Challenges and Solutions for CONTINUOUS CASTING Refractories in Consideration of Clean Steel, Automation and Economy

Dipl.-Ing. Sven Karrasch,
ThyssenKrupp Steel Europe, Duisburg
and
Dipl.-Ing. Wilhelm Parbel,
RHI AG, Vienna

Seminar:
Refractory Technology – Applications, Wear Mechanism, Failures
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Structure

Challenges and Solutions for CONTINUOUS CASTING Refractories in Consideration of Clean Steel, Automation and Economy.

1. Introduction
2. Tundish
3. Ladle shroud
4. Monoblocstopper
5. Subentry nozzle and casting powder
6. Tundish slidegate and tube changing device
7. Operation mistakes
8. Bibliography

1. Introduction
Arrangement of ladle and tundish in a slab casting machine

Protected casting ladle to tundish

Source: SMS-Demag

Maximum metallurgical length = Supported length

\[ L_{\text{mel}} = \frac{1}{2} \pi R + L_{\text{hor}} \]

Metallurgical length: length of strand with liquid core parts.
Two strand slab caster in operation

Cutting machine
Castingtechnologie for the production of strip steel

Conventional Slab Caster
a) Vertical caster
b) Vertical bending caster
c) Curved machine

Thin Slab

Strip Caster (new caster for Salzgitter – 15mm thick) benefits: energy savings and production of HSD (High Strength and Ductility) steel grades

Thin Strip Caster

3.0 Mio. t/year
2.0 Mio. t/year
1.2 Mio. t/year
0.4 Mio. t/year
Today’s needs for refractory components

- Process stability
- Low costs
- Safe handling to machine and operators
- Optimized use

Continuous casting working conditions

<table>
<thead>
<tr>
<th>Product / Wear</th>
<th>Thermal Shock</th>
<th>Corrosion</th>
<th>Erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slide Gate</td>
<td>low</td>
<td>strong Ca-treatment</td>
<td>strong thrombling</td>
</tr>
<tr>
<td>Ladle Shroud</td>
<td>very strong</td>
<td>low to strong tundish powder</td>
<td>strong flow from more than one cubic meter is possible</td>
</tr>
<tr>
<td>Stopper</td>
<td>low</td>
<td>strong steel grades with CaSi-treatment ladle slag in tundish</td>
<td>strong thrombling</td>
</tr>
<tr>
<td>Submerged Nozzle</td>
<td>low to strong</td>
<td>strong casting powder</td>
<td>strong thrombling</td>
</tr>
<tr>
<td>Wear Lining Tundish</td>
<td>low</td>
<td>strong tundish insulation powder ladle slag in tundish</td>
<td>strong impact energy below ladle</td>
</tr>
<tr>
<td>Permanent Lining Tundish</td>
<td>low</td>
<td>low (sometimes strong) covered by wear lining mix influence of alkalis</td>
<td>low to strong tilting the tundish to remove scrap</td>
</tr>
</tbody>
</table>
Main properties of refractory raw materials

- ZrO2 fine ceramic
- ZrO2 refractory
- MgO
- Al2O3 graphite
- Al2O3 ceramic bonded
- Fused silica

Cost and properties of different materials for submerged tubes

<table>
<thead>
<tr>
<th>Material</th>
<th>Cost Index</th>
<th>Thermoshock resistance</th>
<th>Corrosion resistance against Steel</th>
<th>Corrosion resistance against Castingpowder</th>
<th>Property against Clogging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al2O3 - C</td>
<td>100</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>4</td>
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<tr>
<td>Al2O3 – C - BN</td>
<td>250</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
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<tr>
<td>BN sintered</td>
<td>4000</td>
<td>2</td>
<td>3</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Al2O3 densely</td>
<td>400</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>MgO – C</td>
<td>100</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>MgO – C – BN</td>
<td>250</td>
<td>3</td>
<td>-</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>MgO sintered</td>
<td>45</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>-</td>
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<tr>
<td>ZrO2 – C</td>
<td>200</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>4</td>
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<tr>
<td>ZrO2 – C – BN</td>
<td>350</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>ZrO2 sintered</td>
<td>400</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>ZrO2 densely</td>
<td>2000</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Fused SiO2</td>
<td>100</td>
<td>1</td>
<td>2-5</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

