Strength development of alkali activated blended cements

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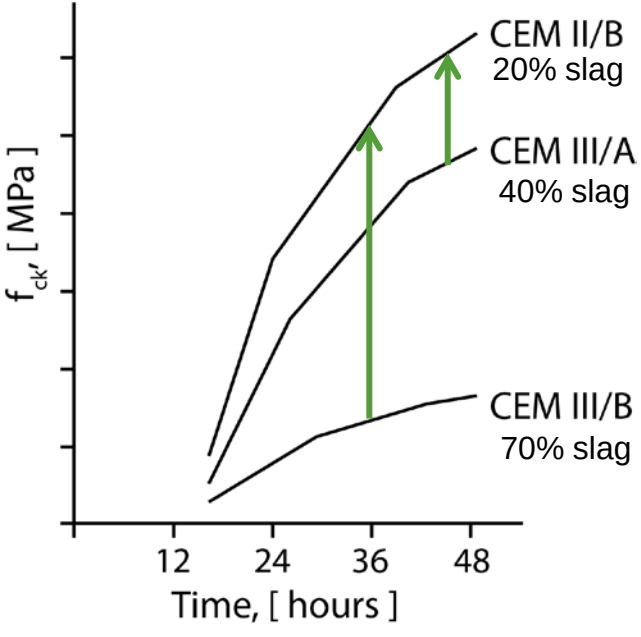
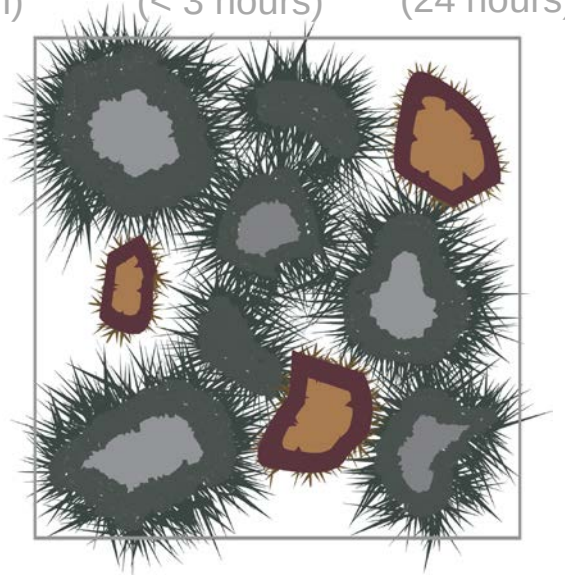
Introduction



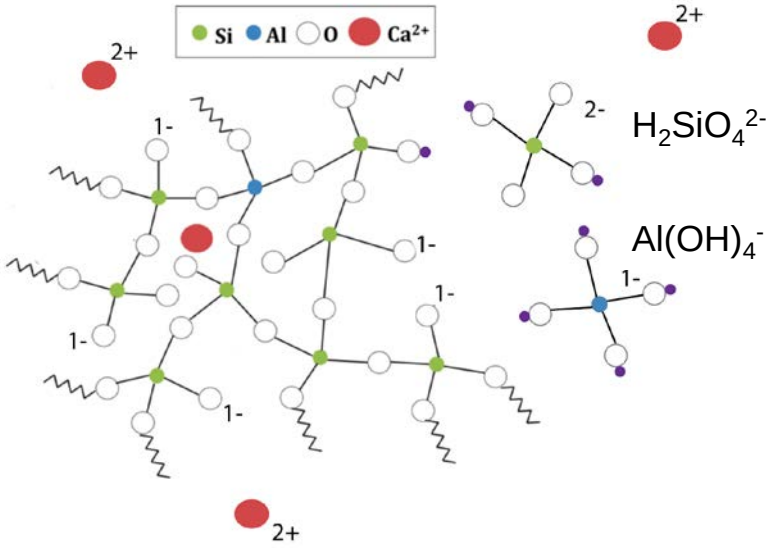
CEMENT: Rapid dissolution (15 min) → Nucleation (< 3 hours) → Rapid growth (24 hours) → Slow growth (> 24 hours)

