STEEL TEEMING LADLE: Ladle Metallurgical Treatment / Refractory Stress / Materials and Lining Concepts

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Seminar:

Refractory Technology –
Applications, Wear Mechanism, Failures
VDEh Stahl Academy
Refactory - Technology
Applications, Wear Mechanism and Failures

Steel Teeming Ladle:
Ladle Metallurgical Treatments / Refractory Stress /
Materials and Lining Concepts

Content

Metallurgical Tasks
- Steel Production overview
- Example: ULC, HIC, TRIP, TWIP

Secondary Metallurgy
- Tasks
- Aggregates vs. Refractories
- Ladle slag
- Purging instrumentation

Teeming ladle
- Lining concepts
- Wear mechanism
- Lab investigation
- Drying- and heating
- Laser- vs. Thermo vision Scan
- Purging
- „Problem areas“ and Check list

Outlook and Summary
From Ore to Steel

What is steel? For Definition see Fe – Fe₃C Diagram
Metallurgical Tasks – Automotive Industry

Chemical Composition:
- \([C] \leq 0.0030\) \((\leq 0.0015)\) %
- \([P] \leq 0.010\) \((\leq 0.008)\) %
- \([S] \leq 0.010\) \((\leq 0.008)\) %
- \([N] < 0.0035\) %
- [Ti]-, [Nb]-, [B]- alloyed

Process Route Steel Plant:
- OHF; Ingot casting
- LD/ EAF; Treatment stand, CCM
- LD-S/ EAF; LF, CASOB, VD-OB, RH-OB; CCM

Metallurgical Tasks – Offshore Industry

API- HIC* Grade:
LD-S/ EAF - RH/VD – CCM
- \([S] \leq 0.0010\) \((\leq 0.0005)\) %
- \([P] \leq 0.0080\) \((\leq 0.0060)\) %
- \([H] \leq 0.0002\) \((\leq 0.0015)\) %
- \([N] \leq 0.0060\) \((\leq 0.0040)\) %

*API- HIC: American Petroleum Institute- Hydrogen Induced Cracks
Metallurgical Tasks – Automotive Industry

- **TRIP* Grade:**
  - [Al] ~ 1 %
  - [Mn] ~ 2 - 15 %
  - [P] < 0.010 %
  - [S] < 0.0030 %

- **TWIP* Grade:**
  - [Al] ~ 5 %
  - [Mn] ~ 20 %

*TRIP: Transforming Induced Plasticity

Material Properties

Stahl-Zentrum
Metallurgical Tasks

- Adjustment of the needed chemical composition and steel temperature
- Deoxidation and removal of non metallic inclusions (NMI)
- Desulphurization de [S]
- Degassing
  - de [H]
  - de [N]
- Decarburization de [C]

→ "Clean Steel"
### Metallurgical tasks in detail

<table>
<thead>
<tr>
<th></th>
<th>Heating</th>
<th>Modification</th>
<th>de [S]</th>
<th>Cleanliness</th>
<th>de [C]</th>
<th>de [H]</th>
<th>de [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>LT</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LF</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAS-OB</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>RH OB</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>VD VOD</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
</tbody>
</table>

### Technical Data from a LF for 160 t

- 2 Ladle transfer cars
- Primary voltage 30 kV
- Transformer power 22 MVA
- Secondary power 45 kA, 160 - 330 V
- Electrode diameter 457 mm
- Heating rate 3 - 5 °C/min
- Energy consumption 10 - 30 kWh/t
- Spec. heating consumption 0.5 kWh/t °C
- Electrode consumption 6 – 10 g/kWh
- Purging facilities (regulation unit, docking stations)
- Wire feeding for Al, CaSi, FeTi and other
- Desulphurization with powder (CaSi, CaC2, Lime)
- Manipulator for temperature and sample
- Alloying system- Bunker system
- Dedusting unit
LF- treatment steps

Ladle Furnace versus Ladle Wear

- Thermal radiation during arcing
- Not efficient bottom stirring
- Splashes of steel and slag
- Short-circuit esp. for the purging plugs
- Overheated slag
- Less slag

- Covering the electric arc with slag
- Enough amount of slag with less oxides
- Optimal length of the arc
- Correct symmetry of the 3 phases
- Small electrode circle
- Effective ladle purging unit
Chemical Heating – CAS-OB, HALT

Treatment tasks:
- Fast Temperature adjustment
- Homogenization
- Alloying
- Deoxidation
- Desulphurization
- Removal of non metallic inclusions

CAS-OB versus Ladle Wear

- Aluminothermy heating
- Splashes and build up of steel and slag on/ into the bell
- Overheated Slag (bad stirring and or too long heating)
- Bad slag chemistry- Less slag – too much carry over slag (high (FeO))

- Enough amount of slag with less oxides
  → optimized Slag metallurgy
- Effective bottom stirring
### Comparison LF versus CAS-OB

<table>
<thead>
<tr>
<th></th>
<th>LF</th>
<th>CAS-OB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating rate [K/min]</td>
<td>3 - 5</td>
<td>7 - 10</td>
</tr>
<tr>
<td>Energy consumption [kWh/t K]</td>
<td>0,4</td>
<td>-</td>
</tr>
<tr>
<td>Oxygen consumption [Nm3/t K]</td>
<td>-</td>
<td>0,03</td>
</tr>
<tr>
<td>Aluminium consumption [kg/t K]</td>
<td>-</td>
<td>0,04</td>
</tr>
<tr>
<td>Refractory consumption bell [kg/ t Steel]</td>
<td>-</td>
<td>approx. 0,15</td>
</tr>
<tr>
<td>Oxygen lance</td>
<td>-</td>
<td>yes</td>
</tr>
<tr>
<td>Graphite electrode consumption [g/kWh]</td>
<td>6 - 10</td>
<td>-</td>
</tr>
<tr>
<td>Investment</td>
<td>high</td>
<td>low</td>
</tr>
</tbody>
</table>

### Steel Grades and Carbon Content

- **Vacuum Treatment if C < 0,025 %**
- **Carbon PVC Quality**
- **Carbon Structural Quality**
- **HSLA - Structural - Ship building**
- **D & EN**
- **UIC**
- **LC**
- **Per**
- **Med. Carb.**
- **High Carbon 1**
- **High Carbon 2**

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Vacuum Plant Nomenclature

Recirculation Processes

- **DH**  Dortmund Hörde (revamped to RH)
- **DH-OB**  Dortmund Hörde - Oxygen Blowing (revamped to RH)
- **RD**  Recirculation Degasser
- **RH**  Ruhrstahl Heraeus
- **RH-OB**  Ruhrstahl Heraeus - Oxygen Blowing (standard)
- **RH-OTB**  Ruhrstahl Heraeus - Oxygen Top Blowing (same as RH-KTB)
- **RH-KTB**  Ruhrstahl Heraeus - Kawasaki Top Blowing
- **VCP**  Vacuum Circulation Process
- **VCP-O**  Vacuum Circulation Process - Oxygen Blowing

Non-Recirculation Processes

- **VOD**  Vacuum Oxygen Degassing (deC under vacuum)
- **VD-OB**  Vacuum Degassing (standard), OB under atmospheric pressure
- **VAD**  Vacuum Arc Degassing

→ Which type fits is depend on the product mix!

RH-Degasser (Ruhrstahl - Heraeus)

Core equipment

- **Vacuum system:**  Mechanical Pumps and/or Steam Injectors
- **Burner:**  Natural gas and Oxygen, 50 K/h
- **Snorkel:**  Lift gas Ar/N₂ up to 2000 Nl/min
- **Oxygen Lance:**  Heating, Desculling and fine adjustment of \([C]/a_{[O]}\) ratio
- **Alloying Equipment**
- **Lifting System:**  Vessel, ladle or transfer car
- **Service Equipment:**  Desculling & Gunning
- **Lowest pressure:**  0,5 mbar
**RH- Process Homogenization**

A deep impulse of steel flow back into the ladle is a precondition for a good homogenization! Take care for:
1. To be as deep as immersed with the snorkels!
2. The number of working lift gas tubes are important!
3. Monitor Ar-lift gas flow and pressure for each line!
4. Operate with a single lift gas regulation system!

