Refractory Lining and Wear of AC and DC FURNACES

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Seminar:
Refractory Technology – Applications, Wear Mechanism, Failures
Wear of linings of AC and DC furnaces

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Leandro Schöttler

1 OVERVIEW ABOUT EAF TECHNOLOGY
2 HISTORICAL BACKGROUND
3 EXAMPLES OF EAF LININGS AND REFRACTORY COMPONENTS
4 HOW DOES EAF OPERATION STRESS THE REFRACTORY?
5 SLAGS AND SLAG FOAMING
6 TAPPING SYSTEMS
7 REPAIR TECHNIQUES FOR EAF REFRACTORY
Electric arc furnace – the all-rounder for steelmaking

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Basic Oxygen furnace (since 1949)</th>
<th>Electric arc furnace (since 1900)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main charging</td>
<td>Liquid pig iron</td>
<td>Solid scrap</td>
</tr>
<tr>
<td>Scrap ratio</td>
<td>0 to 30 %</td>
<td>Up to 100 %</td>
</tr>
<tr>
<td>Alloy content</td>
<td>0 to 5 %</td>
<td>0 to 100 %</td>
</tr>
<tr>
<td>final-[C]-content</td>
<td>ca. 0.02-0.03 %</td>
<td>0.05 – 2 %</td>
</tr>
<tr>
<td>Energy-Input</td>
<td>$O_2$</td>
<td>$O_2$, Gas, el. Power</td>
</tr>
<tr>
<td>Refractory lining</td>
<td>basic</td>
<td>acid - basic</td>
</tr>
</tbody>
</table>
Furnace constructions – refractory solutions

**AC - furnaces – from Low power to UHP (> 0,7MVA/t)**

<table>
<thead>
<tr>
<th>„traditional“ technology</th>
<th>3 electrodes – alternating current (AC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Widely used since the 1920th for all kind of steel and alloys production</td>
<td>Refractory lining concepts of all various stages: No watercooled parts – like „ladle with cover“ Partially watercooled parts Sidewalls: bricklayed Bottom: bricks or masses All kind of tapping systems</td>
</tr>
<tr>
<td>UHP since 1970th</td>
<td></td>
</tr>
</tbody>
</table>

**DC furnaces – always UHP (> 1 MVA/t)**

<table>
<thead>
<tr>
<th>„New“ technology</th>
<th>1 – 2 electrodes different current (DC) Bottom ist anode (+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In operation since 1990th Normally used for carbon-steel production</td>
<td>Complete area above liquid melt is watercooled Sidewalls lined with MgO-C-bricks Bottom mostly lined with masses Tapping system: EBT</td>
</tr>
</tbody>
</table>

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History live!

1906 Heroult DC-furnace
Glockenstahlwerk Lindenberg

1910 Stassano AC-furnace
Input: 80% scrap / 20% pig Iron

Deutsches Werkzeugmuseum Remscheid
Museo Nazionale della Scienza e della Tecnologia „Leonardo da Vinci“ Milano

Furnace examples from beginning to today

<table>
<thead>
<tr>
<th>Stahlwerke</th>
<th>Deutsche Edelstahlwerke</th>
<th>Stahlwerke</th>
<th>Krupp Stahl</th>
<th>Salzgitter AG</th>
<th>MKK Atakas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lindenberg</td>
<td>Remscheid</td>
<td>Südwestfalen</td>
<td>Segen-Gelisweid</td>
<td>Peine</td>
<td>Iskenderun</td>
</tr>
<tr>
<td>1906</td>
<td>Remscheid</td>
<td>Krefeld</td>
<td>1956</td>
<td>1998</td>
<td>2011</td>
</tr>
</tbody>
</table>

| Dimension:            | Ø 5.2 m                 | Ø 5.8 m               | Ø 6.8 m              | Ø 7.3 m              | Ø 9.4 m   |
| El.Power:             | 0.4 MVA                 | 10 MVA                | 30 MVA               | 63 MVA               | 300 MVA   |
| Burner:               | none                    | none                  | none                 | CH/O₂                | CH/O₂     |
| Batch weight:         | 30 t                    | 80 t                  | 110 t                | 100 t                | 250 t     |
| specific Power:       | 0.33 MVA/t              | 0.38 MVA/t            | 0.75 MVA/t           | 1.4 MVA/t           | 1.2 MVA/t |
| daily output:         | ~100t/24 h              | ~650t/24 h            | ~1800t/24 h          | ~3700t/24 h         | ~6000t/24 h |

Taken from: „Electric steelmaking in Europe efficient and Challenging“ – Stahl und Eisen 132 (2012) Nr.9 - combined with own data
EAF Developments over 50 years

Taken from: „Steelmaking_in_Europe_innovative_and_efficient“ – Stahl und Eisen 132 (2012) Nr.10

