General Overview of Wear Mechanisms, Methods for Examination of the Refractory Material after Use

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What is wear of refractories?

- Loss of refractory material during the process of production
- Depends on the process parameters, such as
  - temperatures,
  - slag management,
  - thermal shock,
  - viscosity of the liquid phase...
- Wear cannot be fully avoided, but must be observed during the process
- Extreme wear may lead to break-out of liquid iron or steel or damages in general – worst case
Wear of refractory material

Your experiences with refractory wear during the process

- examples

Your experiences with failure of refractory material, damages

- examples

Mechanisms of wear
Possible reasons for damages (1)

Refractory material
- Changes in composition, different raw materials/different suppliers
- Changes or problems during process of production
- Changes in logistics
- Problems during packing/paletting, wrong label

Problems with refractory storage at the producer/consumer
- Frost
- Humidity/exposure to rain
- Best before....

Definition of use
- Different temperature of use
- Changes in process parameters

Possible reasons for damages (2)

Problems during lining
- Joints
- Wrong water content in masses
- Wrong bricks

Problems during heating/drying
- Heating curve was interrupted (technical problems)
- Heating at higher temperatures/faster gradient than usual

Production process with
- Alterations in temperatures
- Dwell time and cooling of refractory material
- Acyclic use
- ....
How to start investigating…..from the point of view of the customer (1)

Document the damage with pictures and drawings

How to start investigating…..from the point of view of the customer (2)

Is the right material in the correct position?

Datasheet of the producer compared to the results of the internal refractory lab

- Sample number
- Sample name
- Cold crushing strength
- Porosity
- Density
- Chemistry
How to start investigating…..from the point of view of the customer (3)

Was the correct brick/mass installed during lining?

- Check material lists
- Check lab result
- Check with people from the workshop
- Especially for masses: check period of storage and place of storage if there are remaining masses on stock

How to start investigating…..from the point of view of the customer (4)

Are there remaining bricks from the same production on pallets?

Fractures and inhomogeneities

Best: detect during sampling before lining
How to start investigating.....from the point of view of the customer (5)

Was the mass mixed correctly? Is the quality of the mass constant?

Water content
Setting time
Compare with remaining material
Has the composition of the mass changed?

How to start investigating.....from the point of view of the customer (6)

Was the ramming mass compacted enough?
How to start investigating.....from the point of view of the customer (7)

Have the joints been set correctly – 10 mm of joints is too much

Joints wash out

Example 1: tundish lining

Problem:
In a number of tundishes a certain effect showed: the safety lining – consisting of andalusite castable – curved to the inside of the tundish and therefore the stability between safety and wear lining decreased, spalling and increased repair work was the consequence.
- curving of the lining always occurred together with a certain insulation concept

Sampling position within tundish
Example 1: tundish lining

Investigation of the lining concept:

- **Tundish 1**: two layers, with insulation material in the form of fiber mats and the andalusite castable as safety lining

- **Tundish 2**: three layers, with fiber mats, insulating boards and the same andalusite castable as safety lining

Samples for chemical analyses were taken from the inner (hot face) part, the middle and the outer (cold face) part of the safety lining.

Sampled material was ground for:
- chemical analyses
- X-ray diffraction analyses

The chemical analyses were used for quick reference and for the limitation of possible mineral phases in the search process after X-ray diffraction analyses.
Example 1: tundish lining

Detail of cross section, tundish 2, hot side, alterations of mineral phases in andalusite castable due to sodium content of the wear lining, bluish-grey grains are altered andalusite grains

Example 1: tundish lining – XRD analysis

Beside the expected mineral phases andalusite, mullite and aluminum oxide several newly formed minerals, such as nepheline, andesine and sanidine could be observed by using X-ray diffraction.

<table>
<thead>
<tr>
<th>Mineral phases</th>
<th>Tundish 1 hot-middle-cold</th>
<th>Tundish 2 hot-middle-cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>andalusite, Al₂SiO₅</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>mullite, 3Al₂O₃.2SiO₂</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>alumina oxide, Al₂O₃</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>nepheline, NaAlSiO₄</td>
<td>x</td>
<td>0</td>
</tr>
<tr>
<td>andesine, (Na,Ca)(Si,Al)₄O₈</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>sanidine, KAlSi₃O₈</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Detail of hot face
Example 1: tundish lining – XRD results

Development of nepheline-minerals based on temperature gradient:
- Blue: cold face
- Green: middle
- Pink: hot face
Example 1: tundish lining – XRD results

The cold face in tundish 2 shows more mullite than the cold face of tundish 1. As the crystallization of nepheline is dependent on the amount of mullite available, the nepheline content is also higher in tundish 2 than in tundish 1.

The formation of nepheline follows the following formula:

$$3\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2 \ (\text{Mullite}) + \text{Na}_2\text{O} \rightarrow \text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \ (\text{Nepheline}) + 2\text{Al}_2\text{O}_3 \ (\text{Corundum})$$

Example 1: tundish lining – Origin of sodium

In addition to the safety lining gunning material is used as wear lining.

- the gunning material includes 1-3% sodium-silicates as binders
- sodium is therefore constantly available for mineral formation.
- the intense insulation by boards increases the temperature within the tundish wall, so that the andalusite castable can react and andalusite is transformed to mullite.
- the following nepheline formation including a volume increase of about 18% according to literature results in the destruction of the stability of the castable and thus also the curving and spalling to the inside of the tundish.
Example 1: tundish lining – Conclusion

The phenomena of volume increase due to recrystallization within the andalusite castable can be explained by
- mullite formation at a temperature higher than 1200°C and
- recrystallization of mullite to nepheline caused by the sodium-content from the wear lining.

As a consequence:
- the insulation was reduced,
- the temperature for mullite formation is reduced

The extreme curving and spalling of the lining, the classical alkali bursting, could thus be eliminated.

Example 2: RH-degasser/lower vessel

Problem: Sidewall with holes
Example 2: RH-degasser/lower vessel

Definition of sample positions:

Sections 1 and 2 could be prepared easily, sections 3 and 4 were difficult to polish as they were extremely dense.
Example 2: RH-degasser/lower vessel – section 1

Section 1:
surface infiltration, orientation of the hole

Example 2: RH-degasser/lower vessel

Section 1, overview of rim in light microscopy
Example 2: RH-degasser/lower vessel

Section 1, border between original and altered area (rim)

Example 2: RH-degasser/lower vessel – section 1

Dendrites within the brown infiltrated rim – BSE analysis of „hot side“
Example 2: RH-degasser/lower vessel – section 1

BSE-mapping of detailed area of section 1

Filler between grains
Example 2: RH-degasser/lower vessel

Dendrites

Example 2: RH-degasser/lower vessel

„Misuse“ of Laser ablation

interior of section  →  surface
Thank you

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