THE NOWASTE STRATEGY OF GEORGSMARIENHÜTTE – AN ILLUSION OR REALITY?

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Introduction

During the steel production with electric arc furnace (EAF) and the following secondary metallurgy, two types of slags are produced with very different properties. The black EAF slag contains metallic and oxide metals and has good physical properties for further use. In Germany EAF slag is mainly used in road construction and earthworks. The white ladle furnace slag (LFS) is nearly metal free and typically disintegrates during cooling. It is often used for landfill construction, but also as liming fertiliser.

Future changes in legislative regulations in Germany[1] jeopardise the common use of slags in applications like road construction, without further changes of the material. Improvements to modify the slags will have to be performed. The most effective way to do this is to treat the slags in liquid state, *e.g.* by adding conditioning materials, or to recycle them internally.

As one of the bigger electric steel works, Georgsmarienhütte GmbH is working on several research & development projects, in particularly on environmental safety of the utilised slags. Together with FEhS – Institute, GMH has been involved in several public research projects and at the same time on internal projects to identify new ways of recycling their own by-products and unused waste materials. For this work, the four Rs "ReThink – ReDuce – ReCycle – ReUse" are used as an orientation.

ReThink – ReDuce – ReCycle – ReUse

By analysing the process steps and the material flows of the steel work, one of the bigger mass flows, the ladle furnace slag (LFS) was identified as a potential material for internal recycling. This slag contains up to 60 wt% lime, 14 wt% dolomite and appreciable parts of silica and alumina. Typically, primary raw materials like lime and dolomite are employed as a slag former in the EAF. Through internal recycling, LFS is a potential metallurgical substitute for lime and dolomite. The biggest challenge of using LFS as slag former is the internal logistics associated with transport and charge of the material into the EAF. While cooling down the slag in a slag pit, a mineral phase

transition occurs, that results in volume expansion. Due to this expansion, the slag disintegrates into fine particles, causing dust emissions during transport and charging.[2]

Preventing disintegration of Ladle Furnace Slag

During solidification of LFS, several calcium silicate phases are formed from the melt. Further cooling leads to continuously converting of these phases to their modification. At approximately 500°C the monoclinic β_H-C_2S (larnite) converts to rhombical γ-C_2S (calcio-olivine). The different densities of these phases (Table 1) result in a volume expansion of almost twelve percent.

Table 1: Density of β- and γ-modification of dicalcium silicate[6]

	density [g/cm³]	crystal structure
β_H-C_2S (larnite)	3.31	monoclinic
γ-C_2S (calcio-olivine)	2.97	rhombical

As described in literature, the decomposition of dicalcium silicate can be prevented by adding chemical substances that will make the β_H-C_2S-phase thermodynamically more favourable than γ-C_2S at 500°C[3]. The addition of 1 wt% of B_2O_3 or P_2O_5 is sufficient to stabilise the slag. The compounds are integrated into the crystal structure of C_2S and inhibit the effective lattice energy.

Several barriers exist however to implement the recycling of LFS to the EAF in operational practice. On the one hand the addition of boron or phosphorous in EAF will have a negative influence on the produced crude steel, because these elements are steel polluters. On the other hand, a homogenous distribution of B or P in the LFS is a big challenge due to varying viscosity from tap to tap.

Another way of stabilising the dicalcium silicate in LFS is to change the cooling rate, which would not depend on any addition of conditioning substances. With faster cooling rates the crystal growth is inhibited and decomposition is avoided[2]. The very low thermal conductivity of the slag[4] makes it necessary to have a large surface area on the cooling device, to ensure sufficiently fast cooling of the slag for finely crystalline microstructures to form.

Based on several laboratory experiments at FEhS, a pilot scale test plate, shown in Figure 1, was built at the melting shop, where the LFS was solidified rapidly. Several trial campaigns were made to optimise the device and to define the basic conditions necessary to repeatedly achieve high stabilisation rates under industrial conditions, *e.g.* the required temperature of the LFS as well as the maximum thickness of the slag layer on the cooling device.

From these trials, nearly totally stabilised LFS with high lime content was produced with the possibility to charge it to the EAF without inhibiting dust emissions.

