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Selected Aspects of Graphite Applications in Ferrous Metallurgy.

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Agenda

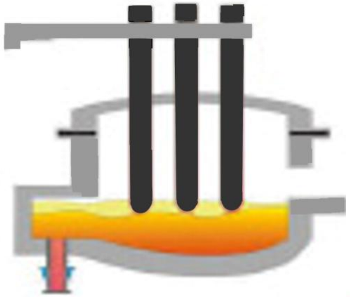
- Introduction
- EAF Electrods
- Macro scale experiments
- Micro scale experiments
- Future experiments/possibilities
- Summary

Introduction

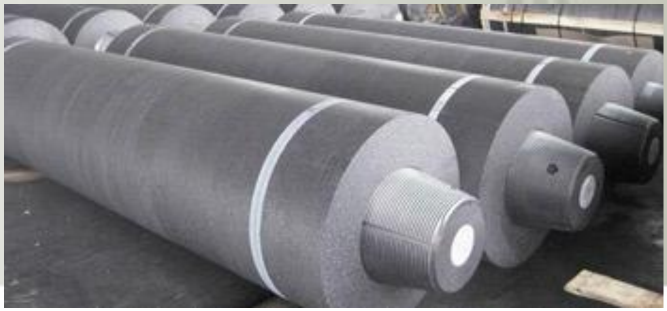
One of the basic units for steel production is an electric arc furnace.

However, one of the most important elements of its construction are graphite electrodes.

The graphite electrode consumption is an essential component of the cost of steel production in EAF.



Introduction



Consumption of graphite electrode is related to different parameters of steel production technology and electrical parameters of supply system.

Average consumption of electrodes is measured in

kg of electrode per ton of steel

and has widely range:

from **less than 1 kg/t** up to

5 kg/t (in special cases up to 10 kg/t)

Assuming consumption of 1-2 kg per ton of world steel production the demand of electrode is about 2 million tons per year .

The graphite electrodes production is a big market.

Mechanisms of Electrode Consumption

The mechanisms of graphite electrode consump-tion fall into two basic categories termed:

- “contin-uous consumption” and
- “discontinuous consump-tion”.

Continuous consumption is further defined as losses due to tip sublimation and sidewall oxidation.

Discontinuous consumption is characterized by losses due to various forms of breakage, butt losses and spalling.

Mechanisms of Electrode Consumption

Tip sublimation

of graphite electrodes occurs at temperatures at or above 3000°C. These very high temperatures exist only when an arc is present. Within milliseconds after the arc is extinguished, sublimation loss stops. During sublimation, graphite is converted directly from a solid to a gas (carbon monoxide), without ever achieving a liquid state.

Mechanisms of Electrode Consumption

Numerous factors affect the rate of sublimation:

- Magnitude of the current passing through the electrode when arcing.
- Cross-sectional diameter of the arc spot at the tip of the electrode.
- Duration of time current is passing through the electrode (power-on time).
- Resistivity of the graphite electrode.
- Arc stability (good arc stability is essential to proper EAF operation).

Mechanisms of Electrode Consumption

By using higher voltages and lower currents (long arc operation), the losses due to sublimation will be reduced while also improving the scrap melting. When running under long arc operation, the conical arc impacts a larger area of the scrap and tends to cut the scrap from the furnace walls much more efficiently.

Mechanisms of Electrode Consumption

- *Calculation of Continuous Graphite Consumption (Sublimation)*

$$C_{Tip} = R_{Sub} \frac{I^2 * t_{po}}{0.454 * P}$$

where

- C_{Tip} = graphite sublimation (lbs/ton),
- R_{Sub} = graphite sublimation rate (kg-hr/kA^2),
- I = current per phase (kA),
- tpo = power-on time (hours) and
- P = productivity (tons/heat).

Mechanisms of Electrode Consumption

sidewall oxidation

Multiple fac-tors influence the magnitude of sidewall oxidation:

- graphite electrode density and resistivity
- tap-to-tap time,
- Temperatutre - arc current,
- gas flowing parameters inside furnace.

Mechanisms of Electrode Consumption

Calculation for Graphite Electrode Consumption (Oxidation)

$$C_{Slide} = R_{Ox} * \frac{A * t_{tap}}{P}$$

where

- C_{Side} = graphite oxidation (lbs/ton),
- Ro_x = average oxidation rate in (lbs/ft^2-hr),
- A = oxidizing electrode surface area (ft^2),
- t_{Tap} = tap-to-tap time (hours) and
- P = productivity (tons/heat).

1 lb = 0,45 kg

ft^2 = 0,09 m^2

Mechanisms of Electrode Consumption

Normally, when electrodes sublime and oxidize, there will be a release of carbon monoxide (CO) gas.

The CO film around the electrode reduces the effect of oxygen attack to the graphite.