**RH-Degasser and Refractory Wear**

- Steel and slag chemistry (HIC, ULC)
- Long treatment time (> 30 minutes)
- Long or short heat sequences
- Thermal stress
- Air entrainment at the flanges (snorkel-vessel)
- Vessel build up – deskulling with O₂-lance

- RH logistic (sequence length, maintenance cycle,..)
- Optimal snorkel treatment (deskulling, gunning)
- Perfect maintenance and refractory service
- Balanced refractory lining
Snorkel Deskulling Facilities

The skull removal facility is,
- An excavator
- A special frame which is located on a service car or on a frame which will be settled onto the ladle transfer car

→ After the scull removal is done gunning should happen!!!!

Snorkel gunning

**Manual** + **Manipulator** = **PERFECT**

Video
## RH- degasser possible life time for each part

<table>
<thead>
<tr>
<th>Part</th>
<th>Life time (heats)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snorkels and legs</td>
<td>80 - 300</td>
</tr>
<tr>
<td>Vessel lower part</td>
<td>~ 300 (600)</td>
</tr>
<tr>
<td>Vessel upper part</td>
<td>&gt; 3.000</td>
</tr>
<tr>
<td>Alloying chute</td>
<td>&gt; 3.000</td>
</tr>
<tr>
<td>Top head (elbow)</td>
<td>&gt; 6.000</td>
</tr>
<tr>
<td>Gunning consumption [kg/t]</td>
<td>0.6 – 1.5</td>
</tr>
</tbody>
</table>

### Vacuum Tank Degasser (VD, VD-OB, VOD)

1. **1 Heat**
2. **2 Tank**
3. **3 Oxygen Lance**
4. **4 Alloying System**
5. **5 Purge Plug**

Source: left: SMS Mevac, Symposium Moscow July 2004; right: MARTI Technology
Purging – HKM VD key figures

- System: 2x bottom purging plug
- Pressure: 14 bar (max.)
- Flow rate: 2x1200l/min (max.)
- Emergency strategy: lance stirring
- Degassing: 5' atm. – deep vacuum (5 mbar), reduced flow rate
- Vacuum treatment: 20', max. flow rate
- Slopping: wet slags (O2-rich) beginning at 500-50 mbar
- Slopping detection: camera on bath
- Reaction on slopping: counter flooding
- Total stirring gas: >16.000l

Source: H. Schröter HKM (2016)

Tank Degasser VD/VD-OB/VOD

- Intensive metal-slag reaction!
- High erosion esp. slag line
- High thermal stress
- Built up and slashing
- Spontaneous boiling reaction
- Slag chemistry (eg. MgO-, CaF$_2$- content)
- Enough free-board
- Controlled vacuum pump down curve
- Efficient and controlled bottom stirring
- Convenient bricks for the slag line
- CaF$_2$- free
- If MgO- bricks MgO- slag saturation

Source Photo: 100 t VD- twin Degasser Handang, China
### Comparison RH/RHOB - VD/VOD

<table>
<thead>
<tr>
<th></th>
<th>RH - RHOB</th>
<th>VD - VOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furnace</td>
<td>LD, EAF*</td>
<td>EAF, LD*</td>
</tr>
<tr>
<td>Product</td>
<td>flat, some times long*</td>
<td>long, some times flat*</td>
</tr>
<tr>
<td>Steel grades</td>
<td>ULC, SULC, HIC, Plates, Pipes</td>
<td>HIC, Plates, Pipes, ULC*</td>
</tr>
<tr>
<td>Freeboard [mm]</td>
<td>300 - 400</td>
<td>500 - 1500</td>
</tr>
<tr>
<td>Ladle shell temperature</td>
<td>less</td>
<td>higher</td>
</tr>
<tr>
<td>Ladle life time</td>
<td>100%</td>
<td>approx. 60 - 80 %</td>
</tr>
<tr>
<td>Treatment time [min]</td>
<td>20 - 40</td>
<td>20 - 45 (VOD up to 120)</td>
</tr>
<tr>
<td>Length of a sequence</td>
<td>Snorel wear</td>
<td>no limit, especially TWIN</td>
</tr>
<tr>
<td>Refractory consumption [kg/t]</td>
<td>approx. 0,45</td>
<td>-</td>
</tr>
<tr>
<td>Gunning consumption [kg/t]</td>
<td>approx. 0,5</td>
<td>-</td>
</tr>
<tr>
<td>Slag metallurgy</td>
<td>no</td>
<td>S; P, Si, Mn, Cr</td>
</tr>
<tr>
<td>Desulphurisation</td>
<td>no</td>
<td>&lt; 10 ppm</td>
</tr>
<tr>
<td>Decarburisation</td>
<td>&lt; 15 ppm in 15-17 min</td>
<td>&lt; 20 - 30 ppm in 25 min</td>
</tr>
<tr>
<td>Degassing [H] in 20 min</td>
<td>&lt; 1.5 ppm</td>
<td>&lt; 1.5 ppm</td>
</tr>
<tr>
<td>Degassing [N] in 20 min</td>
<td>&lt; 40 ppm</td>
<td>&lt; 30 ppm</td>
</tr>
<tr>
<td>Temperature losses [K/min]</td>
<td>0,8 - 1,5</td>
<td>2,0 (250 t) bis 4,5 (bei 10 t)</td>
</tr>
<tr>
<td>Investment</td>
<td>high</td>
<td>lower</td>
</tr>
</tbody>
</table>
Chemical Reactions in a Steel Teeming ladle

Chemical Reactions between Metal-Slag Interface:

\[
\begin{align*}
3 [S] + 3 (CaO) + 2 [Al] &= 3 (CaS) + (Al_2O_3) \\
3 (SiO_2) + 4 [Al] &= 3 [Si] + 2 (Al_2O_3) \\
3 (MnO) + 2 [Al] &= 3 [Mn] + (Al_2O_3) \\
3 (FeO) + 2 [Al] &= 3 [Fe] + (Al_2O_3)
\end{align*}
\]

Desulphurization Efficiency and Ladle Refractory

Source: Kosmider et al, Stahl u. Eisen 1999 Nr. 22, 1215-1221

Each grade has in principle their own slag composition

<table>
<thead>
<tr>
<th>Steel Grade</th>
<th>FeO</th>
<th>SiO2</th>
<th>MnO</th>
<th>CaO</th>
<th>MgO</th>
<th>Al2O3</th>
<th>P2O5</th>
<th>S</th>
<th>TiO2</th>
<th>Cr2O3</th>
<th>Lime</th>
<th>Alumina</th>
<th>MgO</th>
<th>SiO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>ULC-IF</td>
<td>17</td>
<td>7.5</td>
<td>12</td>
<td>20</td>
<td>11.5</td>
<td>30</td>
<td>0.40</td>
<td>0.02</td>
<td>1.3</td>
<td>0.3</td>
<td>0.53</td>
<td>0 (x)</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Drawing</td>
<td>5.4</td>
<td>5.6</td>
<td>3.9</td>
<td>38</td>
<td>13.7</td>
<td>33.1</td>
<td>0.04</td>
<td>0.06</td>
<td>0.2</td>
<td>0.1</td>
<td>0.98</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Steel Desulphurised</td>
<td>6.7</td>
<td>8.5</td>
<td>9.2</td>
<td>52.4</td>
<td>9.2</td>
<td>28.6</td>
<td>0.00</td>
<td>0.20</td>
<td>0.2</td>
<td>0.0</td>
<td>1.41</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Wire without Al</td>
<td>2.7</td>
<td>46.0</td>
<td>5.0</td>
<td>35.0</td>
<td>8.0</td>
<td>4.0</td>
<td>kA</td>
<td>0.05</td>
<td>0.1</td>
<td>0.71</td>
<td>0.71</td>
<td>X</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>Rails, Welding Wire</td>
<td>&lt; 1.5</td>
<td>34.0</td>
<td>2.0</td>
<td>46.0</td>
<td>8.0</td>
<td>7.0</td>
<td>kA</td>
<td>0.05</td>
<td>1.12</td>
<td>1.12</td>
<td>1.12</td>
<td>X</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>Wire with Si, low requirements</td>
<td>6.0</td>
<td>14.0</td>
<td>7.0</td>
<td>44.0</td>
<td>16.0</td>
<td>15.0</td>
<td>kA</td>
<td>0.05</td>
<td>1.52</td>
<td>1.52</td>
<td>1.52</td>
<td>X</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>Wire without Si</td>
<td>6.6</td>
<td>8.0</td>
<td>3.0</td>
<td>55.0</td>
<td>8.0</td>
<td>21.0</td>
<td>0.04</td>
<td>0.20</td>
<td>1.90</td>
<td>1.90</td>
<td>1.90</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Rails</td>
<td>2.7</td>
<td>14.0</td>
<td>1.0</td>
<td>42.0</td>
<td>11.0</td>
<td>29.0</td>
<td>0.04</td>
<td>0.20</td>
<td>0.98</td>
<td>0.98</td>
<td>0.98</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

What's about Fluorspar/ CaF2?