Figure 1: Cooling plate with LFS at the melting shop

The LFS was used to substitute the primary lime and no negative effects on the EAF process, *e.g.* higher energy consumption, were determined. However, it has to be taken into account that in an industrial practice the costs for material handling in the melting shop cannot be neglected and additional process steps are required which result in economic disadvantages.

Metallurgical treatment of EAF slags

Due to oxidising conditions in the EAF, these slags can contain more than 40 wt% of iron oxide. While the metallic iron pieces are separated during the processing of the slag, the iron oxide cannot be recycled. A metallurgical step is necessary to reduce the Fe oxide, which requires a lot of energy and currently outweighs the advantages of the recycling.

Figure 2: Slag pot foam over

Figure 3: Segregated slag/metal

The innovative idea is to use the energy content of the slag for the reduction and to create a special mixture of reducing agents (Al, C, Si) to have self-sufficient energy reducing process. The reduction rate of the EAF slag must not be 100%, which would

lead to a high viscosity with several disadvantages. Beside this, a complete reduction of the EAF slag would result in a phosphorous rich metal, which cannot be recycled internally, so a happy medium has to be found.

First operational trials show good results of the metal quality and the environmental properties of the EAF slag. Accompanied by thermodynamic calculations, operational trials will be performed in the future to optimise the mixture of reducing agents, the process technology (*e.g.* foam over of slag pot, Figure 2) and the properties of EAF slag and reduced hot metal.

Steel Plant Tomorrow

The described processes are just two examples of the NoWASTE strategy of the Georgsmarienhütte, which comprise several new ideas, improvements and changes in the processes. Beside these by-products, several other materials are emitted, *e.g.* filter dust and scale. To achieve a NoWASTE steel work is the aim of Georgsmarienhütte in the following years. The steel work GMH of tomorrow can look like Figure 4.

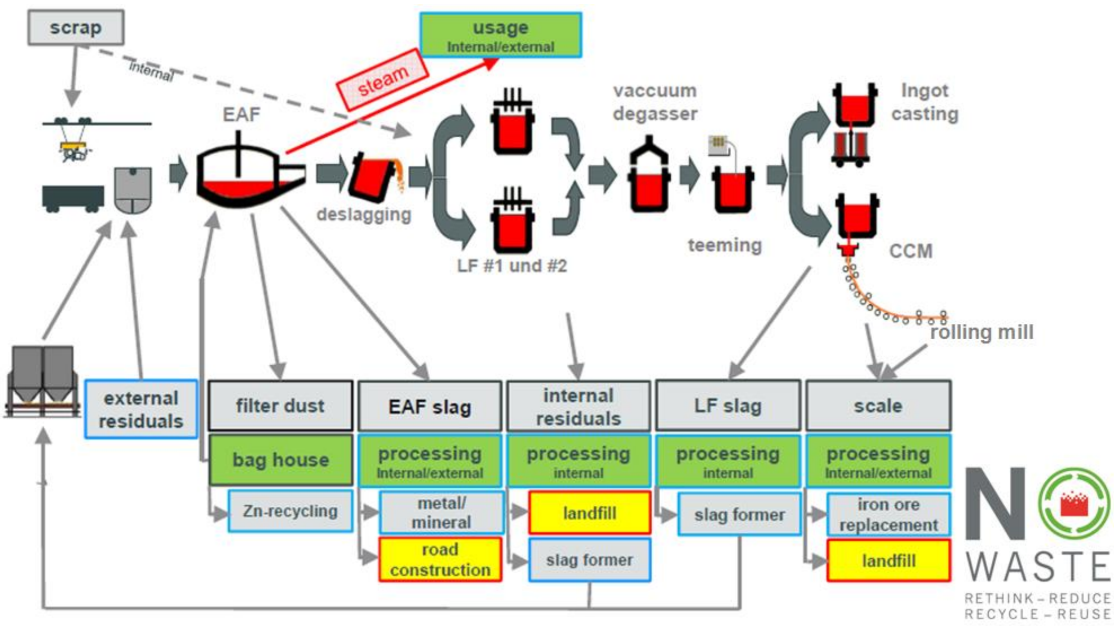

Figure 4: Our vision of a green steel work GMH

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