# Progress in the development of Ternocem

## A belite ye'elimite ferrite cement

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# Progress in the development of Ternocem
Formerly known as BCT

# 1. Background: The $CO_2$ challenge and alternative binders

- **How to (further) reduce $CO_2$ impact of concrete production?**
  - Reduce concrete volumes
  - Reduce clinker content in concrete
  - Use of alternative fuels and raw materials
  - Use of supplementary cementitious materials (SCMs)
  - **Alternative binders**

- **A wide range of alternative binder concepts have been investigated and developed over the past decades**
  - **Hydrothermal activated binders, Alkali activated systems, Mg-Si binders, etc…**

**So far no alternative binder approach reached maturity to replace OPC based concrete in substantial volumes**

# 1. Background: Specific $CO_2$ emission from clinker phases

- Belite cement: only low reduction of $CO_2$, low reactivity, hard to grind
- Calcium aluminate cement: high burning temperature (ca. 1700°C), low $CO_2$
- CSA cement: low burning temperature (ca. 1250°C), low $CO_2$, easy to grind
- Ternocem: low burning temperature 1150 – 1280°C, low $CO_2$, easy to grind

| Phase Chemical | Phase notation | Synthesis from | g $CO_2$/ g phase | % $CO_2$ | |
|---|---|---|---|---|---|
| $3CaO{\cdot}SiO_2$ | $C_3S$ | Limestone + quartz | 0.58 | 100 | OPC |
| $2CaO{\cdot}SiO_2$ | $C_2S$ | Limestone + quartz | 0.51 | 88 | Belite |
| $3CaO{\cdot}Al_2O_3$ | $C_3A$ | Limestone + Al-source | 0.49 | 85 | |
| $CaO{\cdot}Al_2O_3$ | CA | Limestone + Al-source | 0.28 | 48 | CAC |
| 4CaO·3Al2O3·SO3 | C4A3$ | Limestone + Al-source + anhydrite | 0.22 | 38 | CSA |
| 5CaO·2SiO2·SO3 | C5S2$ | Limestone + quartz + anhydrite | 0.37 | 64 | Ternesite |

**Ternocem reduces $CO_2$ emissions by 30%**

# 2. Ternocem clinker technology

## Raw materials

- Limestone / marl
- Bauxite
- Iron sources
- $SiO_2$ sources
- Sulfate sources
- Al-Si bearing minerals
- Pozzolana
- Industrial by-products

## Production / Technology

- Production similar to OPC clinker manufacturing
- Lower energy demands in comp. to OPC
  - 1250 -1350 °C
  - Friable clinker
- Lower $CO_2$ emissions compared to OPC
- $SO_2$ emission mastered

## Cement / Binder

- Based on
  - Ye’elimite $C_4(A_xF_{1-x})_3\$$
  - Belite $C_2S$
  - Ferrite $C_2(AF)$
  - Ternesite
  - Anhydrite / Gypsum $C\$\cdot nH_2O$
  - Minor phases



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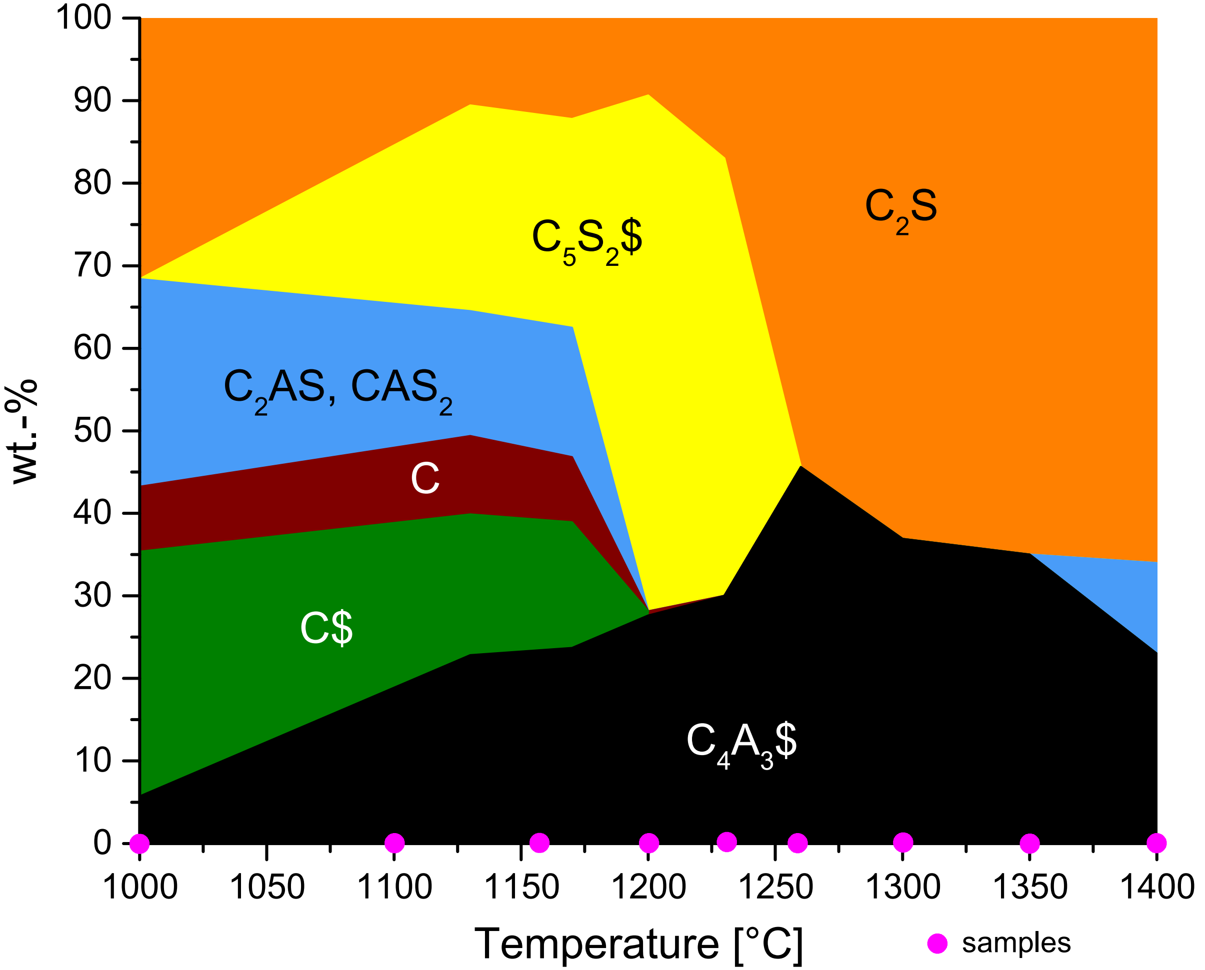
# 2. Ternocem clinker technology: Equilibrium phase composition

