Optimisation of the Environmental Footprint of Calcium-Aluminate-Cement Containing Castables

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This article details the use of Life Cycle Analysis (LCA) methodology as applied to refractory materials and in particular to calcium aluminate cements. Based on a model example, the paper also demonstrates the value of considering the full life cycle of refractory applications, including the installation and usage in order to optimise refractory product types and reduce the overall environmental impact.

1 Introduction

The concept of Integrated Product Policy (IPP) launched by European Commission in 2003 [1] aims at coherent action, using the most appropriate policy tools and involving stakeholders, towards "greener" products that combine lower environmental impacts with enhanced service to consumers. It calls for continuous improvement in product manufacturing and design, and for promoting their uptake by consumers. Increasingly, industry sectors apply life-cycle thinking to inform their approaches towards product policy and communication with customers and authorities. The refractory industry is now increasingly attentive and motivated to promote and develop recycling, due to factors such as sustainability and environmental issues, and security as well as quality of of raw materials.

Refractory products are a vital element in all high-temperature processes and are typically used to insulate and protect industrial furnaces and vessels due to their excellent resistance to heat, chemical attack and mechanical stress. The various types of refractories also influence the safe operation, energy consumption and final product quality. Therefore, designing refractories best suited to each application is of supreme importance.

Refractory products involve a large panel of raw materials; most of refractory raw materials require a large quantity of energy for their production, as it is not possible to use as extracted and need at least crushing and screening; they also often require thermal processing. Nevertheless, the specific resource consumption of refractory products is very low, with less than 10 kg of refractories required per tonne of steel [2]. The environmental burden associated with the production of refractory raw material should be balanced with the overall benefits and performance delivered for the final product. This report details the use of Life Cycle Analysis (LCA) methodology as applied to refractory materials and demonstrates the use within a model example of a refractory application.

2 Life Cycle Analysis methodology

The Life Cycle Analysis (LCA) methodology defined by ISO 14040 and 14044 standards (2006) [3] is recognized as the best methodological framework for assessing the potential environmental impacts of products and services. It provides a clear and comprehensive picture of the energy and materials flows through the whole life cycle of a system and a global and objective basis for comparisons.

The environmental pressures and impacts of products could occur at various stages of their life cycle (along production chain, during use phase, disposal of end-life products); then it is necessary to take into account the full life cycle to compare different product or system, to avoid that the environmental burden is simply shifted to other stages of the life-cycle, or to other geographical areas.

Kerneos, leader in aluminate technologies has used LCA approaches since 2010, as a key lever to serve its sustainable development strategy. From a research and development point of view, Kerneos uses LCA in decision making as a tool for product design improvement and innovation. In such an approach, also called ecodesign, the choice of materials, the selection of technologies, the implementation of specific design criteria are the key parameters to consider. From an industrial point of view, LCA allows the benchmarking of product system options and can therefore also be used in decision making of purchasing and technology investments.

3 Literature and database

There is very little literature available on such a LCA approach for refractory products and applications. A report prepared in 2013 by the European Refractories Producers Federation [2] provides carbon footprint data resulting from a gate to gate exercise focusing on the production phase of different refractory products, and underlines a large range of results per tonne of refractory products, depending on the type of product (shape, composition, firing temperature, usage).

Two publications from the Journal of The Technical Association of Refractories in Japan provides inventory data for the production stage of various alumina raw materials [4], graphite and silicon carbide [5] using public literature. Eco-invent LCA database [6] proposes also generic inventory data for processing of mineral resources (quarrying, mining,

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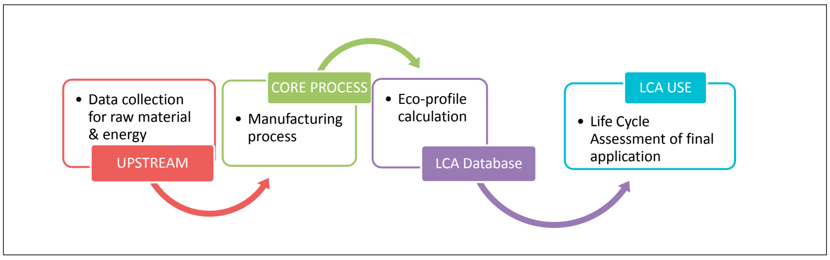