Anything that affects that protective film will accelerate the oxidation losses

Mechanisms of Electrode Consumption

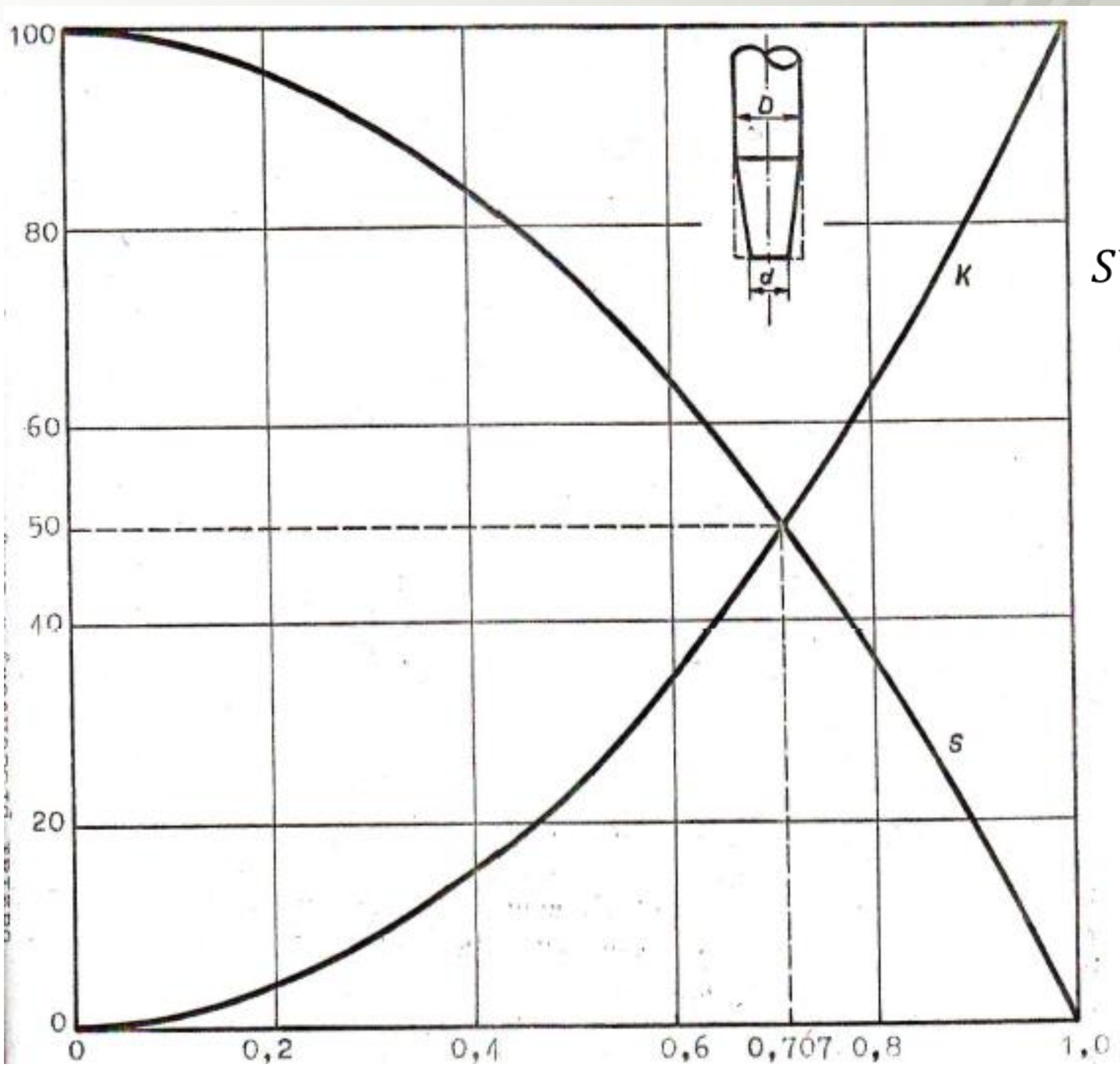
- Calculation for Sidewall Oxidation

$$SWO = \frac{(D^2 - d^2)}{D^2}$$

where

- SWO = sidewall oxidation (pounds),
- ${}_{D}^{2}$ = virgin diameter of graphite electrode and
- d^2 = measured diameter of graphite electrode.

share of tip sublimation to sidewall oxidation



$$SWO = \frac{(D^2 - d^2)}{D^2}$$

ratio

Mechanisms of Electrode Consumption

The discontinuous consumption includes various forms of: breakage, such as socket breaks, pin breaks, body breaks, butt losses and spalling.

The most frequent cause of breakage and butt losses is improper elec-trode additions techniques.

The second most frequent cause of breakage and butt losses is improper scrap mixes and poor scrap loading. Improper scrap mixes can include charging non-conductive material.

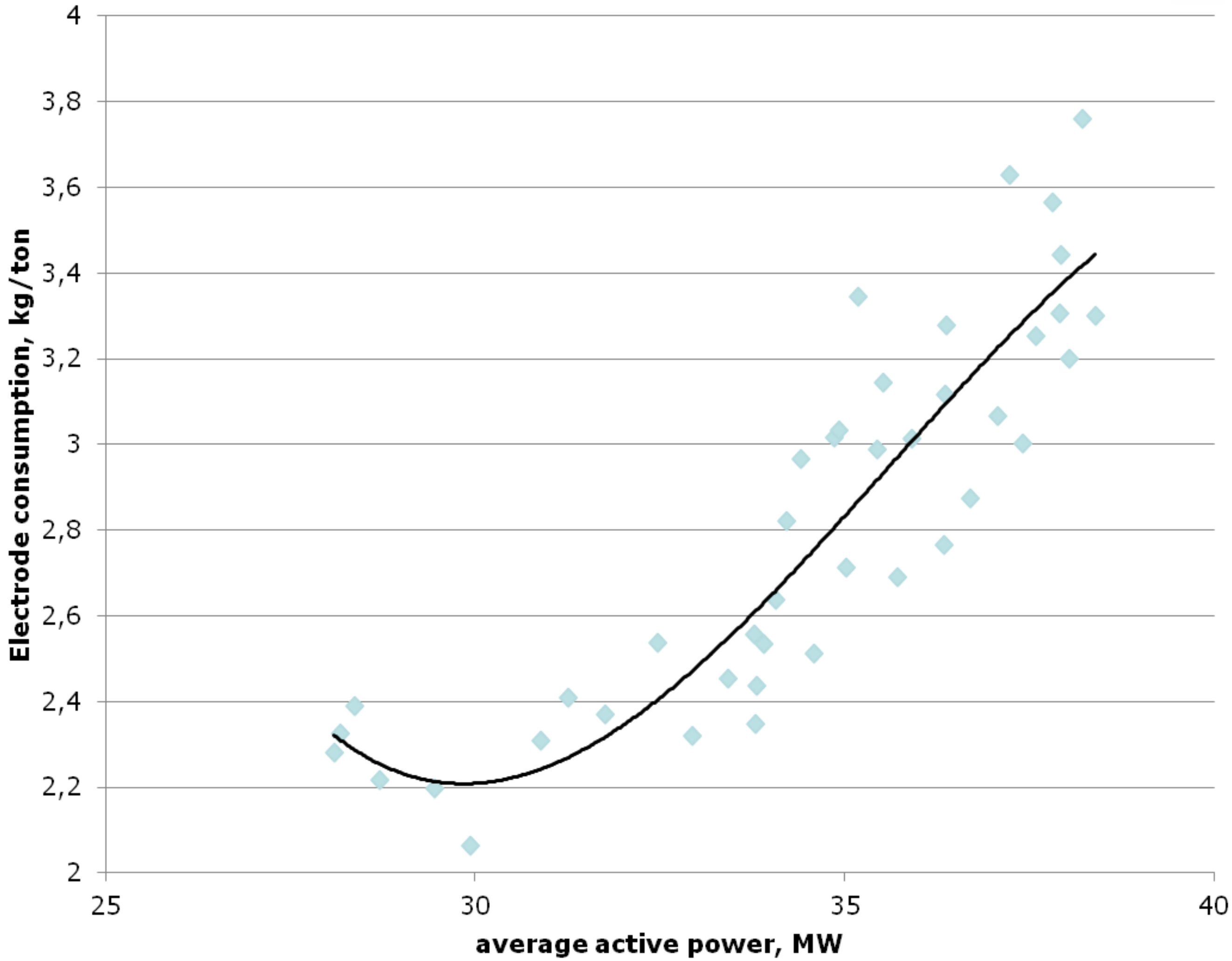
Mechanisms of Electrode Consumption

In a properly operating shop, with good electrode addi-tion and scrap practices:

