ESTEP SPRING DISSEMINATION EVENT

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Energy Balanced Technology for Recycling Iron Oxide Waste in the EAF Process

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Introduction

Ferrostal Steelworks in Gliwice produces 1100 tons of scale per year. The source of this scale is continuous casting proces. The waste consists of scale from the cooler and from the hydrocyclone devices.

a) ***b)***

Iron-bearing wastes from the Ferrostal steelworks in Gliwice:

a) scale from the cooler,

b) scale from the hydrocyclone;

to illustrate grain size, a coin with a nominal value of 1 gr is used

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Introduction

- The scales could be a rich source of pure iron. They differ slightly in chemical and phase composition, and therefore in iron richness

- These materials are an attractive carrier of iron provided that the **appropriate technology for recycling them to the process is used.**

Iron concentrations in scales

Component	Scale from cooler store	Scale from hydrocyclone
	% mass	
$Fe_{met.}$	1.17	3.13
$Fe_{tot.}$	72.93	69.74

The result of phase analysis of scales

Component	Scale from cooler store	Scale from hydrocyclone
	% mas.	
Magnetite Fe_3O_4	40.3 ± 0.8	30.6 ± 1.0
Hematite a-Fe_2O_3	6.8 ± 0.8	2.6 ± 1.0
Wüstite Fe_xO	31.5 ± 0.8	44.5 ± 1.0
Metallic iron, α-Fe	< 1.0	< 1.0
Quartz SiO_2	< 1.0	< 1.0
Other(mainly amorphous phase)	21.4 ± 4.3	21.6 ± 8.7

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Initial state

- Industrial trials of recycling iron-bearing waste in electric arc furnace (EAF) in the form of briquettes which contain iron oxides and carbon have proven ineffective.

- The briquettes were introduced at different stages of the process and in different quantities, but in all cases the **charge was locally cooled** by the endothermic reaction of iron oxide reduction and, as a consequence, the process of steel reduction and smelting was slowed down, and the introduced iron oxides **were largely transferred to the slag**.

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Initial state

- Due to the unsatisfactory results of scale recycling, Ferrostal began searching for a technology that would enable effective recycling of its own iron-bearing waste in an electric arc furnace.
- ŁUKASIEWICZ – Górnośląski Instytut Technologiczny in Gliwice has proposed its own innovative solution of using waste aluminum for exothermic reduction of part of the iron oxides. This reaction balances at least partially the endothermic reaction of iron oxides reduction with carbon.
- As a result, joint development of industrial technology for reducing iron oxides in EAF process was initiated
- The main research issue was the determination of the proportions of both used reducers in order to obtain a balanced energy effect in the iron oxide reduction process and development of the technology for introducing wastes into the EAF process.

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Scope of research work

Research work included:

- Selection of waste carrier of metallic aluminium
- Development of the composition of the mixture of scale and aluminium carrier ensuring minimization of the cooling effect while ensuring high iron yield from the scale (over 90%).
- Selection of the mixture agglomeration technology
- Development of the technology of steel production in the EAF process using the developed mixture in the amount of up to 4% of the charge mass

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Scope of research work

- **Selection of aluminium carrier:** As a result of testing several wastes, aluminium dross from the foundries (approx. 50% Al met.) was selected as the basic aluminium carrier, but other materials were also tested.
- **Mixture composition**: Compositions of mixtures for laboratory and then industrial testing were developed based on balance calculations. The calculations showed that the mixture marked as Mix0 should display slightly negative energy balance, and the others a positive balance.

Raw material compositions of self-reduction mixtures tested under the project

Mixture	Scale from cooler store	Scale from hydrocyclone	Coal	Aluminium dross
Mix0	35	35	20	10
Mix1	35	35	17.5	12.5
Mix2	**35**	**35**	**15**	**15**
Mix3	35	35	12	18

Estimated energy effect of the mixtures

Mixture	Estimated energy effect	Estimated proportion of iron oxides reduced by aluminium
Mix0	**-23 kJ/g**	about 25%
Mix1	**10 kJ/g**	about 31%
Mix2	**43 kJ/g**	about 37%
Mix3	**93 kJ/g**	about 45%

Scope of research work

Agglomeration: Powdery/loose materials cannot be fed into the steel furnace, because they will be largely sucked into the process gas extraction system. For this reason, one of the issues of the research project was to develop the most advantageous method of the mixture **agglomeration**. Two types of briquettes and large-sized agglomerates, in the form of post-consumer barrels, were used.