Source: All data from VDEh members

*All grades for Ca-metallurgy (e.g., Cast-ability for thin slab caster), steel cleanliness, MgO- and CaO saturation,……

Source: 2013 04 VDEh Steel Academy Refractory Technology II, Ladle Metallurgical Treatments & Refractory Stress for a Steel Teeming Ladle

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Slags in the CaO – SiO₂ – Al₂O₃ Diagram

Basic- and acid slags in the CaO – SiO₂ – Al₂O₃ Diagram

Source: H. Deutsch, BHM 1995, Paper # 11
CS- and CA- Slags at the CaO – SiO2 – Al2O3 Diagram

- For lime-aluminate slag:
  \[ \text{CaO} = 40 - 63 \text{ wt. \%} \]
  \[ \text{Al}_2\text{O}_3 = 17 - 55 \text{ wt. \%} \]
  \[ \text{SiO}_2 = 0 - 20 \text{ wt. \%} \]

- For lime-silicate slag:
  \[ \text{CaO} = 40 - 58 \text{ wt. \%} \]
  \[ \text{SiO}_2 = 22 - 60 \text{ wt. \%} \]
  \[ \text{Al}_2\text{O}_3 = 0 - 20 \text{ wt. \%} \]

**Fig. 1:** Isothermal sections of the ternary system \( \text{Al}_2\text{O}_3 - \text{CaO} - \text{SiO}_2 \)

1 = lime-aluminate slag, 2 = lime-silicate slag

Source: C. Brüggmann, J. Pöltschke, Contribution to the slaggling of MgO in secondary metallurgical slags, September 8th and 9th 2010, Refractory Colloquium Aachen, Germany

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Influence of Steel Temperature and MgO-saturation

Source: Schürmann Formula for furnace slag
MgO- saturation – as an example (Steel Plant X)


MgO- saturation and some different Steel Grade Slags

Source: Steel Academy, Refractory Technology Part II, 2008 Secondary Metallurgy and Ladle Refractory Stress.
HKM - MgO- ladle slag saturation method

Theoretical MgO-solubility in CAS-slags ~ 9% (→ see Park Lee Diagram)

Addition of dolomite to prevent wear of lining.

But:

Slag forming by oxidation of aluminium + lime- and dolomite-addition takes time!

During dissolving lime and dolomite also MgO from the lining gets dissolved.
Inductive- vs. RH-steel flow

Steel flow lance vs. Bottom stirring

Source: 2007 VDEh Steel Academy Refractory Technology II, Ladle Metallurgical Treatments & Refractory Stress for a Steel Teeming Ladle
Strömungsverteilung

Source: W. Pluschkell; Stahl und Eisen 101 (1981), S 97/103

Different Plugs

Source: Flyers Product Info from different plug suppliers
Purging Plug Location

Source: 2015, RHI Technology Center Leoben, CFD Simulation- Case study Ladle Purging

Cross section and top view of velocity pattern for one and 2 Plugs with different locations 400 lit/min

Source: 2015, RHI Technology Center Leoben, CFD Simulation- Case study Ladle Purging
Thoroughly distribution of Alloying material

![Graph showing distribution of alloying material over time.](image)

Source: 2015, RHI Technology Center Leoben, CFD Simulation: Case study Ladle Purging.

Soft Stirring and bubble size formation

![Diagram showing soft bubbling mode versus jetting mode.](image)

**Experimental Procedure**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water tank</td>
<td>1000 l</td>
</tr>
<tr>
<td>Pressure valve with mass flow controller</td>
<td>Range 0.5 – 10 l/min</td>
</tr>
<tr>
<td>High speed camera</td>
<td>50 frames per second</td>
</tr>
<tr>
<td>Image processing software</td>
<td>Automated bubble counting</td>
</tr>
<tr>
<td>Determination of bubble dimensions</td>
<td>Averaging of 500 frames for each flow rate</td>
</tr>
</tbody>
</table>


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**Water modeling results**

**Bubble formation of hybrid- porous- and slot plug**

Flow rate: 10 l/min

- hybrid
- porous
- slot

Steel Cleanliness and Soft bubbling 0.2 lit Ar x min⁻¹ x t Steel⁻¹

Source: Neifer, Rödl, Bannenberg, Lachmund; Stahleisen 117 (1997), Nr 5, S 55/63

Stahl-Zentrum

[O] tot over several process steps

Source: A. Gantner, VDEh Seminar Sekundärmetallurgie; Metalurgie des Pfannenofens , 24.10.2012

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Ladle stirring system

Control room PC / HMI

Control Panel

Gas control box

Ar / N₂

Level 2/3

Source: R. Ehrengruber, Excellence Intelligence Gas Control Systems; 2014 ECCC Graz

Purging Visualization L1 control room and docking station

Source: voestalpine Stahl Linz

Source: 2007 VDEh Steel Academy Refractory Technology II, Ladle Metallurgical Treatments & Refractory Stress for a Steel Teeming Ladle
Purging instrumentation and visualization at L1

Source: 2013 04 VDEh Steel Academy Refractory Technology II, Ladle Metallurgical Treatments & Refractory Stress for a Steel Teeming Ladle

% Lance Stirring and different Line Pressure

Source: Viertauer, Exenberger 2003, 14th IAS Steelmaking Conference San Nicolas, Argentina; Efficient Ladle Management at voestalpine Stahl
Purging – Paul-Wurth coupling device steel ladle

Source: H. Schröter HKM (2016)

Purging – Paul-Wurth coupling device VD-Stand

Source: H. Schröter HKM (2016)
Purging – installation and performance data

- Purge plug + well block set
  - Ladle age 0-19/21; lifetime 21 heats

- Replacement purge plug with sleeve
  - Ladle age >21; lifetime 12 heats

Source: H. Schröter HKM (2016)

---

Purging - visualization

Source: H. Schröter HKM (2016)
Purging – validation of purging performance

Source: H. Schröter HKM (2016)

Purging – validation of purging performance

Source: H. Schröter HKM (2016)
### HKM - Ladle Performance Data Functional Products

<table>
<thead>
<tr>
<th>Item</th>
<th>System</th>
<th>Info</th>
<th>Life time (heats)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow control</td>
<td>CS100</td>
<td>Bore size 80mm</td>
<td></td>
</tr>
<tr>
<td>Slide gate plates</td>
<td></td>
<td>81.3% Al2O3, 10.9% SiO2, 5.4% ZrO2, 7.2% C</td>
<td>Max. 300 min casting = approx. 3.1</td>
</tr>
<tr>
<td>Drain nozzle</td>
<td></td>
<td>85.0% Al2O3, 8.0 % SiO2, 4.0% ZrO2, 2.0 % CaO, 0.5% MgO , 4.0% C</td>
<td>2.1</td>
</tr>
<tr>
<td>Inner nozzle</td>
<td></td>
<td>91.8% Al2O3, 0.1% Fe2O3, 0.1% SiO2, 2.4% CaO, 5.6 % MgO</td>
<td>9</td>
</tr>
<tr>
<td>Purging plugs</td>
<td>Multiport</td>
<td>12 x 0,15 x 2mm / 12 x 0,2 x 2mm</td>
<td>Max. 21 (set) / 12 (repl.)</td>
</tr>
<tr>
<td></td>
<td>Double-HP</td>
<td>0.2mm</td>
<td>Max. 21 (set) / 12 (repl.)</td>
</tr>
</tbody>
</table>

Source: H. Schröter HKM (2016)

### Purging – reasons for failure

<table>
<thead>
<tr>
<th>Reason for bad purging</th>
<th>no flow</th>
<th>leakage</th>
</tr>
</thead>
<tbody>
<tr>
<td>rate</td>
<td>7%</td>
<td>5%</td>
</tr>
<tr>
<td>purging plug</td>
<td>++</td>
<td>0</td>
</tr>
<tr>
<td>stand</td>
<td>0</td>
<td>++</td>
</tr>
<tr>
<td>piping</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>PW</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>o-ring</td>
<td>++</td>
<td></td>
</tr>
</tbody>
</table>

Source: H. Schröter HKM (2016)
### Is the lifetime-counting really state of the art?

