Team Work - Failure Case Studies

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Seminar:

Refractory Technology –
Applications, Wear Mechanism, Failures
Team Work – Failure Case Studies

Discussion of results & solutions

Andreas Buhr, Frankfurt am Main

Check list which data to collect for the investigation of failure cases

<table>
<thead>
<tr>
<th>Process conditions of vessel where failure occurred:</th>
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<tbody>
<tr>
<td>- which steel grades produced</td>
</tr>
<tr>
<td>- temperatures, treatment times, stirring intensity, alloying</td>
</tr>
<tr>
<td>elements, slag conditioners</td>
</tr>
<tr>
<td>- process logistics (waiting times in process, unplanned</td>
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<tr>
<td>events, changes in process)</td>
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<table>
<thead>
<tr>
<th>Refractory lining of the vessel concerned:</th>
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<tbody>
<tr>
<td>- Material used, zone lining (balanced lining), brick format</td>
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<tr>
<td>(monolithic lining technique (vibration, self flow,</td>
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<tr>
<td>ramming, gunning,...)</td>
</tr>
<tr>
<td>- Information on wear and permanent/safety lining, and</td>
</tr>
<tr>
<td>mortars etc. used</td>
</tr>
<tr>
<td>- Storage of material, shelf life of refractories</td>
</tr>
<tr>
<td>- Quality control data like batch number, manufacturing</td>
</tr>
<tr>
<td>data, pallet number etc for traceability in</td>
</tr>
<tr>
<td>suppliers process</td>
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| Lining life compared to usual level, any special events     |

| Photos and detailed description of the failure occurred     |

| Samples of used and new material (refractory lining, process |
|   slag)                                                     |
| Proper samples are the basis for any valuable investigation!|
| Ideally, have samples form slag infiltrated hot side to     |
|   unchanged back side of the lining.                        |
Failure cases

| 2. Torpedo car permanent lining – brick failure | 15. Reheating furnace – spalling of roof bricks |
| 3. BOF-LD converter failure         | 16. Preheating furnace – premature damage of wall lining |
| 4. Steel ladle – premature wear in selected areas     | 17. Rotary slide valve plates – extreme wear |
| 5. Steel ladle – joint erosion and deformed bricks | 18. Steel ladle sliding gate plates - breakouts |
| 7. Steel ladle – break out at well block         | 20. Steel ladle – hot spot in slag line |
| 9. Steel ladle – decreasing ladle capacity | 22. Longitudinal cracks in bricked ladles and cracks and spalling in monolithic ladles |
| 10. Steel ladle – extreme wear in ladle bottom | 23. Broken ancors in reheating furnace |
| 11. Steel ladle – hole in monolithic ladle bottom | 24. Extreme wear of torpedo car wear lining |
| 12. Tundish – nearby break out in slag line | 25. Extreme wear of converter bottom 1600 heats |
| 13. Submerged Entry Nozzle – premature damage due to longitudinal crack | 26. Steel ladle reduced lining life of permanent lining |

Case Study 1:
Blast furnace shaft – brick failure

Case of damage:
30 months after new lining of blast furnace the bricks in the middle of the shaft showed severe wear & low remaining thickness.

Information:
High quality fired corundum bricks, properties tested acc. to data sheet information.
Case Study 2:
Torpedo car permanent lining – brick failure

Case of damage:
During replacement of the wear lining the brittle permanent lining bricks were realised. The fired chamotte bricks could be crumbled by low mechanical stress. Replacement required already after 2 instead of after 5-6 years.

Information:
Initially light bricks showed grey discolouration and pinhead sized black depositions in the bricks.

Case Study 3:
BOF-LD converter failure

Case of damage:
BOF converter did not achieve planned lining life of 1400 heats but was taken out of service after 1200 heats. And intensive maintenance was required to achieve that 1200 heats: increase of lime factor, slag coating, gunning.

