Process Conditions and Factors affecting the Refractory Lining Life and the Development of Refractory Materials Technology in OXYGEN BLOWING CONVERTERS

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and

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Seminar:
Refractory Technology – Applications, Wear Mechanism, Failures
Process Sequence and Variables affecting the Durability of Converters and the Development of the Refractory Materials Technology in BOF’s

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Refractory Technology: Part II

• Introduction
• Process description: Combined blowing
• Charge materials
• Process sequence
  1. Places of reaction
  2. Reactions
  3. Process control / process models
• Trends in BOF technology
• Detection of wear areas
• Wear areas inside the converter
• Stirring in the converter
• Tapping
• Maintenance and care
• Development results concerning refractory technology
• Wear mechanisms and actions
• Chamber of horrors
Crude-Steel Production
1960 – 2010 BOF - EAF

Annual Steel Production - Worldwide
Development of Oxygen Steelmaking Processes

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BOF in Blowing Position

Layout of Basic Oxygen Furnace

- Stirring gases: Ar, N₂
- Additives bunker
- Gas cooling hood
- Trunnion ring
- Tilting drive
- Shaft
- Cylinder
- Top cone
- Bottom cone
- O₂ Lance
Sectional View of Oxygen Blowing Lance

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# Table of Scrap Grades

<table>
<thead>
<tr>
<th>Category</th>
<th>Grade no.</th>
<th>Grade description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old scrap</td>
<td>B3</td>
<td>Heavy steel scrap, predominantly thicker than 6mm, prepared suitable for charging, may contain pipes and hollow sections. No automotive body scrap and no car wheels. Free from visible Cu, Sn, Pb and alloys and debris.</td>
</tr>
<tr>
<td></td>
<td>E1</td>
<td>Lightweight steel scrap, predominantly less than 6mm, prepared suitable for charging, may contain car wheels, but must exclude automotive body scrap and domestic appliance scrap. Free from visible Cu, Sn, Pb and alloys and debris.</td>
</tr>
<tr>
<td>New scrap</td>
<td>E2</td>
<td>Heavy new steel scrap, predominantly thicker than 3mm, prepared suitable for charging. The steel scrap must be free from coatings and concrete reinforcing bars and steel bars, also from new productions. Free from visible Cu, Sn, Pb and alloys and debris.</td>
</tr>
<tr>
<td></td>
<td>E8</td>
<td>Lightweight steel scrap, predominantly less than 3mm thick, prepared suitable for charging. The steel scrap must be free from coatings and loose steel strip to avoid problems during charging. Free from visible Cu, Sn, Pb and alloys and debris.</td>
</tr>
<tr>
<td></td>
<td>E6</td>
<td>Lightweight steel scrap (less than 3mm thick), compacted or in the form of compressed packages, prepared suitable for charging. The steel scrap must be free from coatings. Free from visible Cu, Sn, Pb and alloys and debris.</td>
</tr>
<tr>
<td>Shredded scrap</td>
<td>E40</td>
<td>Old steel scrap cut into pieces which in no case are allowed to be bigger than 200mm for 95% of the charge. The remaining 5% must not contain pieces of more than 1000mm, prepared suitable for charging. The scrap should be free from severe humidity, loose cast-iron pieces and waste incineration scrap (in particular tin-plated beverage cans). Free from visible Cu, Sn, Pb and alloys and debris.</td>
</tr>
<tr>
<td>Steel chips</td>
<td>E5H</td>
<td>Homogeneous batches of carbon steel chips, free from excessive amounts of woolly chips, prepared suitable for charging. Chips of free-cutting steel must be clearly identified. They must be free from impurities such as nonferrous metals, scale, grinding dust and the like.</td>
</tr>
<tr>
<td></td>
<td>E5M</td>
<td>Mixed batches of carbon steel chips, free from excessive amounts of woolly chips, loose material and free-cutting steel chips, prepared suitable for charging. They must be free from impurities such as nonferrous metals, scale, grinding dust and the like.</td>
</tr>
<tr>
<td>Lightweight alloyed scrap</td>
<td>EHRB</td>
<td>Old and new steel scrap which consists predominantly of concrete reinforcing bars and lightweight steel, prepared suitable for charging. Must be free from visible Cu, Sn, Pb, alloys and debris.</td>
</tr>
<tr>
<td>Scrap with high share of residues</td>
<td>EHRM</td>
<td>Old and new machine parts and components which are not accepted in the other grades, prepared suitable for charging. May contain cast-iron pieces (housing components). Must be free from visible Cu, Sn, Pb, alloys and parts from ball-bearing housings, bronze race rings and other grades and debris.</td>
</tr>
<tr>
<td>Waste incineration scrap</td>
<td>E46</td>
<td>Shredded scrap from waste incineration plants. Loose steel scrap from domestic waste which has been processed by a magnetic separation plant, prepared suitable for charging. Must be free from visible Cu, Sn, Pb, alloys and debris.</td>
</tr>
</tbody>
</table>
Hot metal – analysis:

<table>
<thead>
<tr>
<th>Element</th>
<th>Range</th>
<th>Element</th>
<th>Range</th>
<th>Temperature: 1340 – 1380 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>4.2 – 4.5%</td>
<td>Si</td>
<td>0.2 – 0.8%</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>0.05 – 0.13%</td>
<td>S</td>
<td>0.01 – 0.07%</td>
<td></td>
</tr>
</tbody>
</table>
Fluxes and Additives

Slag formers:
- Lime
- Dolomite lime
- MgO carriers

Coolants:
- Ore, pellets
- Dust briquettes
- Cooling scrap

Heating agents:
- FeSi
- Coke

Alloying agents:
- Copper
- Nickel
- Molybdenum

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Reactions inside the converter are exothermal. Control of heat balance $\Longrightarrow$ Scrap charging.
Diagram - Melting Losses

Refining Curves

[Diagram showing refining curves for [Mn], [S], [P], and [C] content in relation to the percentage of the blowing period.]

Binary System Diagram CaO / FeO

[Diagram showing the binary system of CaO and FeO with phase transitions and temperatures.]
Diagram - Melting Losses

Refining Curves

- Start range
- Main decarburization phase
- Final blowing phase

Crude Steel / Slag Analysis

Crude - steel analysis

<table>
<thead>
<tr>
<th>Element</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0,02 – 0,03 %</td>
</tr>
<tr>
<td>Si</td>
<td>0</td>
</tr>
<tr>
<td>Mn</td>
<td>0,1 – 0,2 %</td>
</tr>
<tr>
<td>P</td>
<td>0,01 – 0,02 %</td>
</tr>
<tr>
<td>S</td>
<td>0,01 – 0,05 %</td>
</tr>
<tr>
<td>(HM-desulphurization)</td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td>600 – 1000 ppm</td>
</tr>
<tr>
<td>Temperature</td>
<td>1600 – 1780 °C</td>
</tr>
</tbody>
</table>

Slag analysis

<table>
<thead>
<tr>
<th>Component</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>FeO</td>
<td>18 – 25 %</td>
</tr>
<tr>
<td>CaO</td>
<td>48 – 52 %</td>
</tr>
<tr>
<td>SiO₂</td>
<td>15 – 17 %</td>
</tr>
<tr>
<td>MnO</td>
<td>3 – 4 %</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>1 – 2 %</td>
</tr>
<tr>
<td>MgO</td>
<td>2 – 4 %</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>1,3 – 1,5 %</td>
</tr>
<tr>
<td>(S)</td>
<td>0,1 – 0,2 %</td>
</tr>
</tbody>
</table>

Basicity (CaO + MgO / SiO₂): 3 – 4
Slag volumes: 70 – 120 kg/t
**BOF Process Models**