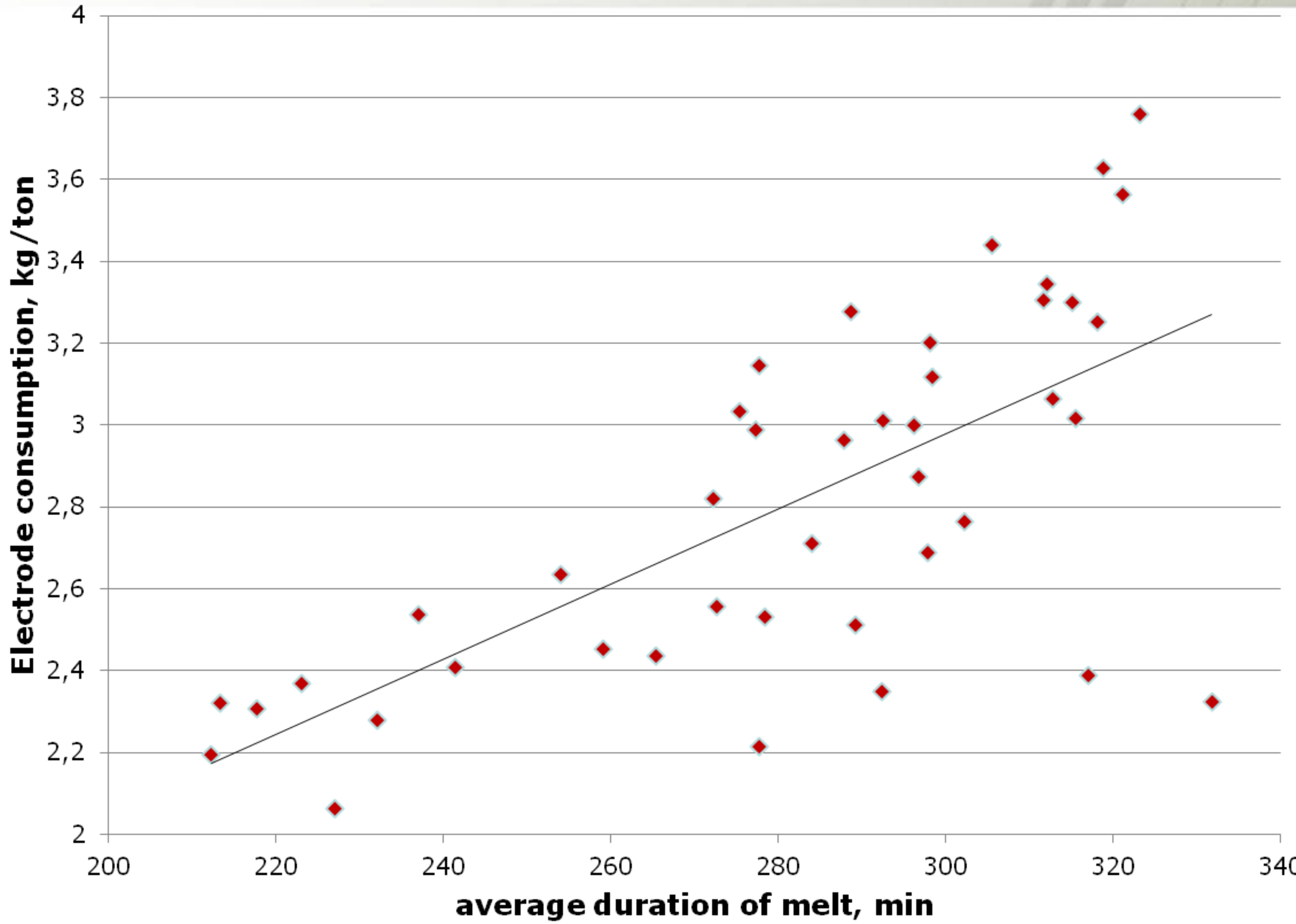
- the continuous consumption should account for approximately 95% and

- discon-tinuous consumption for 5% of the total graphite electrode usage.