- **Ternesite only stable below 1250°C**




PhD Tilman Scholten 2017



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# 2. Ternocem clinker technology: Clinker phase formation

Pre-heating phase

**1000 – 1250°C**

**Formation of:**

$C_2S$, $C_{12}A_7$, $CA$, $CA_2$, $C\$$, $C_4AF$, $C_4A_3\$$

but also $Al_2O_3$, $C_2AS$, $C_3MS_2$, $CMS$

**1250 – 1300°C**

**Formation of:**

$C_2S$, $C_4A_3\$$ and $C_4AF$

**1250 – 1000°C**

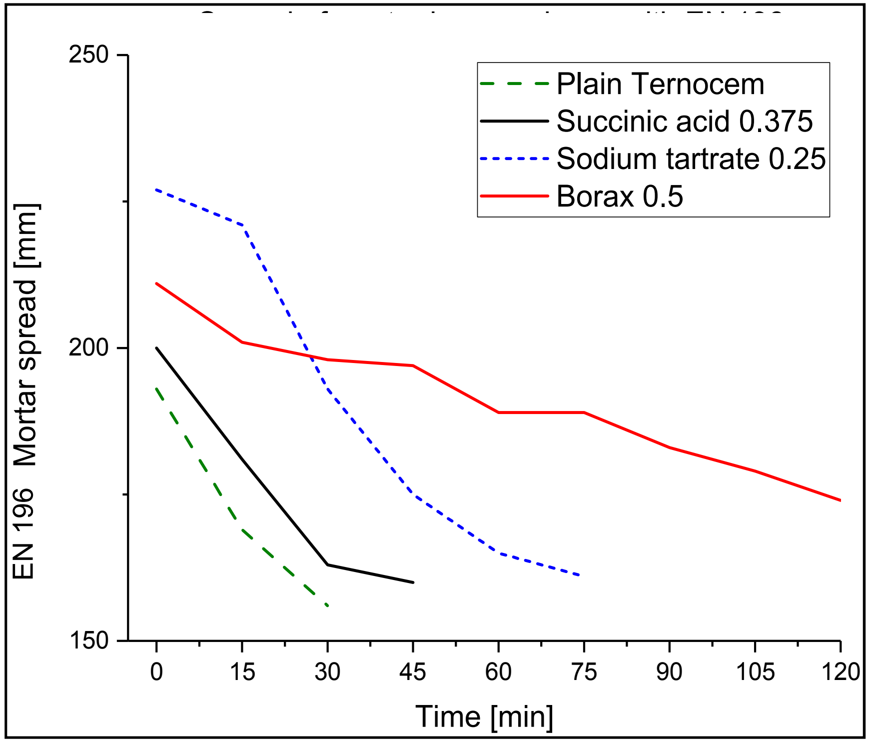
**Formation of:**

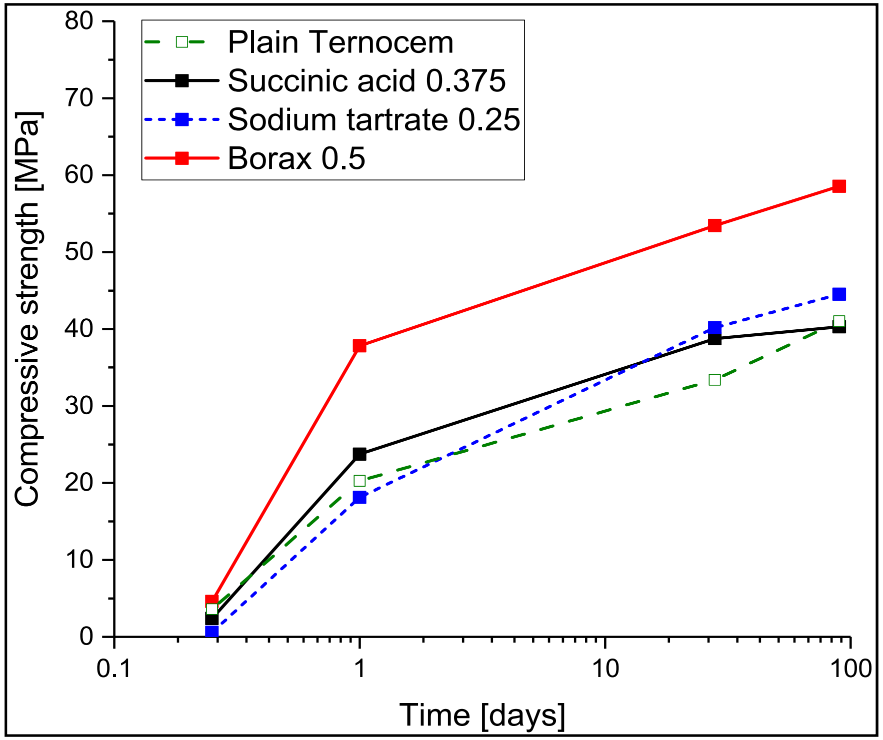
$C_5S_2\$$ and also $C_4(A_xF_{1-x})_3\$$

Cooling phase

# 2. Cement performance: Retarder development

- **Boron acid / salts are the optimal retarders for Ternocem**
- **Performance significantly better compared to other known solutions (e.g. organic acids)**
  - Combination of retarding – microstructure optimization effect
- **Similar results for borax and boric acid**



