Refractory Lining and Wear in the TORPEDO LADLE

Dr. Waltraud Winkler
voestalpine Stahl GmbH, Linz

Seminar:
Refractory Technology – Applications, Wear Mechanism, Failures
Torpedo ladles/ Pipe ladles
Lining and wear

Waltraud Winkler

Seminar „Refractory Technology – Applications, Wear Mechanism and Failures“
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General data

- Number of torpedo ladles: 21, before 17
- Filling weight per ladle: 250 tons of crude iron per filling, up to 300 tons possible
- Filling cycle: about 4x in 24 hours
- Service life: about 1400 fillings, about 350,000 tons
- Tapping temperature: up to 1500°C
- Crude iron temperature: about 1450°C
General data

- Linings per year: 13-14 linings per year (wear lining)  
  safety lining with repair

- Repair of wear lining: 2 repair stops  
  1 mouth repair with bricks, after approx. 750 fillings  
  1 slag area repair with masses, after approx. 1250 fillings

Central ladle shop

- 3000 m²  
- Transport via railway
Central ladle shop
General data

- Amounts of refractory material per ladle:
  - Insulation and safety lining: about 65 t
  - Wear lining: about 104 t
  - Refractory mortars: about 8 t
  - Total weight including crude iron filling: about 600 t

Layers of the lining concept

- Insulation
  - Fire-light bricks on alumina-silica basis

- Safety lining
  - Now Andalusite, before Bauxite

- Wear lining: varies depending on the area in the cylinder
  - Alumina-rich (fired) - A
  - Alumina-carbon (resin-bonded) - AC
  - Alumina-carbon-SiC (resin-bonded) - ASC
New lining – in progress
Insulation

- requirements:
  - Heat resistance
  - Insulation effect
  - Prevention of heat loss
  - Prevention of high shell temperatures (steel shell)
  - Chemically and physically stable

- Typical characteristics of used insulation material:
  - $\text{Al}_2\text{O}_3$ in wt\%: 40
  - Density in g/cm$^3$: 1
  - Cold crushing strength in MPa: 4
  - Classification temperature in °C: 1400

Examples of insulations (1)

The adjustment of insulation, safety lining, and wear lining is usually carried out by simulation calculations. By considering the service temperatures in combination with different lining thicknesses a lining concept can be developed.

This concept stood the test.
Examples of insulations (2)

Aim: Keep the temperature level of the crude iron high during transport

Result: break-out because of excess temperature on the safety lining

Implementation: additional insulating microporous layer directly at the steel shell, then regular insulation and safety lining

The insulation effect is „too good“. In addition to the fire-light brick a microporous layer was installed in order to keep the temperature of the crude iron. During the advancing wear of the wear lining the limit of the chamotte-safety lining was reached.

This concept failed — overheating and break-out!
Safety lining concept

- Requirements
  - no CO-bursting
  - Safety, when the wear-lining „fails“
  - Adjustment to insulation and wear lining according temperature stability

Typical characteristics of the used safety-lining material:
- \( \text{Al}_2\text{O}_3 \) in wt\%: 60
- density in g/cm\(^3\): 2.5
- Porosity in Vol-\%: 15
- Cold crushing strength in MPa: 90
- Refractoriness under load \( t_{05} \) in °C: 1600

CO-bursting

Gases containing CO, set free carbon between 400 and 800°C, as soon as metallic Fe or Fe-oxide within the refractory material serve as catalyst. This reaction is called Boudouard-equilibrium.

\[
2\text{CO} = \text{CO}_2 + \text{C}
\]

<table>
<thead>
<tr>
<th>Temperature in °C</th>
<th>CO(_2) in %</th>
<th>CO in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>450</td>
<td>98</td>
<td>2</td>
</tr>
<tr>
<td>600</td>
<td>77</td>
<td>23</td>
</tr>
<tr>
<td>700</td>
<td>42</td>
<td>58</td>
</tr>
<tr>
<td>800</td>
<td>6</td>
<td>94</td>
</tr>
<tr>
<td>900</td>
<td>3</td>
<td>97</td>
</tr>
<tr>
<td>1000</td>
<td>1</td>
<td>99</td>
</tr>
</tbody>
</table>

High temperatures shift the equilibrium to the CO-side based on the endothermic reaction, low temperatures shift the equilibrium to the C-side of the equation.
Examples of safety linings (1)

- Bauxite:
  - A bauxitic safety-lining generally meets all the listed requirements, but: CO-bursting is a critical factor

Used pieces of a 2-layer safety-lining, B80:
- Hot side, next to wear-lining
- Cold side, next to steel shell

Examples of safety linings (1)

Carbon residues in the fracture plane of a brick. Several residue spots in the same plane lead to increase in volume and destruction of the brick into layers up to crumbling.
Examples of safety linings (1)

<table>
<thead>
<tr>
<th>Quality and format</th>
<th>Al2O3 [%]</th>
<th>Fe2O3 [%]</th>
<th>SiO2 [%]</th>
<th>TiO2 [%]</th>
<th>Glühverl. [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>B80 - format SL 564, new brick</td>
<td>80,8</td>
<td>2,12</td>
<td>12,5</td>
<td>3,35</td>
<td>0,06</td>
</tr>
<tr>
<td>B80 - format 2H6, new brick</td>
<td>80,2</td>
<td>2,65</td>
<td>12,5</td>
<td>3,26</td>
<td>0,07</td>
</tr>
<tr>
<td>B80 - format SL 564, used brick &quot;cold side&quot;</td>
<td>79,2</td>
<td>1,64</td>
<td>14,2</td>
<td>2,99</td>
<td>0,25</td>
</tr>
<tr>
<td>B80 - format SL 564, used brick &quot;hot side&quot;</td>
<td>82,3</td>
<td>1,76</td>
<td>11,3</td>
<td>3,11</td>
<td>0,29</td>
</tr>
</tbody>
</table>

- At max. 1.6 wt-% Fe2O3-content within the brick a critical limit for the vulnerability to CO-bursting exists, this means all factors for classical CO-bursting are evident, especially also the temperatures between 400 and 800°C.

