Recycling of autoclaved aerated concrete (AAC)

Peter Nielsen¹, Jeroen Vrijders², Kris Broos¹, Mieke Quaghebeur¹

¹ Flemish Institute for Technological Research (VITO)
² Belgian Building Research Institute (BBRI)
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What is AAC?

» AAC is a steam-cured mix of sand, cement, lime, anhydrite (gypsum) and an expansion agent.
» AAC is a micro-porous concrete with a low density of 350-800 kg/m³

» AAC was developed in Sweden between 1920 and 1930

» Ytong “**Yxhults ånghärdade gasbetong**”

» Since 1980 a worldwide increase in the use of AAC materials.
» Produced in Belgium since 1955 with a yearly production of about 250,000 m³ since 1965
» current amount of AAC released estimated at around 250,000 m³
Production of AAC

» Raw materials:
   » finely ground sand powder, cement and lime
   » expansion agent and water
   » anhydrite or gypsum (CaSO$_4$)

» Production process:
   1) raw materials are mixed and poured into molds where they rise to form a cake
   2) after pre-curing the cake is demoulded and wire-cut into blocks
   3) the blocks are placed in an autoclave for steam curing
Production of AAC (II) – Mineralogy

The diagram illustrates the mineralogical changes during the processing of AAC (Autoclaved Aerated Concrete) over time. The processing time is shown on the x-axis, ranging from 0 to 840 minutes, and the percentage of various minerals is shown on the y-axis from 0% to 100%.

Key minerals and their changes over time include:
- **Anhydrite**
- **Ettringite**
- **C₃S**
- **CSH-Gel**
- **Lime**
- **Portlandite**
- **Quartz**
- **CSH(I)**
- **Tobermorite**
- **Hydrogarnet**
- **Hydr. ell.**
- **Others**

Each mineral's percentage change is color-coded and depicted over the processing time, allowing for a visual understanding of how their proportions evolve during the autoclaving process.
Properties of AAC

» light weight (350-800 kg/m$^3$) about a fifth the weight of normal concrete (2200 – 2600 kg/m$^3$)
» Low energy consumption
» Good thermal properties (insulation)
» Acoustic insulator (sound absorbing)

*Source: FeBeCel handbook 2000: Le Béton Cellulaire – Matériaux d’Avenir, p. 32
Recycling of AAC

» Recycling into new AAC products
» Stabilisation and improvement of soils or dredgings
» Filler for cat litter box
» As aggregate in floor screed / concrete
Recycling of AAC into new AAC

- At Xella in Belgium nearly 15% of the primary raw materials, i.e. approx. 20% of the sand fraction is replaced by recycled AAC
- Mainly limited to production waste because of:
  - problems with the cutting wires
  - visual contamination of finished products
Recycling of AAC in construction materials

- Recycled aggregates from C&D waste are in Belgium mainly used as (sub)base for road construction
  - low compressive strength (3-8 Mpa) of AAC
  - high sulphate leaching of AAC
  => not suited for sub(base) applications
- Recycling in floor screed, and other sand-cement based materials
  - the properties of AAC can be beneficial (light weight, insulation)
  - for outdoor use immobilization of sulphate is needed
Sulphate leaching – limit values

» Sulphate leaching limits for landfilling of inert waste
  » 1000 mg/kg (or it has to comply with 1500 mg/l for \( C_0 \) at \( L/S = 0.1 \)
  l/kg and 6000 mg/kg at \( L/S = 10 \) l/kg).

» Sulphate leaching limits for recycling as a construction material
  » In the Flemish region no limit value is set at the moment
  proposed limit value 2200 mg/kg (standard column leaching test)
  » In the Netherlands 2430 mg/kg dm (“besluit bodemkwaliteit” –based
  on risk assessment the limit value was set at 1730 mg/kg dm)

Typical sulphate leaching for AAC aggregates: 6000-15000 mg/kg
Long term leaching of sulphate from AAC

- Standard column leaching test (L/S= 10) (CMA2/II/A.9.3, NEN 7383)
  - Particle size < 4 mm, eluate: demineralised water
  - Leached SO4 at L/S = 10 can be compared to limit values.

- Aeration periods of 1 week at L/S = 10, 20, 30, 40 and use of acidified water (pH = 4) to simulate ageing

- Evaluation of leaching concentrations at L/S= 20, 30, 40 and 50 to gain insight in long term leaching of AAC

- Examination of the mineralogy of AAC using XRD-analysis
Leaching behaviour of SO$_4$
Model results – $\text{SO}_4^{2-}$ in solution

- Aerated Autoclaved Concrete (AAC) fresh
- Aerated Autoclaved Concrete 1971-1972

Graph showing sulphate ($\text{SO}_4$) in mg/l vs pH.
Model results - $\text{Ca}^{2+}$ in solution

![Graph showing calcium concentration vs pH with different species like anhydrite, gypsum, calcite, and ettringite.](image)

- **Aerated Autoclaved Concrete (AAC) fresh**
- **Aerated Autoclaved Concrete 1971-1972**
A = aragonite (CaCO$_3$)
C = calcite (CaCO$_3$)
V = vaterite (CaCO$_3$)
T = tobermorite (crystalline CSH: Ca$_5$Si$_6$O$_{16}$(OH)$_2$·4H$_2$O)
H = hydroxylellestadite (Ca$_{10}$(SiO$_4$)$_3$(SO$_4$)$_3$(OH,F)$_2$)
G = gypsum (CaSO$_4$·2H$_2$O)
Q = quartz (SiO$_2$)

Total SO$_4$ = 3,30 %
Total SO$_4$ = 1,05 %
Total SO$_4$ = 3,60 %
XRD analysis before and after leaching

Q = Quartz
C = calcite
T = tobermorite
E = hydroxyl-ellestadite
G = Gypsum

AAC fresh production waste (2010)
AAC after leaching at L/S = 40
Leaching behaviour of SO$_4$
## Immobilisation of sulphate

### leaching SO$_4^{2-}$ (EN 12457 part 2)

<table>
<thead>
<tr>
<th></th>
<th>60 g CEM I</th>
<th>113 g CEM I</th>
<th>60 g CEM III</th>
<th>113 g CEM III</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAC (270 g) + mixed aggregates (405 g)</td>
<td>6800 mg/kg</td>
<td>99 mg/kg</td>
<td>32 mg/kg</td>
<td>6900 mg/kg</td>
</tr>
<tr>
<td>pH</td>
<td>10.37</td>
<td>12.25</td>
<td>12.35</td>
<td>10.66</td>
</tr>
</tbody>
</table>

### SO$_4$ leaching from cement stabilized AAC

![Graph showing SO$_4$ leaching vs pH](image)

**mg/kg SO$_4^{2-}$**

**pH**

**SO$_4$ leaching from cement stabilized AAC**
Conclusions

» AAC waste can be recycled:
  » as raw material for new AAC production
  » in indoor applications where contact with water is avoided and as a result leaching of sulphates is not an issue.
  » as an aggregate in sand-cement applications where the leaching of sulphates is controlled by chemical immobilization

» There are at least two recycling facilities in the Flanders region that accept AAC waste for recycling, one of the remaining challenges however, is to get the AAC waste to the recyclers.
Acknowledgements

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» IRCOW
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