions in order to achieve the desired composition of the steel. This is achieved through addition of slag formers and various elements.
At the site there is also a power plant, oxygen plant, and lime kiln. The power plant utilizes the excess process gases from the steel production to produce electricity and district heating to the municipality of Luleå. The annual production is around 2.1 Mt of steel products.

3. Novel treatment method of black dross and its effects on the steel industry

The novel treatment method for black dross from aluminum recycling suggested in the study is a zero waste concept were the black dross is used as a raw material for production of a pre-fused synthetic calcium-aluminate slag for the steel industry. Calcium-aluminate is a strategic consumable in the secondary metallurgy stages for production of high quality and high strength steel. The situation today is that all pre-fused calcium-aluminate is imported to Sweden, mainly produced from virgin material. The generation of black dross will not be reduced by using this novel approach; however it will provide a possibility to increase the overall industrial material efficiency and reduce the environmental impact by removing the need for landfill of potential environmental hazardous material and at the same time increase the economic competitiveness of the participating industries and promote inter-industrial recycling.
A new cooling process for the black dross in conjunction with the novel treatment method is also suggested. The new cooling process will allow for metallic aluminum of the dross to be recovered and recycled to the melting furnaces. For the production of calcium-aluminate, the black dross is flash-melted with addition of lime, requiring some type of fossil fuel.
Calcium-aluminate is a high quality slag former for the secondary metallurgy, usually used for high performance steel qualities, providing fast metallurgical processing, good refining performance, low melting point, low viscosity, good fluidity, and improved ladle metallurgy energy balance. The performance of the steel plant is highly affected by the treatment time for each process stage, working towards set targets for tapping temperature at each process stage and at the continuous casting. Increased treatment time means that the tapping temperature for previous processes needs to be increased or intermediate chemical heating is required, and consequently, reduced treatment time means that the tapping temperature could be lowered. In the LD converter the carbon content in the hot metal from the blast furnace is lowered by supersonic blowing of oxygen on the melt, which forms carbon monoxide and carbon dioxide. The reactions are exothermal, which means that it is possible to add and melt steel scrap in the order of 15 – 20 % in comparison to the hot metal amount. By reducing the treatment time for the processes following the converter it is possible operate with a lower tapping temperature at the converter, allowing for a larger addition of steel scrap and consequently reducing the hot metal production. A schematic overview of the studied system, including aluminum recycling plant, steel site and energy- and material flows, can be seen in Figure 2.

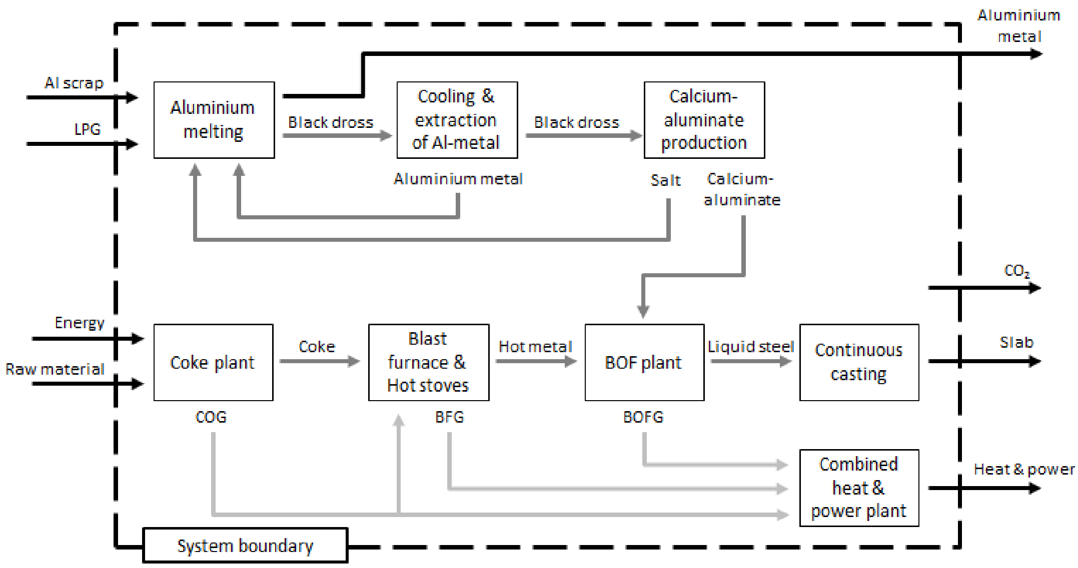

Figure 2: Schematic overview of energy- and material flow in aluminum recycling plant and steel site

The use of calcium-aluminate will reduce treatment time in the secondary metallurgy by 5 min; the following major plant wide effects can be seen in Table 1.

Table 1: Effect of the use of calcium-aluminate at the steel site

Ladle size	t/heat	130
Ladle addition	kg calcium-aluminate/heat	500
Temperature saving	° C	5
Increased scrap rate	kg scrap/heat	325
Reduced hot metal production	kg hot metal/heat	342

The reduced hot metal production will affect the energy balance of the plant since the by-product blast furnace gas is one of the major energy carriers at a steel site. In the same way it will also reduce the need for coke, and may consequently affect the available amount of coke oven gas.