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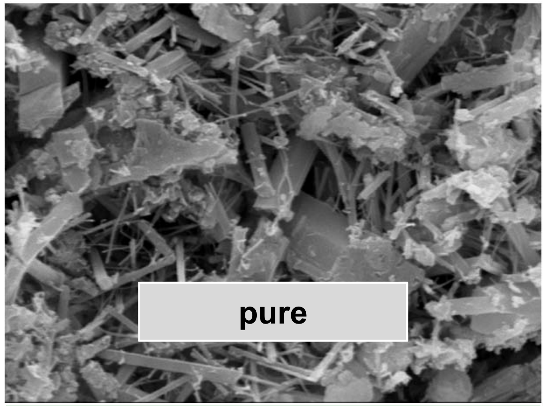
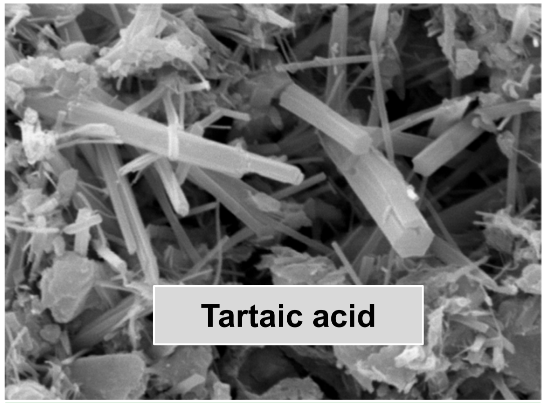
# 2. Cement performance – Effect of retarders

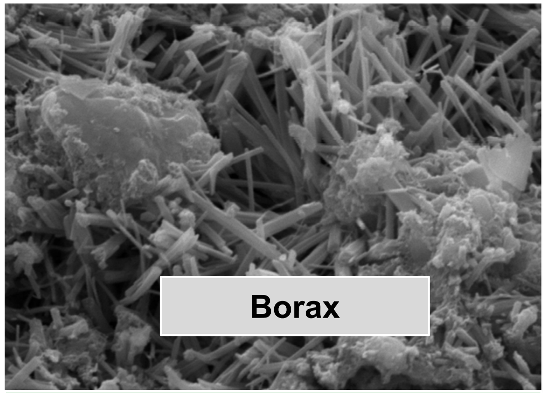
- **Ettringite morphology / microstructure identical to pure system when Borax is used**



