Alternative charge

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RFCS VALEAF workshop „State of the art“
Dalmine, 12.03.2015

What do we mean by „Alternative charge“?

Topic 6: Alternative charge

Sub-Topic 6.1: Techniques and guidelines to use alternative iron sources

Sub-Topic 6.2: Use of char from biomass replacing coal

Sub-Topic 6.3: Recycling of by-products

Research driven by

CO_2 emission certificates

Zero waste production

Closing material loops

Reducing landfilling/disposal costs

Landfilling bans

regulations and/or costs!?

Project	Consortium	Duration
Economic advantages of integrated processing of steelworks EAF wastes, mainly containing Zn, Pb, Cd, FeOx, Zn ferrite and others, with total recovery	Ferriere Nord	1995-1998
The in-plant by-product melting (IPBM) process	MEFOS, CRM, CSM, FEhS	1996-1998
Briquetting of self-reducing blendings of waste iron oxide mixtures	Profilarbed, CRM, BFI	1997-2000
High purity zinc and ferroalloys recovery from EAF dusts through a combined pyro-hydrometallurgical treatment	CSM, TK AST, TKN, ASO, TECHINT	1998-2001
Foaming of the slag and recycling of stainless steel dusts by injection into the electric arc furnace for stainless steels	UGINE, KEP, IRSID, FEhS	1999-2002
Efficient utilisation of raw materials used in secondary steelmaking as flux in steelmaking furnaces	FEhS, DEW, HORN, RIVA, CENIM-CSIC, FQZ Brandenburg	2000-2003
Pre-processing of metallurgical wastes by direct reduction for recovery of iron, zinc and lead	CRM, IRSID, TKS	2000-2003
Upgrading and utilisation of residual iron oxide materials for hot metal production – URIOM	BFI, Böhler, CSM, Tribovent	2007-2010
Sustainable EAF steel production – GREENEAF	FERRIERE, CSM, DEW, IMPERIAL COLLEGE, Marienhütte, RWTH-IOB, Tecnocentro	2009-2012

Running projects

Project	Consortium	Duration
Control of slag quality for utilisation in the construction industry – SLACON	FEhs, CSM, GERDAU, RIVA, BFI	2012-2015
Biochar for a sustainable EAF steel production – GREENEAF2	CSM, FERRIERE, GMH, Imperial College, Marienhütte, RWTH-IOB	2014-2016
Recycling of industrial and municipal waste as slag foaming agent in EAF – RIMFOAM	MEFOS, ARCELOR (2x), CSM, FERALPI, HÖGANÄS	2014-2017

Statistics

Period	Nr of EAF Projects	Topic „Alternative Charge“	
1991 - 2014	69	12	17 %

Sub-Topic: Techniques and guidelines to use alternative iron sources

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Briquetting of self-reducing blendings of waste iron oxide mixtures

The **objectives** of the project were to develop technologies to manufacture self-reducing briquettes out of waste iron oxides and to recycle them in an electric arc furnace or a cupola furnace.
CRM has investigated and determined the optimal characteristics (binder, size, grain size, compositions and activator for the reduction reaction) for briquettes containing mixtures of mill scale, mill sludges, EAF dust and coal as reduction agent. The **goal** to obtain briquettes, in which iron oxides are totally reduced when these briquettes are loaded with the scrap into an electric arc furnace, **was achieved**.
Trials at ProfilARBED have shown that it is possible to recycle mill and EAF by-products conditioned in self-reducing briquettes in an EAF without influence on the performance and on the environment. The iron content of the slag does not increase as the iron of the by-products is almost completely reduced. Zinc is completely removed and the concentration in the EAF dust increases.

