**Autoclaved Building Material**

**Definition:**
Autoclaved building products

1. Lime-silica bricks
Definition:
Autoclaved building products

1. Calcium silicate bricks (KS – Kalksandstein)
   • high density bricks
   • high compressive strength
   • water absorption
   • freezing resistance

2. AAC - Aerated Autoclaved Concrete (Porenbeton)
   • lightweight, low density blocks with high pore volume
   • low compressive strength
   • unique thermal properties
   • acoustic insulation
Calcium Silicate Bricks

History

- 1866: Method to cure sand and lime under steam pressure was patented by Van Derburg in England

- 1880: Further development and patent by Dr. Wilhelm Michaëlis. He succeeded in producing a real “artificial sandstone”

- 1894: Start of industrial production in Germany after introduction of the first rotation presses (originally developed for production of cattle feed)

- 1924 first technical standard published in Germany (DIN 106) for dimensions and size tolerances (2 mm), compressive strength (15 N/mm²),

Production of Calcium Silicate Bricks

1. Sand
2. Sand mixture
3. Lime (CaO)
4. Mixer
5. Reactor
6. 2nd mixer
7. Forming
8. Hacking
9. Autoclave
10. Steam production
11. Water supply
12. Steam
13. Storage
Calcium Silicate Bricks

History 1

- 1879: foundation of "Yxhult Stenhuggeri Aktiebolag" in Kumla, Sweden, for mining of vast limestone deposit situated near the city of Yxhult

- Drastic shortage of energy in the 1st world war in Sweden → government raised the standards for thermal insulation

- 1918: Swedish researchers start developing new building material to meet the requirements

- 1923: Dr. Axel Ericsson, architect and researcher at Stockholm University developed a procedure for manufacturing of AAC

History 2

- 1928: Karl August Carlèn, majority shareholder of "Yxhult Stenhuggeri Aktiebolag", realized the potential of the new building material and acquired a license for manufacturing. He invested a large part of his assets to convert the quarry to a production facility for AAC.

- 1929: Start of industrial production of "Yxhults Anghårdade Gasbetong," (= hardened aerated concrete of the city of Yxhult

- Abreviation of "Yxhults Anghårdade Gasbetong," to Ytong

- 1940: registration of the brand name Ytong → the world's first registered brand name for a building product
Production of Aerated Autoclaved Concrete

http://www.youtube.com/watch?v=x7C-QTZwMUs

Mineral reaction

Reaction partners:
Quartz + Lime + Water form new mineral phases: CSH-phases
Mineral reaction

Reaction partners:
Quartz + Lime + Water
form new mineral phases: CSH-phases

Conditions in the autoclave:
170°C  →  8 bar
200°C  →  16 bar
**Mineral reaction**

**CSH-phases**

Soluble in hot HCl: $\rightarrow 11\text{Å}$-Tobermorite

Soluble in cold HCl: $\rightarrow$ CSH-II

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**Table:**

<table>
<thead>
<tr>
<th>Hauptgruppen</th>
<th>Morphologische Formen</th>
<th>Beispiele einiger Neubildungphasen</th>
<th>C/S Verhältnis</th>
<th>Röntgenreflex</th>
<th>2θ-Werte CuKα</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Gelähnlich</td>
<td>1. Orientierte Morphologie</td>
<td>Tobermorit-Gel</td>
<td>29.96</td>
<td>31.94</td>
<td></td>
</tr>
<tr>
<td>2. Subkristallin</td>
<td>2. Fasernähnlich</td>
<td>CSH (II)</td>
<td>1.1 &amp; 0.8</td>
<td>29.96</td>
<td>31.94</td>
</tr>
<tr>
<td></td>
<td>3. Spiral-strukturiert</td>
<td>CSH (I)</td>
<td>0.8</td>
<td>7.82</td>
<td>30.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tobermorit C$_2$S$_2$H$_5$</td>
<td></td>
<td>7.82</td>
<td>30.03</td>
</tr>
<tr>
<td></td>
<td>4. Strahlenform</td>
<td>Gyrolit C$_2$S$_2$H$_2$</td>
<td>6.7</td>
<td>4.01</td>
<td>26.18</td>
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<tr>
<td></td>
<td></td>
<td>Tobermorit C$_2$S$_2$H$_5$</td>
<td>0.8</td>
<td>7.82</td>
<td>30.03</td>
</tr>
<tr>
<td>3. Kristallin</td>
<td>5. Plattennah</td>
<td>C$_2$SH (A)</td>
<td>2.00</td>
<td>27.74</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Nadelform</td>
<td>Xinonit C$_2$S$_2$H</td>
<td>1.00</td>
<td>24.36</td>
<td>27.6</td>
</tr>
</tbody>
</table>

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**Mineral reaction**

Newly formed CSH-phases (Tobermorite) and etched quartz crystal
Mineral reaction

Experiment of Peters / Iberg (1978) showed the relative mobility of the two reaction partners.

→ Silica moves towards the source of calcium.

Raw material

Quartz-rich sands in Switzerland.