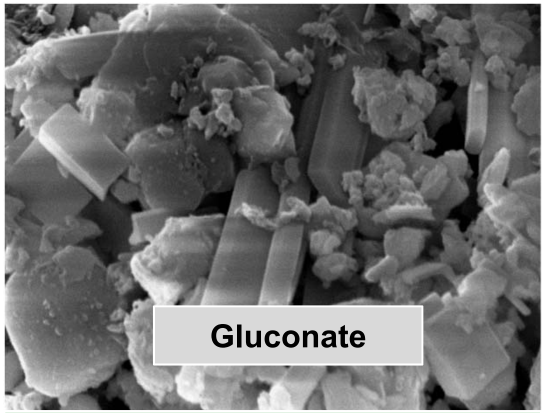

**CAH 7000x 5µm**




**CAH-T 7000x 5µm**



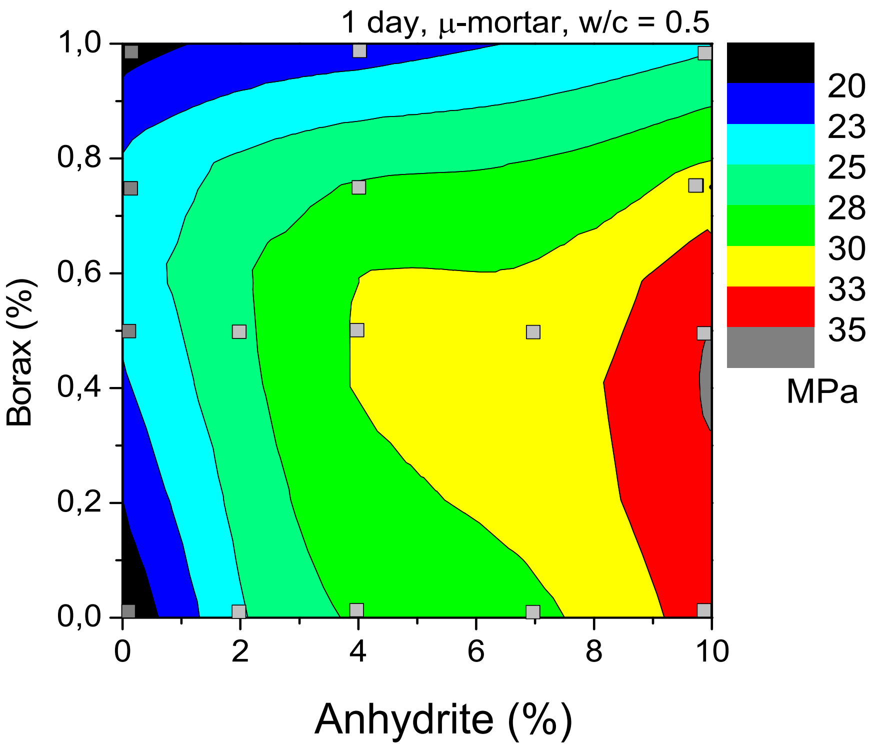

**CAH-B 7000x 5µm**

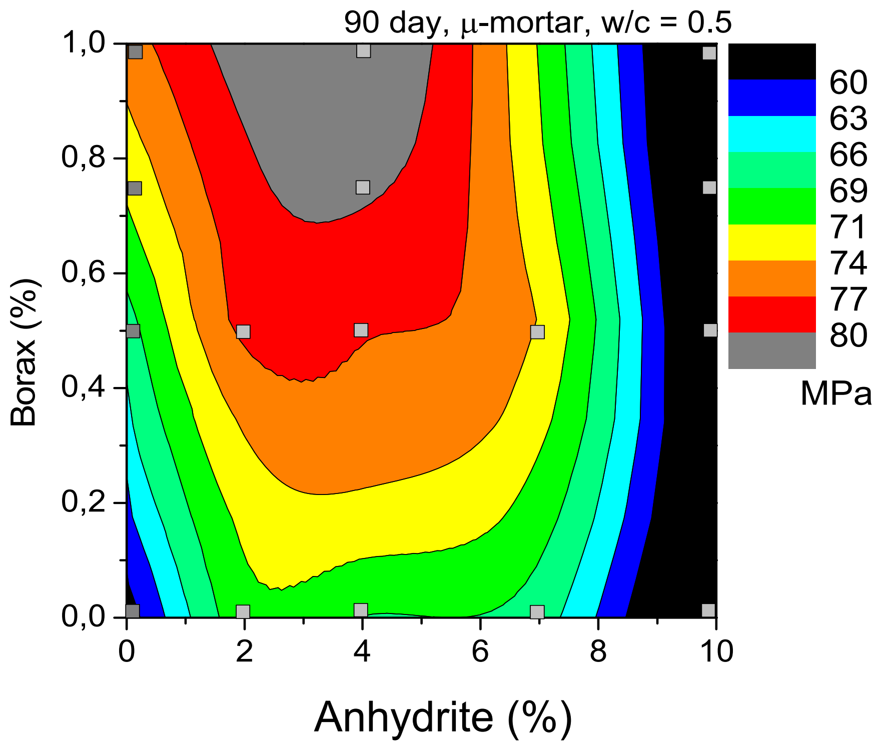



**CAH-G 7000x 5µm**

# 2. Cement performance: Strength development flexibility

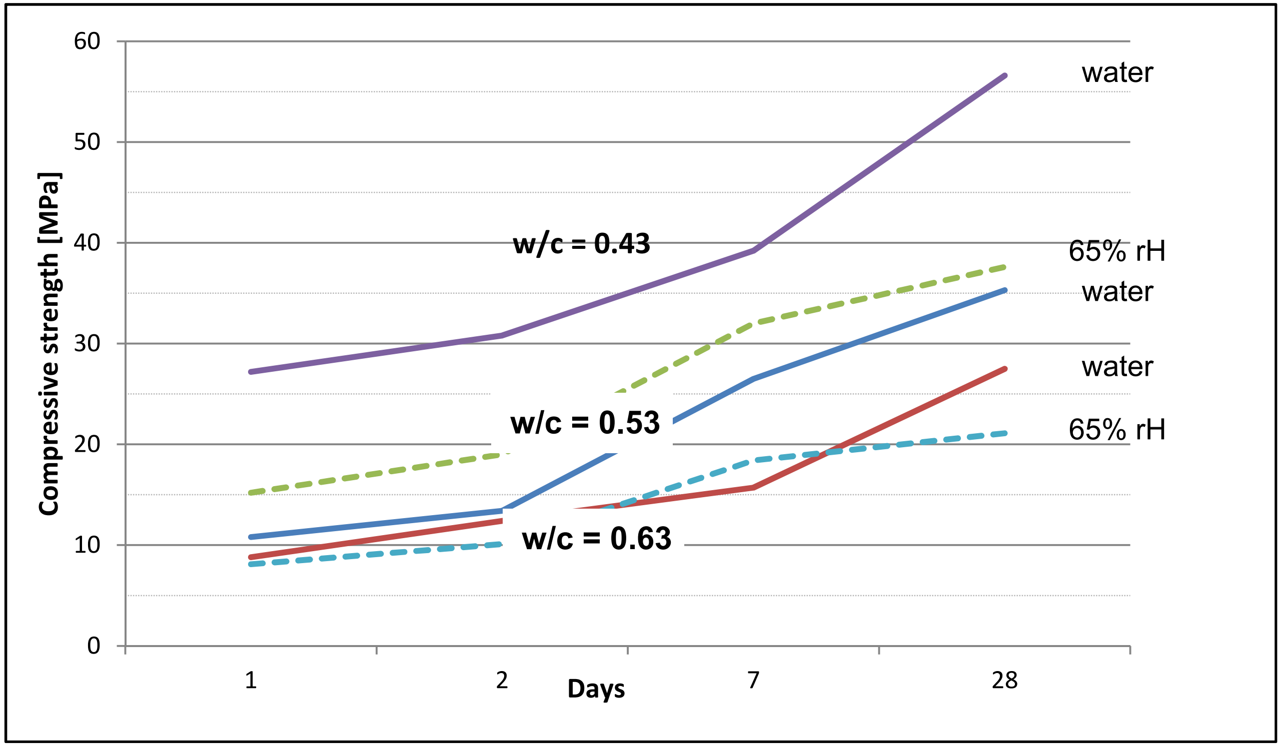
- Sulfate level strongly determines early and late strength
- Strength development can be adapted to type of application



# 3. Concrete technology: Effect of w/c ratio and storage

- **Strength not very sensitive to curing (under water / 65 % rH)**
- **Strength development and its dependence on w/c roughly comparable to CEM I**