Fig. 1 Goal and scope of the study

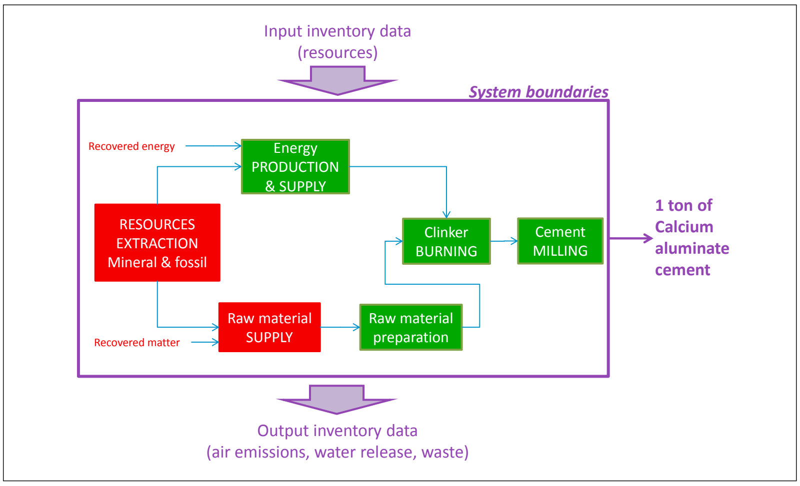

Fig. 2 System boundaries of calcium aluminate cement production, from cradle to gate

crushing, drying, burning, BAYER process). Main sources are coming from limestone or bauxite mining plants.

Regarding Calcium Aluminate Cements (CAC), used as specific hydraulic binders and especially recommended for refractory materials, because of such special properties as high early strength and high temperature resistance, LCA results are not available in public databases. Thanks to its expertise developed for few years, Kerneos can progressively provide specific data for each product.

4 Scope and hypotheses

As a general rule, the selection of life cycle inventory system boundaries shall reflect the goal and scope of the study, in relation to the defined "functional unit". The functional unit, used as a common denominator, provides the basis for the addition of material flows and environmental impacts for any of the life cycle stages for the studied product.

As shown in the Fig. 1, eco-profile results are given for the production stages, from "cradle to gate", i.e. including upstream processes (raw material and energy production and supply) and core processes (clinker and cement manufacturing). Results per tonne are then used for a Life Cycle Assessment (LCA) of a final application, to determine the overall impact, including all life cycle stages.

A long list of impact assessment indicators is proposed in LCA tools. Results are provided in this paper in order to illustrate the LCA results with two indicators (i.e. the impact on climate change and the non-renewable energy consumption). Both indicators have been selected in accordance to priority given by the European Commission in terms of reduction of greenhouse gases emissions, and improvement of energy efficiency [6]:

- The impact on climate change is usually assessed through the indicator developed by the International Panel for Climate Change, where greenhouse gases emissions are weighted using global warming potential coefficient, and expressed in tonne of CO_2 equivalent [9].
- Energy comes from natural resources, such as petroleum oil, natural gas, uranium, wood, and biomass. The indicator studied measures the quantity [MJ] of non-renewable energy resources extracted from the environment (excluding energy from secondary fuels).

Furthermore, the results of the study should be considered with regard to the hypothesis, assumptions and methodology chosen. The uncertainty level largely depends on the quality of data sources: in general, the order of magnitude is 10–15 % of uncertainty in a LCA study. Main uncertainties come from LCA databases, some data missing or being not necessarily representative of the state-of-the-art. Furthermore, as LCA results largely depend on the performance of the upstream business chain, data shall not be considered as absolute values but need to be updated with regard to significant changes in LCA databases.

5 Results and discussion

5.1 Results for 1 t of CAC

First set of results refers to the production of 1 t of CAC and is based on a cradle-to-gate system (Fig. 2), representative of Kerneos average CAC production data.

The production stage covers manufacturing and transportation of raw materials and fuel, electricity production, manufacturing and associated processes in the plant, up to the point (also called "factory gate") where the product is ready for transportation to the customer.

Fig. 3 presents CO_2 emissions generated for the production of three products from Kerneos range, used in refractory castables. A major difference is the Al_2O_3 and mineralogical phases content and the production process. While 70 % alumina containing Secar® 71 is produced in a sintering process using a rotary kiln, the 50 % alumina containing Secar® 51 and the 40 % alumina containing cement Ciment Fondu® are produced in a fusion process using a reverberatory furnace.