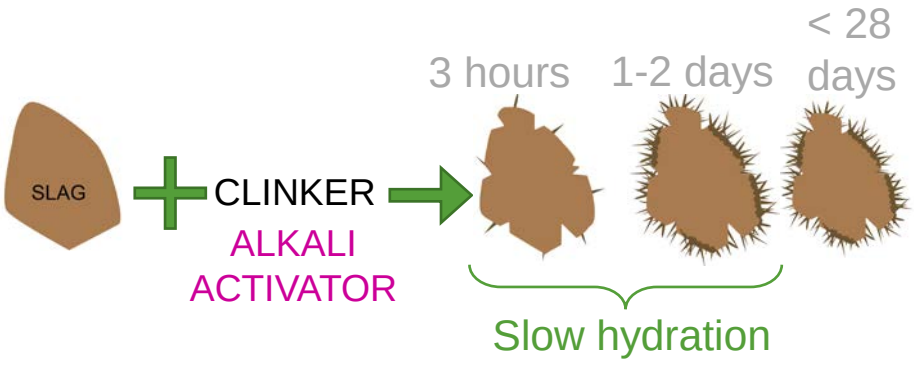


SLAG: Slow dissolution → Ions attracted back to slag surface, block hydration → Slow growth

Target: Accelerate the early-strength development of concretes with slag to the level of CEM II/B (Oiva).

Dissolution and chemical activation





Glass structure dissolution:

1. Ca^{2+} separates from oxigen (ionic bond)
2. Hydrolysis and dissolution of Si – O – Al linkage
3. Formation of negatively charged surface, which attracts positive ions (H^+,Ca^{2+}) → **slow hydration**

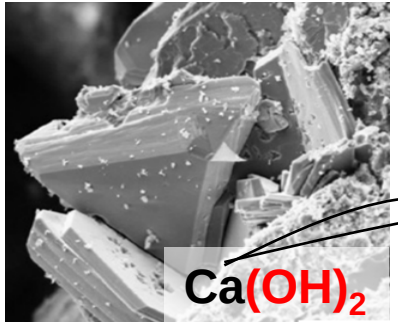
Chemical activation:

Add ions which can increase pH of solution

↓

Dissolution
Nucleation

Activators



Activation of slag requires high pH levels (>12)