- **Static model**
- **Dynamic model**

---

**Model - Charged Material**

- **Order calculation (scheduled data)**
  - Slag model
    - (Fe) content
    - Basicity
  - Heat balance model
    - Hot metal
    - Scrap
    - Lime

- **Correcting calculation (real data)**
  - Heat balance model
    - Blowing oxygen
    - Lime
    - Coolant
Volume of Oxygen to adjust the P-content and the steel temperature after sublance measurement

Temperature Increase vs. $O_2$ Volume Blown

Increasing steel temperature as a function of blowing oxygen after sublance measurement
End blow – Fe-content as a function of Sublance Measurement

Steel temperature: 1,680-1,720°C
Lime: 9,150 kg

End-blow temperature

Influence - Tapping Temperature on P-Content

Final phosphorous content in $10^{-3}$ [%]

P-content of melt in $10^{-3}$ [%]
Influence - Metallurgy on Refractory Lining

1st Blowing phase
Si, P, Mn
CaO <- (FeO)
(C2S/C3S)
(C3P/C4P)

Temp. low

2nd Blowing phase
(FeO) + C -> Fe + CO

Temp. increasing

3rd Blowing phase
P, Temp.

CaO + FeO => (P₂O₅)

Proper de-phosphorization requires low temperatures
However, a high temperature is needed at the end of blowing

Fe + 1/2 O₂ -> FeO

Temp. high

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**Refractory Technology: Part II**

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- **Chamber of horrors**

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**Trends in BOF technology**

<table>
<thead>
<tr>
<th>Trends</th>
<th>Consequences</th>
<th>Influence on refractories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase of &quot;direct tapping&quot;</td>
<td>↓ T, ↓ FeO</td>
<td>+</td>
</tr>
<tr>
<td>Ladle furnace</td>
<td>↓ T, ↓ FeO</td>
<td>+</td>
</tr>
<tr>
<td>Bottom purging</td>
<td>↑ homogeneousness, ↑ bath agitation</td>
<td>+/-</td>
</tr>
<tr>
<td>Increase of special steel (LC, ULC, Low-P)</td>
<td>↑ ppm O₂, ↑ T, ↑ FeO, ↑ rebloows</td>
<td>-</td>
</tr>
<tr>
<td>Increase of domestic scrap</td>
<td>↓ slag viscosity, aggressive slag</td>
<td>-</td>
</tr>
<tr>
<td>Slagcoating, slagsplashing</td>
<td>↑ protection</td>
<td>+</td>
</tr>
<tr>
<td>Enhancement of productivity</td>
<td>↑ T, ↓ maintenance, alternating temperature</td>
<td>+/-</td>
</tr>
</tbody>
</table>
A - Hot metal impact
B - Scrap impact
C - Slag zone upright vessel
D - Slag zone de-slagging position
E - Slag zone tapping position
F - Bottom joint
Laser Scan – Measuring the Residual Thickness

Laser Scan – BOF Lining

Pre-wear in slag zone and tapping breast
Laser Scan – BOF Bottom

2184 heats
Laser Scan – BOF Bottom

Pre-wear areas - BOF

scrap impact
scrap impact

trunnion

slag lines

scrap impact

trunnion
BOF – Slag Lines

Pre-wear areas - BOF

- Scrap impact
- Trunnion
- Slag lines
- Bottom, bottom joint and bottom cone
Radial installation, without bottom joint

Installation without bottom joint non-removable bottom

Installation with bottom joint, removable bottom

Radial installation, without bottom joint

System end arch brick, incl. bottom joint
Radial bottom with horizontal side wall bricks:
- Keys
- End arches

Radial bottom, defined bottom joint (here labyrinth joint and filler bricks)