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Time, Heats</td>
<td>123</td>
<td>15</td>
</tr>
<tr>
<td>Contact Time with Steel [min]</td>
<td>12.800</td>
<td>1.600</td>
</tr>
<tr>
<td>Time without Steel [min]</td>
<td>10.200</td>
<td>2.500</td>
</tr>
<tr>
<td>Heats/Day</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Operation Days</td>
<td>21</td>
<td>3</td>
</tr>
<tr>
<td>Bubbling:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tapping [min]</td>
<td>580</td>
<td>70</td>
</tr>
<tr>
<td>Secondary Metallurgy [min]</td>
<td>2.300</td>
<td>320</td>
</tr>
<tr>
<td>Lance [min]</td>
<td>90</td>
<td>50</td>
</tr>
</tbody>
</table>

$n = 53$; Ladle Campaigns 2006 Feb.-August
Purge Plug Checking Device

Tests:
1. Leckagen Detektion
2. Gasdurchgang Spüler Nm³/h
3. O₂ - Spüler freibrennen

→Standardized process and documentation!

Source: R. Ehrengruber, Excellence in inert gas control systems for the steel Industry, ECCC Graz

Plug Cleaning „washing“

Reinigen des Spülers mit der O₂-Lanze

FALSCH : "FREIFRIEHEN"  
Gerätekehle "BOHRN" mit der O₂-Lanze

RICHTIG : "FREIWASCHEN"  
FREISCHNITZ oder SCHLAMMENFÖRMIGE NÄHRENUNG mit der O₂-Lanze

Luft 6 bar
Sauerstoff max. 3-4 bar

Source: R. Ehrengruber, Excellence in inert gas control systems for the steel Industry, ECCC Graz

Stahl-Zentrum
Gas Coupling – a safety issue!

Source: MTAG Technology; Product Folder, own photos

Control Ladle Purging

Source: A. Gantner, VDEh Seminar Sekundärmetallurgie; Metallurgie des Pfannofens, 24.10.2012
Steel plant and ladle logistic (1/2)

Scheduling without a logistic model is not possible!

Steel plant and ladle logistic (2/2)

Scheduling without a logistic model is not possible!
**Ladle Logistics – Temperature Distribution**

![Temperature Distribution Diagram](image)

**Source:** voestalpine Stahl GmbH

---

**HKM - Gantt diagram as production planning tool**

![Gantt Chart](image)

**Source:** H. Schröter HKM (2016)
Ladle Logistics versus Bottom Stirring

| Heats/ Ladle | 6.0 | 5.9 | 6.0 | 5.3 | 5.1 | 6.9 | 6.3 | 5.3 | 5.9 | 5.8 | 6.1 | 2.5 | 3.4 | 3.6 | 3.8 | 3.5 | 5.8 | 5.8 | 6.6 | 6.4 |
| Number of Ladles/ Day | 16 | 16 | 16 | 15 | 14 | 15 | 15 | 15 | 16 | 15 | 15 | 12 | 15 | 14 | 14 | 15 |
| Heats/ Day | 96 | 95 | 95 | 85 | 77 | 96 | 94 | 89 | 92 | 33 | 48 | 54 | 53 | 42 | 87 | 81 | 93 | 96 |
| % Lance Bubbling > 1 | 7 | 10 | 8 | 24 | 7 | 14 | 13 | 11 | 7 | 10 | 11 | 36 | 23 | 11 | 9 | 29 | 8 | 15 | 13 | 4 |

1 LF1 Problem with the Bubbling System!
2 Reduced Production!

The key factor for efficient bottom stirring are a high number of heats per day AND ladle!

Source: voestalpine Stahl GmbH

Ladle Refractories Overview

Ladle wear lining

- Bricks
  - Non-basic
    - Burned
    - Unburned
  - Basic
    - Burned
dominated
  - Magnesia-chrome
    - Doloma-carbon
    - Magnesia-carbon

Monolithics

- Basic
  - Burned
dominated
- Non-basic
  - Unburned

### Overview of Ladle Refractory Working Linings

<table>
<thead>
<tr>
<th>Type</th>
<th>Advantage</th>
<th>Disadvantage</th>
<th>Application area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnesia-Carbon (MgO-C)</td>
<td>High refractoriness</td>
<td>Low resistance in oxidising atmospheres</td>
<td>Bottom, Sidewall, Slagline</td>
</tr>
<tr>
<td></td>
<td>Resistant: basic slags + infiltration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alumina-Magnesia-Carbon-Spinell (AMC)</td>
<td>Abrasion resistance</td>
<td>Lower chemical resistance (silica slags)</td>
<td>Bottom, Impact area, Sidewall</td>
</tr>
<tr>
<td></td>
<td>Irreversible thermal expansion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monolitic (Alumina-mixes)</td>
<td>Fast installation</td>
<td>Longer heating time</td>
<td>Bottom, Sidewall</td>
</tr>
<tr>
<td></td>
<td>Less break out material</td>
<td>Equipment investment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C-free lining</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dolomite-Carbon</td>
<td>Infiltration resistant to basic, low FeO slags</td>
<td>Danger of Hydration</td>
<td>Bottom, Sidewall, Slagline</td>
</tr>
<tr>
<td></td>
<td>Low structural spalling</td>
<td>Low resistance: alumina slags</td>
<td></td>
</tr>
<tr>
<td>Burnt Alumina-Spinel</td>
<td>C-free lining</td>
<td>Lower chemical resistance</td>
<td>Bottom, Sidewall</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burnt Magnesia-Chromite</td>
<td>Corrosion resistant at slag change</td>
<td>Infiltration and C2S Disintegration</td>
<td>Bottom, Sidewall, Slagline</td>
</tr>
<tr>
<td></td>
<td>High erosion resistance</td>
<td>Low resistance against temperature changes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35%-100% VOD heats</td>
<td>(spalling)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower resistance against reducing slags</td>
<td>Lower resistance against reducing slags</td>
<td></td>
</tr>
<tr>
<td>Burnt Doloma</td>
<td>Lower infiltration</td>
<td>Low resistance against temperature changes</td>
<td>Bottom, Sidewall, Slagline</td>
</tr>
<tr>
<td></td>
<td>Resistance against reducing slags</td>
<td>(spalling)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20%-70% VOD heats</td>
<td>Lower corrosion resistance at slag change</td>
<td></td>
</tr>
</tbody>
</table>

Source: RHI-AG; Product Management Linings Steel (2016)

### Layered Lining of the Ladle

- **Insulation**
- **Pre-insulation**
- **Safety lining**
- **Backfilling**
- **Wear lining**

Source: RHI-AG; Product Management Linings Steel (2016)
Common Wear Linings for Steel Ladles

**Slag line:**
- MgO-C, 10-15% C
- Dolomite-C

**Side wall and bottom:**
- MgO-C, 5-10% C
- Dolomite-C
- Al2O3-MgO-C-bricks (AMC)
- Monolithic
- Burned Alumina-Spinell bricks