a)

b)

Large-size agglomerates

Briquettes used in experimental melts obtained:

a) on a vibratory plate compactor with the use of a mineral binder,
b) on a roller briquetting machine with the use of an organic binder

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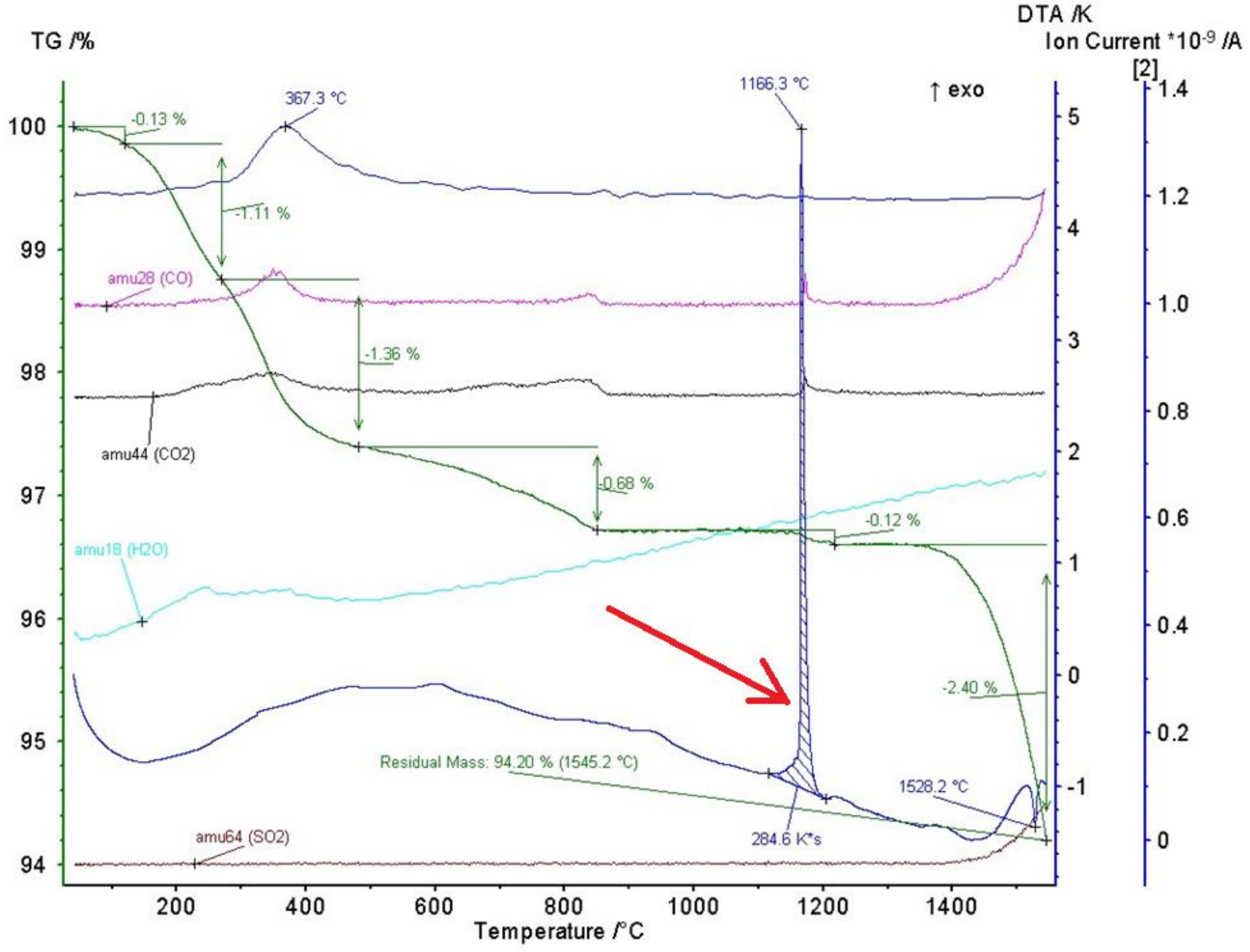
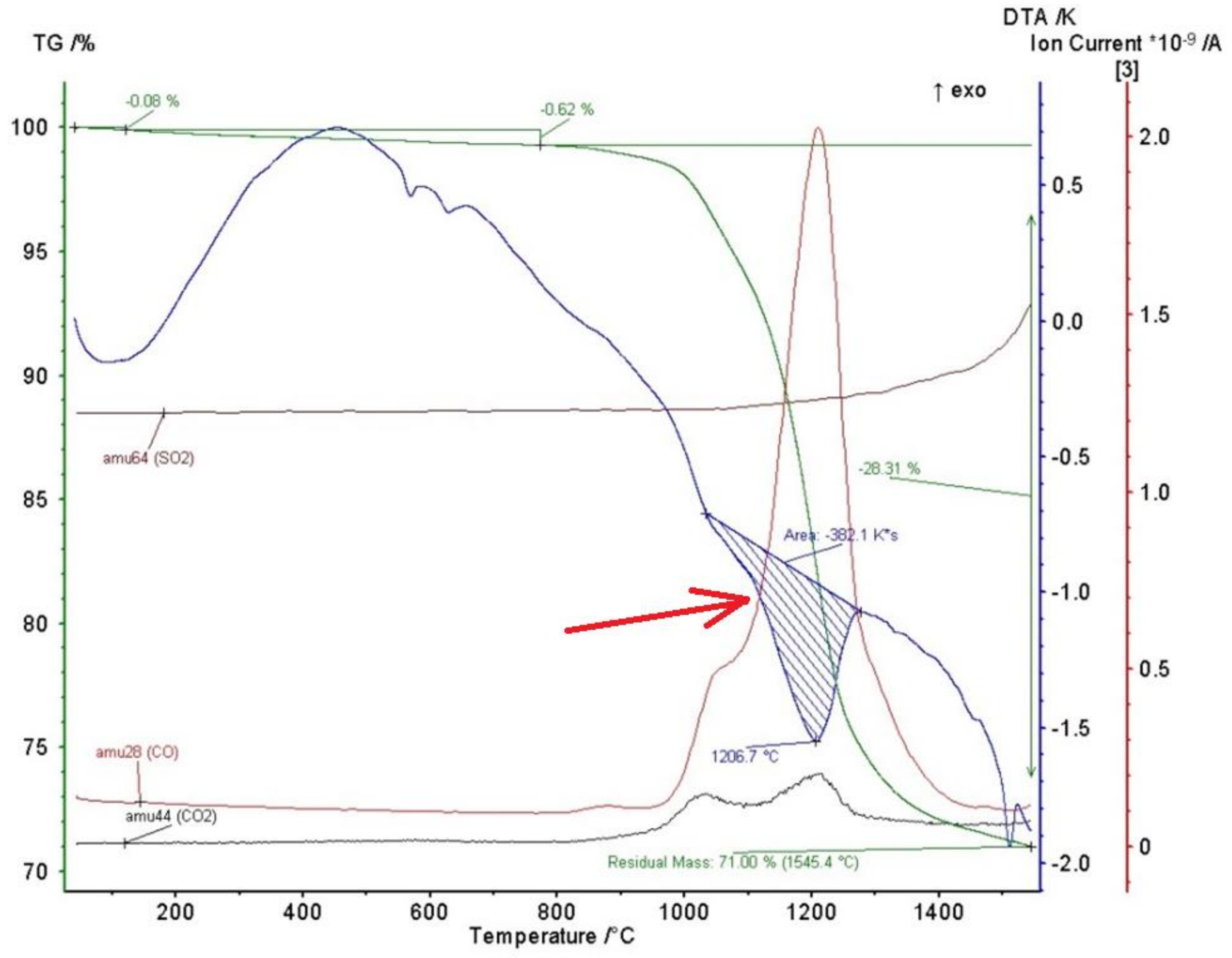
Research results - the influence of the reducer on the energy balance