Information:
Pitch bonded Magnesia Carbon bricks, about 98 % MgO + 8 resp. 6 % C. (data sheet info)

<table>
<thead>
<tr>
<th></th>
<th>Hot metal impact area</th>
<th>Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk density g/cm³</td>
<td>3,11 - 3,21 (3,07-3,17)</td>
<td>3,10 - 3,15 (3,12-3,22)</td>
</tr>
<tr>
<td>App. Por. %</td>
<td>3,4 - 4,7 (ca. 2)</td>
<td>1,0 - 5,0 (ca. 2)</td>
</tr>
<tr>
<td>CCS MPa</td>
<td>46 - 54 (ca. 40)</td>
<td>31 - 64 (ca. 40)</td>
</tr>
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Case Study 4:
Steel ladle – premature wear in selected areas

Case of damage:
Specific areas of the bricked ladle side wall showed premature wear after 24 heats, ladle taken out of service (usual lining life 44 heats). Residual thickness only 40-65 mm compared to 150-180 mm in other areas.

Information:
Ladle side wall lining with pitch bonded doloma bricks.
**Case Study 5:**
Steel ladle – joint erosion and deformed bricks

**Case of damage:**
Wall/slag line area of bricked ladle showed strong wear in joints and crack formation. Cracks filled with process slag. Ladle out of service premature, remaining brick thickness 60-100 mm. Back side of the wear lining bricks showed deformation.

**Information:**
Ladle lined with pitch bonded doloma bricks, back filling was done with a wet olivine based mix.
Case Study 6:
Steel ladle – extreme wear after first heat

Case of damage:
After the first heat an extreme high wear of the ladle side wall was recognized. Ladle was kept in use but with special attention. Further lining life without special observations. Overall lining life about 25% lower due to high wear during first heat.

Information:
Pitch bonded MagCarbon bricks in slag line, pitch bonded doloma bricks in side wall, high alumina castable in the bottom.

Case Study 7:
Steel ladle – break out at well block

Case of damage:
During the 7th heat a break out in the well block area occurred.

Information:
Bottom of doloma bricks, well block high alumina cement bonded pre-cast shape, doloma ramming mix around well block.
Composition and bulk density of well block checked ok.
Ramming mix is steel infiltrated like a sponge.
Sample of new ramming mix (same shipment as used for installation) ok regarding composition and particle size distribution.
Case Study 7:
Steel ladle – break out at well block

Ramming mix infiltrated with steel like a sponge.

Case Study 8:
Steel ladle – steel infiltration beneath bottom

Case of damage:
Purging plug could not be removed after 15 heats for exchange. Ladle taken out of use. During break out of the lining a big steel infiltration beneath the bottom was recognized, which “welded“ the purging plug at its steel sheet jacket.

Information:
Bottom high alumina castable, pre-set purging plugs in well blocks used.
Ladle was taken out of service after the first heat for 10 hours.
**Case Study 8:**
Steel ladle – steel infiltration beneath bottom

**Case Study 9:**
Steel ladle – decreasing ladle capacity

**Case of damage:**
Steel ladles showed a decreasing capacity with increasing lining life. Lower tapping weight reduced the productivity of the steel plant.

**Information:**
During break out of the wear lining accretions of several cm´s thickness were observed at the surface of the side wall, composition of the accretions:

- $\text{Al}_2\text{O}_3$ 30 - 60 %
- $\text{CaO}$ 3 - 20 %
- $\text{SiO}_2$ 2 - 8 %
- $\text{Fe}_{\text{met}}$ 4 - 50 %
- $\text{CaO}:\text{Al}_2\text{O}_3$ 0,1 - 0,3

Ladle lining by fired Andalusite bricks.
Case Study 10:
Steel ladle – extreme wear in ladle bottom

Case of damage:
Ladle must be taken out of service before the second heat because of extreme crater formation at the positions of the purging plugs.

Information:
Bottom resin bonded doloma bricks, purging plugs and well blocks high alumina.
Bricks and well blocks show high slag infiltration, slag containing Fe₂O₃ up to 30 resp. 55 %.

Case Study 10:
Steel ladle – extreme wear in ladle bottom

Craters formed at purging plug positions
Case Study 11:
Steel ladle – hole in monolithic ladle bottom

Case of damage:
During the ladle maintenance after 15 heats (purging plug exchange) a hole of the size of a human arm was detected in the bottom. The bottom required a new lining.