1 very good 2 good 3 satisfying 4 not satisfying 5 insufficient
Principle of an isostatic form

Compaction with steel plates
- for normal shapes

Pressing force on the full surface
- for special shapes for example long tubes

Production route of isostatically produced refractory components

Mixing raw materials
- Demixing
- Moisture absorption
- Uncontrolled moisture decreasing
- Mixing temperature
- Addition of binder
- Grain size distribution

Isostatic moulding
- Applied pressure
- Pressing duration

Drying/burning
- Temperature control
- Atmosphere inside the oven
- Heating-up rate
- Cooling rate

Storage supplier
- Careless storage
- Moisture

Packaging
- Insufficient packaging
- Mistaken piece

Machining/assembly
- Thickness of cement/glue

Storage customer
- Careless storage
- Moisture

Tundish preparation
- Reaction with other materials
- Thickness of cement/glue

Casting platform (preheating)
- Reaction with other materials
- Preheating temperature (too high/low)
- Preheating duration (too long/short)
- Preheating rate control

Transportation – mechanical damage

Casting
2. Tundish

Tundish – different shapes

- B („boat“)-type
- V-type
- T-type
- H-type

even C-type or curved shape to improve the fluid flow
Tundish with different products to influence temperature and flow conditions

Complete cleaned tundish before relining
# Properties of refractory material for permanent lining of tundishes

<table>
<thead>
<tr>
<th>Application</th>
<th>Tundish Insulation</th>
<th>Tundish Permanent Lining</th>
<th>Bricks for Tundish Permanent Lining</th>
<th>Tundish Impact Plate</th>
<th>Tundish Well Blocs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Microporous Insulation</td>
<td>Insulation board</td>
<td>Bauxite</td>
<td>Andalusite</td>
<td>Bauxite Sintered Alumina</td>
</tr>
<tr>
<td>1. Chemistry (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>0,6</td>
<td>42,0</td>
<td>84,0</td>
<td>65,0</td>
<td>86,0</td>
</tr>
<tr>
<td>SiO₂</td>
<td>66,0</td>
<td>55,0</td>
<td>10,5</td>
<td>33,0</td>
<td>7,5</td>
</tr>
<tr>
<td>CaO</td>
<td>3,1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1,9</td>
</tr>
<tr>
<td>MgO</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0,4</td>
<td>-</td>
<td>1,3</td>
<td>-</td>
<td>1,3</td>
</tr>
<tr>
<td>TiO₂</td>
<td>28,3</td>
<td>-</td>
<td>2,8</td>
<td>-</td>
<td>2,0</td>
</tr>
<tr>
<td>2. Phy. Properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>0,13</td>
<td>0,39</td>
<td>2,85</td>
<td>2,72</td>
<td>2,62</td>
</tr>
<tr>
<td>Open Porosity (%)</td>
<td>-</td>
<td>-</td>
<td>15,5</td>
<td>13,5</td>
<td>25,0</td>
</tr>
<tr>
<td>Cold crushing Strength (N/mm²)</td>
<td>-</td>
<td>-</td>
<td>90,0</td>
<td>-</td>
<td>30,0</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>400°C</td>
<td>0,04</td>
<td>0,09</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>600°C</td>
<td>0,05</td>
<td>0,12</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>800°C</td>
<td>0,06</td>
<td>0,19</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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**Heating curve for casted permanent lining**

- **Air Setting**
  - 0°C to 150°C
  - 15°C/hours
  - Hold 15 hours
  - 15°C/hours
  - 25°C/hours
  - 50°C/hours
- **Heating**
  - 150°C to 800°C
  - 50°C/hours
  - Hold 8 hours
  - 15°C/hours
  - Hold 8 hours
  - 15°C/hours
  - Hold 8 hours
  - 50°C/hours