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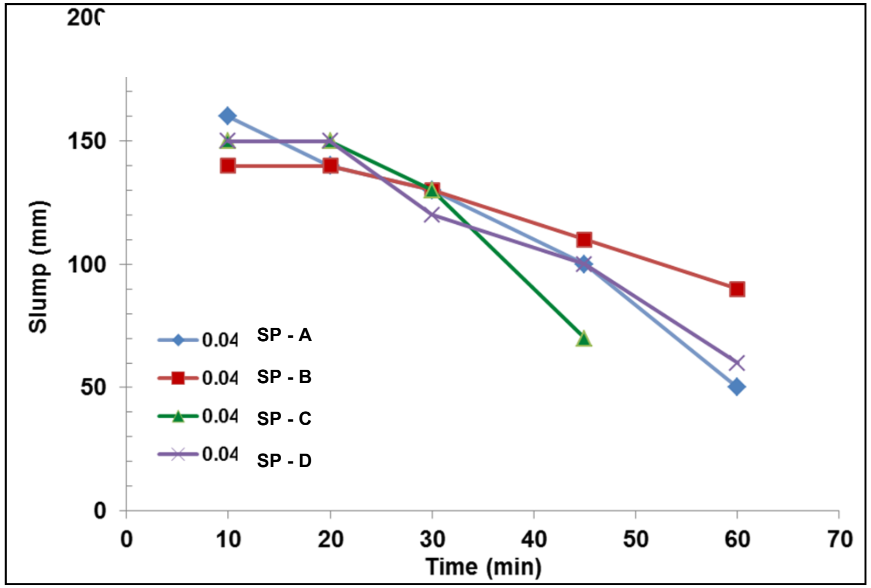
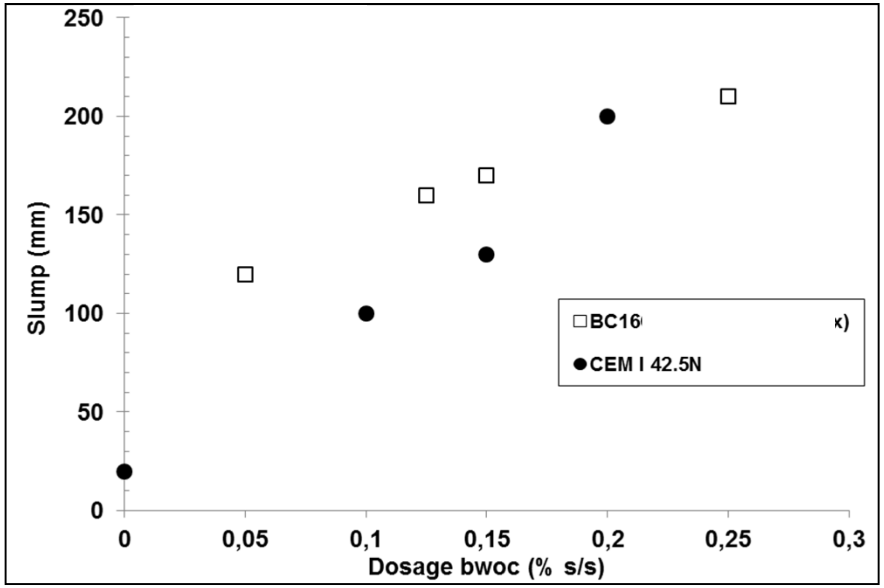
# 3. Concrete technology: Workability

- **Performance of conventional superplasticizers (SP) similar to OPC concrete**
- **Ternocem concrete less sensitive to variations in SP dosage**
- **Open time seems well controlled by retarder**



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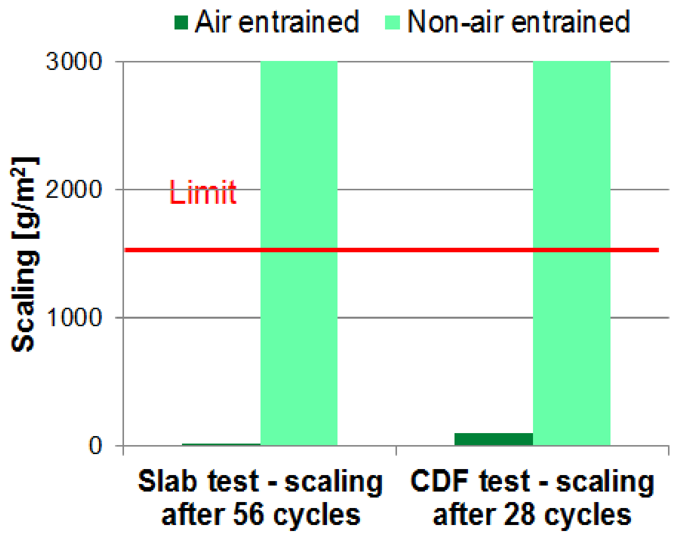
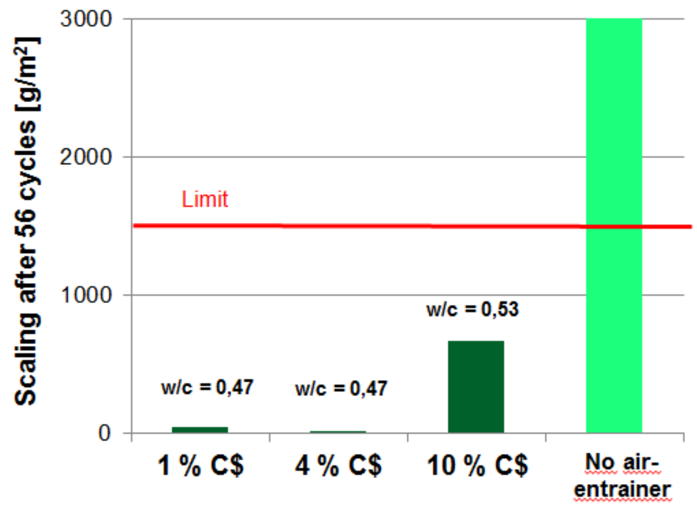
# 3. Concrete technology: Freeze-thaw & de-icing salt resistance

- **Air-entrained concrete has excellent scaling resistance**
- **Existing air-entraining agents are suitable**
- **Slab tests and CDF tests give comparable results**
- **Excellent resistance even for high w/c for all sulfate levels**