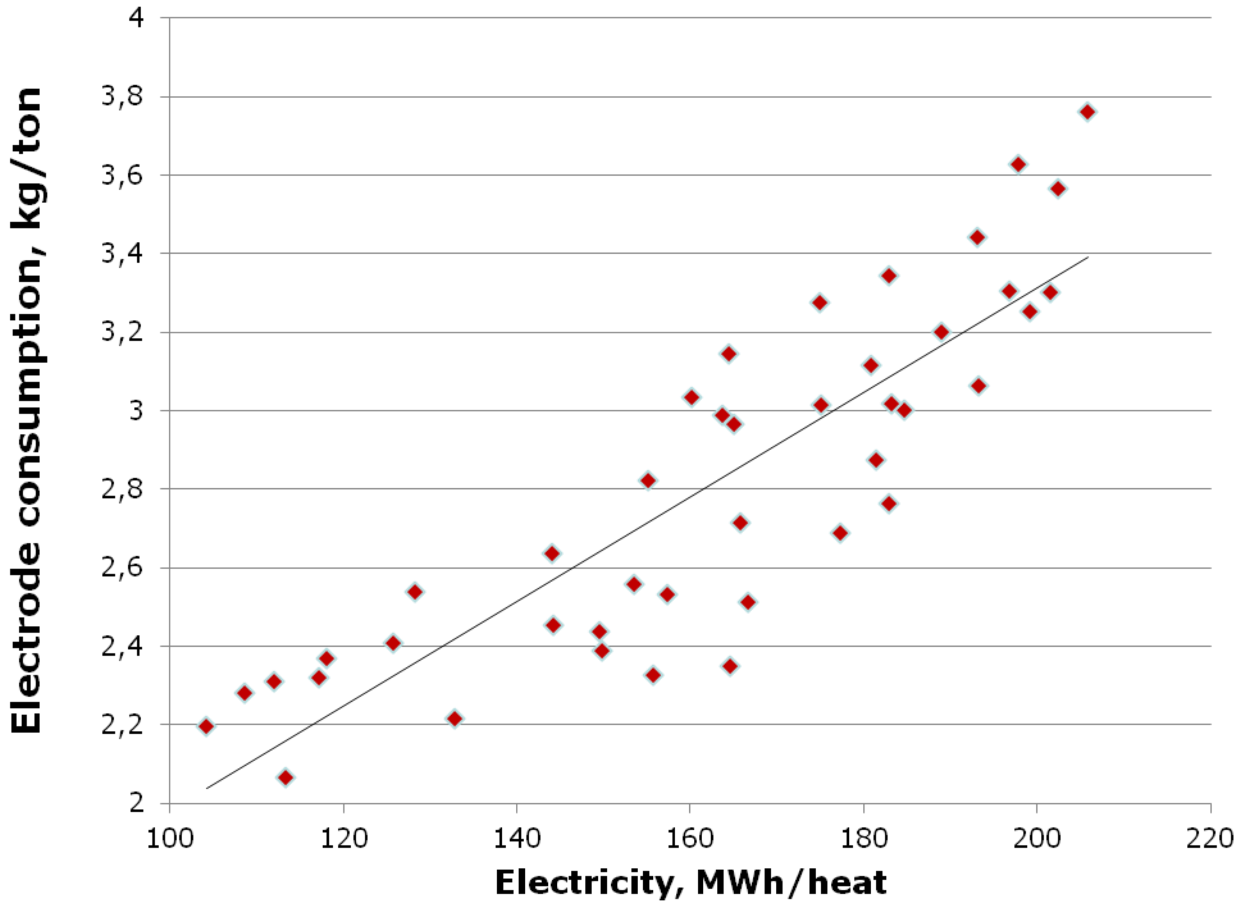
Some examples of electrode consumption



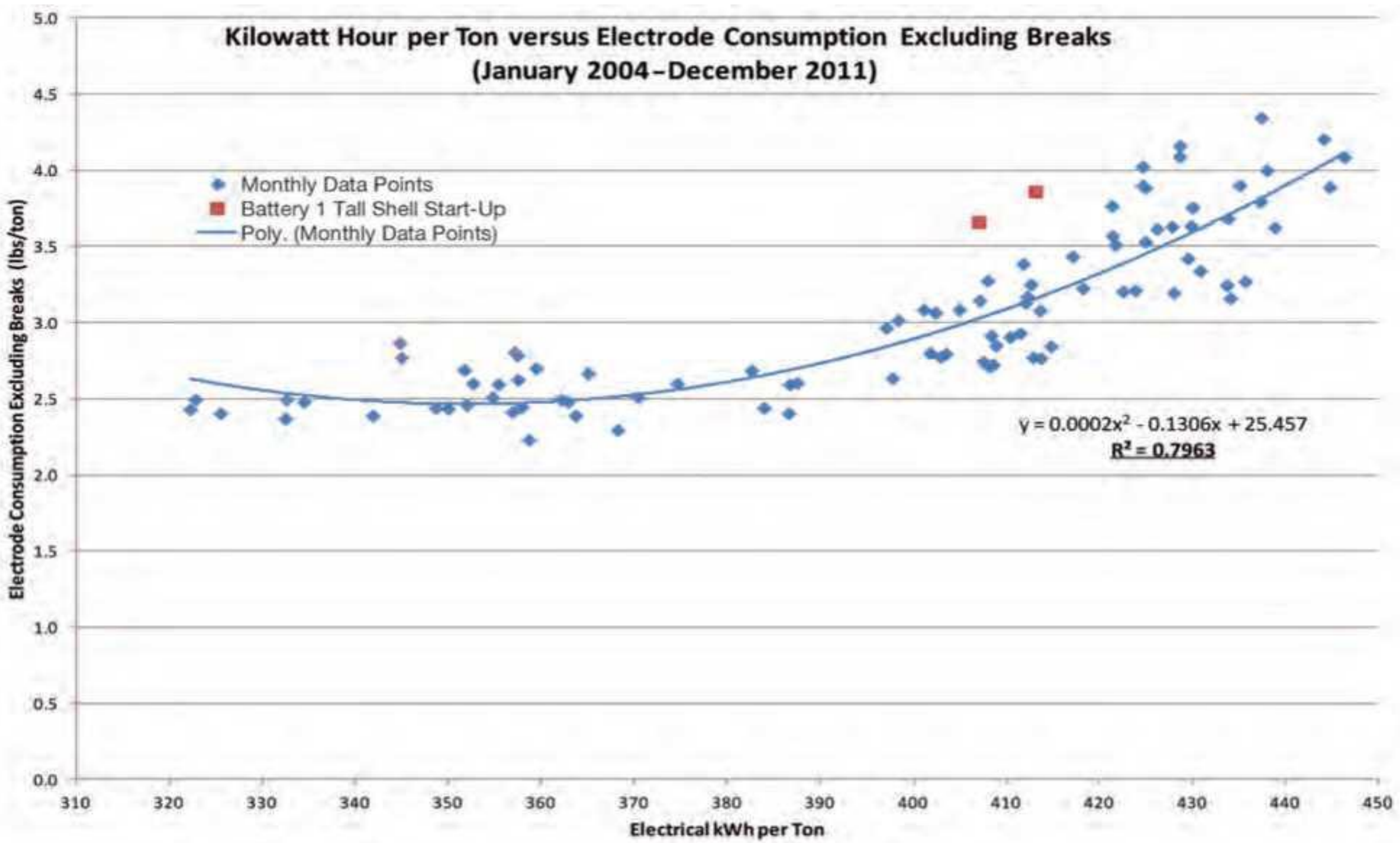
Some examples of electrode consumption



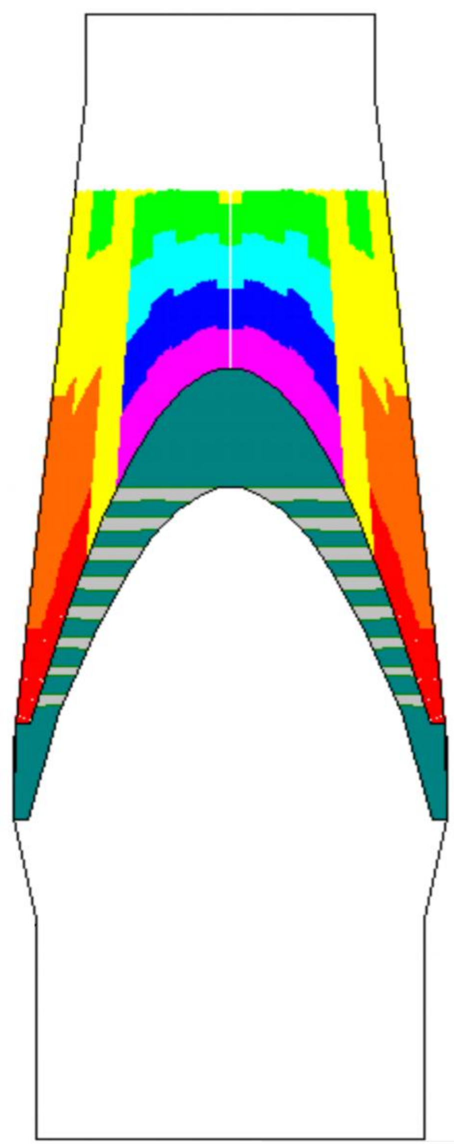
Some examples of electrode consumption

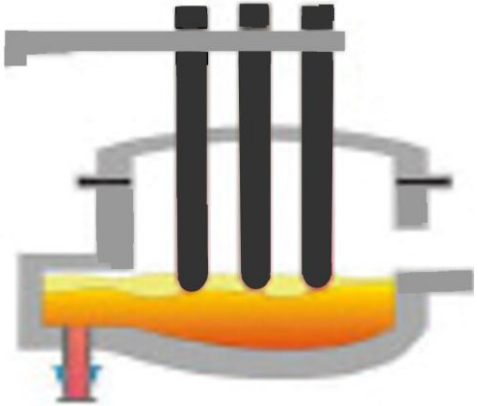


Some examples of electrode consumption



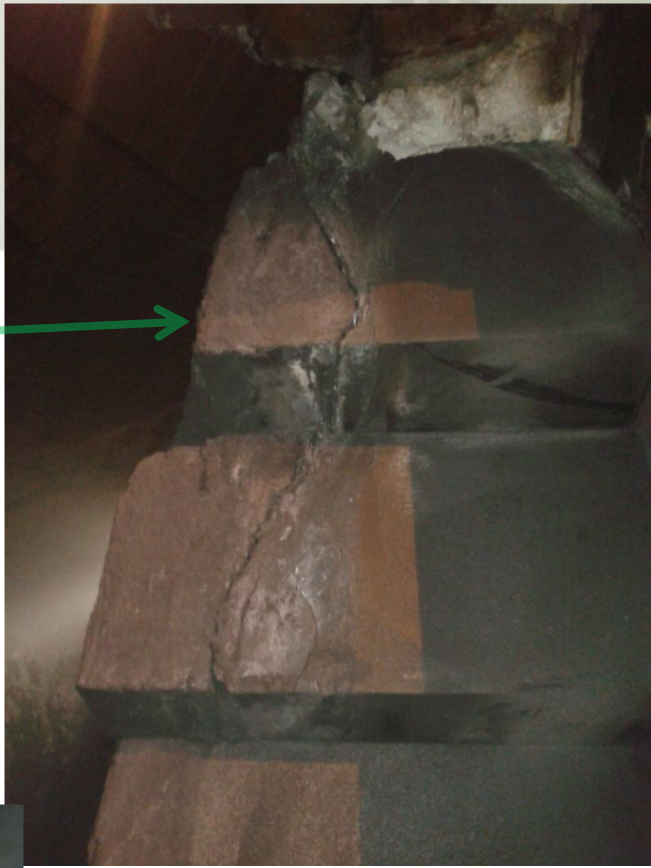
Subjects of interest.