5.2 Perspective regarding other refractory raw materials

Three main categories could be distinguished amongst the refractory raw materials, by considering the energy intensity of production stages [4–6]:

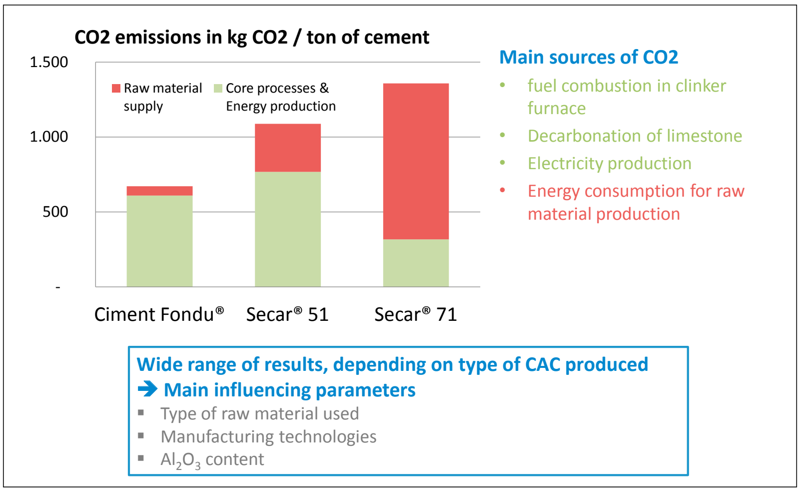

Fig. 3 Impact of raw material production: example of CO_2 emissions of CAC production [kg CO_2/t]

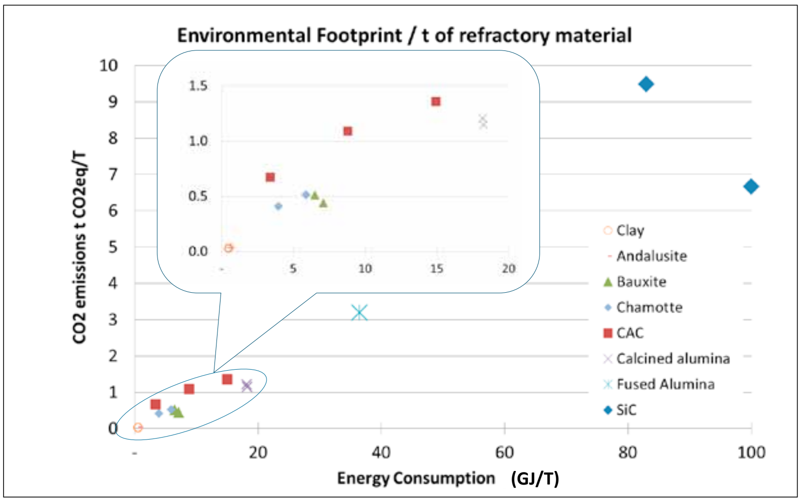

Fig. 4 Environmental footprint for 1 t of refractory material

Tab. 1 Detailed hypotheses and results

Scenarii		Products				
		Brick	CC	MCC	LCC	ULCC
Composition [%]	Bauxite	95	83	80	86	83
	Secar 71		15	12	5	2
	Clay	5	2			
	Reactive alumina					7
	Fume silica			5	5	4
	Calcined alumina			3	4	4
Intrinsec footprint	CO_2 emissions [t]	1,1	0,7	0,6	0,6	0,6
	Energy [GJ/t]	13	8,4	8,2	7,7	8,3
Performance in use	No. of heats	300	300	1000	1700	2000
	No. of relinings/a	35	35	11	6	5
	Density [kg/m³]	2750	2380	2820	2740	2860
	Consumed [t/a]	290	251	84	51	45
LCA results	CO_2 emissions [t/a]	316	180	58	32	30
	Energy [TJ/a]	3,9	2,4	0,8	0,4	0,4

- Natural raw materials, such as clay, graphite, andalusite, kyanite with a low environmental footprint (less than 100 kg CO_2/t and 5 GJ/t).
- Calcined raw materials with an intermediate environmental footprint (from 5 –7 GJ/t), including bauxite and chamotte.
- Synthetic raw materials, involving an higher quantity of energy, such as calcium aluminate cements (from 4–15 GJ/t), calcined/ reactive alumina (18 GJ/t), fused alumina (36 GJ/t), and silicon carbide (80 –100 GJ/t).

Fig. 4 gives a comparative view of energy and carbon footprint of the production of various refractory raw materials, based on data available in LCA software, which is not always sufficiently precise or representative for each raw material used for refractory applications.

5.3 Model illustration: permanent lining of tundish

In 2014, Kerneos published first LCA data applied to calcium aluminate cements in non-refractory applications [6] and confirmed that a direct comparison of the carbon footprint per tonne of product is not relevant and it is necessary to consider the entire life cycle of the application including the installation & usage. The same holds true for refractory applications and to illustrate this key message in the context of refractory castables containing calcium aluminates, a simplified life cycle analysis example has been constructed below.