Information:
Bottom wear lining by high alumina vibration castable. Standard lining life was 50 heats.
Case Study 12:
Tundish – nearby break out in slag line

Case of damage:
Already during the third campaign of a new installed tundish permanent lining a severe wear in the slag line was recognized and the campaign had to be stopped immediately. After removing the wear lining it became obvious that only parts of the slag line showed a severe wear (up to 90% of lining thickness), whereas other areas were untouched.

Information:
Tundish permanent lining of Andalusite low cement castable, wear lining slurry spray mix based on Magnesia/Olivine.
During the tundish campaign concerned the electromagnetic slag detection system on one of the steel ladles did not work, and a slag carry over from the ladle to the tundish could have happened.
Case Study 13:
Submerged entry nozzle (SEN) – premature
damage due to longitudinal crack

Case of damage:
After 30 minutes of casting a longitudinal crack was observed in the SEN, which extended from the SEN slag line into the main body. The continuous casting campaign was stopped immediately.

Information:
SEN with alumina/graphite main body and ZrO$_2$/graphite slag line. Zirconia material in slag line was partly stabilised ZrO$_2$. Chemical-mineralogical composition and physical properties (bulk density, open porosity) of SEN checked and ok when compared to data sheet. SEN pre-heater positions were checked but found ok.

Case Study 13:
Submerged entry nozzle (SEN) – premature
damage due to longitudinal crack

SEN preheaters – correct positioning is important to avoid thermal stresses
### Case Study 14:
Submerged entry nozzle (SEN) – premature damage due to foot fallen off

**Case of damage:**
During the third heat of a casting campaign suddenly the foot of the SEN fell off, which resulted in a slab break out in the casting machine due to the missing direction of the steel flow in the mould.

**Information:**
The SEN concerned had a remaining wall thickness of only 1-3 mm (new: 30mm), and showed an extreme wear at the inside of the SEN. The outer diameter still showed the usual range of wear. Investigations of the SEN proved material to be ok.

### Case Study 15:
Reheating furnace – Spalling of roof bricks

**Case of damage:**
Already during the first routinely maintenance checks of the reheating furnace massive damage by spalling of the bricks in the roof was observed. This required ongoing and intensive repairs by gunning and replacement of parts of the lining.

**Information:**
The variety of steel grades produced in the rolling mill required numerous changes of the kiln temperature during use. Therefore the furnace roof lining was made with lightweight bricks (low heat capacity) to accelerate the adjustment of kiln temperature. Lightweight bricks of class 30 (classification temperature 1650 °C) on basis of Corundum/Mullite and bulk density 1,1 g/cm³.
Case Study 15:
Reheating furnace – Spalling of roof bricks
Case Study 15:
Reheating furnace – Spalling of roof bricks

Bild 46: Feuerleichtzustellung der Decke eines Hübalkomfoens in den Heizzonen

Case Study 15:
Reheating furnace – Spalling of roof bricks

Bild 50: Feuerleichtzustellung und Reinigung
Case Study 16: Preheating furnace – premature damage of wall lining

Case of damage:
The preheating zone of a galvanizing furnace for steel sheet showed extreme damage already at the first maintenance check. The bricks are deformed at the hot side and big joints have opened. The older brick lining just besides the damaged wall did not show any damage.

Information:
Kiln temperature measured by user: 1250 °C.
Lightweight bricks of class 26 (classification temperature 1430 °C) were used. Investigation of used and new bricks from the lining did not show any quality issues.
Case Study 17:
Rotary slide valve plates – extreme wear

Case of damage:
Plates were washed out at the holes and thickness of the plates was reduced by up to 30% of the initial value. Plates needed to be replaced already after 1 instead of 3 heats to ensure a proper flow control.

Information:
$\text{Al}_2\text{O}_3$ – $\text{ZrO}_2$ Slide gate plates

New wear pattern occurred together with changes in the ladle process technology: new ladle lining, start of ladle furnace, Ca-treatment of steel, changes in ladle slag composition.