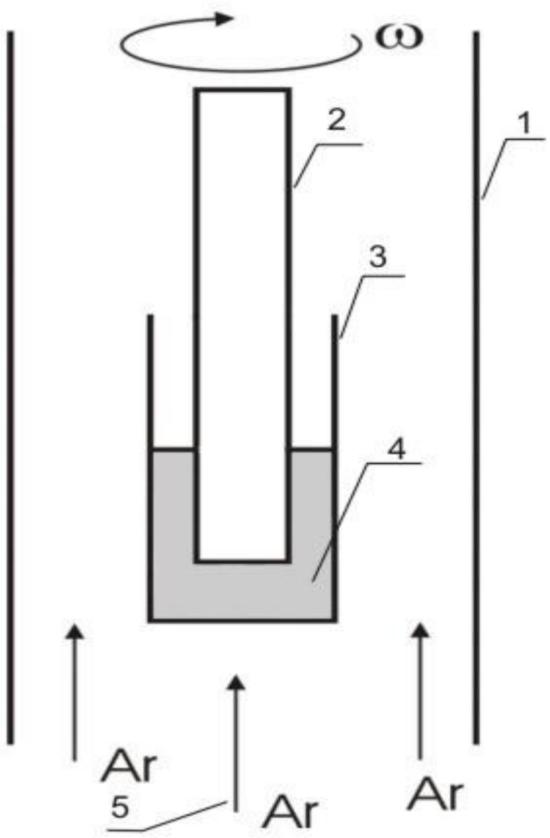
Why we are working at ?

Lining corrosion of blast furnace hearth .



Tap hole

Past experiments – macro scale experiments



Cylindrical samples of material submerged in liquid metal under a rotary movement:

temperature: 1500^oC

atmosphere: protection by Ar, final Ar, CO, CO_2 (p_{O2}= 5.10^{-10}at) due to oxidation of graphite tube

crucible: alumina (99,5 % Al_2O_3)

metal phase: Fe – aprox. 2% C

rotation speed: 80 rpm

Past experiments

Orienting experiments in time range 0.5–2 h in purpose to choosing the proper time of exposure to metal.

- *Corrosion of material occurred rather by removing of grains from the body of sample.*
- *Formation of a 'neck' in the place of contact of liquid and gas phase is visible for such material.*

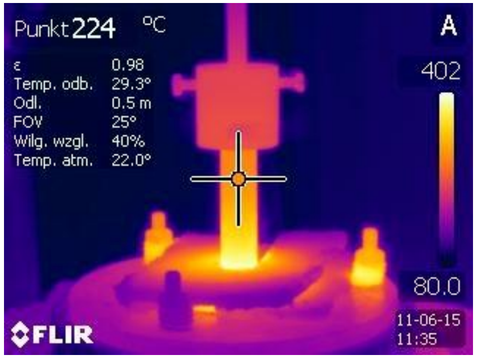
Time of experiments limited to 1 hour because:

- progress of disintegration (weight change) for time over 1 hour is rather small
- analysed concentration of carbon in iron after the experiments reached a value of about 3.3 % for the time of about 1 hour and remained nearly constant for a longer time of experiment.
- time of residence of pig iron in blast furnace is usually not longer than 1 hour (if periodic tapping in every 2 hour = 1 hour residence and ~ 1 hour of tapping)

Past results

Generally:

Grain extraction from the surface of sample seems to be depend mainly on basic as anthracite and/or graphite, grain size, ceramic additives and porosity.



Research – slag graphite interactions – micro scale

Mixtures components:

- **Sample I**

– mixture of chrome slag (50) + scale (20) + pure SiO_2 (20)+ pure Al_2O_3 (10)

- **Sample II**

– mixture of chrome slag (48) + converter slag (24) + scale (9,5) + pure SiO_2 (9,5) + pure Al_2O_3 (9)

- **Sample III**

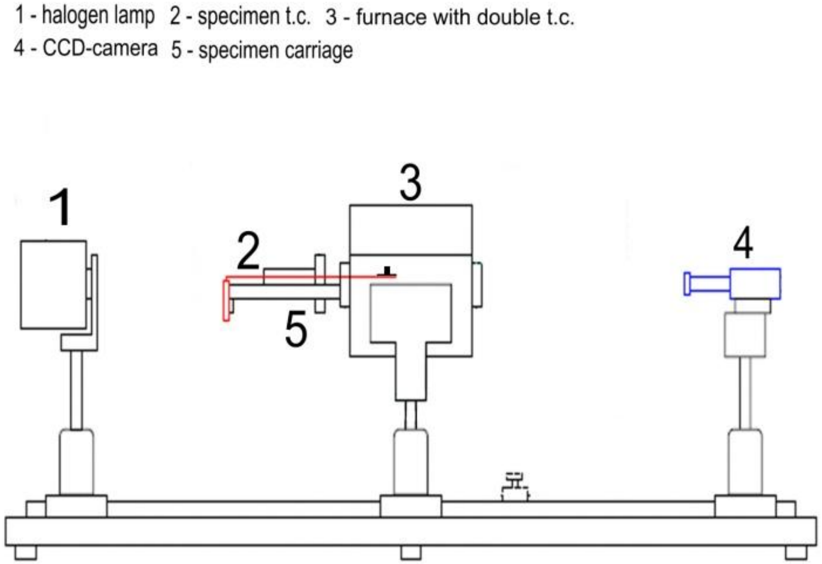
– mixture of converter slag (50) + scale (24) + pure SiO_2 (14) + pure Al_2O_3 (12)