Radial (fully inclined) concept

### BOF – Installation Mixes

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backfill mixes (dry)</td>
<td>• storage life</td>
</tr>
<tr>
<td>Ramming mix (light moist)</td>
<td>• free flowing (dry mixes)</td>
</tr>
<tr>
<td></td>
<td>• good compressibility for dry mixes</td>
</tr>
<tr>
<td></td>
<td>• stability of shape</td>
</tr>
<tr>
<td></td>
<td>• quick and reliable drying for ramming mixes</td>
</tr>
<tr>
<td></td>
<td>• backfill mixes only sinter (no bonding)</td>
</tr>
<tr>
<td></td>
<td>• ramming mixes (sulphate, phosphate, borate,</td>
</tr>
<tr>
<td></td>
<td>chromate) + combination</td>
</tr>
<tr>
<td></td>
<td>• sinter type</td>
</tr>
<tr>
<td>Bottom joint mix</td>
<td>• storage life</td>
</tr>
<tr>
<td></td>
<td>• good compressibility</td>
</tr>
<tr>
<td></td>
<td>• high stability after coking</td>
</tr>
<tr>
<td></td>
<td>• high refractoriness</td>
</tr>
<tr>
<td></td>
<td>• C-content</td>
</tr>
<tr>
<td></td>
<td>• sinter type</td>
</tr>
</tbody>
</table>
Pre-wear areas - BOF

- Mouth, upper cone
- Slag lines
- Scrap impact
- Trunnion
- Bottom, bottom joint and bottom cone

Lining thickness - brick

- Length:
  - Effective thickness: 690 mm
  - Nominal brick length:
    - Standard: 600 mm
    - Inclined: 550 mm
  - Plus decreased steps: 60 mm to 35 mm

Internal force progression:

- Standard: shear stresses into the neighbouring brickwork (vertical expansion inserts)
- Inclined: following the vessel contour
  - Less expansion inserts!
Development of Lining Concepts - I

Konventionelles Konzept
late 1980’s

„FE“-Konzept
mid 1990’s

„FE“-Konzept
1997

S: Sintermagnesia
LC: Large Crystal
SM: Schmelzmagnesia
D: Dichtgeprüft
T: Tiefgetränkt
C: C-Gehalt

Example of a modern BOF lining concept

Development of Lining Concepts - II
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• Wear mechanisms and actions
• Chamber of horrors
Permeability
- specific flow rate 0.01 - 0.25 Nm³/t, min
- flow rate per element up to >100 Nm³/h
- maximum gas pressure 8-18 bar

Fully functional
- with low flow rates
- $p_{gas} > p_{ferrostatic}$
- ability to start after gas flow interruptions

Wear rate of the elements
- should correspond to the wear rate of the bottom
- constant flow rate independent of the length of the element

Safety
- against breakouts - in case of abrupt unforeseen loss of gas flow and pressure
Types of Purging Elements - I

Purging element:

MHP- (Multi Hole Plug) purg plug

Single hole purge plug (tuyere)

trends:
- BOF bottom stirring is standard in Europe and Japan
- North America, trend of using bottom purging is increasing

goal:
- Requirement to purge until end of vessel campaign

Types of Purging Elements - II

- hydraulically pressed
- Isostatic pressed
- Fused MgO – high grade
- pitch-bonded
- 14 – 18 % C
- resin-bonded
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Pre-wear areas - BOF

Requirements - BOF Taphole

<table>
<thead>
<tr>
<th>Requirements</th>
<th>target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbulence free tapping</td>
<td>- Lowest possible reaction with the atmosphere (air)</td>
</tr>
<tr>
<td>Compact tapping stream</td>
<td>- Minimized Reoxidation and N2 pick-up</td>
</tr>
<tr>
<td>Optimised preconditions for slag detection as well as prevention</td>
<td>- Reduced amount of carry over slag into the ladle during tapping</td>
</tr>
<tr>
<td></td>
<td>- Lowest possible carry over slag at the end of tapping</td>
</tr>
<tr>
<td></td>
<td>- Reduced demand of alloys, saving of alloys due to reduced re-oxidation</td>
</tr>
<tr>
<td>Constant tapping times</td>
<td>- Even tapping conditions</td>
</tr>
<tr>
<td>High taphole lives</td>
<td>- Increased availability of the vessel</td>
</tr>
<tr>
<td>Easy and quick repair</td>
<td>- High availability, Minimised manual work; safety issue</td>
</tr>
<tr>
<td>Prevention of steel infiltrations</td>
<td></td>
</tr>
<tr>
<td>Minimised risk of breakouts in the taphole area</td>
<td>High system security</td>
</tr>
</tbody>
</table>
Pipe in pipe system