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Refractory Technology, 26th April, 2016, Cologne
Sven Karrasch tkSE AG - Wilhelm Parbel RHI AG 19

Refractory Technology, 26th April, 2016, Cologne
Sven Karrasch tkSE AG - Wilhelm Parbel RHI AG 20
Compare of tundish costs
concrete - bricks

Cost level for Tundish with monolithic lining

Cost level for conventional lining with bricks

Wearlining – slurry mix or dry mix
Wearlining of a tundish with dry mix

Manual gunning with slurry mix
Full automatic gunning with slurry mix

Properties of refractory material for tundish wear lining

<table>
<thead>
<tr>
<th>Chemistry (%)</th>
<th>low iron content</th>
<th>high iron content</th>
<th>Olivin additions</th>
</tr>
</thead>
<tbody>
<tr>
<td>MgO</td>
<td>91,00</td>
<td>84,00</td>
<td>78,00</td>
</tr>
<tr>
<td>SiO2</td>
<td>4,80</td>
<td>3,50</td>
<td>16,00</td>
</tr>
<tr>
<td>Fe2O3</td>
<td>0,50</td>
<td>5,50</td>
<td>2,50</td>
</tr>
<tr>
<td>CaO</td>
<td>3,00</td>
<td>5,80</td>
<td>2,20</td>
</tr>
<tr>
<td>Density g/ccm</td>
<td>1,5-1,8</td>
<td>1,4-1,7</td>
<td>1,2-1,5</td>
</tr>
</tbody>
</table>

Binding
- Phenolic Resin: well known, expensive, health@environmental issues
- Sodium Silicate: low cost, can cause damage to permanent lining
- Glucose/Suggar/Dextrine: moderate cost, no toxic fumes, no issues with refractory

Typ of mix: slurry mix or dry setting mix

cost reduction possible by optimised lining thickness and decreasing of the density
Tundish with furnitures and stoppers ready to use

Design of an improved impact pot

- Further improved flow conditions
- Maintain advantage of the impact pot for misaligned systems

Special shaped protrusions on the sidewall guarantee an efficient turbulence dissipation, even at high ladle shroud inclination angles:
  - Lower risk of “open eye”
  - Reduction of flow bias
  - Reduced splash tendency
Use of simulation

- Deeper process understanding
- Identification of problem areas
- Conceptual design studies
- Detailed product development
- Improvement of existing designs

CFD simulation

CFD simulation comparing a lipped impact pot with the novel TUNFLOW™

<table>
<thead>
<tr>
<th></th>
<th>Lipped impact pot</th>
<th>TUNFLOW™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rel. Max. Velocity [%]</td>
<td>100</td>
<td>76</td>
</tr>
<tr>
<td>Rel. Max. Turbulence [%]</td>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>
Water model test comparing a lipped impact pot with the novel TUNFLOW™

**Dye injection and RTD curve**

- Vertical LS
- Misaligned LS

**Results of water model test**

Water model test comparing a lipped impact pot with the novel TUNFLOW™

**Surface turbulence and start of casting**

- Optimised kinetic energy dissipation resulting in a reduced surface turbulence
- Better compensation of misaligned LS situation
3. Ladle shroud

Comparison ladle shroud with casting box

- Ladle shroud
- Casting box
- Tundish
- Liquid steel
- Argon
**Ladle shroud**

**Metall can**
Additional mechanical strength for heavy treated products

**“C-free” liner**
C-free liner or decarburized zone for cold start of shroud

**Reinforcement made by zirkon or magnesia**
High performance against ladle slag and basic tundish slag.

**Argon purging**
Additional device for the gasket by argon purging

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**“ZAAG”**
Zero Air Aspiration Gate

Remote chart recorder showing shrouding efficiency.
**Refractory material for ladle shrouds**