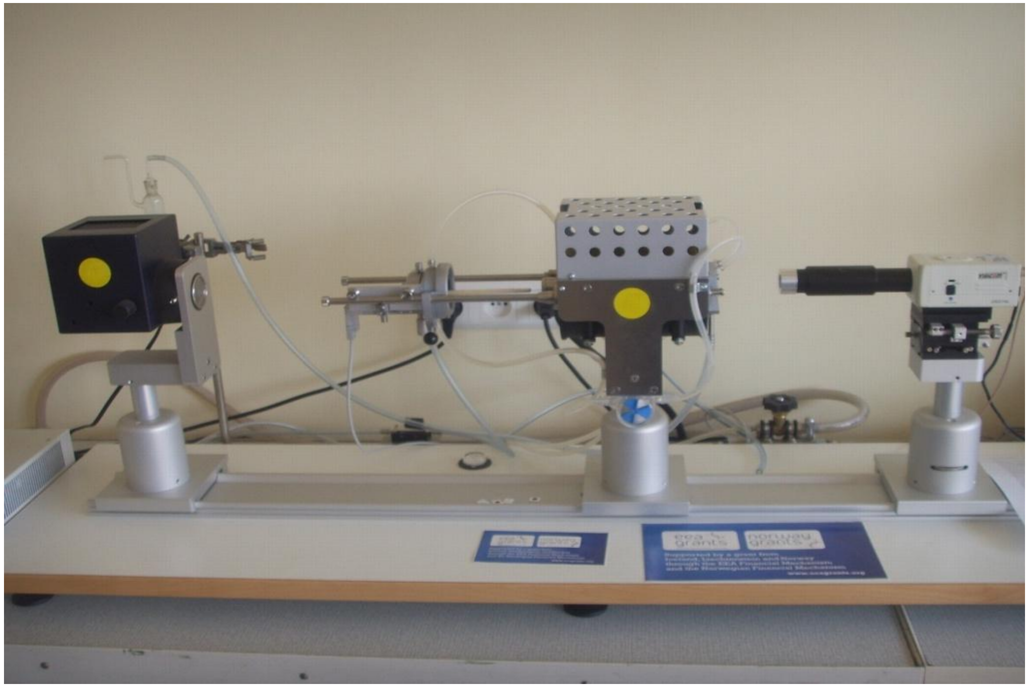
- **Sample IV** – chrome slag
- **Sample V** – BOF slag
- **Sample VI** – synthetic slag melted from pure oxide components (SiO_2, Al_2O_3 , MgO, CaO)

Chemical compositions – Spectrometer Twin-X.

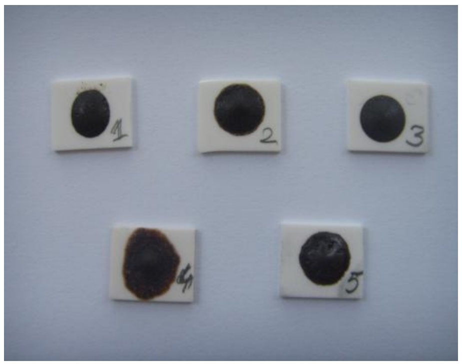
Sample I		Sample II		Sample III		Sample IV		Sample V		Sample VI	
[%]											
MgO	1,63	MgO	1,80	MgO	2,86	MgO	3,23	MgO	4,74	MgO	1,15
Al2O3	12,51	Al2O3	11,65	Al2O3	13,52	Al2O3	6,78	Al2O3	0,88	Al2O3	13,65
SiO2	**28,72**	SiO2	**26,63**	SiO2	**26,31**	SiO2	**28,47**	SiO2	**18,85**	SiO2	**59,78**
P2O5	0,06	P2O5	0,15	P2O5	0,20	P2O5	0,06	P2O5	0,50	P2O5	-
K2O	0,05	K2O	0,04	K2O	0,15	K2O	0,04	K2O	0,88	K2O	-
CaO	25,42	CaO	30,96	CaO	25,80	CaO	48,90	CaO	50,70	CaO	20,72
TiO2	**0,76**	TiO2	**0,73**	TiO2	**0,12**	TiO2	**1,29**	TiO2	0,17	TiO2	-
Cr2O3	**4,83**	Cr2O3	**4,81**	Cr2O3	**0,00**	Cr2O3	**9,64**	Cr2O3	**-**	Cr2O3	-
MnO	**1,11**	MnO	**1,08**	MnO	**1,21**	MnO	**1,59**	MnO	**2,40**	MnO	-
FeO	**19,21**	FeO	**22,02**	FeO	**29,72**	FeO	-	FeO	**20,87**	FeO	-
B1	0,89	***B1***	1,16	***B1***	0,98	***B1***	1,72	***B1***	2,69	***B1***	0,35

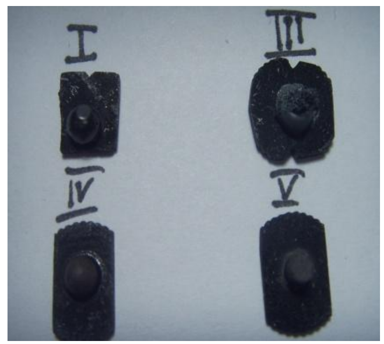
Equipment – Hightemp microscope - Hesse Insruments

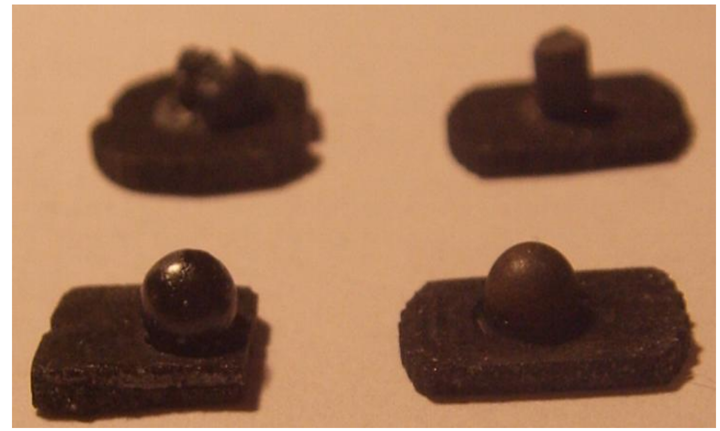




Results - Images of samples.