Figure 2. 1 Various briquette formats

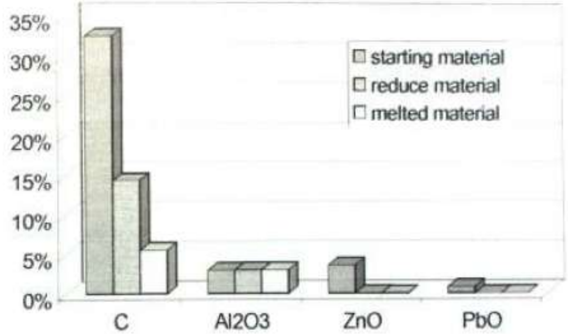


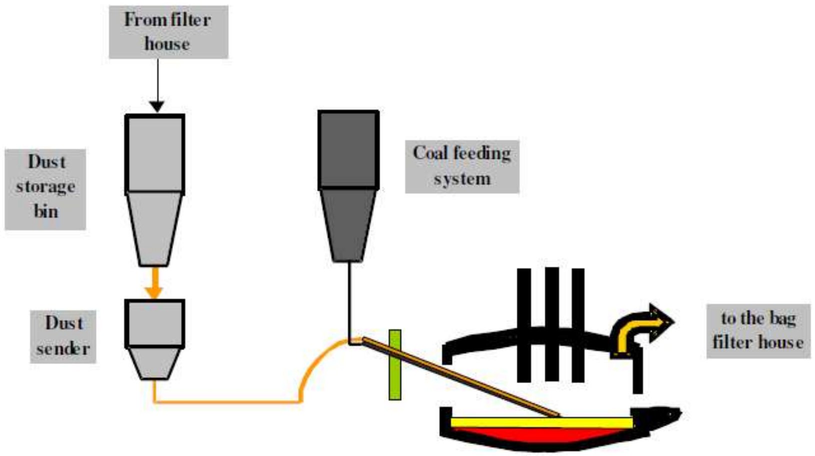
Figure 2. 11 Results of reducing and melting trials

Figure 3.5 Briquettes produced with the roll compactor

Foaming of the slag and recycling of stainless steel dusts by injection into the electric arc furnace for stainless steels

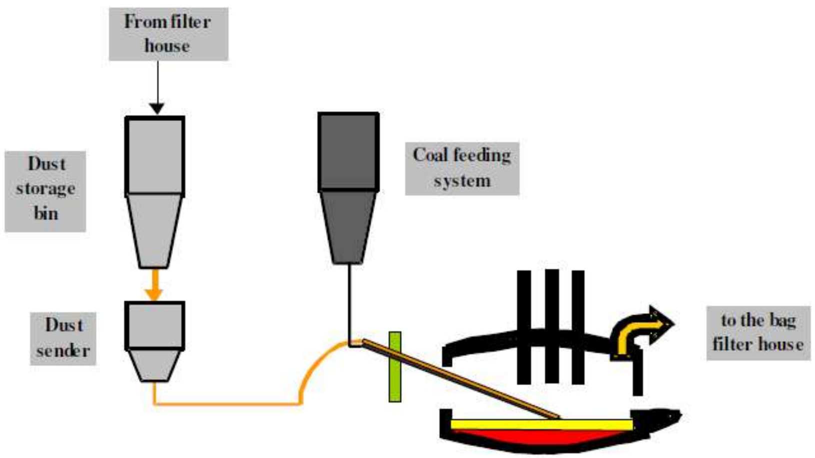
This project was concerned with the study of the **dust recycling and the slag foaming** in the stainless steelmaking electric arc furnace by pneumatic injection of dust generated by stainless steelmaking. The pneumatic injection conditions of dust alone, co-injected with carbon and/or with FeSi or blended with coke, were optimised to allow a stable process in particular for the slag foaming implementation.

The recycling of the dust by pneumatic injection into the electric arc furnace, with or without slag foaming implementation, does not alter the produced slag in relation with its metallurgical functions and also with the technical properties of the solidified slag after tapping. An analysis based on the proportion and nature of the solid phases in the slag and on the liquid phase viscosity allowed defining the required slag conditions to assure a quick and stable development of the slag foaming during all the period with flat bath.



Foaming of the slag and recycling of stainless steel dusts by injection into the electric arc furnace for stainless steels

Dust recycling **plant tests** by co-injection with carbon and/or FeSi, as reducing agents, were carried out. Ferro-silicon use as further reducing agent has allowed reaching recovery ratio of Cr, Mn, Ni and Fe respectively of 81 %, 38 %, 97 % and 93 %. In addition, this practice leads to a decrease of the chrome oxidation in the slag at least by 20 % but nevertheless with chromium oxide content still relatively high. The zinc content in the new dust increases significantly depending of the zinc content in the recycled dust.
An **industrial pilot** equipment was implemented to inject a blend with electric arc furnace dust (70 %) and coke (30 %) with an oxygen injection by two specific lances on an industrial EAF. This equipment was designed for realisation of the slag foaming. The slag foaming process is now applied on all heats made in that EAF, except those with strong residual constraints.