### Ladle Shrouds

<table>
<thead>
<tr>
<th>Material</th>
<th>Alumina/Graphit</th>
<th>Magnesia/Faserstoff</th>
<th>Fused Silica</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Remark</strong></td>
<td>Long Castingtime</td>
<td>Normal Castingtime</td>
<td>Single Heats</td>
</tr>
<tr>
<td><strong>Chemistry (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al2O3</td>
<td>59,0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td></td>
<td>67,0</td>
<td>99,0</td>
</tr>
<tr>
<td>SiO2</td>
<td>3,0</td>
<td>20,0</td>
<td></td>
</tr>
<tr>
<td>Si-met</td>
<td>5,0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>29,0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Phy. Properties</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>2,51</td>
<td>1,60</td>
<td>1,93</td>
</tr>
<tr>
<td>Open Porosity (%)</td>
<td>16,0</td>
<td></td>
<td>12,0</td>
</tr>
<tr>
<td>Modulus of rapture (N/mm²)</td>
<td>8,0</td>
<td></td>
<td>10,0</td>
</tr>
</tbody>
</table>

**Ladle shroud – poor thermoshock resistance**

Longitudinal cracking shortly after opening the ladle

Low depth of decarburization
4. Monobloc stopper

Monobloc stopper (MBS) different types

Regelung des Durchflusses | Flow regulation

Argon Management

Verhindert die Bildung und den Ansatz von Alumina (Clogging). In Zusammenarbeit mit unserer Tochter FC-Technik bieten wir unseren Kunden komplette Systemlösungen.

Argon management

Prevents the formation and setting of alumina (clogging). We offer complete system solutions in cooperation with our subsidiary FC-Technik.

Verted design
Restricted design
Porous plug design
Stopper fixing system

Stopper argon injection system

- CONNECTION
  - Gas tight Assembly
  - System for long sequence casting

- CONTROL BORE
  - Non Blocking High Performance Control
  - Bore Plug

- ENHANCEMENT
  - Material concepts for the full range of steel applications
Refractory material for stoppers

<table>
<thead>
<tr>
<th>Material</th>
<th>Body and Nose High Alumina/Carbon</th>
<th>Nose Magnesia/Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bemerkung</td>
<td>Standard</td>
<td>Long Casting Time</td>
</tr>
<tr>
<td>1. Chemistry(%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>52,0</td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td></td>
<td>70,0</td>
</tr>
<tr>
<td>SiO₂</td>
<td>5,0</td>
<td>0,5</td>
</tr>
<tr>
<td>Si met</td>
<td>5,0</td>
<td>5,0</td>
</tr>
<tr>
<td>C</td>
<td>32,0</td>
<td>17,0</td>
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</table>

2. Phy. Properties

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>2,40</th>
<th>2,52</th>
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</thead>
<tbody>
<tr>
<td>Open porosity (%)</td>
<td>16,5</td>
<td>17,5</td>
</tr>
<tr>
<td>Modulus of rapture (N/mm²)</td>
<td>8,0</td>
<td>5,5</td>
</tr>
</tbody>
</table>

Additional ZrO₂ for body (0-8%) and slag zone (up to 75%).

Quality costs of different stopper systems
5. Subentry nozzle and casting powder

Subentry nozzle

unused - used
A - reinforced stopper seat
B - glazed Surface
C - Body
D - Slag reinforced area
E - Port geometrie
F - Insulation

The submerged nozzle is the refractory tube to cast steel controlled from tundish to mould, and to protect the steel against the atmosphere.
Submerged Nozzle

<table>
<thead>
<tr>
<th>Application</th>
<th>Stopper seat</th>
<th>Body</th>
<th>Reinforced Slagband</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>High Alumina/Graphite</td>
<td>High Alumina/Graphite</td>
<td>Zirconoxide/Graphite</td>
</tr>
<tr>
<td>Remark</td>
<td>Standard</td>
<td>High Corrosion-resistance</td>
<td>Standard</td>
</tr>
</tbody>
</table>