EAF operation in the past and today

Traditional operation: 1-step Steelmaking

- alloying,
- De-[S]
- De-slagging
- EAF 0,1-0,3 MVA/t
- Tap to Tap 4 – 5 h
- Tapping
- Ingot casting

UHP Steelmaking: primary metallurgy in furnace / secondary metallurgy in ladle

- EAF only for melting 1-1,5 MVA/t
- Tap to Tap < 60 min
- Slag „free“ tapping
- All metallurgical steps (alloying, de-[S], degassing) are done in the ladle
- Continuous casting
Examples for AC furnace linings

Permanent lining: bricks

Wear lining walls: bricks

Wear lining bottom: ramming mass
  roof: bricklaid
  Above liquid steel: water cooled panels

Tap hole: spout

Permanent lining: bricks

Wear lining walls: bricks

Wear lining bottom: ramming mass
  roof: water cooled panels
  And monolithic heartpiece
  Tap hole: EBT
Examples for AC furnace linings

Permanent lining: bricks
Wear lining walls: bricks
Above liquid steel: water cooled panels
Wear lining bottom: ramming mass
Tap hole: EBT surrounded with bricks

Permanent lining: bricks
Wear lining walls: bricks
light blue: MgO-C medium quality
blue: high quality MgO-C(slagline)
yellow: top quality MgO-C (Phase-bricks)
Wear lining bottom: ramming mass
EBT Tap hole and bottom purge plug: surrounded with bricks

Examples for Anode types (DC furnaces)

Pin Typ
Conductive bricks type

Fin Typ
Billet Typ
Monolithics in EAF

Several electrode heartpiece designs for water cooled roofs of AC furnaces

Monolithic electrode heartpiece designs for water cooled roofs of DC furnaces

Demands for monolithics:
- lifetime has to meet the maintenance cycles (scheduled downtime)
- Temperature, erosion, thermo-shock resistance

Stress factors:
- smart choice of material out of SiO$_2$-Al$_2$O$_3$ system

Taphole systems in EAF

EBT compounds

Repair praxis for EBT Tap
# Big differences in EAF design...

... but also accordance in refractory use

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wear lining of walls</td>
<td>Usually MgO-C bricks in balanced lining&lt;br&gt;Hot spots in highest qualities (100% fused)&lt;br&gt;Dense pressed, impregnated…&lt;br&gt;Upper wall and base of wall often in cheaper qualities&lt;br&gt;Carbon content 10 – 15%</td>
</tr>
<tr>
<td>Wear lining of bottom</td>
<td>Depending on steel grade&lt;br&gt;For carbon steel production: only MgO hearth mass&lt;br&gt;For alloyed and stainless steel production: MgO hearth mass on MgO-C bricks</td>
</tr>
<tr>
<td>Perament lining</td>
<td>Mostly burnt MgO bricks&lt;br&gt;For better mechanical strength: with tongue and groove</td>
</tr>
<tr>
<td>Electrode heartpiece</td>
<td>Cast alumina monolithics, sometimes segmented</td>
</tr>
</tbody>
</table>

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4. **HOW DOES EAF OPERATION STRESS THE REFRACTORY?**
5. **SLAGS AND SLAG FOAMING**
6. **TAPPING SYSTEMS**
7. **REPAIR TECHNIQUES FOR EAF REFRACTORY**
Wear and stress factors on refractory in EAF practice

- charging
- melting
- metallurgical work
- tapping
- maintenance

Mechanical stress

Heavy scrap falling into the furnace explosions in case of wet scrap
Wear and stress factors on refractory in EAF practice

**Arcing – Hot spots**
High current of electrical arc (80,000 A) > 3500°C in the center of the arc can melt down every refractory material – for example:
Production of fused magnesia

**Oxy fuel burner**
High energy burner with excess oxygen cause very high temperature with oxidizing flames
Danger of carbon burn out of MgO-C bricks

**Oxygen input**
Strong oxidizing effects with oxygen lances „cutting – burning”

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**Decarburisation**

oxidizing carbon: \( \text{O}_2 + \text{C} \rightarrow \text{CO}, \text{CO}_2 \)

**Oxidation of non wanted elements:**
P, Si, Al, Cr, Mn…

**Metallurgical work (Oxygen input)**

[] in steel-melt
( ) in slag-phase
{} in gas-phase

High oxygen level to „burn away“ non-wanted elements produces corrosive slag and causes „Slagline wear”
### Special areas – special solutions