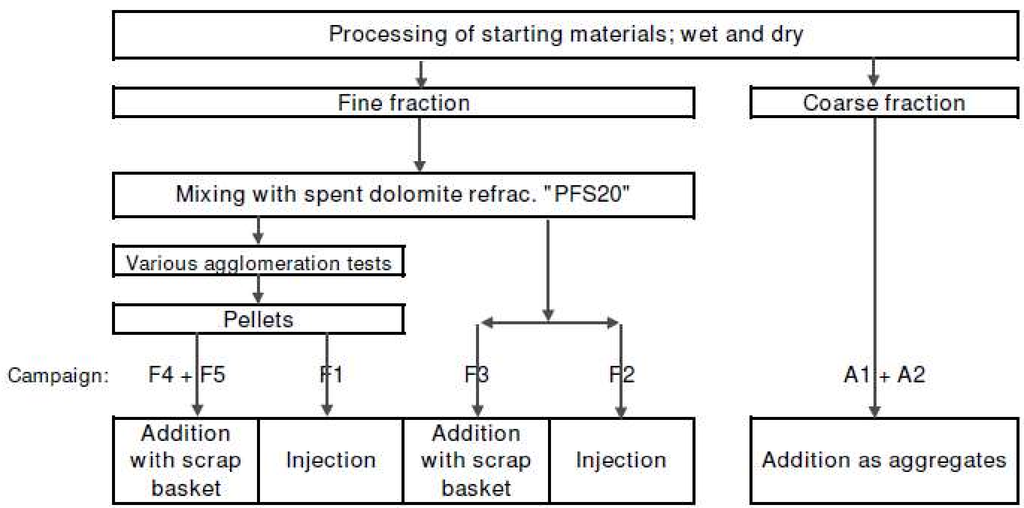
Efficient utilisation of raw materials used in secondary steelmaking as flux in steelmaking furnaces

The **general aim** of the project was a further step towards steelmaking without residues. The **activities** of the research group were focused on the recycling of slag from secondary steelmaking and spent refractory materials as fluxes in primary steelmaking.
The recycling of liquid ladle slag has been tested, successfully. The control of steel quality, especially sulphur in steel, process performance and the composition of EAF slag revealed no detrimental impact according to the recycling of the ladle slag.

Efficient utilisation of raw materials used in secondary steelmaking as flux in steelmaking furnaces

The recycling of solid materials has the advantage that a selection of favoured slag compositions, the adjustment of desirable mixtures and the production of uniform qualities is possible. An optimised synthetic slag former has been developed on the base of ladle slag and spent dolomite. This synthetic slag former has advantages with respect to the early formation of liquid slag, an improved foaming of slag by adjustment of the melting temperature as well as the viscosity and the minimised consumption of refractory material.
The **recycling** of ladle slag, mixtures of ladle slag and spent refractory materials as well as the recycling of spent MgO-refractory materials is beneficial to all investigated processes. However, the optimal recycling procedure depends on the operational conditions in the steel works. It will not be possible to recycle the liquid ladle slag in every steel shop.

Recycling of solid materials into the EAF



Upgrading and utilisation of residual iron oxide materials for hot metal production – URIOM