The mixtures were initially tested using thermal analysis TG/DTA. This allowed for verification of the results of energy balance calculations.

Below are shown extreme cases (not physically tested on a larger scale) of using only one reducer - C or Al, red arrows indicates the energy effect of the reduction reaction



Thermal analysis results of a mixture with a composition of 85% scale, 15% aluminum dross in an argon atmosphere

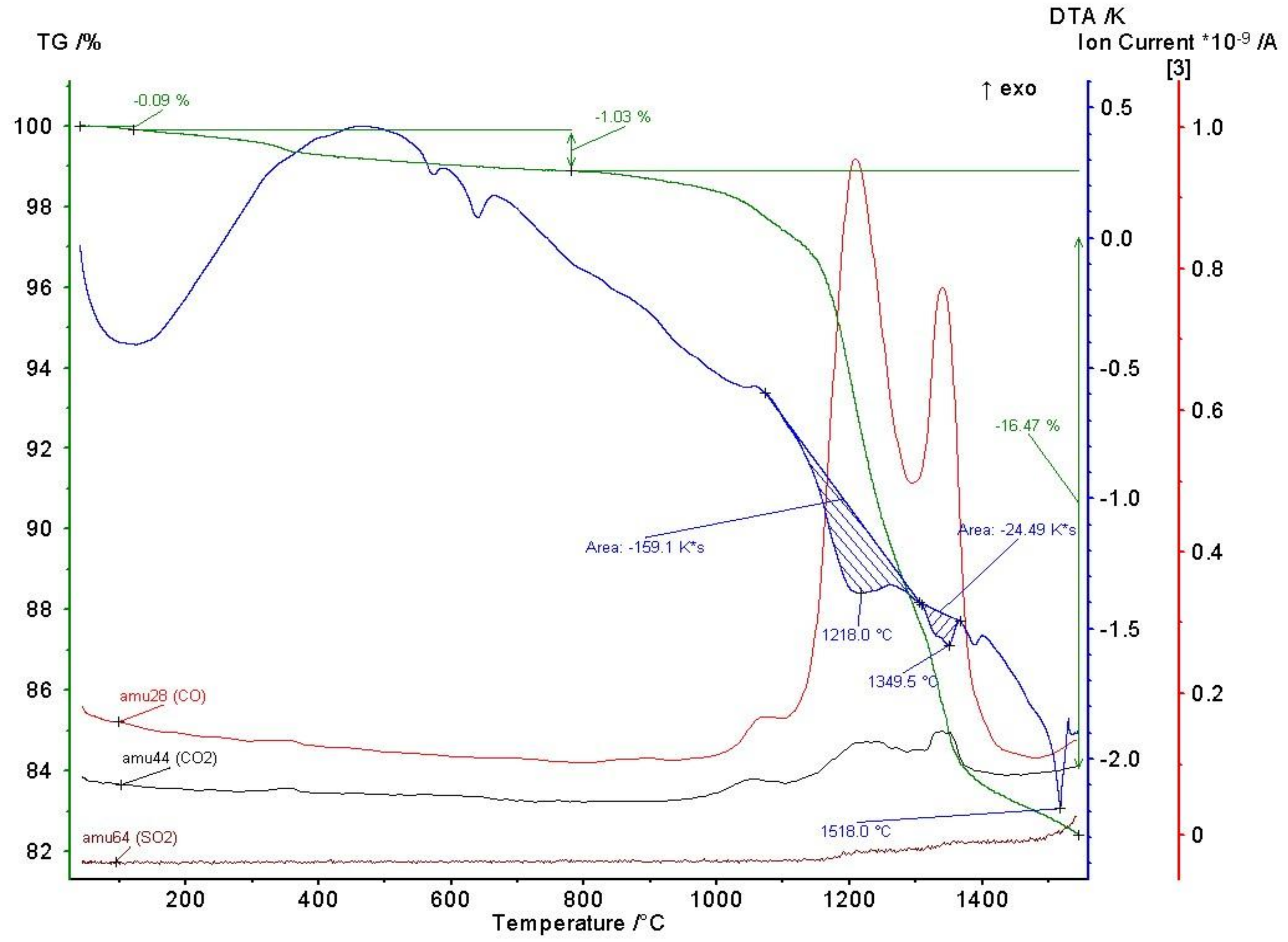


Thermal analysis results of a mixture with a composition of 75% scale, 25% coal in an argon atmosphere