<table>
<thead>
<tr>
<th>Geological Formation</th>
<th>Quartzgehalt Gew.%</th>
<th>Andere Mineralien</th>
<th>Abbau und Verwendung</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rödligandes (Perm)</td>
<td>schwankend bis 94 %</td>
<td>Felsspäte, z.T. etwas kalk- und einenhaltig</td>
<td>keine begrenzte Abbaurampflichkeiten</td>
</tr>
<tr>
<td>von Jura und Tertiär</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rütt im Juragebirge</td>
<td>schwankend 90 – 96 %</td>
<td>z.T. etwas kalk- und einenhaltig</td>
<td>keine, geringe Mächtigkeit, schwieriger Abbau</td>
</tr>
<tr>
<td>Beypowersden und Quarzand des Südschichtkern im Juragebirge</td>
<td>schwankend, 70 – 90 %</td>
<td>Kadillit, oft stark einenhaltig</td>
<td>keine, begrenzte Vorkommen, schwierige Abbauverhältnisse</td>
</tr>
<tr>
<td>Obere Messelolsche</td>
<td>91 – 96 %</td>
<td>Felsspäte, Glimmer, Kalk</td>
<td>begrenzter Abbau, div. Verwendung (Gießerei, chem. Industrie, Stromsand etc.)</td>
</tr>
<tr>
<td>Heiden von Benken</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obere Mesosolsche</td>
<td>50 – 60 %</td>
<td>Felsspäte, Karbonate, Tonnemlrade, Glimmer</td>
<td>keine, begrenzte Mächtigkeit des entkalkten Horizontes</td>
</tr>
<tr>
<td>der Region Busdorf – Born – Frinburg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obere Steinsolsche</td>
<td>ca. 50 %</td>
<td>Felsspäte, Glimmer, Karbonate, Tonmineralen</td>
<td>begrenzter Abbau, Verwendung als Magnesiamittel für die Zieglerindustrie</td>
</tr>
<tr>
<td>Glümersandabscheidung der Nordostschweiz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ablagerungen der Eis- und Nachsezeit</td>
<td>30 – 55 %</td>
<td>Felsspäte, Karbonate, Tonmineralen</td>
<td>sehr großer Abbau, Verwendung in der Baubranche</td>
</tr>
</tbody>
</table>
Comparative study

Pure quartz-sand vs sand from fluvioglacial deposits

- Amount of quartz is not critical
- Impure sand can be used as raw material

Alternative raw material

Pure raw material:
- Sand and CaO are combined from different sources

Do rocks and other materials exist that have both reaction partners already combined?

- Research project at University of Berne 1977 – 1986 investigating:
  - Carbonate-bearing sandstones from the Swiss Molasse Basin
  - Muds from gravel washeries
  - Carbonatous mudstones
  - Microstructure of autoclaved products from these sources
Alternative raw material
Muds from gravel washeries
**Applied Mineralogy and Non-Metallic Resources II**

**Autoclaved Building Material**

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**Alternative raw material**

Sandy mudstone

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**Alternative raw material**

Clay-rich mudstone
Preliminary study
Example mudstones
Analysis of mineralogical composition of 41 mudstone samples

Sample selection
Selection of 8 representative samples for specimen fabrication

Sample treatment
• Sampling of 40 – 80 kg directly from Molasse Basin
• Drying at 110° C in the laboratory oven
• Jaw crusher size reduction and grinding to grain size of < 1 mm in laboratory grinder
• Pelletizing (with ideal diameter of 1 – 3 mm)
• Analysis of mineralogical composition of untreated samples (XRD)
• Activation of pelletized mudstone samples (after pre-study for ideal activation conditions)
### Sample treatment continued

- Analysis of mineralogical composition after activation
- Grinding of activated pellets to grain size of <0.5 mm
- Hydration and casting/pressing in moulds
- Analysis of mineralogical composition after hydration
- Hardening in autoclave (2 hrs heating 20 – 200°C, 6 hrs soaking time, 3 hrs cooling time)
- Analysis of mineralogical composition of end product
- Chemical analysis of content of quartz and new phases
- Analysis of physical properties
- Thin section analysis

### Sample fabrication
Mineralogical reaction monitored with autoclave XRD-camera

Manufacturing of samples
Analysis of physical properties

- Density of blocks
- Compressive strength
- Tensile strength
- E-Modulus
- Water absorption
- Shrinkage and swelling
- Thermal conductivity

Optical analysis

Thin section
Cast sample
Optical analysis
Thin section
Pressed sample

SEM analysis
Crushed samples
SEM analysis
Polished samples
320 x

SEM analysis
Polished samples
1250 x
SEM analysis
Polished samples
5000 x

Conclusion
- Calcium silicate bricks can be manufactured from alternative raw material consisting of carbonate, quartz and clay minerals
- Especially sandy mudstones which have not been of economical significance seem to be most suited
- This increases the volume of potential raw material for brick manufacturing
- Pressed samples manufactured of sandy mudstones compare well with industrial calcium silicate bricks
- 2 patents resulted from the research program for alternative raw material for autoclaved building material