4. Results

Besides the energy saving effects from the use of calcium-aluminate, it may also provide improvements in quality of the steel, and process control and steering, etc. However, these improvements are difficult to quantify and will therefore only be mentioned in descriptive terms. The environmental impacts that follow with landfill of waste are described in a similar way.
For this work, it is assumed that 16,000 t calcium-aluminate per year is produced and that LPG is used during the process. Lime and dolomitic lime are added during the melting process. Some metallic aluminum is recovered in the cooling process and the specific yield of production of calcium-aluminate from dross for the concept will depend on the aluminum content of the black dross and the composition of the slag former which is desired. Some details for the calcium-aluminate production can be seen in Table 2.

Table 2: Consumption details for the novel black dross treatment method

Specific raw material & energy consumption		
LPG	GJ/t calcium-aluminate	2.25
Dolomitic lime	t/t calcium-aluminate	0.12
Burned lime	t/t calcium-aluminate	0.12
CO_2 emission	t/t calcium-aluminate	0.21
Annual raw material & energy consumption		
Calcium-aluminate production	t/y	16,000
Black dross	t/y	17,025
LPG	GWh/y	10.6
Dolomitic lime	t/y	1,900
Burned lime	t/y	1,900
CO_2 emission	t/y	3,274

The increased recovery of metallic aluminum through new cooling processes of black dross would to some extent be able to decrease the demand of primary aluminum. As previously mentioned the production route of aluminum from virgin material is energy intensive and requires large amounts of electricity and the increased recovery of aluminum from black dross would thus lead to possible energy savings. For this work, an electricity consumption of 15 kWh/kg aluminum is used. The environmental impact of the increased aluminum recovery can be seen in Table 3.

Table 3: Environmental impact of increased recovery rate of metallic aluminum

Increased Al recovery rate from dross	%	8
Increased Al recovery	t	1,362
Electricity consumption for primary aluminium	kWh/kg	15
Annual electricity saving	GWh/y	12.8
Reduced CO_2 emission	t/y	255

The aluminum recycling process in itself will not be affected by the production of calcium aluminate, other than through the increased recovery rate through the new cooling process of the dross.

As previously mentioned calcium-aluminate is used as slag former for high strength steel though for most of the production burnt lime is used as a slag former, and this production scenario will serve as comparison for the extended use of calcium-aluminate. For the steel site of SSAB Europe Luleå, the previously described possibility for reduced hot metal production will decrease the consumption of raw material, but also reduce the availability of blast furnace gas for production of heat and electricity in the combined heat and power plant. Based on the calculations in Table 1, it would be possible to decrease the hot metal production by 6.2 kt per year through an extended utilization of calcium-aluminate as a slag former. This would affect the raw material consumption according to Table 4.

Table 4: Consumption data and environmental impact for SSAB Europe Luleå

		Reference case	Utilization of calcium-aluminate
Hot metal production	%	2,253.5	2,247.3
Pellet consumption	t	3,066.5	3,058.1
Pulverized coal consumption	kWh/kg	335.8	334.8
External coke consumption	t/y	34.8	32.9
Electricity production	GWh/y	694.2	692.5
Total energy consumption	GWh/y	11,220	11,192
Total CO_2 emission	t/y	3,772	3,763

As can be seen the annual environmental saving potential for the steel plant is around 28 GWh, corresponding to 9 kt of CO_2. The total energy saving amounts to 31 GWh per year, corresponding to 8 kt CO_2. The steel production used as reference in this study would require 8.7 kt calcium-aluminate annually at SSAB Europe Luleå site if it was to be used during production of all types of steel. The result presented is based on that production, meaning that there is an excess of roughly 7 kt of calcium-aluminate (based on an annual production of 16 kt) which would result in further energy saving. The use of calcium-aluminate in Sweden can be estimated to roughly 20 - 25 kt, which means that the treatment method could potentially lead to balancing the production and consumption of calcium-aluminate in Sweden, on basis of waste from aluminum recycling. The European potential production of calcium-aluminate in a similar way is around 500 kt/y, significantly reducing the amount of landfilled material and simultaneously reducing the need for import of material.

As previously mentioned, the use of calcium-aluminate would not only lead to energy savings but also lead to improvement in control and steering of processes, potentially resulting in reduced amount of discarded steel products, improving the general production efficiency of the steel sites.

5. Conclusions

The work presented in this study suggests a novel treatment method of black dross from aluminum recycling in which it is fused to calcium-aluminate, transforming a waste by-product from the aluminum industry to a valuable product for the steel industry. The use of calcium-aluminate as a slag former in the secondary metallurgy would lead to energy savings through reduced process time and energy losses, allowing for reduced hot metal production and increased use of recycled scrap. The calculated energy saving for the reference case in this study amounts to 31 GWh/y, though only including utilization of roughly half of the produced calcium-aluminate.

The suggested treatment method would also remove the need for landfilling of roughly 17,000 ton of potentially environmentally hazardous material for the reference scenario. At the same time it increases the recovery of aluminum which would increase the material efficiency of the aluminum recycling process.

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