<table>
<thead>
<tr>
<th>Area</th>
<th>Stresses</th>
<th>Countermeasures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrode heartpiece</strong></td>
<td>Thermal shocks, temperature,</td>
<td>Electrode spray cooling, Sufficient electrode regulation</td>
</tr>
<tr>
<td></td>
<td>erosion, arcing</td>
<td>system</td>
</tr>
<tr>
<td><strong>Sidewall upper area</strong></td>
<td>erosion, oxidation</td>
<td>Water cooled panels</td>
</tr>
<tr>
<td><strong>Sidewall / slagzone</strong></td>
<td>erosion, corrosion, temperature</td>
<td>Slag foaming, slag conditioning, precautionary gunning</td>
</tr>
<tr>
<td><strong>Sidewall / Hot spots</strong></td>
<td>erosion, arcing, corrosion,</td>
<td>use best refractory dolomite additions precautionary</td>
</tr>
<tr>
<td></td>
<td>temperature</td>
<td>gunning</td>
</tr>
<tr>
<td><strong>Sidewall / bank</strong></td>
<td>erosion, oxygen attack,</td>
<td>dolomite additions precautionary fettling</td>
</tr>
<tr>
<td></td>
<td>corrosion, temperature</td>
<td></td>
</tr>
<tr>
<td><strong>bottom</strong></td>
<td>mechanical damage, erosion,</td>
<td>Soft charging dolomite additions Hearth mass additions</td>
</tr>
<tr>
<td></td>
<td>oxygen attack, corrosion,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>temperature</td>
<td>Depending on system Periodic bricks replacement / Gunning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>repair</td>
</tr>
<tr>
<td><strong>Tap</strong></td>
<td>erosion, temperature,</td>
<td>carefull O2 lance operation, cautious cleaning</td>
</tr>
<tr>
<td></td>
<td>oxygen attack</td>
<td></td>
</tr>
<tr>
<td><strong>Door</strong></td>
<td>mechanical damage oxygen</td>
<td>careful operation praxis water cooled copper elements</td>
</tr>
<tr>
<td></td>
<td>attack</td>
<td></td>
</tr>
<tr>
<td><strong>Burner sidewall lances</strong></td>
<td>temperature, oxygen attack</td>
<td></td>
</tr>
</tbody>
</table>
# Wear and stress factors on refractory in EAF practice

<table>
<thead>
<tr>
<th>Wear Factor</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erosion</td>
<td>Mechanical attack</td>
</tr>
<tr>
<td></td>
<td>Fast flowing steel/slag melt -&gt; Taphole / slag door</td>
</tr>
<tr>
<td></td>
<td>Particle flow -&gt; offgas-pipe / Injection points</td>
</tr>
<tr>
<td></td>
<td>Scrap charging -&gt; Wall damages</td>
</tr>
<tr>
<td></td>
<td>Marangoni convection in slagline</td>
</tr>
<tr>
<td>Corrosion</td>
<td>Chemical attack</td>
</tr>
<tr>
<td></td>
<td>Slags with low basicity (MeO_x, SiO_2) bring MgO-C into solution</td>
</tr>
<tr>
<td>Oxidation</td>
<td>Oxygen attack</td>
</tr>
<tr>
<td></td>
<td>Binding-carbon gets oxidized – brick structure gets lost</td>
</tr>
<tr>
<td>Melting point</td>
<td>Thermal overload</td>
</tr>
<tr>
<td></td>
<td>Melting point MgO-C starts with 1850° C</td>
</tr>
<tr>
<td>Hydratation</td>
<td>Disintegration of refractory by water</td>
</tr>
<tr>
<td></td>
<td>Leakages during operation</td>
</tr>
<tr>
<td></td>
<td>Leakages during maintenance</td>
</tr>
<tr>
<td>Thermal shocks</td>
<td>Thermo-mechanical cracking</td>
</tr>
<tr>
<td></td>
<td>Startup: 0 to 1750° C in 60 Minutes</td>
</tr>
<tr>
<td></td>
<td>Downtimes, cold gunning</td>
</tr>
</tbody>
</table>

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Wear and stress factors on refractory in EAF practice

**Functions of slags**
- To „serve and protect“
- To absorb unwanted compounds of the steel melt
- Thermal covering of the steel melt
- Protection of the furnace refractory

**Aims**
- Basicity: ratio basic (CaO,MgO) to acid components (SiO₂, MeOₓ, Al₂O₃)

**Reduction slag**
- Special case in stainless steel production: Oxidized Chrome is reduced with Al, Si

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Slag foaming – essential prerequisite for UHP praxis

**Slag foaming** is induced by blowing oxygen into the liquid steel and fine coarse coal (0-1mm) injection into the slag.