**Impact area:**
- Al2O3-MgO-C-bricks (AMC)
- MgO-C, 5% C, fused Magnesia

Source: RHI-AG; Product Management Linings Steel (2016)

---

Ladle Refractory Solutions

- Carbon and resin bonded wear lining bricks
  - Magnesia, Alumina-Magnesia, Doloma
- Burnt wear lining bricks based on:
  - Magnesia-Chromite, Alumina-Spinel, Doloma
- Monolithic wear lining
  - Low-cement, self-flowing, oxycarbide
- Ramming, casting and gunning mixes
  - Alumina, Magnesia, Doloma (ramming only)
- Purge plugs
  - Porous, Slot, Star, Labyrinth, Segment, Hybrid
- Permanent lining and Insulation
- Prefabs

Source: RHI-AG; Product Management Linings Steel (2016)
### HKM - Ladle Permanent Lining Configuration

**Wall:**
- 30mm steel shell
- 20mm vermiculite board
- 90mm Andalusite

**Slag zone:** Magnesia-spinel
- 32mm burnt Magnesia

**Bottom:**
- 54mm steel shell
- 30mm insulating alumina castable
- 90mm high alumina castable
- 32mm burnt Magnesia

Source: H. Schröter HKM (2016)

---

### HKM - Ladle Thermal Conductivity Calculation

![Graphical representation of thermal conductivity calculation](source: H. Schröter HKM (2016))
Monolithic bottom and sidewall, MgO-C bricks slag line

Metallurgical results between different lining concepts

ULC grades are produced at an RH degasser!
**VD- treatment and decarburization**

![Graph showing cumulative frequency of achievable carbon content for different refractory materials](image)

ULC grades are produced at an VD degasser!

Source: H. Lachmund, VDEh Seminar Steel Ladle Lining, July 2014

**HKM - Steel ladle key data**

- 280t capacity
- 125t tara (relined)
- 40t wear lining
- Vac. / Al-thermic heating limit = 0-72 heats
- Av. wear = 72 heats
- Bottom stirring (2x purging plug; Paul-Wurth-clutch)
- CS100 Slide gate

Source: H. Schröter HKM (2016)
HKM - Steel Ladle Refractories

<table>
<thead>
<tr>
<th>Part</th>
<th>Quality</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slagzone</td>
<td>97-98%MgO High Purity Fused Magnesite / &gt;9%C</td>
<td>5P</td>
</tr>
<tr>
<td>Wall</td>
<td>96-97%MgO Fused Magnesite + Sintered Magnesite / &gt;9%C</td>
<td>3P</td>
</tr>
<tr>
<td>Reinforced wall (Tapping)</td>
<td>97%MgO Fused Magnesite + Sintered Magnesite LC / 5%C</td>
<td>4P/5P</td>
</tr>
<tr>
<td></td>
<td>92%Al2O3 (Tab) / 6%MgO / 6%C</td>
<td></td>
</tr>
<tr>
<td>Tapping-pad</td>
<td>81,5-92%Al2O3 (Fused Alumina/Tab) / 5-7,5%MgO / 4-7,3%C (Resin)</td>
<td>350mm</td>
</tr>
<tr>
<td>Bottom</td>
<td>77-86%Al2O3 (Bauxite) / 6-9%MgO / 5-7% C (Resin)</td>
<td>250mm</td>
</tr>
<tr>
<td></td>
<td>94%MgO Sintered Magnesite / 4%C (Resin)</td>
<td></td>
</tr>
</tbody>
</table>

Limit Max 71 heats for VD (Ladle top and slag line)

Source: H. Schröter HKM (2016)

---

Benchmark life time and refractory consumption

<table>
<thead>
<tr>
<th>Part</th>
<th>Average [Heats]</th>
<th>Standard Deviation [Heats]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Time, Heats</td>
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<td>320</td>
</tr>
<tr>
<td>Lance [min]</td>
<td>90</td>
<td>50</td>
</tr>
</tbody>
</table>

Impact Area: 0.03 ~ 1.80
Impact Area: 0.18 ~ 0.8
Impact Area: 0.25 ~ 0.4
Impact Area: 0.37 (0.19*) ~ 0.65
Impact Area: ~ 0.09
Impact Area: ~ 0.01
Impact Area: ~ 0.04
Impact Area: ~ 0.03

Source: SAP consumption [kg] refractory; FJ 2006

* [kg] rest material weight / number of heats / heat weight

Source: A. Viertauer, 3rd. int. Symposium Steel Ladle Lining; Efficient Ladle Management at voestalpine Linz, Ijmuiden NL 2004
HKM - Ladle empty and steel contact time since 2003

Now 3 - 4 heats / day

Source: H. Schröter HKM (2016)

HKM - Ladle Performance Figures

- Heats/day 3-4
- Vacuumdegassing 55-70%
- Alumothermic Heating 5%
- Ladle Heating Stands 7 (1100°C)

Source: H. Schröter HKM (2016)
HKM - Tapping Temperature 2004 - 2015

Source: H. Schröter HKM (2016)

HKM - Ladle Servicing

- Visible inspection of refractory
- Gunning of the top, well block, purging plugs
- Inspection and replacement of slide gate plates, nozzles & purging plugs
- Check of AMEPA system
- Check of purging system
- Heating of ladles
- Cleaning

Source: H. Schröter HKM (2016)
HKM - Ladle Service

- Cooling 3 shifts
- Breakout and lining (work lining) 7 shifts
- Maintenance 1-2 shifts
- Preheating (1100°C, Oxygen 300°C-800°C) 24h

Source: H. Schröter HKM (2016)

Evaluation of action fields

HKM - Ladle Remaining Wear Lining Thickness Report

Source: H. Schröter HKM (2016)
**Bottom Construction**

**Continuous:**
- Stable construction
- Bottom change not possible
- Correct bottom brickwork in order to get a flat basis for the side wall

**Inserted:**
- Bottom change possible
- Easier installation
- Bottom joint is a weak point
- Therefore choose a good ramming mass and work carefully

Source: RHI-AG, Product Management Linings Steel (2016)

---

**P-Shapes (Side Arch Bricks)**

Brick height 250mm, Width approx. 100mm

- High brick weight
  - Example: 4P8 ~ appr. 14kg
- Less Joints
  - Specific joints 14m/m²
- Installation
  - Layer per layer - one or two cuts per layer required
  - High brick height leads to:
    - Fast installation
    - High mechanical stability
- Problems with steps and open joints in conical ladles

Source: RHI-AG, Product Management Linings Steel (2016)
Problems with P-Shapes in Conical Ladles

**Installation following the ladle conus:**
opening of V-joints at the upper end of the layer

**Installation vertical:**
steps with the disadvantage of:
loss of effective brick length increased spalling

**Solution:** in conical ladles use bricks with a height of 100mm (Mini Keys or SU-shapes) only!

---

**Mini Keys (MK)**

Brick height 100mm, Width 150mm in the middle

- Easy to handle due to less brick weight
  - Example: MK7/8 ~ appr. 8kg

- Many joints
  - Specific joints 18,7m/m²
  - 33% more than P-shapes

- Installation
  - Layer per layer - one or two cuts per layer required
  - Spiral lining also possible, but not in common use

- Suitable for conical ladles
Lining with P- and MK-Shapes: The Closing Brick

The closing bricks shall:

- Not be in the trunnion area
- Not be directly above purge plug and slide gate
- From one ring to the next not be directly above each other.
- Fit the remaining gap tightly, which means that it has to be inserted with a rubber hammer (inserting only by hand is not enough)
- If the remaining gap is smaller than 50mm two closing bricks have to be cut and inserted with at least 2 uncut bricks between them

Source: RHI-AG; Product Management Linings Steel (2016)

Sidewall Construction - Find the Mistakes!
Lining with P- and MK-Shapes: The keys

- **Mix of keys 1:1**
  - Uniform gap between wear and permanent lining
  - Small deviations of key no problem

- **Mix of keys >3:1**
  - Strongly varying gap between wear and permanent lining
  - Small deviation of key can make ladle “un-line able”