**c = 390 kg/m³**
**w/c = 0.43**




**c = 325-350 kg/m³**
**w/c = 0.47-0.53**



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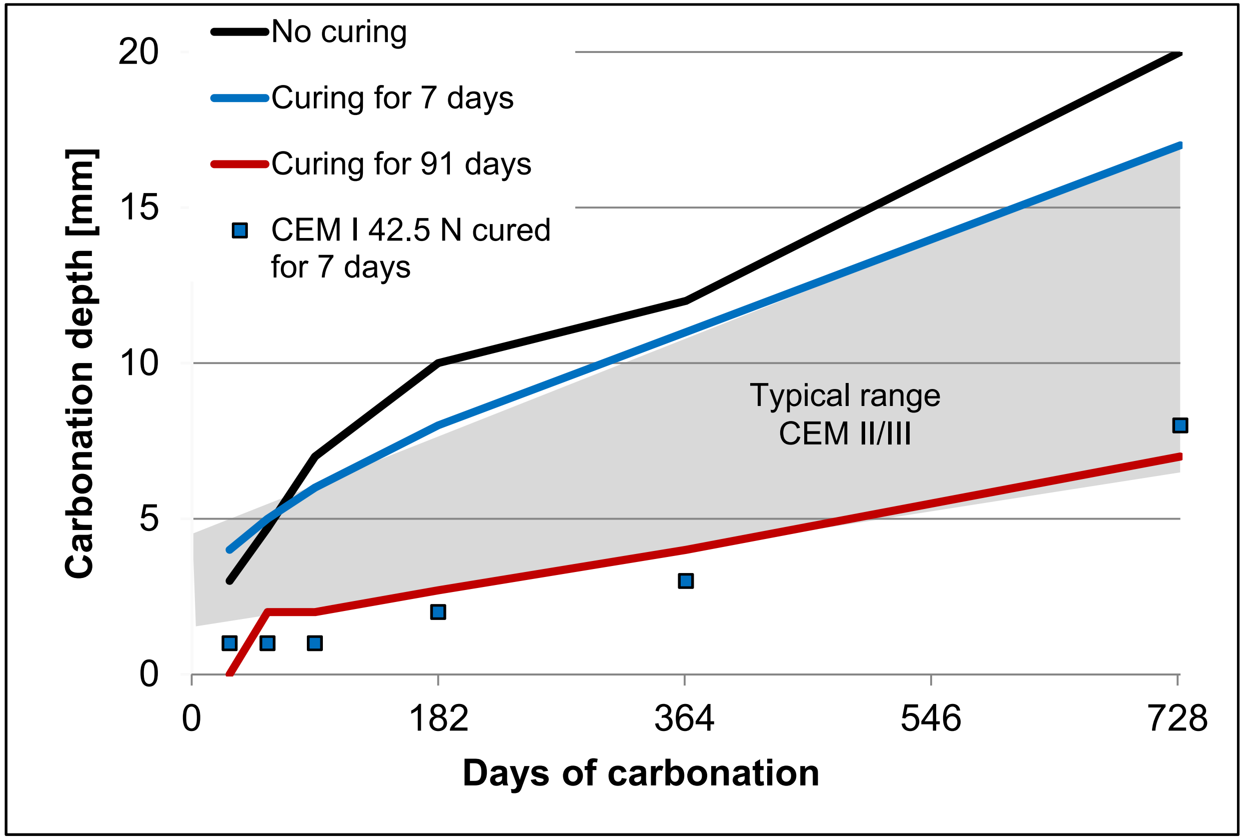
# 3. Concrete technology: Carbonation

- **Carbonation rates generally higher than OPC cements, comparable to composite cements**
- **Belite reactivity is important to have a good carbonation resistance**
- **Carbonation resistance improved by increased curing time or lowered w/c ratio**



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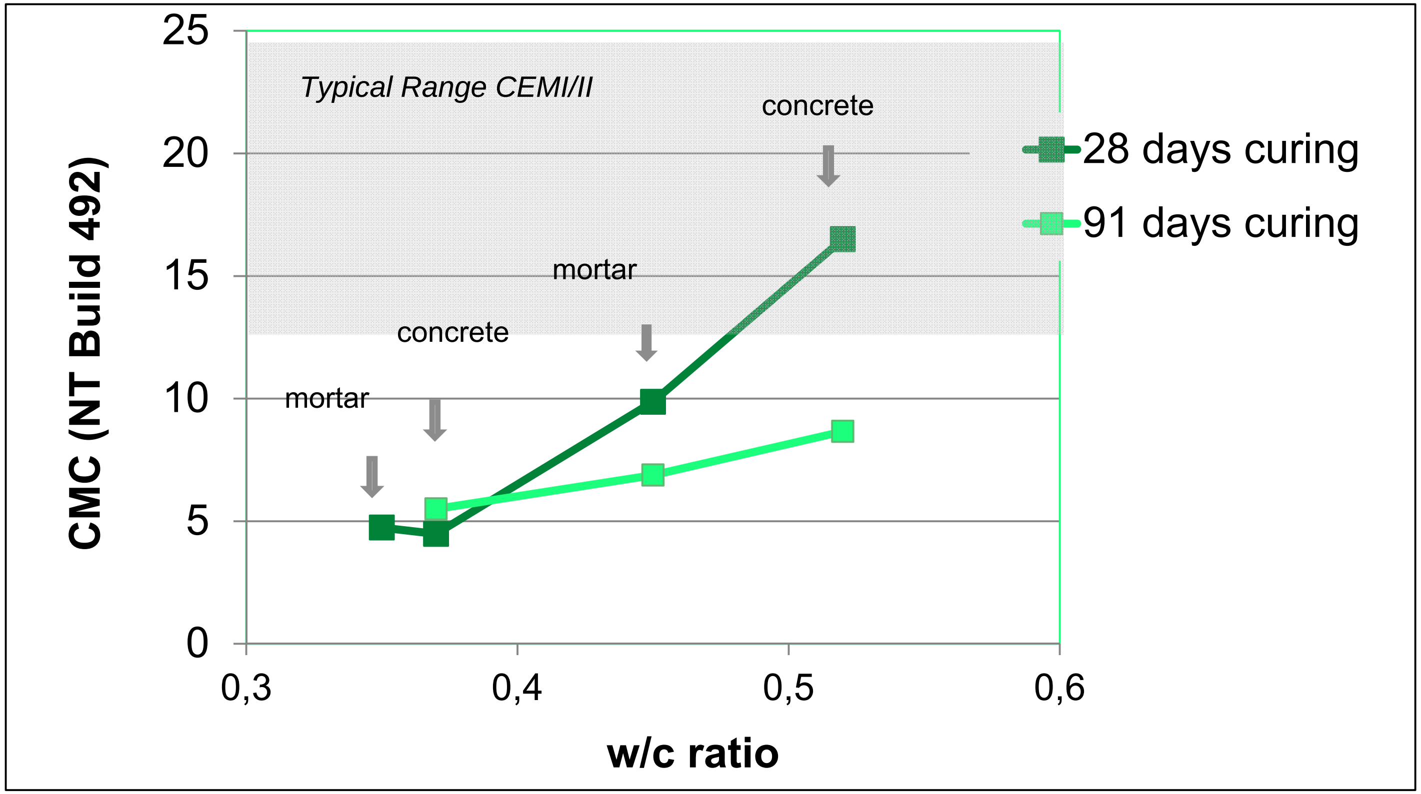
# 3. Concrete technology: Chloride ingress