1. Chemistry (%)

<table>
<thead>
<tr>
<th></th>
<th>Al₂O₃</th>
<th>MgO</th>
<th>ZrO₂</th>
<th>CaO</th>
<th>SiO₂</th>
<th>Si-met</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>52,0</td>
<td>70,0</td>
<td>74,0</td>
<td></td>
<td>5,0</td>
<td>5,0</td>
<td>32,0</td>
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<tr>
<td></td>
<td>52,0</td>
<td></td>
<td>74,0</td>
<td></td>
<td>6,0</td>
<td>0,5</td>
<td>15,0</td>
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</tbody>
</table>

2. Phy. Properties

<table>
<thead>
<tr>
<th></th>
<th>Density (g/cm³)</th>
<th>Open Porosity (%)</th>
<th>Modulose of rature (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2,40</td>
<td>16,5</td>
<td>8,0</td>
</tr>
<tr>
<td></td>
<td>2,52</td>
<td>17,0</td>
<td>5,5</td>
</tr>
<tr>
<td></td>
<td>2,40</td>
<td>16,5</td>
<td>8,0</td>
</tr>
<tr>
<td></td>
<td>3,62</td>
<td>17,0</td>
<td>7,0</td>
</tr>
<tr>
<td></td>
<td>4,00</td>
<td></td>
<td>7,5</td>
</tr>
</tbody>
</table>

Special SEN for CSP/thin slab caster

The development of these special SEN takes care of

1. The small space inside of the mould
2. A long lifetime
3. Flow inside the mould
   - Enough flow in the upper part to get the mould powder liquid
   - Not too much flow in the upper part to avoid high turbulences
   - Low flow in the lower part to avoid inclusions
Heating curve
isostatic products

Preheating procedures

Appearance of longitudinal cracks at slab-surface

Carbon content of steel grade
Casting Powder
Steel flow in mould
SEN – geometry
SEN – immersion depth
Argon amount in SEN
Accuracy of mold-level measurement
Gap between SEN and mould
Kind of refractory SEN-slagmaterial
> Influences the melting of casting powder

Oscillation of mould
• Stroke
• Frequency

Width of the strand

Casting speed

Cooling devices and parameters
• Cooling mould
• Secondary colling
Flow conditions in the mould in relation of port angles and argon flow

High argon rate
Slight deeps in the mould
High casting volume

Slight argon rate
High deeps in the mould
Small casting volume

Clogging

Casting powder

Main functions of casting powder:
• Lubrication between strand and mold
• Insulation of meniscus against heat loss and oxidation.
**Composition of casting powder**

<table>
<thead>
<tr>
<th>Mineral Carriers</th>
<th>Carbon Carriers</th>
</tr>
</thead>
<tbody>
<tr>
<td>• fly ash</td>
<td>• fly ash (30% C, 120 μm)</td>
</tr>
<tr>
<td>• cement</td>
<td>• coke fines (90 μm)</td>
</tr>
<tr>
<td>• blast furnace slag</td>
<td>• natural graphite (40 μm)</td>
</tr>
<tr>
<td>• lime stone (CaCo3)</td>
<td>• carbon blacks of different grain size</td>
</tr>
<tr>
<td>• lime (CaO)</td>
<td>• lamp black, flame black</td>
</tr>
<tr>
<td>• sand (SiO2)</td>
<td></td>
</tr>
<tr>
<td>• wollastonite (CaO*SiO2)</td>
<td></td>
</tr>
<tr>
<td>• feldspar</td>
<td></td>
</tr>
<tr>
<td>• petalite (LiO2<em>Al2O3</em>8SiO2)</td>
<td></td>
</tr>
<tr>
<td>• spodumene (LiO2<em>Al2O3</em>4SiO2)</td>
<td></td>
</tr>
<tr>
<td>• soda ash (Na2CO3)</td>
<td></td>
</tr>
<tr>
<td>• fluorspar (CaF2)</td>
<td></td>
</tr>
<tr>
<td>• NaF</td>
<td></td>
</tr>
<tr>
<td>• MnO2</td>
<td></td>
</tr>
<tr>
<td>• borax (Na2O<em>2B2O</em>10H2O)</td>
<td></td>
</tr>
<tr>
<td>• bauxite (Al2O3*2H2O)</td>
<td></td>
</tr>
<tr>
<td>• bentonite</td>
<td></td>
</tr>
<tr>
<td>• cryolithe (3NaF*AlF3)</td>
<td></td>
</tr>
<tr>
<td>• lithium carbonate (Li2CO3)</td>
<td></td>
</tr>
<tr>
<td>• magnesium carbonate (MgCO3)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.1% quartz powder</td>
</tr>
<tr>
<td>19.7% cement</td>
</tr>
<tr>
<td>15.0% lime stone powder</td>
</tr>
<tr>
<td>11.0% fluorspar</td>
</tr>
<tr>
<td>20% petalite</td>
</tr>
<tr>
<td>10% soda ash</td>
</tr>
<tr>
<td>2.5% flame black</td>
</tr>
<tr>
<td>12.7% coke fines</td>
</tr>
</tbody>
</table>