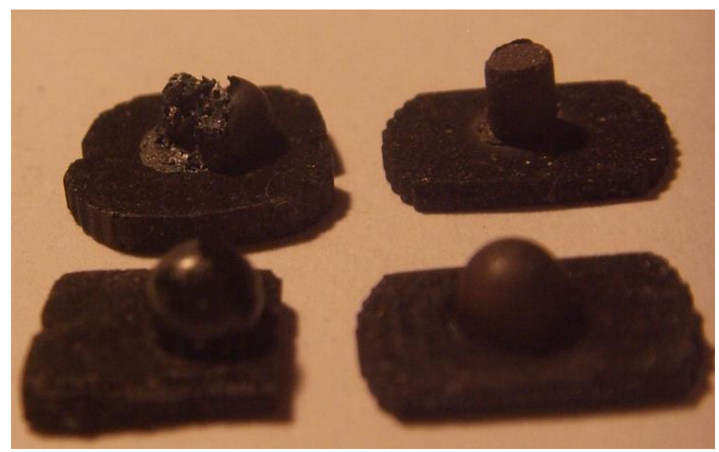




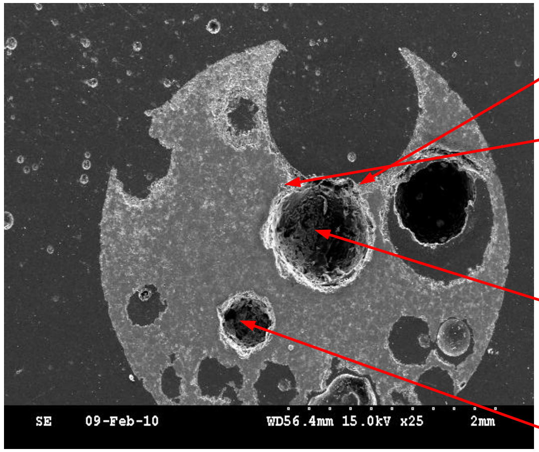


II

VI

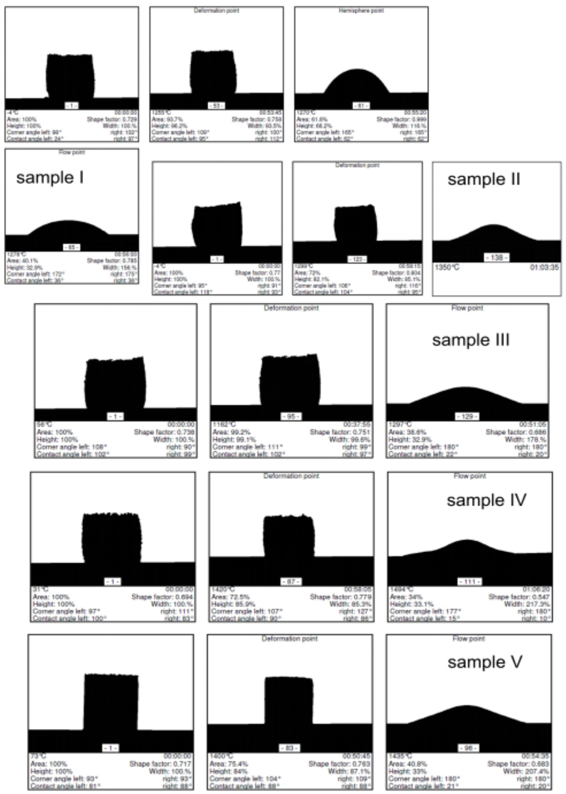


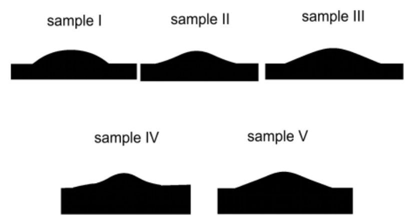
Analysis of SEM

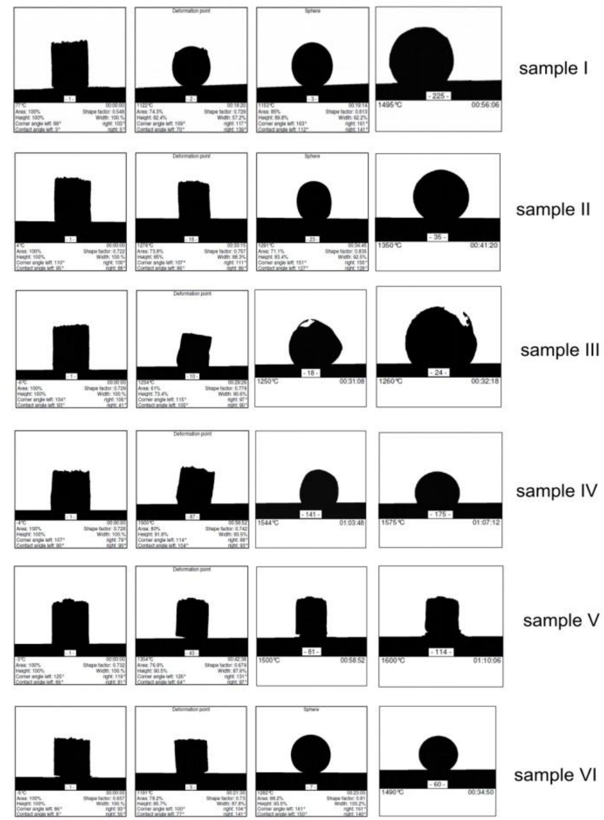


	C	O	Mg	Al.	Si	Ca	Ti	Cr	Mn	Fe
	[%]									
	Area of analysis near by right edge of bigger "crater"									
I area	48,34	22,86	0,66	2,28	4,10	12,08	0,30	1,57	0,76	7,04
	Area of analysis near by left edge of bigger "crater"									
II area	19,41	23,72	1,86	6,24	10,11	22,81	0,35	3,93	1,44	10,13
III area	59,82	30,82	0,32	0,95	2,29	3,58	0,03	0	0	2,19
	Area of analysis bottom of bigger "crater"									
IV area	64,45	31,9	0,02	0,33	0,51	1,83	0	0,07	0,04	0,83
	Area of analysis bottom of smaller "crater"									
V area	52,43	31,86	0,27	-	3,10	8,73	0,00	0,17	0,00	3,44

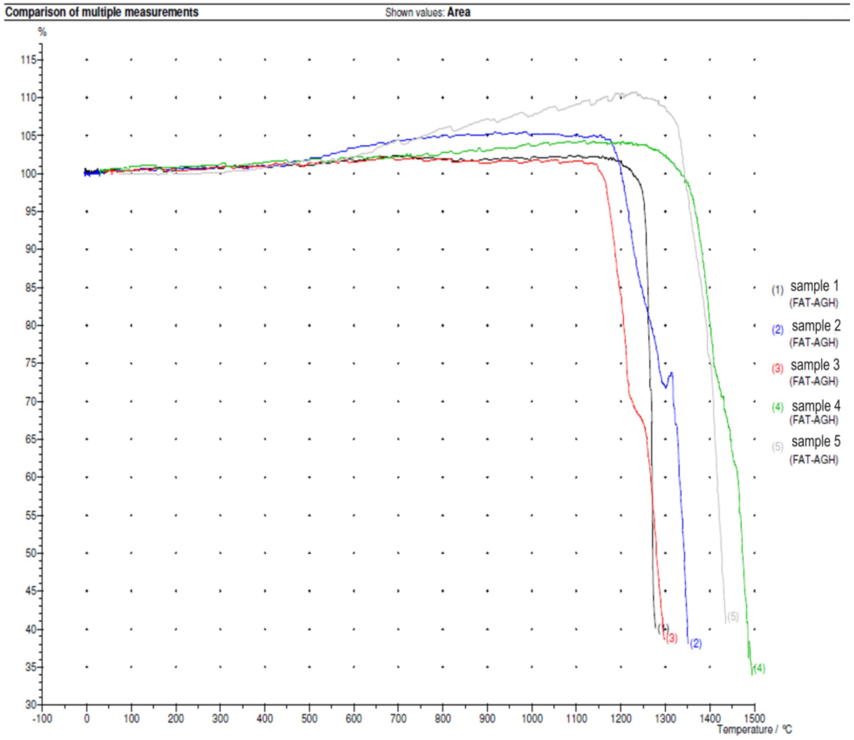
Pictures of samples (experiments and results of investigation)