Source: RHI-AG; Product Management Linings Steel (2016)

Semi Universal (SU)
Brick height 100mm, Width 210mm on the cold side

- **Brick weight**
  - Example: SU745 ~ appr. 10,5kg

- **Joints**
  - Specific joints 17,4m/m²
  - 25% more than P-shapes

- **Installation**
  - Especially developed for spiral lining
  - Fast installation
  - Only one shape per ladle
  - Starter set or ramp necessary (cast, rammed)
  - Lower mechanical stability – no closed rings
  - Layer by layer also possible, but not in common use

- **Suitable for conical ladles**

Source: RHI-AG; Product Management Linings Steel (2016)
Permanent Lining Bricks

Rectangular shapes  SL Shapes  NF Shapes

Bottom, Insulating bricks  Safety lining side wall

→ Wedged SL-Shapes are preferred in the sidewall for better safety

Source: RHI-AG, Product Management Linings Steel (2016)

Monolithic Safety Lining

Two possibilities:

1.) Casting **behind the brick layers**. Depending on the material of the monolithic safety lining and the shape of the wear lining bricks, application every 1-7 layers

2.) Casting **with a template** like the monolithic steel ladle lining is also a possibility (Not for dry monolithic material)

Source: RHI-AG, Product Management Linings Steel (2016)
Template for monolithic ladle

Self flowing mixes
- Template with reinforcements in Impact and purge plug area

Thixotrophic mixes
- Template with electric vibrators

Demands on the Permanent Lining of Ladles

- Emergency operation: Permanent lining has to withstand at least 1 heat or more
- Permanent linear change > 0% at 1600°C
- Thermal conductivity not too high
- Sufficient strength
- Sufficient refractoriness
- Resistance to carbon bursting
### Safety Lining Solutions

<table>
<thead>
<tr>
<th>Product Type</th>
<th>Thermal Conductivity</th>
<th>Cold Crushing Strength</th>
<th>Cold Shock Resistance</th>
<th>Emergency Properties</th>
<th>Application Area</th>
<th>Danger of Carbon Bursting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burnt Bauxite</td>
<td>medium</td>
<td>high</td>
<td>very high</td>
<td>medium</td>
<td>Bottom/Sidewall</td>
<td>Yes</td>
</tr>
<tr>
<td>Burnt Mullite</td>
<td>Low-medium</td>
<td>high</td>
<td>very high</td>
<td>medium</td>
<td>Bottom/Sidewall</td>
<td>Low</td>
</tr>
<tr>
<td>Magnesia-Chromite</td>
<td>medium</td>
<td>medium</td>
<td>high</td>
<td>very high</td>
<td>VOD-ladles</td>
<td>Yes</td>
</tr>
<tr>
<td>Burnt Magnesia</td>
<td>high</td>
<td>high</td>
<td>low</td>
<td>high</td>
<td>Slagzone</td>
<td>No</td>
</tr>
<tr>
<td>Burnt Magnesia-Spinel</td>
<td>high</td>
<td>high</td>
<td>Medium-high</td>
<td>high</td>
<td>Slagzone</td>
<td>No</td>
</tr>
<tr>
<td>Dry Monolithic Material</td>
<td>medium</td>
<td>low</td>
<td>high</td>
<td>medium</td>
<td>Universal</td>
<td>No</td>
</tr>
<tr>
<td>Burnt Fireclay</td>
<td>low</td>
<td>medium</td>
<td>high</td>
<td>very low</td>
<td>Not advised</td>
<td>Yes</td>
</tr>
<tr>
<td>Magnesia Carbon</td>
<td>very high</td>
<td>low</td>
<td>medium</td>
<td>very high</td>
<td>Not advised</td>
<td>No</td>
</tr>
</tbody>
</table>

Source: RHI-AG; Product Management Linings Steel (2016)

### Types of Ladle Insulation

<table>
<thead>
<tr>
<th>Product Type</th>
<th>Thermal Conductivity</th>
<th>Cold Crushing Strength</th>
<th>Maximum Application Temperature</th>
<th>Application Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulating Fired Brick</td>
<td>low</td>
<td>very low</td>
<td>1400°C</td>
<td>Preinsulation</td>
</tr>
<tr>
<td>Ceramic Fiber</td>
<td>very low</td>
<td>extremely low</td>
<td>1250°C</td>
<td>Insulation</td>
</tr>
<tr>
<td>Vermiculite</td>
<td>low</td>
<td>ok</td>
<td>1100°C</td>
<td>Insulation</td>
</tr>
<tr>
<td>Microporous Insulation</td>
<td>extremely low</td>
<td>nonexistent</td>
<td>1000°C</td>
<td>Not advised</td>
</tr>
</tbody>
</table>

Source: RHI-AG; Product Management Linings Steel (2016)
Thermal conductivity through a ladle side wall

Drying and Heating

Source: RHI-AG; Product Management Linings Steel (2016)

Source: R. Exenberger, VDEh Seminar Steel Ladle Lining, Saarbrücken/ Germany, Sept. 2014
**HKM - Ladle Preheating**

![Image of graph showing SEM: SMW Gas Allgemein](image)

Source: H. Schröter HKM (2016)

---

**MgO – C Bricks and Oxidation**

![Image of burnt-out and intact carbon binding matrix](image)

Reason: Oxidation!
HKM - Ladle Preheating - decarburization

Wear Influence by process

Metallurgical
- Reactions with steel / slag / fluxes / alloying materials
- Reactions with atmosphere / vacuum
- ....

Process
- Electric arc radiation
- Erosion caused of purging / flow / tapping
- ....

Logistics
- Contact time full / empty / transport
- Thermal stress
- ....

Wear is a complex matter of various facts!
Wear influence – Refractory material properties

**Chemic**
- Infiltration
- Reduction
- Oxidation
- Evaporate
- Structure changing

**Thermic**
- Expansion
- Treatment time- contact time
- Thermal stress and shock
- Structure changing

**Mechanic**
- Erosion
- Transport
- Cleaning

---

**Refractory Lab**

**Function:**
1. Reference material samples
2. Analysis and physical properties of reference material, sewed plates
3. „Fingerprint“ by xrd of reference material
4. 4x/a sampling, retained samples, weight, dimensional accuracy, bulk weight
5. Possibility to determine bulk density, waterabsorption, open porosity, linear shrinkage (drying @110°C), sieve analysis

Source: H. Schröter HKM (2016)
Refractory Lab: Fingerprint by XRD

1. Average sampling
2. Grind the granulated material < 90 µm
3. Press the sample for XRD measurement
4. Start XRD measurement with PANalytical Cubix³
5. Interpretation of the diffractogram

Source: P. Peternel SZMF, K. Walter, HKM 2016
Refractory Lab: Fingerprint by XRD

Mineralogical composition

Main Components
- Natural silicates
  - Wollastonite
  - Albite
  - Quartz
- Artificial silicates
  - Blast furnace slag
- Fly ash
- Gases

Carbon
- Coke breeze
- Graphite
- Carbon black

Fluorite
- Cryolite
- Viliaumite

Chemical composition

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>52</td>
</tr>
<tr>
<td>Na2O</td>
<td>30</td>
</tr>
<tr>
<td>BaO</td>
<td>7</td>
</tr>
<tr>
<td>SiO2</td>
<td>5</td>
</tr>
<tr>
<td>K2O</td>
<td>5</td>
</tr>
<tr>
<td>Li2O</td>
<td>5</td>
</tr>
<tr>
<td>Al2O3</td>
<td>6</td>
</tr>
<tr>
<td>FeO</td>
<td>6</td>
</tr>
<tr>
<td>B2O3</td>
<td>5</td>
</tr>
</tbody>
</table>

Example: Mould Flux

HKM - Lab test for permanent lining

Test method: Induction Furnace Slag Test

Temperature: 1700°C
Holding time: 4 hours
Melt: Steel CrMnSi 6-4
Slag: CA-rich
Atmosphere: Air

Slag Composition:

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>52</td>
</tr>
<tr>
<td>Al2O3</td>
<td>30</td>
</tr>
<tr>
<td>SiO2</td>
<td>7</td>
</tr>
<tr>
<td>MgO</td>
<td>6</td>
</tr>
<tr>
<td>CaF2</td>
<td>5</td>
</tr>
</tbody>
</table>

Source: P. Peternel SZMF, K. Walter, HKM 2016
Source: H. Schröter HKM (2016)
HKM - Ladle Permanent Lining Configuration

Wall
Main Component:
- Alumina enriched Andalusite
- Wear Rate (CA-slag): 19 mm/h

Slag zone
Main Component:
- Fused Magnesite + Bauxite
- Wear Rate (CA-slag): 1 mm/h

Source: H. Schröter HKM (2016)

Refractory Lab
Benefits:
- Long term evaluation of material properties (e.g. nut feather system, worn form, 1x reclamation refractory supplier)
- Quick test for material confusion by comparison of sewed plates (2x reclamations ref. supplier, 1x contractor)
- Detection of inner cracks (1x reclamation ref. supplier) and damaged edges (1x prohibition of delivery)
- Quick Test for water content, linear drying shrinkage (1x reclamation ref. supplier)
- Detection of raw material substitution (1x ref. supplier liquidation before reclamation)
- Gaining knowledge of the employees
- Open and honest discussion with the supplier and contractor
- Delivery of less flawed material
- Gaining safety of the process

Source: H. Schröter HKM (2016)
New and used Ladle

Source: A. Viertauer, VDEh Steel Academy, Refractory Technology Steel Ladle Lining, Efficient Ladle Management at voestalpine Stahl, Linz 2006

Laser Mirror Scanner

Fixed Installation

„Moving Device“

Source photos: left voestalpine Stahl GmbH, right: Ferrotron

Source: A. Viertauer, VDEh Steel Academy, Refractory Technology Steel Ladle Lining, Efficient Ladle Management at voestalpine Stahl, Linz 2006
Ladle Refractory – Wear Measurement

Measurement Steps

1. Trunnion Ring
2. Wall North
3. Bottom
4. Wall South

Source: A. Viertauer, VDEh Steel Academy, Refractory Technology Steel Ladle Lining, Efficient Ladle Management at voestalpine Stahl, Linz 2006
Laser Measurements during a campaign

1st The information about „remaining thickness“ is just an information!
2nd Each measurement has to be checked for plausibility!
3rd The area between bottom and wall is not measured, it is calculated! There are two coordinate systems one for the bottom – one for the wall!
4th Joints and small holes can not be detected! The reason is the density of the measuring points and the mathematical inter- and extrapolation!

Source: A. Viertauer, VDEh Steel Academy, Refractory Technology Steel Ladle Lining, Efficient Ladle Management at voestalpine Stahl, Linz 2006
**Hot Spot Detection**

1. **Source Image**
2. **Binarized Image**
3. **Alarms in Image**

**Threshold Configuration**
- Threshold for hot spot detection
- Threshold for percentage calculation
- Threshold for temperature resolution

**Alarms Configuration**
- High Value: ≥ 180°C
- Very High Value: ≥ 200°C
- Ultra High Value: ≥ 220°C

**Source:** Paper AIS Tech 2006 Cleveland, May 2006; SIEMENS-VAI

**Hot Spot Detection at the LF**

1. **Measure**
   - Position the ladle in measurement view and perform measurement.

2. **Evaluate**
   - Study results and approve or unapprove ladle.

3. **Approve / Unapprove**
   - Operator declares ladle to be safe.

**Source:** Flyer Hot Spot Detection, Agellis Group, 2014
Cobble stoning – deep horizontal and vertical joints

Source: 2007 VDEh Steel Academy Refractory Technology II, Ladle Metallurgical Treatments & Refractory Stress for a Steel Teeming Ladle
Ladle Gunning – especially slag line and lip ring

Source: Photos: RHI, voestalpine Linz, Bhushan, JSW- T

Lipring

Function:
- Vertical Fixing of the Lining

Problems:
- Forces from slag skull removal
- Slag and steel splashing and overflow
- Scaling
- Installation to complicated
- Bending upwards by thermal expansion of the lining

Results:
- Loss of bricks
- Opening of horizontal joints → Steel infiltration
- Bended Lipring
- No vertical fixing

Source: Product Management RHI
Lipring – Classic Installations

Short Lipring, unprotected, bad clamping,...

Reinforced on the outside, unprotected

Inclined lipring, protected, expensive closing brick

Reinforced on the outside, quickly exchangeable, unprotected

Inclined lipring, protected, expensive closing brick

Source: Product Management RHI

Lipring

Optimal solution:
- High mechanical stability
- Good clamping of the lining
- Easy and fast installation
- High thermal stability
- High lifetime => less maintenance
- Allowance for the thermal expansion of the lining
- Enough free board

A tailor made solution for each customer has to be found

Source: Product Management RHI
Prewear Impact Area – two solutions

Source: 2007 VDEh Steel Academy Refractory Technology II, Ladle Metallurgical Treatments & Refractory Stress for a Steel Teeming Ladle

Spalling

Drying Simulation: Shrinking hot side 0.275 mm and cold side 0.199 mm

Source: CD Laboratory Leoben, Photos: voestalpine Linz
Spalling

Ladle crane transport → Tension- and compression load

Source: CD Laboratory Leoben, Photo: voestalpine Linz

Spalling of resin bonded material

Source: H. Schröter HKM (2016)
HKM - Bricks moved out – shrinking 1/2

Ladle was laying horizontal and getting cold!

Source: H. Schröter HKM (2016)

HKM - Bricks moved out – shrinking 2/2

Bricks move out when ladle laying while cold

Source: H. Schröter HKM (2016)
Horror Cabinet

HKM - Ladle Break out – false repair
Ladle 66, age 60, breakout 0°, joint layer 15/16

Source: H. Schröter HKM (2016)
HKM - Ladle Break out – false repair

After lining no open joints

Source: H. Schröter HKM (2016)

HKM - Ladle false repair

Steel infiltration in joints layers:
15/16, 16/17, 17/18

Source: H. Schröter HKM (2016)
HKM - Ladle false repair

Monolithic skimmer lost (view on bricks)

“Hotrepair” with Olivine / Sintermagnesia gunning refractory in the age 46

Source: H. Schröter HKM (2016)

HKM - Steel Ladle

Source: H. Schröter HKM (2016)
HKM - Ladle wrong ladled material

Spilling layer 3, 0°, 1x brick

Source: H. Schröter HKM (2016)

HKM - Ladle wrong labeled material

“Right” material  Spilled brick  “Wrong” material

Source: H. Schröter HKM (2016)
HMK - Ladle wrong labeled material

Labeling in brickworks – white line

Source: H. Schröter HKM (2016)

HMK - Ladle wrong labeled material

Material completely labeled – mistake by supplier

Source: H. Schröter HKM (2016)
HKM - Ladle material confusing

Only 4P/4-formats affected

Source: H. Schröter HKM (2016)

Horror Cabinet – explosion of wrong material

HKM - Ladle Servicing

ULC castable exploded through heating up

→ porosity too low!

Source: H. Schröter HKM (2016)
Problem Area Slag Line – Constructive Solutions

Break – Through Ladle Slag Line

Slag composition after the break through:

<table>
<thead>
<tr>
<th></th>
<th>Fe</th>
<th>SiO₂</th>
<th>Mn</th>
<th>CaO</th>
<th>MgO</th>
<th>Al₂O₃</th>
<th>P₂O₅</th>
<th>Cr₂O₃</th>
<th>K2O</th>
<th>TiO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0,52</td>
<td>4,94</td>
<td>0,07</td>
<td>50,48</td>
<td>15,14</td>
<td>27,75</td>
<td>0,013</td>
<td>0,01</td>
<td>0,001</td>
<td>0,154</td>
</tr>
</tbody>
</table>

Does the permanent lining have emergency running properties?