Result: 28.7% SiO2, 28.7% CaO, 0.38% MgO, 4.9% Al2O3, 0.06% TiO2, 0.93 FeO, 5.9% Na2O, 0.29 K2O, 5.2 F, 0.80 LiO2, 13.3% Cfree, 10.6% CO2, 16.2% Ctotal

**Examples of casting powder**

<table>
<thead>
<tr>
<th>Non-casting Flux Factors</th>
<th>Casting Flux Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>steel grade</td>
<td>viscosity</td>
</tr>
<tr>
<td>strand format</td>
<td>solidification temperature</td>
</tr>
<tr>
<td>casting velocity</td>
<td>structure (crystallinity)</td>
</tr>
<tr>
<td>specific caster conditions</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LC Al-killed steel</th>
<th>B&lt;&gt;1, viscosity &lt;=0,1 Pa*s, solidification temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC Al-killed steel</td>
<td>high basicity (longitudinal cracking), high crystallinity, low viscosity</td>
</tr>
<tr>
<td>ULC Al-killed steel</td>
<td>low C-content, higher viscosity</td>
</tr>
<tr>
<td>High Si-AL- killed steel</td>
<td>low solid-temperature of powder</td>
</tr>
<tr>
<td>Stainless Steels</td>
<td>higher viscosity, lower solidification temperature</td>
</tr>
</tbody>
</table>
Clogging parameter

Steel-Grade
AL killed

Purity of the steel

Air leakages

Refractory material
Ladle / Tundish / Casting Material

Flow conditions and geometry in the submerged tube

Freeflow – „Anti-clogging“ nozzles

Minimising of clogging for IF- steel grades
/ Increasing of sequence length

Clogging after 4 heats

Anti-Clogging liner after 6 heats
Refractory solutions to avoid Clogging

**Slit purging in subentry nozzle**

Purging slit and permeable material in the wall of the submerged nozzle disabled clogging in the tube.

**BN disabled beaus of low wettability clogging**

Mixes with CaZrO₃ segregate CaO, which react with Al₂O₃ to low melting phases (see. Taikabutsu Overseas).

**Inner coating with special refractory material**

Carbon free interior coating (63% Al₂O₃ + 35% SiO₂).

Because of the coating the following reactions should be avoided:

\[
\begin{align*}
\text{SiO}_2(s) + C(s) & = \text{SiO}(g) + CO(g) \\
3\text{SiO}(g) + 2\text{Al} & = 2\text{Al}_2\text{O}_3(s) + 3\text{Si} \\
3\text{CO}(g) + 2\text{Al} & = \text{Al}_2\text{O}_3(s) + 3\text{C}
\end{align*}
\]

(see Müller et al.)