=

high number of OH^- ions

NaOH

↓

↑ pH

Na_2SO_4

+

$Al(OH)_4$

+

Ca^{2+}

↓

Ettringite + **↑ pH**

Na_2CO_3

+

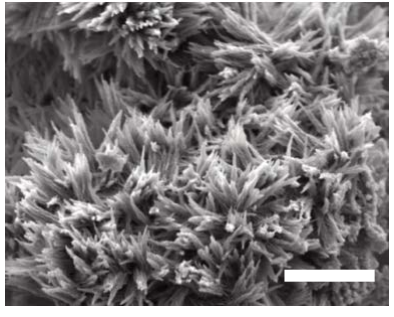
$Al(OH)_4$

+

Ca^{2+}

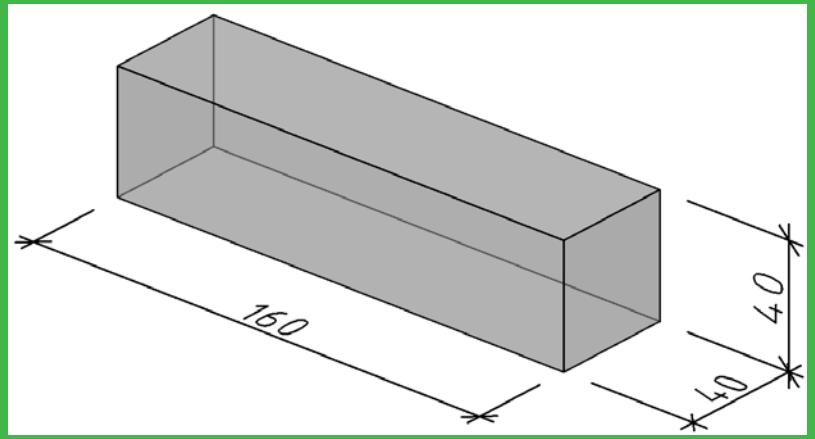
↓

Afm + **↑ pH** + $CaCO_3$



C(N-)-A-S-H

Alkali activation of blended cement paste



Ekaterina Illarionova part of Doctoral thesis

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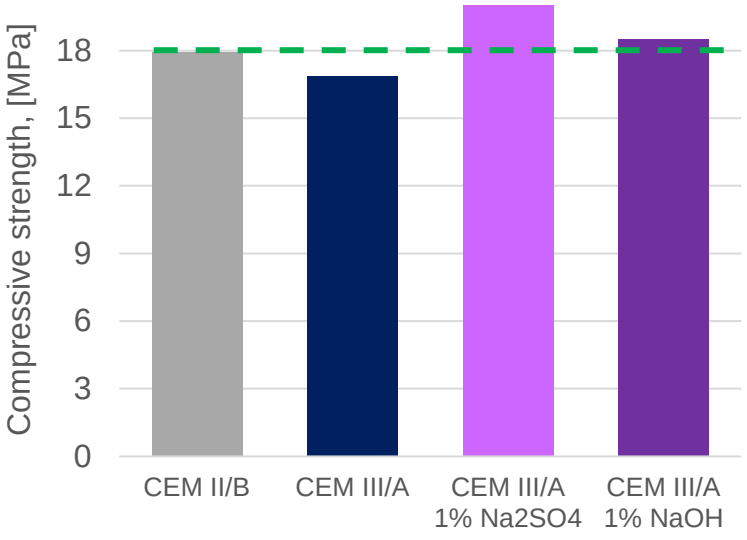
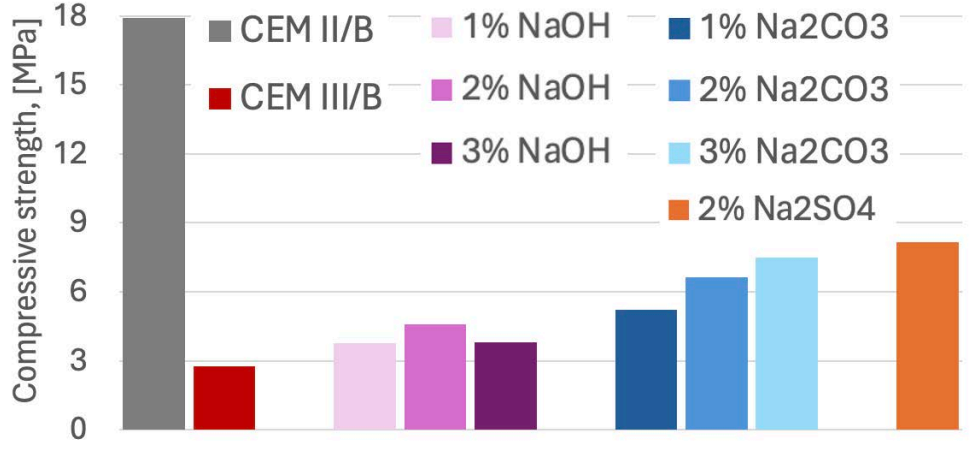
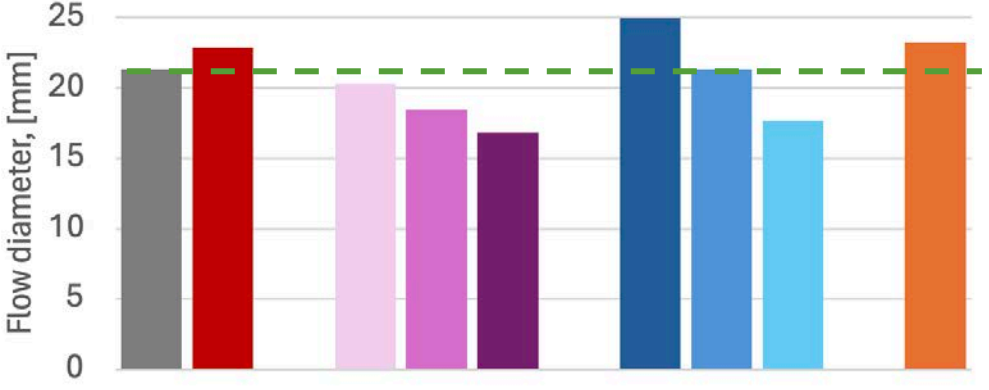
Compressive strength - Prisms