- **Migration coefficients within common range**
- **Significant impact of w/c and curing time / aging**
- **Chloride profiles different than common concretes – under investigation**



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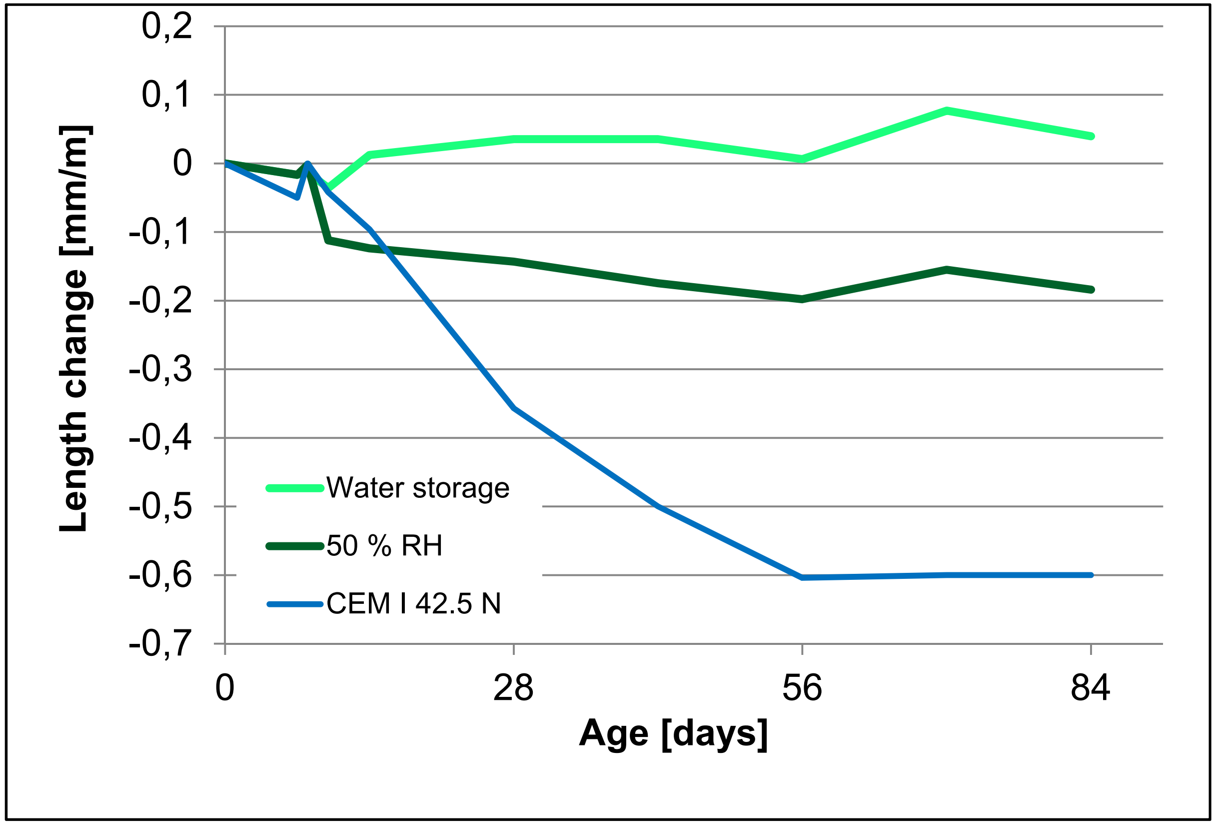
# 3. Concrete technology: Shrinkage

- **Excellent volume stability at all ages and exposures**
- **Independent of w/c curing time conditions**
- **Low risk of cracking**