Carbon free interior coating to avoid reaction with oxygen coming from the permeability of the SEN. On the inner hot surface the reaction CO = C+O takes part. The free oxygen reacts with aluminium of the liquid steel to Al₂O₃ which sticks to the inner surface of the SEN (see Poirier et al.)

**Surface Condition with interior coating**

Permeability of Al₂O₃-C material for submerged nozzles

![Graph showing permeability of Al₂O₃-C material](image)

*Fig. 2: Influence of prefireing temperature under reducing atmosphere on the gas permeability of an Al₂O₃-C SEN measured at room temperature [15]*
Corrosion mechanisms for submerged nozzles in contact with steel slag and air

- Immersed submerged nozzle
- Casting powder (slag)
- Liquid steel
- Atmosphere

Corrosion rate of different material refractory materials in contact with steel and slag

- Corrosion of dense Zirconia extrem low
- But because of thermo shock not usable
Submerged Nozzle & Submerged Shroud

Slag band Options & Positions

- Zirconia material increases the casting time
- Quality of Zirconia depends on required casting time.
- Steel level in the Mould should be within the safe zone of the Zirconia enhancement area.
- There should be a 30mm minimum clearance at the top and bottom of the enhancement area where the steel level is not present.

6. Tundish slidegate and tube changing device
# Refractory material
tundish slide gate systems

<table>
<thead>
<tr>
<th>Application</th>
<th>Slidegate nozzles</th>
<th>Slidegateplates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>High Alumina</td>
<td>High Alumina</td>
</tr>
<tr>
<td></td>
<td>High Alumina Graphite</td>
<td>Standard</td>
</tr>
<tr>
<td>Remark</td>
<td>Standard</td>
<td>For argon purging</td>
</tr>
<tr>
<td>1. Chemistry (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>6,0</td>
<td></td>
</tr>
<tr>
<td>ZrO2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al2O3</td>
<td>91,5</td>
<td>89,0</td>
</tr>
<tr>
<td>SiO2</td>
<td>0,1</td>
<td>0,6</td>
</tr>
<tr>
<td>C</td>
<td>10,0 Cr2O3</td>
<td></td>
</tr>
<tr>
<td>2. Phy. Properties</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>2,85</td>
<td>3,20</td>
</tr>
<tr>
<td>Open Porosity (%)</td>
<td>18,0</td>
<td>19,0</td>
</tr>
<tr>
<td>Modulus of rapture (N/mm²)</td>
<td>32,0</td>
<td></td>
</tr>
</tbody>
</table>
Submerged nozzle changer

Profitability of an SNC system compared to a conventional submerged nozzle

Conventional casting means two sequences with 1400 mt with one caster preparation time. Compare to a SNC system. With a SNC system you can produce approx 30 minutes longer in 24 hours, Benevit is higher productivity and saving ref.
7. Operation mistakes

Submerged nozzle with hole in the slag line
Wrong casting position

Critical Aspect

- Immersion depth
  Target immersion 120mm *minimum* from top of port, *not* from the bottom of the monotube

Negativ Result

- Interface corrosion at the bottom of the Zirconia slag band caused by mould powder
- Increased turbulence in the mould
- Increased slag line corrosion
- Increased risk of non metallic inclusions in slab

Failure of stopper 1/3

- Horizontal breakage after preheating of the SEN/stopper System
- Mechanical damage might be the reason for that failure
- Broken parts were cut
- In each part some cracks are visible

*Crack in sample before and after decarburization*
Failure of stopper 2/3

- Sample with such a crack was prepared
- The crack system could be found inside the blue framed area.

Microscopy of the stopper sample

Failure of stopper 3/3

- Inhomogeneous phase distribution
- Agglomerates of phases
- Graphite is also inhomogeneous
- The stopper failed because of the weak parts and not because of a mechanical damage

Detailed microscopy of the stopper sample
Thank you for your attention!

sven.karrasch@thyssenkrupp.com
wilhelm.parbel@rhi-ag.com