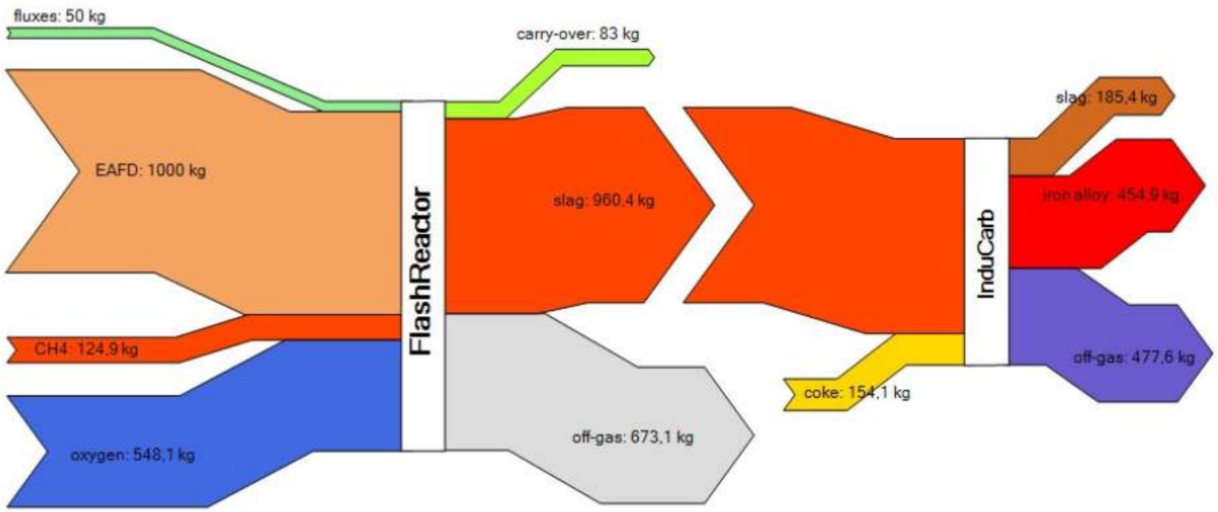
Within the URIOM research project two new technologies for **recovery of iron and chromium** containing residues from **stainless steelmaking** were developed and assessed based on modelling results or lab scale and technical scale experiments. Finally, the different processes and process variants were evaluated and compared. The following processes have been investigated:

- Inductively heated coke bed reactor (ICBR) process
- New briquetting technology using vegetable binders. The produced briquettes are directly recycled to the electric arc furnace

Experiments on a **new briquetting technology** using vegetable binders and direct recycling in the EAF, concerning the analysis of the briquettes melting behaviour, conducted during this project, both in VIM furnace and in pilot plant scale, have shown an iron recovery higher than 90 %. Results of the analysed process, however, need to be confirmed and validated with industrial tests in an EAF.

Upgrading and utilisation of residual iron oxide materials for hot metal production – URIOM

As a result of the investigations concerning the **inductively heated coke bed reactor** process, the industrial applicability of a coupled process (flash reactor/coke bed reactor) is proven by lab scale and technical scale trials. Further, the basic design of the inductively heated coke bed reactor including coke feeding system and off-gas treatment is available. Potential customers for application of the new process variants are stainless steel producers respectively foundries or smelters operating a cupola furnace.



Mass balance for the treatment of 1 t of EAFD with the combined Flash Reactor – ICBR process

Sub-Topic: Use of char from biomass replacing coal

Project	Consortium	Duration
Sustainable EAF steel production – GREENEAF	FERRIERE, CSM, DEW, IMPERIAL COLLEGE, Marienhütte, RWTH-IOB, Tecnocentro	2009-2012
Biochar for a sustainable EAF steel production – GREENEAF2	CSM, FERRIERE, GMH, Imperial College, Marienhütte, RWTH-IOB	2014-2016
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Sustainable EAF steel production – GREENEAF

The project GREENEAF was carried out with the **objective to replace coal and natural gas** in EAF with char and syngas produced by biomass pyrolysis. Generally speaking, in the electric furnace coal (and consequently char) is used as injected powder or charged into the basket. The syngas can be used for EAF burners.

The characteristics of char and biogas, and the related pyrolysis process, are tailored in order to match the requirements for their utilization in EAF. The following **activities** have been carried out within the project:

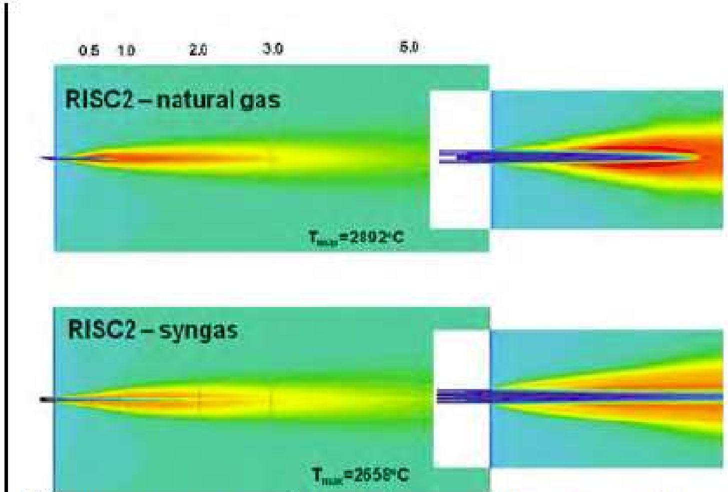
- Biomass selection and classification respect their origin and characterisation activities
- Tailoring of biomass pyrolysis: Laboratory tests to define the pyrolysis kinetics of the selected biomass, and on the basis of these results design of industrial pyrolysis; then chemical and physical characterization of char produced by biomass pyrolysis has been carried out to define pyrolysis plant process parameters. About fifteen tons of char has been produced for industrial trials