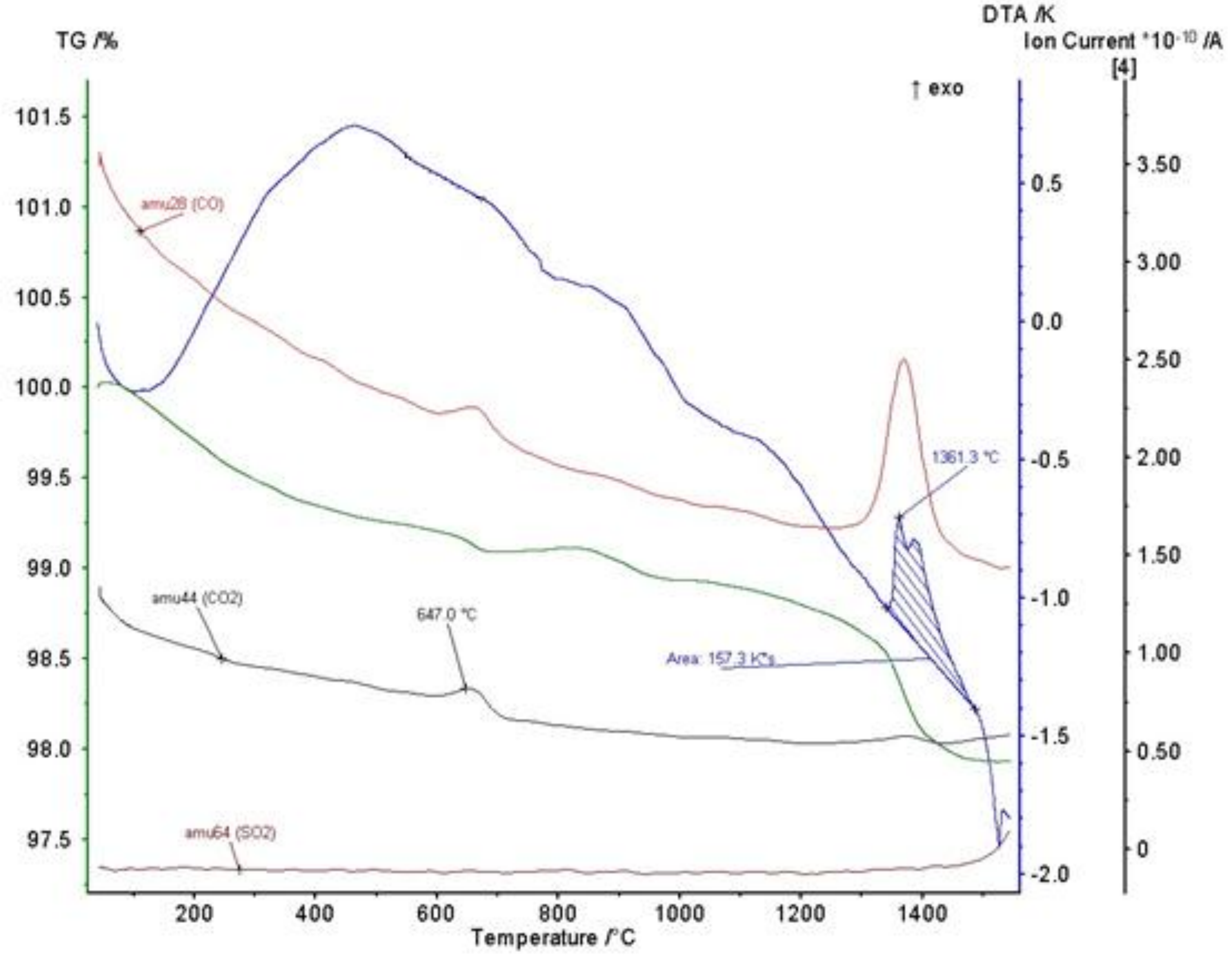
Research results - the influence of the proportion of reducers on the energy balance

Results of thermal analysis of selected self-reducing mixtures that were tested in industrial conditions

Below are examples of mixtures (with two reducers) with negative and positive energy



Thermal analysis results of a mixture with a composition of 70% scale, 20% coal, 10% aluminum dross in an argon atmosphere



Thermal analysis results of a mixture with a composition of 70% scale, 12% coal, 18% aluminum dross in an argon atmosphere

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Research results - metallurgical laboratory tests

a) b)

Metallurgical laboratory tests of the self-reduction composite; reaction after introducing into the furnace the mixture with:
a) 15% of dross,
b) 18% of dross

Metalurgical tests in a laboratory furnace showed that the aluminium dross content should not exceed 15% due to the violent exothermic reaction, which ruled out Mix3.

