Compaction of crushed salt for safe containment – a summary of the KOMPASS projects

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Compaction of Crushed Salt for Safe Containment

A summary of the KOMPASS projects

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Outline

1. The Origin
2. Evolution of the KOMPASS projects
3. Experimental studies
4. Microstructural investigations
5. Numerical modelling
6. Conclusion & outlook
1. The Origin

- Investigations on crushed salt have been performed during the last decades
  - Focus on the mechanical evolution
  - Crushed salt as stabilization for the host rock

- Important paradigm shift in repository design with the Site Selection Act (2017)
  - Shift from limited release to safe containment
  - Crushed salt as geotechnical barrier
  - Focus on the evolution of hydraulic properties

Ref: Korthaus, Callahan, Hansen, Hunsche, Spiers, Stührenberg, WIPP Site, Asse mine, Gorlegebn mine…

DAEF state-of-the-art report (2017)

Need for future R&D work
2. Evolution of the KOMPASS projects

KOMPASS-I ➔ KOMPASS-II ➔ MEASURES

09/2018 – 08/2020  ➔  07/2021 – 06/2023  ➔  XX/2024

➢ Improve scientific database behind using crushed salt for long-term isolation of high-level nuclear waste
➢ Improve prediction of crushed salt compaction process
➢ Work with relevance for long-term safety of HLW repository in rock salt
Outline

1. The Origin
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3. Experimental studies – The KOMPASS reference material

Aim: Choice of an easy available & permanent reproducible crushed salt material for generic investigations (also beyond the projects)

➢ Staßfurt-sequence in a bedded Zechstein
➢ Optimized grain size distribution

![Graph showing grain size distribution and volume fraction vs. grain size](image)

**Tab. 4.1** Grain size fractions in the raw salt material and the optimized mixture

<table>
<thead>
<tr>
<th>Material-fraction</th>
<th>Grain size distribution $d_{38}$-$d_{95}$ [mm]</th>
<th>$d_{50}$ [mm]</th>
<th>$m$ [-]</th>
<th>Optimized mixture [wt.-%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Überkorn (ÜK) – oversized grains</td>
<td>3 - 10</td>
<td>6.03</td>
<td>3.44</td>
<td>-</td>
</tr>
<tr>
<td>Band 6 (B6) – production line 6</td>
<td>0.4 - 4</td>
<td>1.90</td>
<td>2.06</td>
<td>65.6</td>
</tr>
<tr>
<td>Band 8 (B8) – production line 8</td>
<td>0.1 -1</td>
<td>0.49</td>
<td>1.58</td>
<td>20.2</td>
</tr>
<tr>
<td>Feinsalz (FS) – fine salt</td>
<td>0.03 -0.3</td>
<td>0.14</td>
<td>2.01</td>
<td>14.2</td>
</tr>
<tr>
<td>sum</td>
<td></td>
<td></td>
<td></td>
<td>100.0</td>
</tr>
</tbody>
</table>

**Fig. 4.3** Salt grain fractions and grain size distributions

[KOMPASS-I, 2020]
3. Experimental studies – Pre-compaction methods

Aim: Produce samples for long-term compaction tests

➢ Low initial porosity (15 – 20 %)
➢ Natural grain structure
➢ Short-term, but under in-situ relevant stress/strain

TUC:

BGR:

IfG:

Friction effect on compaction:
- End effects bottom/top: higher
- Center of the cylinder is higher consolidated than the outsides

KOMPASS projects, L. Friedenberg (GRS), SafeND 2023, Berlin
3. Experimental studies – Long-term compaction tests

Aim: Systematically investigation of crushed salt compaction behaviour
➢ Addressing influencing factors

TUC test program:

New IfG crushed salt compaction cell:

[KOMPASS-II, in preparation]
3. Experimental studies – Long-term compaction tests

**Aim:** Systematically investigation of crushed salt compaction behaviour
   ➢ Addressing influencing factors

**BGR test program:**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Moisture</th>
<th>Temperature</th>
<th>Duration</th>
<th>Pressure steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>TK-038</td>
<td>0.1 w.-%</td>
<td>50 °C</td>
<td>34 d</td>
<td>5, 10 MPa</td>
</tr>
<tr>
<td>TK-041</td>
<td>0.35 w.-%</td>
<td>50 °C</td>
<td>145 d</td>
<td>5, 10, 15, 20 MPa</td>
</tr>
<tr>
<td>TK-042</td>
<td>0.35 w.-%</td>
<td>50 °C</td>
<td>72 d</td>
<td>10, 15 MPa</td>
</tr>
<tr>
<td>TK-044</td>
<td>0.5 w.-%</td>
<td>33 °C</td>
<td>144 d</td>
<td>4, 8, 12, 16, 20 MPa</td>
</tr>
<tr>
<td>TK-045</td>
<td>0.5 w.-%</td>
<td>50 °C</td>
<td>220 d</td>
<td>4, 8, 20 MPa</td>
</tr>
</tbody>
</table>

[grs triaxial compaction tests:]

<table>
<thead>
<tr>
<th></th>
<th>BGR sample</th>
<th>IfG sample</th>
<th>TUC sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vol. strain [%]</td>
<td>4 – 7</td>
<td>8 – 11</td>
<td>9 – 14</td>
</tr>
<tr>
<td>Porosity [%]</td>
<td>6 – 9</td>
<td>4 – 8</td>
<td>4 – 9</td>
</tr>
<tr>
<td>Permeability [m²]</td>
<td>5.4*10⁻¹⁶</td>
<td>Gas tight</td>
<td>Permeable</td>
</tr>
</tbody>
</table>

[KOMPASS-II, in preparation]

KOMPASS projects, L. Friedenberg (GRS), SafeND 2023, Berlin
3. Experimental studies – In-situ experiment

Aim: Test the KOMPASS reference material under in-situ conditions

➢ Collaboration with the SAVER project (TU BAF)
➢ KOMPASS backfill body in the Sondershausen mine

KOMPASS reference material

Dry crushed salt

[KOMPASS-II, in preparation]
4. Microstructural investigations

Aim: Reduce the uncertainties regarding the actual contribution of microstructural deformation mechanism to the overall compaction

- Establishment and improvement of microstructural investigation methods
- Relating the abundancy of indicators for microscale deformation mechanism to compaction conditions
- Focus on comparison of different pre-compaction methods
- Investigation of different influencing factors on the microscale deformation mechanism (grain size, humidity)

![Image a.](684/OED01/Dry "Big Cell" Block)
![Image b.](684/OED04/Wet 3 "Big Cell" Block)

[KOMPASS-II, in preparation]
5. Numerical modelling

Aim: Improve/develop models for describing the mechanical/hydraulic property changes of crushed salt compaction over a wide range of influencing parameter

- Application of various constitutive models
- Benchmark calculations against laboratory experiments
- Application of a virtual demonstrator
- Development/optimization of constitutive models

[KOMPASS-II, in preparation]
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6. Conclusion & outlook

The KOMPASS projects contribute to the improvement of the scientific knowledge for using crushed salt as backfill for HLW containment.

B U T . . . The KOMPASS projects also identified some important shortcomings!

- Laboratory program is not completed
- Effects of laboratory shortcomings has to be addressed
- Hydraulic properties of crushed salt need to be considered
- Need for optical experiments on the activation and quantification of micro deformation mechanism
- Constitutive models are not calibrated in its entireness
- Update the permeability reduction with time for the long-term safety analysis

To be continued... MEASURES (coming 2024)
THANKS TO THE KOMPASS-FAMILY!

FKZ: 02 E 11951A-D

THANKS FOR YOUR ATTENTION!