Microscopical investigations (reflected light and electron microscopy) of the wear area showed new phases formed during use: $\text{CaZrO}_3$ und metallic Zr around $\text{ZrO}_2$ grains.
Case Study 17:
Rotary slide valve plates – extreme wear

Case Study 18:
Steel ladle sliding gate plates - breakouts

Case of damage:
Occasionally (10x per year) breakouts at the sliding gates occur. Steel layer is formed between the plates. Both sliding gate systems at the steel work are concerned: CS 80 (breakout during 6. heat vs. 8 heats normal lining life) and LV 12-5 (breakout after 5. heat vs. 6 heats normal lining life).

Information:
$\text{Al}_2\text{O}_3$ sliding gate plates: 80% $\text{Al}_2\text{O}_3$, $\text{ZrO}_2$, minor $\text{SiO}_2$, fired + C impregnated
s. Photos from breakouts
Ca-treatment of steel can occur, also cleaning of the well block with oxygen lance burning during ladle maintenance in service or occasionally oxygen lance burning for opening the sliding gate at the continuous caster.
Case Study 18:
Steel ladle sliding gate plates – breakout, CS 80 system

Break out between upper and lower sliding plate at 6. heat (normal lining life 8 heats)

Upper plate (fixed)  Lower plate (sliding)

Case Study 18:
Steel ladle sliding gate plates – breakout
LV 12-15 system

Breakout at 5. heat
Normal lining life 6 heats

Lower plate (sliding)  Upper plate (fixed)
Case 18 additional from another plant:
steel ladle sliding gate plates break out

Very severe wear already after first heat; casting was stopped in between because flow couldn’t be controlled any more.

Normal wear pattern after 4 heats

Case Study 19:
Steel ladle bottom – spalling at surface of the bottom

Case of damage:
After the 5. heat of the ladle bottom campaign (normal lining life is 126 heats)

Information:
Monolithic steel ladle bottom by alumina-spinel self-flowing castable and AluMagCarbon bricks in impact area. Spalling of about 50% of bottom surface and impact area as flat layer of about 40 mm thickness, s. photo).
Case Study 19: Steel ladle bottom – spalling at surface of the bottom

Incident information:
A steel ladle has been taken out of service because a hot spot was noticed in the slagzone area of the steel ladle at the moment it arrived at the casting machine. A break-out has been avoided by opening the sliding gate plate as soon as possible to lower the level of steel in the ladle.

During wrecking several holes have been noticed (see also pictures)

Additional information:
- Normal life of the slag line is 80 heats, this ladle was taken out after 27 heats
- Thickness around the holes was around 140 mm (original 200 mm)
- Slagline consists of MgO-C bricks, with a top ring of fired spinel bricks and bauxite ramming material
- The ladle is cleaned after every heats with a cradle (see picture on the bottom right)

Impact pad by AluMagCarbon bricks

Case Study 20: Steel ladle – hot spot in slag line

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A steel ladle has been taken out of service because a hot spot was noticed in the slagzone area of the steel ladle at the moment it arrived at the casting machine. A break-out has been avoided by opening the sliding gate plate as soon as possible to lower the level of steel in the ladle.

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- The ladle is cleaned after every heats with a cradle (see picture on the bottom right)
**Case study 21:**
Break out between inner nozzle and well block

**Case of damage:**
During casting of the ladle a glow at the sliding gate appeared and casting was stopped immediately. After removal of the sliding gate a big steel infiltration was found.

**Information:**
The failure happened during the 3rd heat of the inner nozzle, which is normally used for 12 heats. According to the documentation, the screws of the sliding gates were fixed when the inner nozzle was exchanged.

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**Case study 22:**
Longitudinal cracks in bricked ladles and cracking and spalling in monolithic ladles

**Case of damage:**
Longitudinal cracks appear in bricked ladles and a network of cracking (about 500 mm distance) in monolithic ladles, followed by spalling of thin plates of approximately 20-30 mm thickness. In both cases the lining life is reduced.