Biochar briquette (left) and anthracite coal (right)

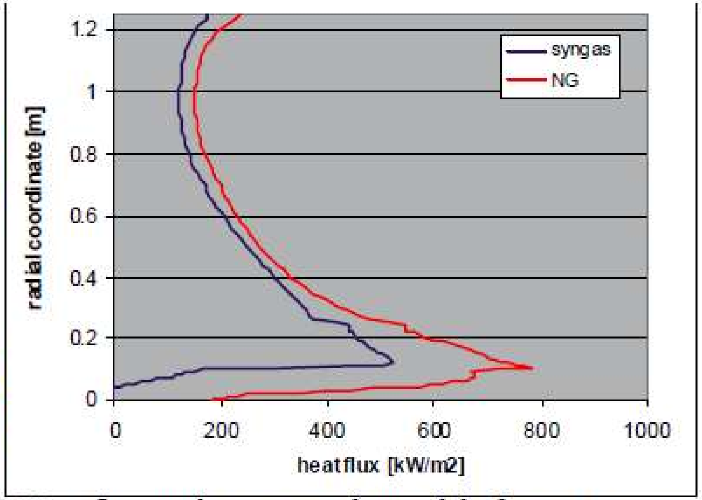
Sustainable EAF steel production – GREENEAF

- EAF pilot plant experimentation: First tests of char utilization have been carried out in the pilot Furnace
- Industrial experimentation: industrial tests with char have been carried out
- Simulation of syngas utilization: due to the difficulties to have syngas available close to the steel plant syngas utilization for EAF burners has been simulated by CFD calculation.

The **results** obtained have demonstrated the technical feasibility of the used approaches while the economical evaluation has shown the sustainability of replacing the coal with char from biomass, in addition to environmental benefits due to CO_2 reduction, even if at the moment there is not a real assessed market of charcoal for steelmaking purposes.



Flame temperature during the same process condition of a burner fed by natural gas and syngas



Heat flux on the scrap in front of the burner, in case natural gas (NG) and syngas

Biochar for a sustainable EAF steel production – GREENEAF2

The **objective** of this proposal is to apply as a standard practice the utilization of char from biomass as a substitute for fossil coal in the electric arc furnace. Previous carried out project GreenEAF demonstrated the feasibility of utilization of char in the EAF, but following aspects need to be investigated further:

- charging in the bucket: preliminary industrial trials were promising, but char reactivity must be controlled and EAF operating practice optimised;
- injection: in order to promote slag foaming, injection systems have to be improved. Modification of injection systems have already been studied but field validation is required.

The effects on: plant productivity, costs, environmental issues, materials handling and storage are also evaluated.

Recycling of industrial and municipal waste as slag foaming agent in EAF – RIMFOAM

High electric energy and coal prices in combination with carbon dioxide taxes have driven European steelmakers to look for **alternative chemical energy resources** other than primary coal to remain competitive on the global steel market. This requires higher flexibility in the steel production route regarding raw material preparation and melting operation. This project seeks to **partly substitute carbon and oxygen** with industrial and/or municipal waste (ASR, rubber tyres, plastics, biomass waste and byproducts, EAF dust and mill scale) **for slag foaming** purposes in the EAF. The goal is to explore cost- and energy-effective alternative slag foaming agents while maintaining or improving the slag foaming intensity, preserving the liquid steel quality and keeping emissions at a low level.
The extensive material tests and pilot/industrial trials in the project will ensure that partial substitution of coal with waste materials can be done without increased environmental footprint or compromised steel quality.