Examples of safety linings (2)

- Andalusite:
- Based on the Fe2O3-content in Bauxite (a fact depending on the raw material from the mines) the safety-lining was changed to Andalusite.
Layers of the lining concept

- Insulation
  - Fire-light bricks on alumina-silica basis

- Safety lining
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- Wear lining: varies depending on the area in the cylinder
  - Alumina-rich (fired) - A
  - Alumina-carbon (resin-bonded) - AC
  - Alumina-carbon-SiC (resin-bonded) - ASC
Wear-lining concept

- **requirements:**
  - Thermal resistance (bath) – Alumina-rich - A
  - Mechanical resistance (impact) – ASC
  - Chemical resistance (slag-zone) – AC

Wear lining: B80-bricks, bath

- **Characteristics:**

  - **Chemical analysis:**
    - Al2O3: 80 – 85%
    - SiO2: 10 – 15%
    - Fe2O3: < 2%
    - TiO2: < 3%

  - **Physical analysis:**
    - Density: 2,8 g/cm³
    - Porosity: ca. 18 Vol.%
    - Cold crushing strength: ca. 90-100 MPa
    - Refractoriness under load: T05 = ca. 1500°C
Wear lining: AC-bricks, slag-zone

- **Characteristics:**
  - Raw material: tabular alumina, corundum
  - Type of binding: resin-bonded (synthetic resin) with antioxidants
  - Chemical analysis:
    - Al₂O₃: 97%
    - SiO₂: 1%
    - Fe₂O₃: 0.5%
    - TiO₂: 1%
    - C: 5%

- **Physical analysis:**
  - Density: 3.2 g/cm³
  - Porosity: 5-6 Vol.%
  - Cold crushing strength: 60 MPa
  - Refractoriness under load: T₀₅ > 1600°C

- **Specific characteristics:**
  - Pure raw material (tabular alumina) -> high refractoriness
  - Resin-bonded -> low porosity, low slag attack
  - Small SiO₂ – content -> low attack by Mn, as there is little possibility for the development of low-melting Mn-silicates

- **Effectiveness of the resin-bonding:**
  - Synthetic resin provides carbon and works as slag-stop respectively changes the wettability of the refractory surface. In order to protect the surface during heating, coatings are suggested by the producers.
Wettability of the refractory

- Bad
- Good

Function of the resin-bonding (synthetic resin):

- Synthetic resin provides carbon, therefore:
  - Wettability of the refractory material gets worse, therefore less attack by crude iron and slag
  - Pores are filled, therefore the porosity of the material is reduced
  - Reduction of the thermal and mechanical stresses
  - Reduces FeOx and MnO

Wear lining: ASC-bricks, impact area

- Characteristics:
  - Raw material: silicon carbide, corundum
  - Type of binding: resin-bonded (synthetic resin) with antioxidants
  - Chemical analysis:
    - Al2O3: 82%
    - SiO2: 1%
    - SiC: 6%
    - C: 8%
  - Physical analysis:
    - Density: 3.2 g/cm³
    - Porosity: 5-6 Vol.%
    - Cold crushing strength: 60 Mpa
Wear lining: ASC-bricks, impact area

- Specific characteristics:
  - resin-bonded -> low porosity, low slag attack
  - Addition of SiC -> hardness of SiC is very high, therefore the material is very resistant against mechanical abrasion
  - Disadvantage of SiC-content: SiC reacts in a temperature range above 800 °C up to about 1200°C in combination with oxygen, CO₂ and water vapor and forms SiO₂ and CO₂. SiO₂ is formed as Cristobalite, whereby crystal growth may lead to fractures and wear of the refractory material.

Mortars and their applicability

Experimental setup:

Bauxite-mortar or high alumina/SiC-mortar is used

Joint stable, slag does not enter

Slag enters far into the mortar and joint
Mortar and joint

- Purpose of the mortar and joint:
  - Mortar is both for sticking together bricks and for expansion compensation.
  - The bricks expand during heating, so the “growth” can be compensated by the mortar.
  - The joint should be 2mm wide at the most, as it is the weak point during crude iron attack.

Wear mechanisms

- In the contact area of several phases (liquid-liquid-solid/liquid crude iron/slag/refractory material) the differences in concentration and temperature result in a gradient in surface and interfacial tension. This gradient results in diffusion, what causes a current into the direction of the higher surface- respectively interfacial tension. The material transfer is accelerated and an edge develops.

This mechanism is called Marangoni-convection.
Visual checks in hot condition

- In regular intervals during their service-time
- Cleaning of the mouth
- Observation and assessment of:
  - mouth area
  - impact zone and adjacent areas
  - splash guard

Assessment of the general condition of the mouth-mass, the refractory lining and the appearance of joints in the impact area

Assessment of repairs, masses and gunning-material, trials

Assessment of wear, estimation of remaining thicknesses, spalling
Repair in hot condition

- Gunning

An alumina-rich mass and water are dosed with special gunning nozzles and applied to the hot refractory surface.

Criteria for good processing capability and application are:
- Adhesion on the hot surface
- Little rebound material
- Protection of the lining for a long time-span

Visual check in cold condition
Intermediate checks and repair

Repair in cold condition

- New mouth area
  - New mouth (andalusite mass with steel needles for more durability)
  - New impact area and adjacent area depending on wear
Repair in cold condition

- Area with reduced thickness are cast with self-flowing masses

Case of damage: wrong bricks on pallet