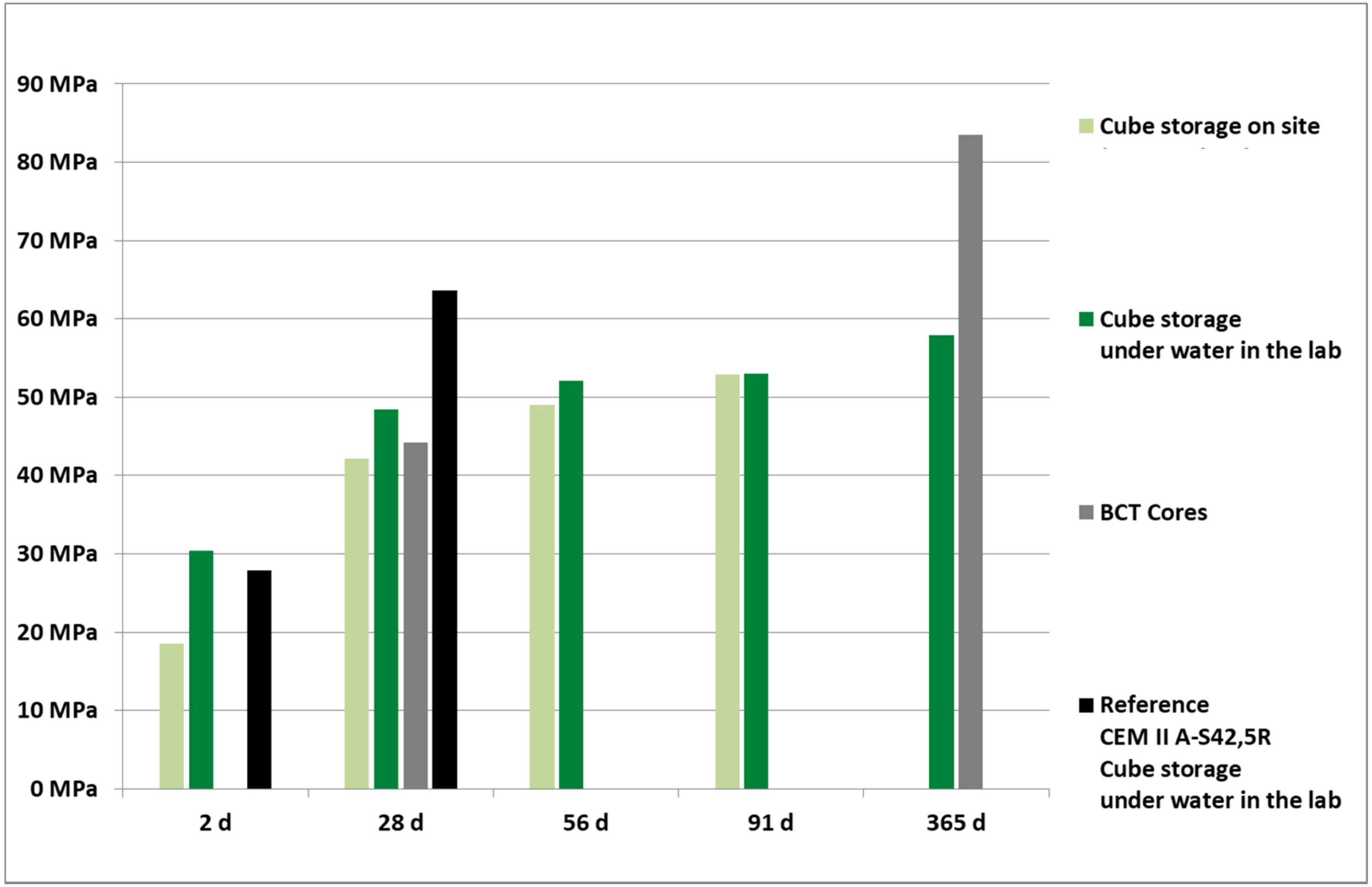


# 4. Ternocem applications: Concrete field trial, Germany 2014

- **The first concrete slab with Ternocem casted in 2014**
  - Good workability and good surface finishing
  - Acceptable strength levels at 28 days
  - Extremely high strength levels beyond

# 4. Ternocem applications: Concrete field trial, Germany 2014

## Strength development



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# 4. Ternocem applications: Railways sleepers production 2016

- **Key requirements on concrete for pre-stressed sleepers**
  - Workable for about 30 – 40 Min.
  - High early strength ≥ 30 MPa at 6 h
  - Frost resistant

- **Pilot production**
  - Abetong, Vislanda, Sweden
  - August 2016

- **Results**
  - Strength 33,0 MPa at 6h in lab
  - In production 32,3 MPa after 9 h (cutting)
  - 28 days strength: 58,6 MPa (lab); 61,3 MPa (sleepers)

# 4. Ternocem applications: Railways sleepers production 2016

- **Good flow and compactable concrete despite low w/c ratios (w/c ≙ 0.36) used for the production**



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# 4. Ternocem applications: Railways sleepers production 2016

- **Good finishing surfaces**
- **No deleterious reactions observed at contact zone to OPC concrete**




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# 4. Ternocem applications: ECO-Binder - Test at precast, Italy 2017

- **Despite high temperatures (>30°C) slump stable at 21±2 cm over 2 hours**
- **Open time - around 4 hours**

- **Compressive strength reached**
  - 30 MPa after 20 hours
  - 35 MPa after 3 days
  - 46 MPa at 28 days

# 4. Ternocem applications: Pre-cast wall elements, Sweden 2017

- **Good workability**
- **Open time – between 1.5 and 2 hours**
- **Easy finishing**

- **Compressive strength reached**
  - 20 to 23 MPa after 6 hours
  - 30 to 35 MPa after 1 day



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# 4. Ternocem application: Road in Lixhe plant, Belgium 2018

- **Concreting at -2°C, frost in first nights**

# 4. Ternocem application: Road in Lixhe plant, Belgium 2018

- **Strength results:**

| | 20°C | outside |
|---|---|---|
| 2d (MPa): | 34,4 | 1,2 |
| 7d (MPa): | 44,5 | 37,7 |
| 28d (MPa): | 53,4 | 53,7 |

- **60 m no joints, no cracks**
- **In use since March**



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# 4. Ternocem application: mortar formulations

- **Promising characteristics and benefits for building chemistry**
  - More simple „single“ binder formulations can be used

| **Cement** ***(what can be achieved)*** | **BYF - Low sulphate** | **BYF - High sulphate** |
|---|---|---|
| **Early strength** | > 10 MPa after **4 hours**<br>> 20 MPa with accelerator | > 15 MPa after **4 hours**<br>> 30 MPa with accelerator |
| **Workability time** | From 15 to > 120 minutes | From 15 to > 120 minutes |

- **Typical properties**
  - Formulation of low to zero shrinkage or expansive cements
  - Normal to fast setting and high early strength
  - Resistance to sulfate attack and against weak acids
  - No efflorescence tendency
  - Excellent finishing surfaces and abrasion resistance



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# 5. Outlook

**The Ternocem technology is in an advanced development stage but still several hurdles need to be overcome before commercialization.**

- Mastering of concrete technology – workability in various applications
- Establish / optimize durability and long-term performance of concrete
- Technical approval / standardization prerequisite on cement and concrete level
- Market launch, acceptance by customers

**Pilot market introduction ongoing in Sweden**



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