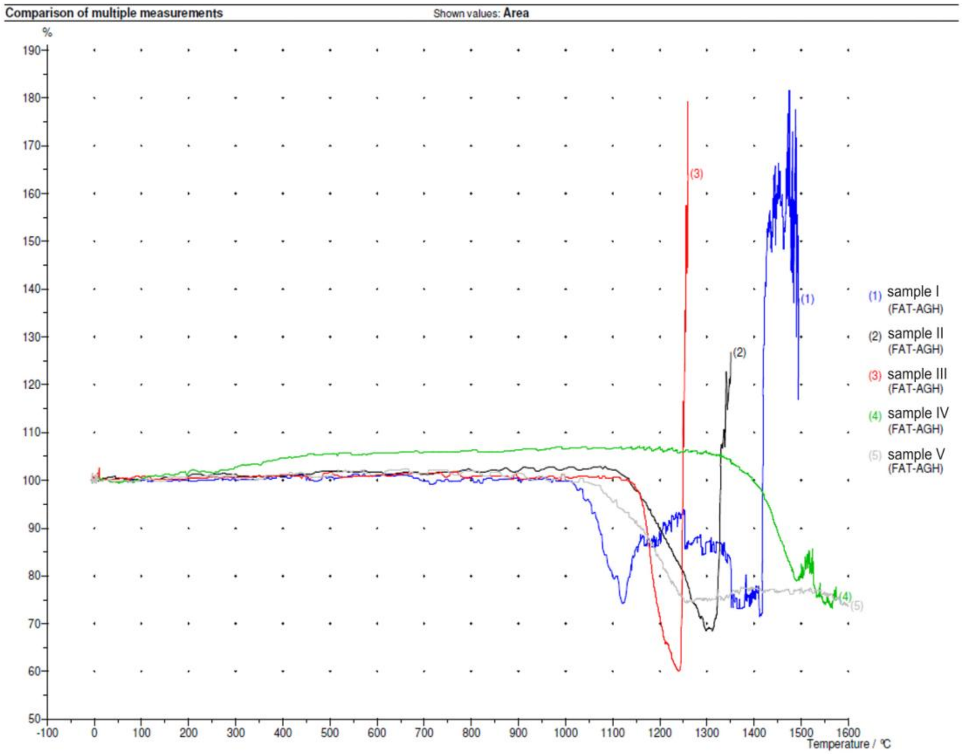




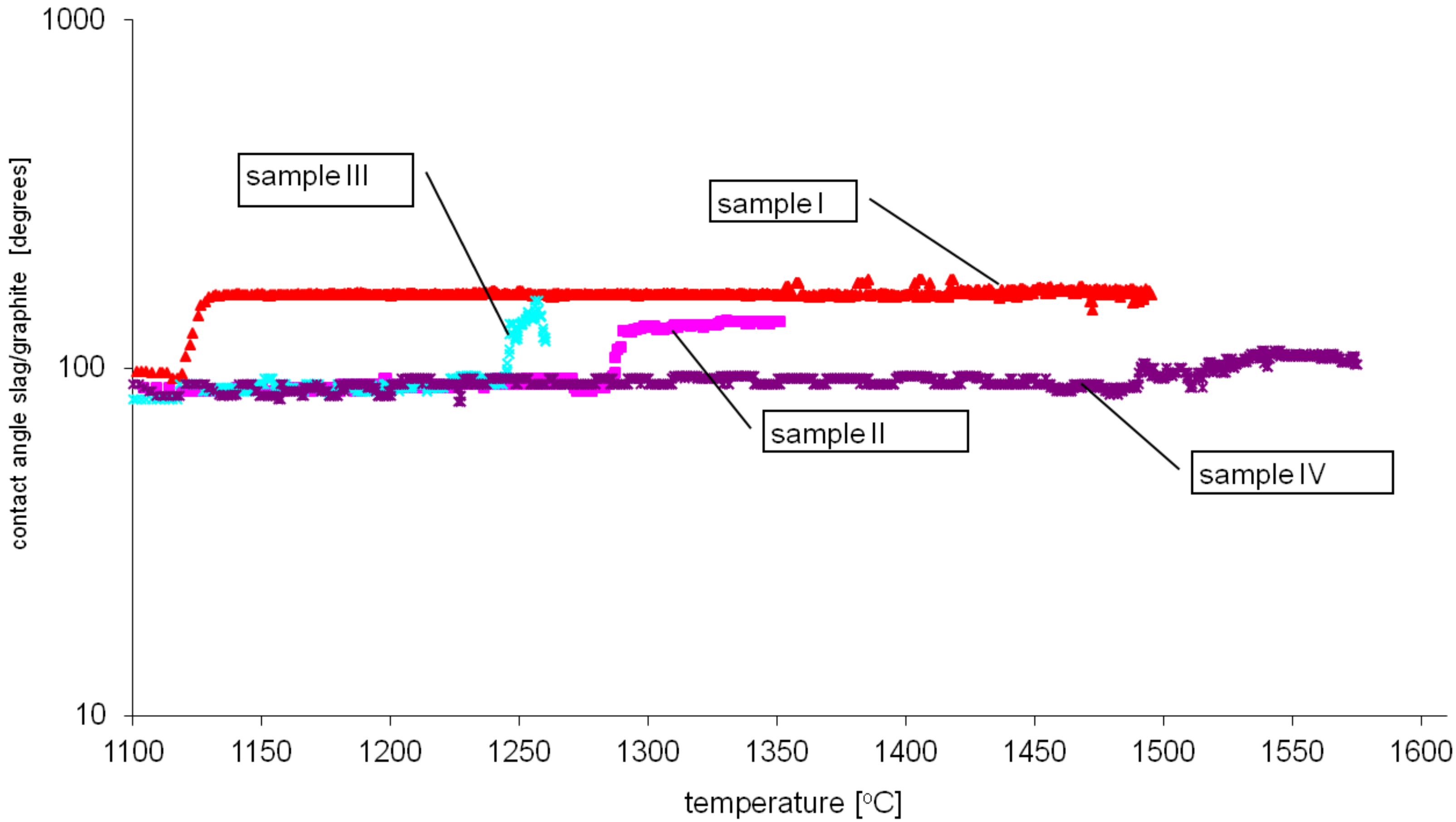


Area changes of samples



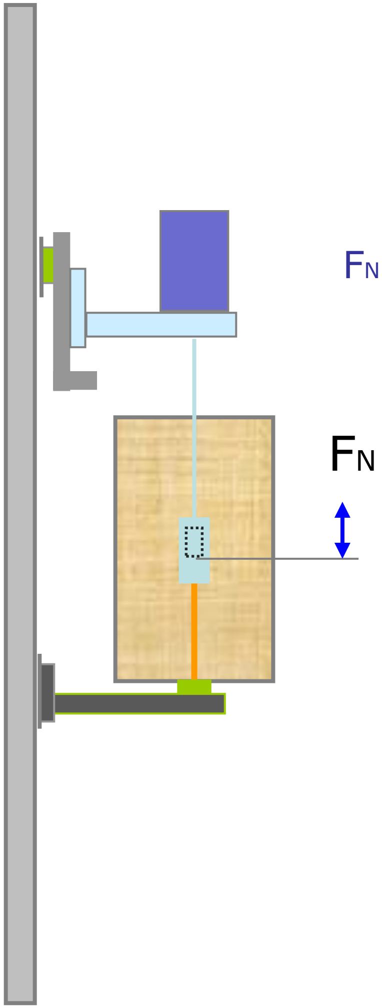


Slag/graphite wetting angles



Equipment – Thermal expansion - Future

The main elements of the high temperature rheometer



F_N – Normal Forces are control.

High temperature rheometer FRS1600

Summary.

We still did not solve a lots of problem with graphite and carbon at ferrous metallurgy.

There are many challenges and ideas and we are open for it.

Thank you for your attention