Sub-Topic: Recycling of by-products

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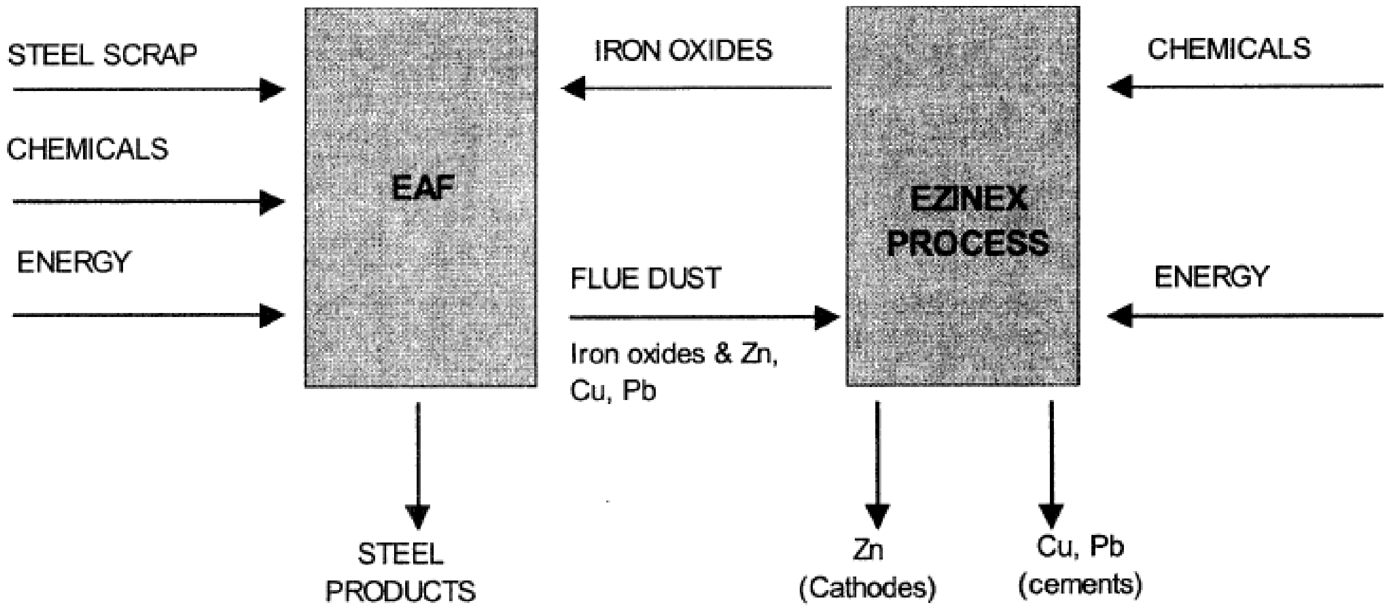
Economic advantages of integrated processing of steelworks EAF wastes, mainly containing Zn, Pb, Cd, FeOx, Zn ferrite and others, with total recovery

The research was **aimed** at determining optimum conditions for the total recycling of EAF dusts by measuring the economic value of each element. To this end, a hydro-metallurgical extraction, separation and reclaiming system of all non-ferrous metals was implemented, wherein all ferrous items were to be recycled and reused in the electric arc furnace.

The plant called **Ezinex**® was used. A hydro-metallurgic system treats the dusts produced and recycled in the electric arc furnace.

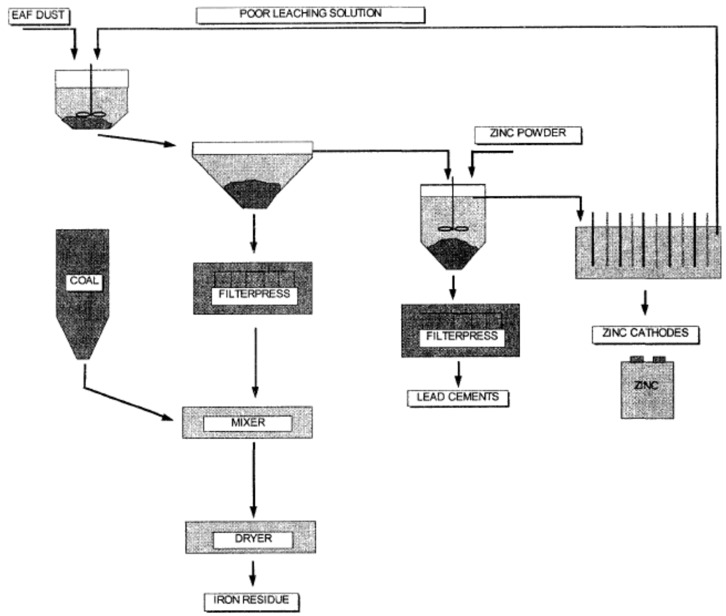


Economic advantages of integrated processing of steelworks EAF wastes, mainly containing Zn, Pb, Cd, FeOx, Zn ferrite and others, with total recovery

This system allows to carry out the extraction of nearly pure zinc metal in the form of cathodes; the separation of lead and heavy metals in the form of cements, and the production of a ferrous residue which, once it has been dried, converted into pellets and mixed to reductants, is introduced into the electric furnace to recover iron.