The considered application is that of a tundish permanent lining as part of the continuous casting process in steel production, with the following input hypothesis:

- The functional unit of the studied system is defined as follows: "protection of the tundish device with a nominal refractory volume of 3 m³ during 1 year (330 working days) of steel production".
- Refractory product types: generic refractories in the form of fired brick, conventional castable (CC–15 % CAC); medium cement castable (MCC–12 % CAC), low cement castable (LCC–5 % CAC) and an ultra-low cement castable (ULCC–2 % CAC) are considered (Tab. 2).
- All products are based upon calcined bauxite as the main aggregate and in the case of the deflocculated castables fume silica

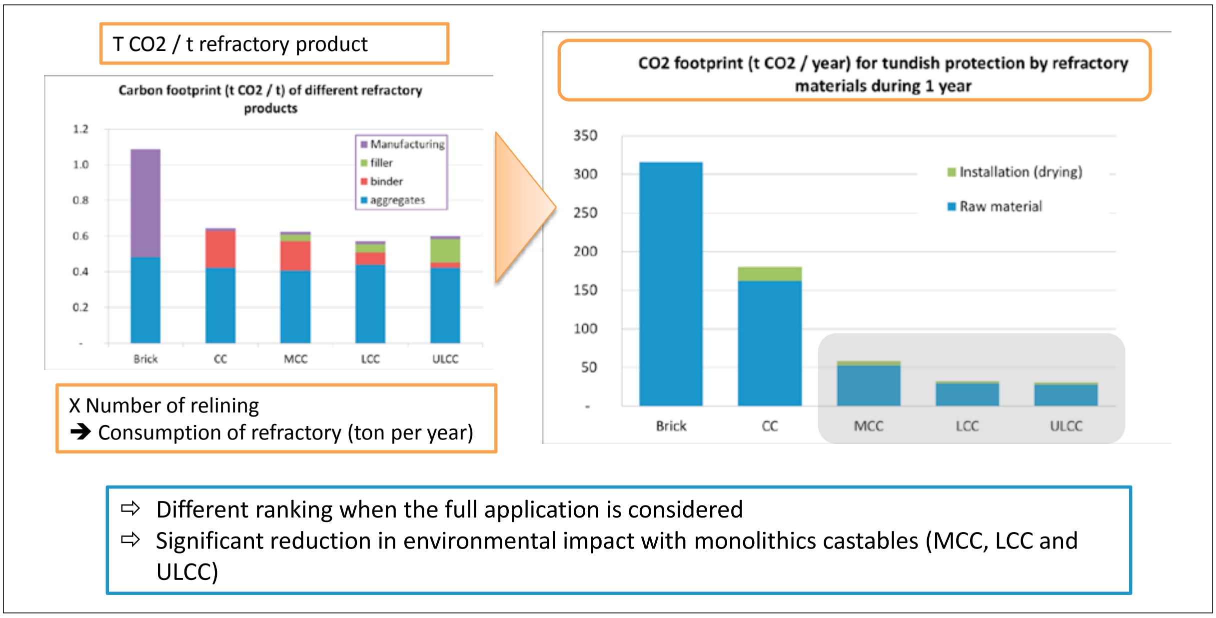

Fig. 5 From CO_2 footprint for 1 t of refractory product to impact of full application (1 year of tundish protection with permanent lining)

and calcined/reactive alumina additions are made. Product properties such as installed densities have been estimated from particle packing models.

- The performance data are assumed to be estimated to illustrate the impact of the service life, considering the difficulty to take into account all process parameters (see Tab. 1). The model does not consider any recycling for a 200 mm thick lining.
- Carbon footprints of individual materials, the energy usage for refractory installation as well as firing of refractory bricks are taken from available data bases and public sources [2].

In order to keep the illustration simple the following aspects are not considered: bricks installation, castable mixing, and impact of location and transport of refractory products to point of use. As it can be seen from Tab. 1, the carbon footprint of an individual product is not directly connected to the footprint relating to the functional unit. For bricks, a large part of emissions is linked to the energy involved in their processing. As published by PRE [2] and illustrate in the Fig. 5, there is a clear differentiation in energy intensity for manufacturing stage between fired shaped products and unshaped products. Then, when the full application is considered, a different ranking of the different illustrative examples can be seen and the significant reduction in environmental footprint when moving to monolithic castables, especially for LCC and ULCC.

6 Conclusion

Life Cycle Inventory data (LCI) of calcium aluminate cements production are provided in this paper with a comparative view of other data available in the literature on refractory raw materials. Energy consumption and greenhouse gases emitted during the production phase of CAC are depending on the process of manufacturing and also the type of raw material used.

A direct comparison of footprint of different materials is not relevant and it is necessary to consider the entire life cycle of the application including the installation, usage and service life.

In a second set of results it can be seen that moving to higher performing castable types will not only improve the performance ratio but also significantly decrease the carbon footprint of the illustrated example. This shows how LCA can be a powerful tool to optimise refractory product types and reduce the overall environmental impact of refractories through the usage life cycle.

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