Foamy slag consist at minimum of 90% gas, normally only 5% are solid

To achieve good foaming, the slag has to have the right viscosity (composition + temperature)
Slag temperature is ca. 100 K higher than steel temperature

The foaming slag runs out of the furnace door. It is collected either in a slag pot or in a slag pit area below the furnace.
Slag foaming – poor versus good

No slag foaming

- poor energy input $\cos \varphi = 0.7-0.8$
- long time melting, Tap to Tap > 60 min
- High load on refractory by arcing
- Danger of sparkover (water leakages)
- High electrode consumption
- High current needed,
- No long arcs possible
- Furnace runs rough and very loud

Good slag foaming

- Electric arc is complete covered
- Best energy input $\cos \varphi = 0.9$
- High secondary voltage, long arcs
- Low electrode consumption
- Fast process, Tap to Tap < 60 min
- Best wear protection for refractory
- Furnace runs smooth and quiet

Slag systems c-steel versus stainless-steel

C-steel slags (simplified)

- Already at 1600°C big liquid area
- Good condition for slag foaming
- High FeO content,
- Depending on oxygen input

Stainless steel slags (simplified)

- Liquid areas not below 1700°C
- Reachable slag foaming only possible
- In a narrow process window
- High SiO$_2$ values caused by reduction additions
**OVERVIEW ABOUT EAF TECHNOLOGY**

**HISTORICAL BACKGROUND**

**EXAMPLES OF EAF LININGS AND REFRACTORY COMPONENTS**

**HOW DOES EAF OPERATION STRESS THE REFRACTORY?**

**SLAGS AND SLAG FOAMING**

**TAPPING SYSTEMS**

**REPAIR TECHNIQUES FOR EAF REFRACTORY**

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**Tap systems**

- **Spout**
  - Hot heel operation: possible
  - Slag free tapping: impossible
  - Maintenance work: very low
  - Steel quality change: possible
  - Portfolio suitability:
    - Carbon steel: limited
    - Special steel: limited
    - Tool steel: limited
    - Stainless steel: capable

- **Siphon spout**
  - Hot heel operation: possible
  - Slag free tapping: possible
  - Maintenance work: moderate
  - Steel quality change: possible
  - Portfolio suitability:
    - Carbon steel: capable
    - Special steel: capable
    - Tool steel: capable
    - Stainless steel: capable

- **Centric bottom**
  - Hot heel operation: impossible
  - Slag free tapping: impossible
  - Maintenance work: high
  - Steel quality change: possible
  - Portfolio suitability:
    - Carbon steel: limited
    - Special steel: limited
    - Tool steel: limited
    - Stainless steel: easy

- **Excentric bottom**
  - Hot heel operation: always
  - Slag free tapping: possible
  - Maintenance work: very high
  - Steel quality change: difficult
  - Portfolio suitability:
    - Carbon steel: capable
    - Special steel: capable
    - Tool steel: capable
    - Stainless steel: not suitable
How to detect wear on furnace lining?

Traditional

Visual check after each tapping
Especially after "special heats"
  e.g. high tapping temperature, long treatment time, heavy scrap charging

With technical assistance

Temperature measurements at shell behind refractory / thermocouple installations at steel shell and on bottom

Laser measurement equipment gives map of residual thickness

Example: Laser scan of an EBT furnace
Refractory maintenance in EAF

Traditional

- Shoveling / gunning by operator
- Hearth mass additions by hand
  by big bag
  or fettling machine

Fettling machine

State of the art

- Gunning by robot – radio controlled
  - Different storage silos can be installed
  - Gunning material for the wall / hot spots
    Hearth repair material
    Taphole filling material
  - The gunning robot relieves the operator from
    hard, dangerous work
  - The robot reaches all areas in the furnace
    That gives more safety in work
    and furnace operation
  - Repair timeouts can be reduced
    due to faster refractory repair
Refractory maintenance in EAF

Gunning robot at work

Gunning by robot – radio controlled

Best available refractory is “water”

Steel cooling modules „tube on tube”

Copper cooling modules

Controlled heat dissipation behind brickwork gives longer lifetime to refractory

Bottom

Conventional UHP AC furnace shell
Example for Hot spot / Door repair

- Furnace door
- Offgas suction pipe
- Tap
- Finished repair of hot spot phase I + II and furnace door

Example for Hot spot / Door repair

- New bricklaying
- Gunning
- Slag door with new bricks and gunning
- Finished repair of hot spot phase I + II and furnace door
- Partial break out and new bricklaying
- Transitions fit with gunning material
- Hearth mass renewed
- Covered with metal sheets against first scrap impact
Example: bricksize change gives operation reliability

Bricksize swap from 450 mm to 550 mm length
Because of dangerous slagline wear
Trouble with breakouts inbetween repair cycles

Relining practice - different strategies

Depending on steelshop utilization rate
Optimization between costs and availability

Full production
No downtime for repairs
Gunning repairs between heats
Use of gunning robot

Disconinuous production
Downtime used for bricklaying repair
Periodically bricklaying repair
Manual gunning if needed
Thank You For Your Attention!