For over two years, trials have been carried out at the EAF and the research proved that furnace recycling of this fraction is feasible and does not cause any process or product anomalies; moreover it is more economical than other used fume collection systems.

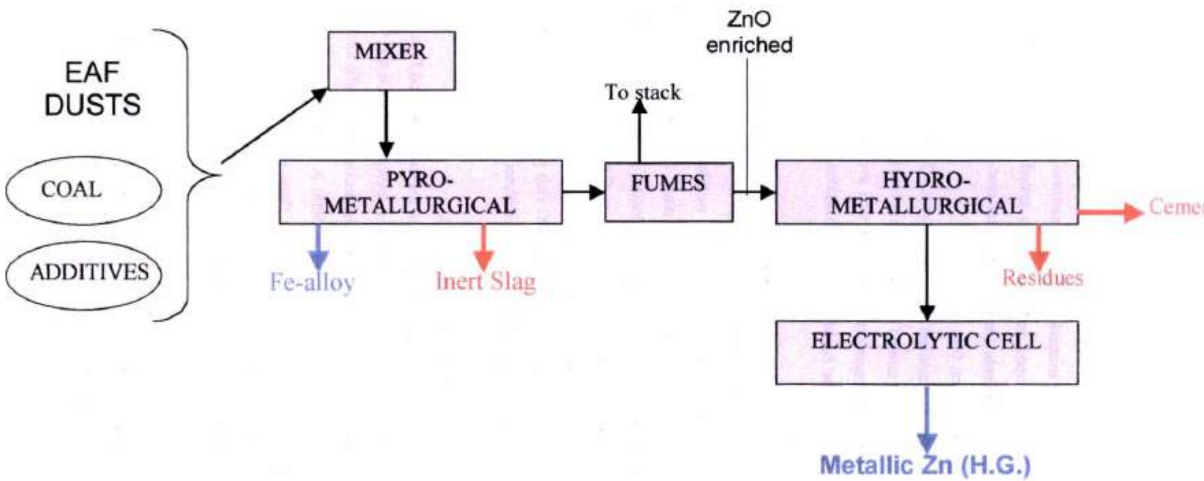
Hydrometallurgical option is mentioned in the Best Available Techniques (BAT) Reference Document for Iron and Steel Production



High purity zinc and ferroalloys recovery from EAF dusts through a combined pyro-hydrometallurgical treatment

An innovative **pyro-hydrometallurgical treatment** aimed at recovering metallic zinc from powders rich in ZnO has been realised. These powders are produced from the thermal fumigation of EAF dusts (mix of dusts manufactured from carbon steel and stainless steel) in an **arc-plasma furnace**, producing ferroalloys, totally inert slag and ZnO-rich powders. These powders are treated via a hydrometallurgical process and the zinc produced has a purity higher than 99.90 % (zinc of high-grade quality).
The innovating process for the recovery of zinc and ferroalloys (**Full-Rec process**) has been realised.
Technical-economic evaluation of Full-Rec technology, according to the industrial scale for 65 000 t/y EAF dust treatment, showed an investment internal return rate of over 20 %.

Follow-up project „FULL-REC 2“



Pre-processing of metallurgical wastes by direct reduction for recovery of iron, zinc and lead

The **aim** of this research project was to evaluate a new recycling route for the various iron-bearing wastes that arise in the steel industry. The proposed recycling route consists in pre-processing these wastes by the COMET direct reduction process.

COMET **pilot plant trials** were carried out with EAF dust micro-pellets. When increasing the processing temperature, the zinc and lead content of the dust collected in the bag filters increases while the zinc and lead content of the DRI produced decreases. For a furnace maximal temperature of 1325 ºC, the **DRI** produced contains 58% iron (with a metallization of 75%), nearly no more zinc (0.08%) and less than 1% lead.