Mixture	Scale from cooler store	Scale from hydrocyclone	Coal	aluminium dross
Mix0	35	35	20	10
Mix1	35	35	17.5	12.5
Mix2	**35**	**35**	**15**	**15**
Mix3	35	35	12	18

Research results - metallurgical laboratory tests

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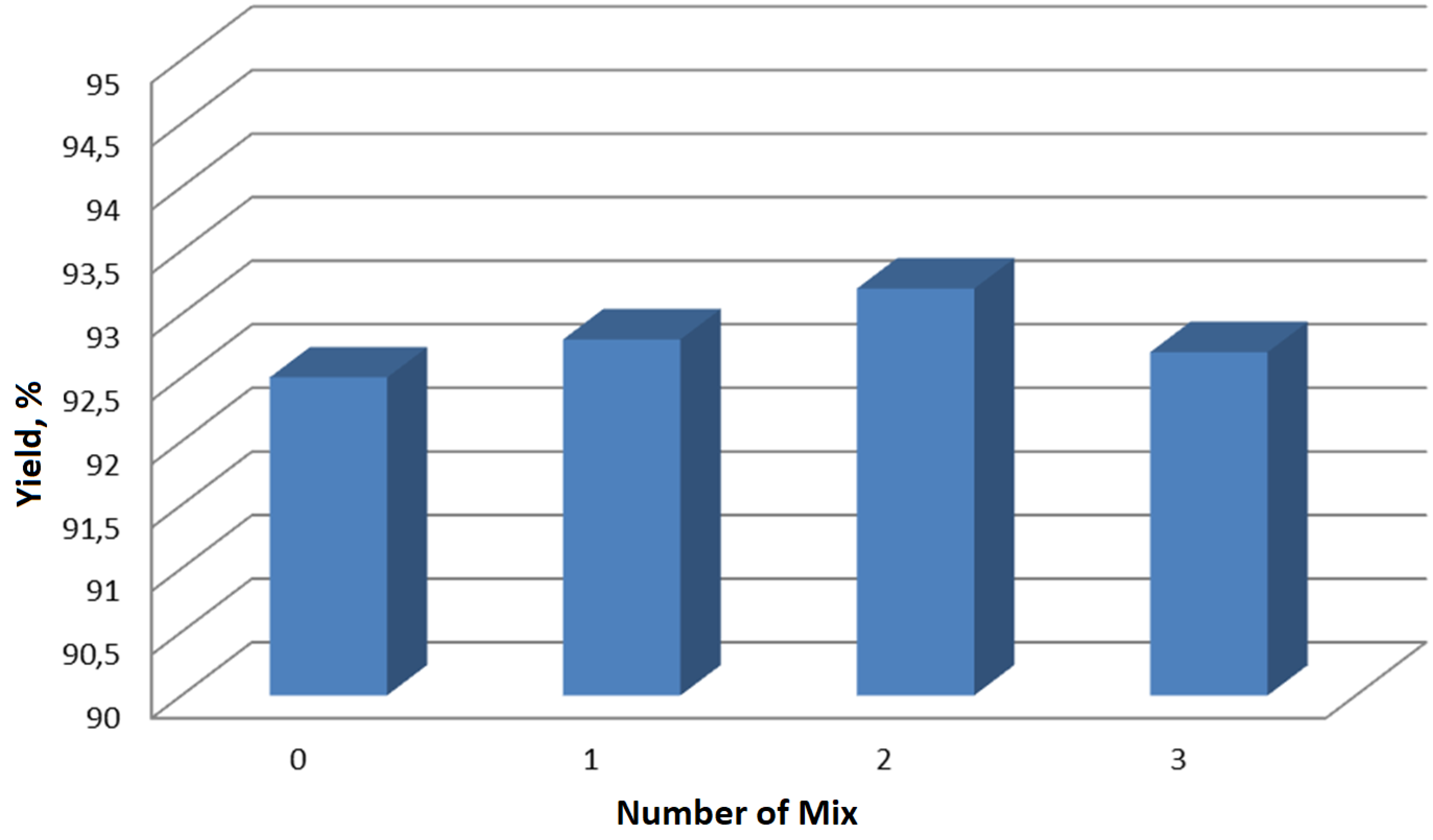
Iron yields obtained during testing of mixtures in laboratory metallurgical experiments