Source: 2007 VDEh Steel Academy Refractory Technology II, Ladle Metallurgical Treatments & Refractory Stress for a Steel Teeming Ladle
**Prewear Wall - Bottom**

Source: 2007 VDEh Steel Academy Refractory Technology II, Ladle Metallurgical Treatments & Refractory Stress for a Steel Teeming Ladle

---

**Damaged Plugs**

- too intensive $O_2$ cleaning
- too high line pressure
  
  $(>> 20 \text{ bar})$

Source: RHI
Blocked purging slits – possible Reasons?

- Very thin carbon layer
- Deep steel penetration

Stirring is not possible – what could be the reason?
Possible reasons are:
- Ladle logistic
- “Water pump effect”
- Quick disconnecting – negative flow (back attack)
- Contaminated purging gas

Deep steel penetration in the purging slots!
Stirring was not possible – what could be the reason?

AI closed the purging slots!

Source: 2013 04 VDEh Steel Academy Refractory Technology II, Ladle Metallurgical Treatments & Refractory Stress for a Steel Teeming Ladle

HKM - Ladle slide gate break out

Plate age 2; 138’ casting;
Ca = 7 / 13
→ Nut in slide gate

Source: H. Schröter HKM (2016)
HKM - Ladle Servicing

Purging plug breakout (280 t steel in the VD-tank)

Source: H. Schröter HKM (2016)

HKM - Ladle purge plug break out

Source: H. Schröter HKM (2016)
HKM - Ladle Purge Plug break out

DE-samples
red = purging plug from breakout ladle
black = new purging plug (chemistry ok)

Limiting factors of wear: deskulling

Deskulling + ladle design
Limiting factors of wear: steel bath / slag level (tapping weight)

Premature wear of Alumina-based refractories by lime saturated slag

Limiting factors of wear: ladle lifetime

<table>
<thead>
<tr>
<th>Wear mechanism</th>
<th>Heating up</th>
<th>tapping</th>
<th>slag</th>
<th>pressure</th>
<th>Heat transition</th>
<th>Time ladle empty</th>
<th>purging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoidable</td>
<td>Decarburization by Lambda &gt; 1, or long time between heating up and 1st melt</td>
<td>Premature wear by tapping beam out of position</td>
<td>Premature wear by aggressive slags (Basicity low esp. in combination with CaF₂, no MgO adding, SiO₂)</td>
<td>High wear rates by (over)insulation</td>
<td>Decarburization by long times ladle empty (hot state)</td>
<td>Wear by bad position of plugs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Explosions by water overdose, wrong material (dense), too steep temperature curve</td>
<td>Premature wear by high amount of BOF slag in SEM</td>
<td></td>
<td></td>
<td>High temperatures losses due to short or no ladle heating during time ladle empty</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not avoidable</td>
<td>Decarburization by false air, cold face</td>
<td>wear by tapping beam in right position</td>
<td>Wear by slag infiltration</td>
<td>Reduction of MgO by Al, C under vacuum</td>
<td>wear by high border temperatures</td>
<td>Decarburization in time ladle maintenance, slag droppings between melts</td>
<td>Wear by bath moving while purging</td>
</tr>
<tr>
<td></td>
<td>Wear by high tapping temperatures</td>
<td>Wear by slag solving MgO, CaO, Al₂O₃ etc. during forming</td>
<td></td>
<td></td>
<td>Temperature shock due to Temperature drop while empty</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: H. Schröter HKM (2016)
### Limiting factors of wear: ladle lifetime

<table>
<thead>
<tr>
<th>Wear mechanism</th>
<th>deskulling</th>
<th>Electrothermic / aluothermic heating</th>
<th>Steel bath</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Avoidable</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Damage of refractory by late deskulling</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Damage of refractory by bad deskulling</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Not avoidable</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Damage of refractory by ‘tooth‘ing‘ of steel with refractory</td>
<td>Wear by hot spot (radiation heat impact, low viscosity of slag)</td>
<td>Solution of carbon in liquid steel</td>
</tr>
<tr>
<td></td>
<td>Wear by low slag basicity in case of Al-thermic heating</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: H. Schröter HKM (2016)

### Frequency of mistakes

Steel Plant Operations

Refactories

Lining Installation

Source: H. Schröter HKM (2016)
Frequency of mistakes - Refractories

- Wrong labeling
- Insufficient mixing (mixing time too short / long, esp. fine material in low values spread worse, demixing by vibration in silo/vehicle)
- False stored / overlaid material (binder reacted with moisture, material damaged by frost)
- Dimensional accuracy insufficient (Form "washed out", warpage through drying / burning)
- Foreign bodies in material (cuttings, abrasion dust, bolts, pieces of conveyor belts, etc.)
- Wrong components in recipe (Mistakes in program, dirty production line, leak bunkers, rests from former load in silo/vehicle, mistakes of staff, weighing mistakes, wrong bunkercontent, insufficient raw material entrance inspection, purpose, etc.)

Source: H. Schröter HKM (2016)

Frequency of mistakes - Refractories

- Wrong amount in recipe (insufficient weighing, exhausting of fine material)
- Damaged material (outbursts on edges, pressing layers, over pressing, damaged form, etc.)
- Insufficient pretreatment (material not dried, wrong temper-/burning temperature curve, insufficient impregnation)
- Wrong choose of material

Source: H. Schröter HKM (2016)
Frequency of failures – Lining Installation

- Too much / less water / binder ("with less water the mass is not flowing")
- Wrong adjusted gunning machine (pressure, watervalve)
- Impure tools (plate mixer is running for days, insufficient cleaning of mixer between mixes)
- Drying time too short (spilling)
- Heating curve: too steep (spilling), too long (decarburization), too short (spilling in service)
- Confusion of material
- Insufficient joints (too wide, throughout joints)

Source: H. Schröter HKM (2016)

Frequency of failures – Lining Installation

- Damage through lining (metal hammer)
- Wrong tools (gunning of a casting material, dents in the pattern, worn feeler gauage)

Source: H. Schröter HKM (2016)
Frequency of mistakes – Steel Plant Operations

- Manipulation by telescope digger (damage of lining through deskulling, pushing of well block and purging plug)
- Touch down of the ladle (damage of purging pipework or PWK, accidental opening of slide gate, warpage / damage of slide gate housing / -linkage)
- Misjudgment and negligence (early drop at high residual thickness, no detection of too low residual thickness or gap between slide gate plates)
- Flawed repairs (wrong material, too much / few water / mortar, deficient setting of purge plugs, inner nozzles, slide gate plates, SEN)
- Deficient heat balance (“too long” parking of ladle - decarburization, cool down of ladle – opening joints, frequent heating / over boiling under vacuum)
- Wrong position of tapping beam (premature wear of sidewall- or bottom lining)
- Chemistry of Slag (“wasting” of fluorspar in case of dry slag / low purging, too high amount of converter slag / “super blown” heats)

Source: H. Schröter HKM (2016)

Outlook - Refractory Control System

Input data
Access
- Residual lining thickness
  Lining thickness data during lifetime e.g. determined by Laser measuring device
- Production parameter
  Relevant data of every heat e.g. tapping temperature, re-blow rate, Foamy slag conditions, vacuum treatment, ...
- Maintenance data
  Gunning data (amount of mix, areas....)
  Slag splashing
  Other repair methods e.g. hot fix, setting
- Refractory Lining
  Lining Design
  Brick & mix qualities

A.I. analytics software
Explore & discover
- Forecast of refractory lifetime
- Maintenance proposal
- Timing of maintenance to reach targeted lifetime (method, schedule, required time...)
- Production parameter
- Identification of top relevant parameters (slag, steel contact time, ...)
- Cause and effect analysis
  Holistic understanding of mechanism (input for new refractory development)

Output
Share

Content

Metallurgical Tasks
- Steel Production overview
- Example: ULC, HIC, TRIP, TWIP

Secondary Metallurgy
- Tasks
- Aggregates vs. Refractories
- Ladle slag
- Purging instrumentation

Teeming ladle
- Lining concepts
- Wear mechanism
- Lab investigation
- Drying- and heating
- Laser- vs. Thermo vision Scan
- Purging
- „Problem areas“ and Check list

Outlook and Summary