**What could be the root cause(s) for such failure and how could it be avoided?**
Case study 22: Longitudinal cracks in bricked ladles and cracking and spalling in monolithic ladles

Information: The left picture shows longitudinal cracks only in the slag line, but they can appear in the whole side wall as well. The longitudinal cracks are not depending on joints but may run through bricks as well as shown by the example in the right picture.

Information: The left picture shows the orthogonal cracking (approx. 500 mm distance between the cracks), the right picture shows the spalling of a thin plate with approx. 20-30 mm thickness. In addition the model for the cracking.
Case Study 23: Broken anchors in reheating furnace

A walking beam furnace was inspected 9 months after a complete relining. During the inspection it was noticed that many of the installed wall panels were moving forward towards the inside of the furnace (picture below on the left). An urgent archeologically wrecking of one of the panels was done. All anchor bricks were broken on the interface between the hot face castable and insulation back lining (pictures right). The metallic part was still in good condition.

Additional information:
- The walls of the furnace were prepared outside the site and were transported in one piece (including the metallic shell) to the furnace and installed there (see picture on the right).
- The insulating castable was of good quality (and within specification of the supplier) and installed in a proper way. (CCS ~18 N/mm²)
- The dense castable was of good quality (within specification of the supplier) and installed in a proper way. (CCS ~70 N/mm²)
- Other anchors of the same batch and the part of the broken anchor were within specification of the supplier. (CCS ~95 N/mm²)
- The installation was done according to drawing (see on the left)
**Case study 24:**
**Extreme wear of the torpedo car wear lining**

To lower the energy loss of the torpedo car, 12.5 mm of insulating board was introduced. After around 800 heats high and strange wear is observed in (mainly) the upper part of the torpedo car. Other torpedo cars didn’t show this phenomenon. QC check: brick is OK

**Bricks from the upper part of the torpedo car**

**Old situation**

**New situation**

Mind experiment: take 3 bricks (from a series of hundred bricks) and heat this from one side
Mind experiment:
"no" problem as long as there is sufficient space between the bricks

Mind experiment:
The first stresses develop, this tension depends on how much expansion the system would like to do, and the material characteristics at that temperature

Brick just touch each other, no tension is generated
Case Study 25: Extreme wear in the bottom of the converter after 1600 heats.

Because of a reline of a blast furnace, one converter was put aside to cool down after 1400 heats. During this period a part of the top-skull had fallen down onto the bottom. At a certain moment during this period the converter was turned about 60 degrees.

After 18 days the converter was heated up according the normal procedure, with the skull still on the bottom.

The first week after heating up, the lining performed well. Then, in 1 heat, more than 400 mm in the centre of the bottom was lost (including a part of the safety lining).
Case 26: Ladle permanent lining life

Problem:
- Increased failure safety lining.
  During wrecking of the wear lining (large repair) the safety lining is falling out too often.
  Until 2013: 560 heats.
  From 2013: 140 - 280 heats.

What was tried:
- Tongue/groove design (50 mm thick) – not the improvement that was hoped for.
- Tighter vertical tolerances wear lining cylinder.

What we know:
- Current quality appears to have less growth (PLC) after 1500°C than previous quality, now 0.7% instead of 3%.
- Even with 3% growth the level before 2013 is not obtained. (280 – 420 is what we get)
- More steel penetration through the wear lining.

Taking into account:
- Maximum wrecking temperature is 300°C.
- Lower limit at the moment at 200°C (started from Feb’16)
Requirements

- Resistance to liquid steel (sidewall & bottom) → high refactoriness, high thickness
- Resistance to liquid slag (slagline) → high purity, use of carbon, high thickness
- Structural integrity → high strength, high thickness, high PLC
- Low heat losses → low thermal conductivity (high porosity)
- Low weight → low density, low thickness

This requirements can only be achieved with multi-layer design

It is not acceptable to have:

- Thicker layers
- Heavier bricks
- Higher thermal conductivity

Questions:

- How much growth is necessary to increase the lifetime of the safety lining?
- What is the effect of the wrecking temperature? Taking into account the cooling-period.

Other solutions ???