The **dust** collected in the bag filters during trials with EAF dust micro-pellets is very rich in zinc oxide (55.3%) and in lead oxide (9.4%) and contains less than 0.4% iron, thanks to the very low dust carry away during charging and processing with the COMET process.

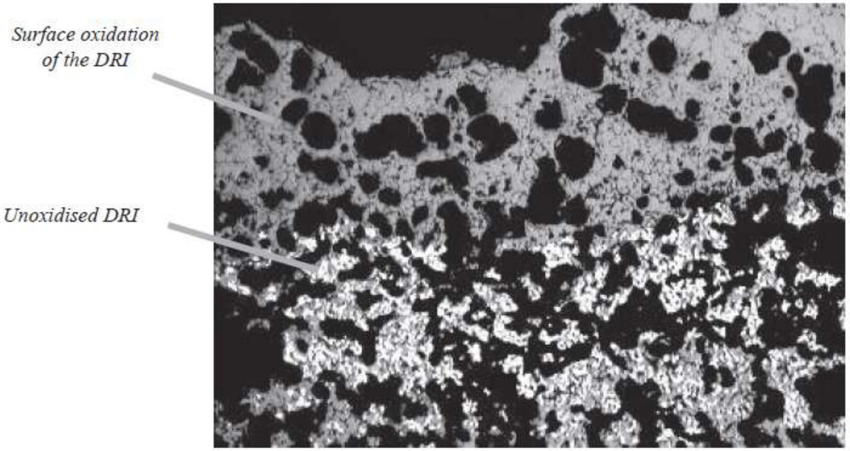


Figure 4 – Surface oxidation of the DRI produced during set-up trials

Control of slag quality for utilisation in the construction industry – SLAGCON

During steelmaking, slag is generated in different kinds of processes. **Processed slag** can be used as building material if certain quality criteria are met. Slag quality is defined by mechanical properties and by environmental behaviour of slag. Maximum concentrations of leachable substances in the slag eluate, for example fluoride, molybdenum, chromium and vanadium, have been fixed to define slag quality. Slag quality and the possibilities of slag utilisation can be improved by:

a) immobilisation of these leachable substances

b) recycling of washing/cooling water from slag treatment with elimination of leachable components.

The **project aims** at ensuring and increasing the utilisation of steelmaking slags in the construction industry by improving the quality of slag. For this purpose, new techniques have to be developed to immobilise the critical elements and separate remaining leachable substances (e.g. fluoride, molybdenum, chromium and vanadium) from the washing/cooling water and to condition these separated substances for disposal or reuse.

International state of the art

Recycling and closed material circles in the steel industry

Recovery of zinc oxide from secondary raw materials: new developments of the Waelz Process

OxyCup Furnace — Smelting Steelmill Fines, Dust and Sludge to Liquid Hot Metal and Slag

EAF smelting trials of briquettes at Avesta Works of Outokumpu Stainless AB for recycling oily mill scale sludge from stainless steel production

Recycling of Electric Arc Furnace Dust: Evaluation of the Iron Metal Incorporation in Hot Metal Bath

Reduction of iron from iron-carbon briquets in electrosmelting of steel

Development of a new method of recycling stainless steel by products into EAF

Oxide-carbon briquettes are a reserve for steelmaking shops

International state of the art

Kinetics of Reduction of FeO in EAF Steelmaking Slag by Metallurgical Coke and Waste Plastics Blends

Utilization of Waste Plastics in EAF Steelmaking: High-temperature Interactions between Slag and Carbonaceous Materials

Reduction of FeO in EAF Steelmaking Slag by Blends of Metallurgical Coke and End-of-Life Tyre

Influence of Carbonaceous Materials on Slag Foaming Behavior during EAF steelmaking

Recycling of Rubber Tyres in Electric Arc Furnace Steelmaking: Carbon/Slag Reactions of Coke/Rubber Blends

Biomass use in the steel industry: back to the future?

Charcoal from agricultural residues as alternative reducing agent in metal steelmaking

Recycling Agricultural Waste from Palm Shells during Electric Arc Furnace Steelmaking

Biomass as a Source of Renewable Carbon for Iron and Steelmaking

Charcoal, renewable energy source for steelmaking process

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