Iron yield from respective mixtures

- **The iron yield from all mixtures is over 90% (from 92.3% to 93.5%)**
- **The variability of the results is so small that it is difficult to draw conclusions about the significant effect of the proportions of reducing agents on the iron yield**

Therefore, the main factor influencing the selection of the proportions of endothermic and exothermic reducer should be the energy balance of the iron reduction processes

compositions of self-reduction mixtures

Mixture	Scale from cooler store	Scale from hydrocyclone	Coal	Aluminium dross
Mix0	35	35	20	10
Mix1	35	35	17.5	12.5
Mix2	**35**	**35**	**15**	**15**
Mix3	35	35	12	18

Industrial trials

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Industrial tests included 150 experimental melts in 17 series differing in technological parameters

During each series of experimental melts, tests were performed in various configurations with a mixture share of more than 3% of the charge mass:

A. Time of loading into the furnace
– with 1st charging basket
– with 2nd charging basket
– with 3rd charging basket
– with 1st charging basket and with 3rd charging basket (in two portions)

B. Agglomerate size and shape:
– pillow-shaped briquettes,
– cylindrical briquettes with dimensions of (height and diameter) approx. 100 mm,
– mixture poured into post-consumer perforated steel barrel with capacities of 60–300 l, and then packed in big-bags.

C. Mass of the material fed in furnace

– for briquettes: 1.06-3.90 Mg/heat

– for large-sized agglomerates: 2.25-3.90 Mg/heat

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Self-reducing mixture prepared for industrial testing (large-size agglomerates)

Large-size agglomerates in big-bags, prepared for loading in the charge basket

Charge basket used for loading scrap and agglomerates into the furnace. The agglomerates are placed at the bottom of the basket

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Industrial trials result

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- **The use of waste metallic aluminium in self-reducing mixtures has eliminated the problems occurring in EAF when using mixtures with only carbon as a reducing agent.**
- **The use of aluminum dross in a self-reducing mixture reduces the energy demand compared to carbon-only mixtures**
- **Compared to melts without the addition of self-reducing agglomerates, energy consumption is 2% higher if aluminum dross is used**
- **The use of purer aluminium carriers (metallic aluminium concentration about 80%) in the amount of approximately 15% of the mixture completely eliminates the cooling effect of using self-reducing iron-bearing mixtures, but the cost of the mixture is higher.**
- **Tests showed that the mixture can be introduced in any basket or divided into portions - it should be noted that adding briquettes in the first basket is effective due to the practice of working witch ”hot heel” in the Ferrostal Steelworks**
- **Iron recovery from scale is comparable to that from scrap – over 90%**

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Industrial trials result

- **Based on a series of experimental smelts performed under the conditions of the Ferrostal Steelworks, it was found that the introduction of self-reducing agglomerates in the first charge basket gave the best results in iron reduction and electricity consumption, although the differences between the baskets were small**

- **When introducing a larger amount of agglomerate, the whole charge can be divided into smaller portions fed into subsequent charge baskets.**

- **When loading the charge, the briquettes should be close to the bottom of the charge basket so that they are weighed down by the scrap above it and thus immersed in the liquid steel (hot heel in the case of the first charge basket). This has a strong effect on the heating rate and cuts off the access of atmospheric air to the agglomerate**

Conclusion from industrial trials

- **The technology of returning scale to the electric arc furnace using self-reducing mixtures, in which the aluminothermic reaction is used to reduce some iron oxides, has proven its usefulness when using the mixture in an amount of up to 3.9% of the charge mass (above was not tested). The original goal was to use up to 3% of the charge**

- **The technology eliminated the disadvantages of typical self-reducing mixtures based only on a carbon reducer:**
  - **strong cooling effect**
  - **low reduction of iron oxides (in a cold mixture)**

- **The self-reducing mixture can be agglomerated by briquetting or packing in post-consumer steel barrels to create large-sized agglomerates. Briquettes have proven to be more convenient to use**

- **Briquetting of self-reducing mixtures containing aluminium dross is possible using various technologies and using various binders. Organic binders do not introduce ballast into the mixture like ceramic ones and are therefore the most suitable.**

- **Good results in terms of energy balance are obtained by using a metallic aluminum carrier richer than aluminum dross, but this increases the cost of the mixture**

- **Due to the experimental confirmation of the effectiveness of the technology of recycling oxide-bearing iron waste, a decision was made to implement the technology into production practice.**

Thank you for your attention

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