Isojet C system

Taphole block

Taphole repair sets

Contours of Total Pressure (mixture) (pascal) (Time=2.5000e+00)
Sep 30, 2004
FLUENT 6.1 (3d, segregated, vof, rnik, unsteady)
Standard channel layout

Optimised channel layout

Contour of Turbulent Kinetic Energy (m²/s²)

BOF Taphole - design
Slag detection – optical
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Removing the worn taphole sleeves by means of counter percussion hammering system

Calibrating the taphole channel

### BOF – Repair Mixes

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gunning mixes</td>
<td>bonding system</td>
</tr>
<tr>
<td></td>
<td>Phosphate</td>
</tr>
<tr>
<td></td>
<td>Silikat - glas</td>
</tr>
<tr>
<td></td>
<td>sinter</td>
</tr>
<tr>
<td>Hot repair mixes (C-containing)</td>
<td>sinter</td>
</tr>
<tr>
<td>storage life</td>
<td></td>
</tr>
<tr>
<td>quick flowing</td>
<td></td>
</tr>
<tr>
<td>no formation of lumps</td>
<td></td>
</tr>
<tr>
<td>quick coking time</td>
<td></td>
</tr>
<tr>
<td>stability</td>
<td></td>
</tr>
</tbody>
</table>
Wet fines deformation and build up

Coarse grain slowing down and embedding

Impact velocity:
\[ v = 20 - 25 \text{ m/s} \]

gunning bed

gunning layer

Shooter – mobile gunning unit

Pressure vessel machine to feed the spraying unit (ANKERJET)
Conrep – gunning Robot

Conrep – gunning result
Flow rate effects on gunned refractory layer

High BD rate means more material in equal gunning mix thickness resulting in longer chemical resistance.
Low OP rate means less slag infiltration and therewith higher lifetime and improved anti-wash-out effect (mechanical erosion).

Legend:
BD: bulk density
OP: open porosity
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### BOF Operating Conditions in Various Regions

<table>
<thead>
<tr>
<th></th>
<th>Europe</th>
<th>North America</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity</td>
<td>high, 25-35 heats/day</td>
<td>low, 15-20 heats/day</td>
<td>high 21-40 heats/day</td>
</tr>
<tr>
<td>Slag splashing</td>
<td>increasing</td>
<td>Standard (Slag splashing)</td>
<td>little</td>
</tr>
<tr>
<td>Tapping temp.</td>
<td>1660 - 1780°C</td>
<td>1650-1680°C</td>
<td>1650-1670°C</td>
</tr>
<tr>
<td>Slag formation MgO (%)</td>
<td>w/o dolo-lime: 2-5</td>
<td>Dolo-lime: 8-14</td>
<td>&quot;low slag operation&quot; 10-15</td>
</tr>
<tr>
<td>Hot metal, Si (%)</td>
<td>&lt; 0.7</td>
<td>&lt; 0.8</td>
<td>&lt; 0.3</td>
</tr>
<tr>
<td>HM de-phosph.</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Scrap charge (%)</td>
<td>≤ 20</td>
<td>≤ 30</td>
<td>-5</td>
</tr>
<tr>
<td>Bottom stirring (%)</td>
<td>100</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>Avg. lives (heats)</td>
<td>2000-3500, max. 8500</td>
<td>6000-10000, max. 50000</td>
<td>3000-6000, max. 8000</td>
</tr>
</tbody>
</table>

### Trend - Refractory Consumption in Europe

![Graph showing trend in refractory consumption in Europe from 1976 to 2013](image-url)
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Erosion

**Operational demand (= pre wear mechanism)**

Erosion resistance

**Required brick properties (= measures)**

- **C- content**
- **Bonding system**
- **Antioxidants**
- **MgO**
Operational demand (= pre wear mechanism)

1. Erosion

2. Erosion resistance

3. Slag attack

4. Corrosion resistance

+ Temperature, FeO

Required brick properties (= measures)
**RHI** Requirements - MgO – C bricks

**SMS group**

**Required brick properties (= measures)**

| C - content | 2. ↓ |
| Bonding system | |
| Antioxidants | 4. ↑ |
| MgO | ↓ |

**Infiltration Prevention**

**RHI**

**SMS group**

**Reduction of Iron-oxids of the infiltrated media**

\[(\text{CaO-FeO}_2\text{SiO}_2)_{\text{liq.}} + \text{CO} \xrightarrow{\text{eutectic. 1300°C}} \text{[CaO-SiO}_2\text{]}_{\text{solid}} + \text{Fe}_\text{met} + \text{CO}_2 \xrightarrow{\text{eutectic >1650°C}}\]

“Non-wettability” of the infiltrated media

(with CaO/SiO2<2)

**MgO**

**Carbon**
Wear Mechanism of MgO – C Bricks

slag coating

De-carburization

Partly De-carburized (Binder)

Requirements - MgO – C bricks

Operational demand (= pre wear mechanism)

Erosion

Oxidation

Slag attack

+ Temperature, FeO

Erosion resistance

Oxidation as well as Redox resistance

Corrosion resistance

Required brick properties (= measures)
Required brick properties (= measures)

<table>
<thead>
<tr>
<th>C - content</th>
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2.  ↓
3.  ↓
4.  ↑

- Erosion resistance
- Oxidation as well as Redox resistance
- Corrosion resistance

- Requirements - MgO – C bricks
Operational demand (= pre wear mechanism)

1. Erosion
2. Erosion resistance
   - continuous wear (erosive brick wear)
3. Oxidation
   - Oxidation as well as Redox resistance
4. Slag attack
   + Temperature
   - Corrosion resistance

Required brick properties (= measures)
Required brick properties (= measures)

2. Erosion resistance
3. Oxidation as well as Redox resistance
4. Corrosion resistance

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</table>
**Required brick properties (= measures)**

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<th>1.</th>
<th>2.</th>
<th>3.</th>
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<td>↓</td>
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<td>Pitch</td>
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<tr>
<td><strong>Antioxidants</strong></td>
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<td><strong>MgO</strong></td>
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<td>Periclaz xx</td>
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**Pitch vs. Resin bonding**

<table>
<thead>
<tr>
<th></th>
<th>Pitch bonding</th>
<th>Resin bonding</th>
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</thead>
<tbody>
<tr>
<td><strong>C-content</strong></td>
<td>high</td>
<td>lower</td>
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<tr>
<td><strong>Graphitising</strong></td>
<td>high</td>
<td>lower</td>
</tr>
<tr>
<td><strong>Strength (original)</strong></td>
<td>lower</td>
<td>high</td>
</tr>
<tr>
<td><strong>Strength (after coking)</strong></td>
<td>high</td>
<td>lower (without Antiox.)</td>
</tr>
<tr>
<td><strong>Porosity (after coking)</strong></td>
<td>lower</td>
<td>higher (without Antiox.)</td>
</tr>
<tr>
<td><strong>Flexibility</strong></td>
<td>high</td>
<td>lower</td>
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</tbody>
</table>
- Introduction
- Process description: Combined blowing
- Charge materials
- Process sequence
  1. Places of reaction
  2. Reactions
  3. Process control / process models
- Trends in BOF technology
- Detection of wear areas
- Wear areas inside the converter
- Stirring in the converter
- Tapping
- Maintenance and care
- Development results concerning refractory technology
- Wear mechanism and actions
- Chamber of horrors
CHAMBER OF HORROR

wear cases

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have a guess!!