CEM III/A



CEM III/B





- **CEM III/A:** Chemical activation was effective with 1% of Na_2SO_4
- **CEM III/B:** More complex chemical activation is needed

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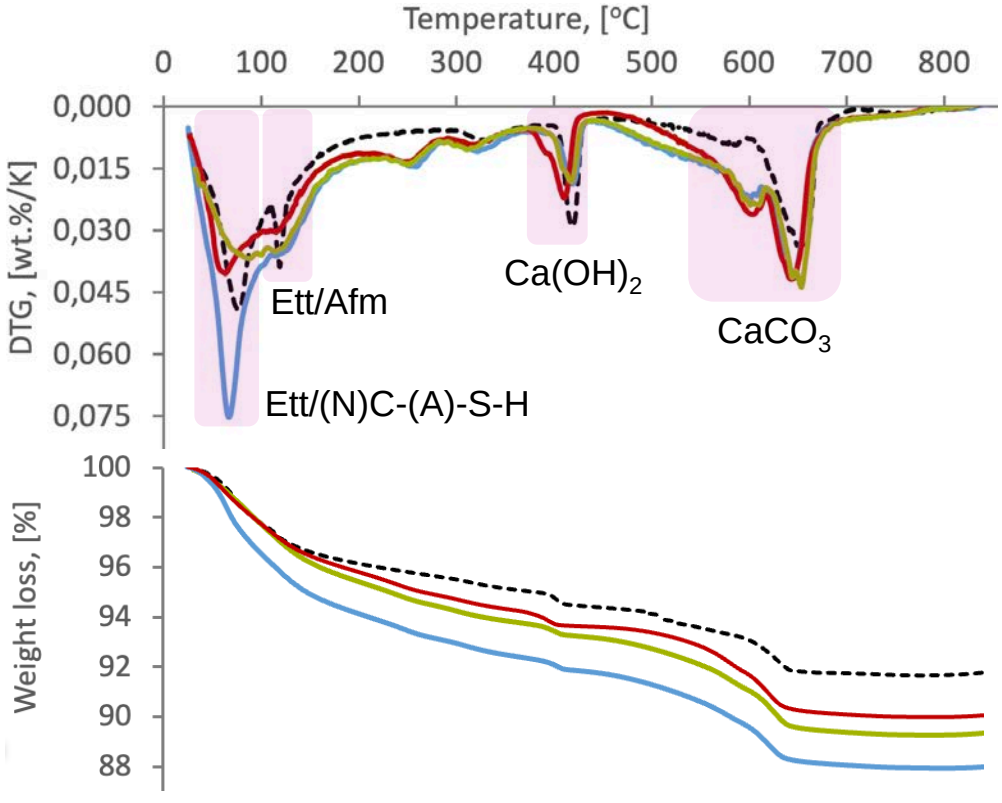
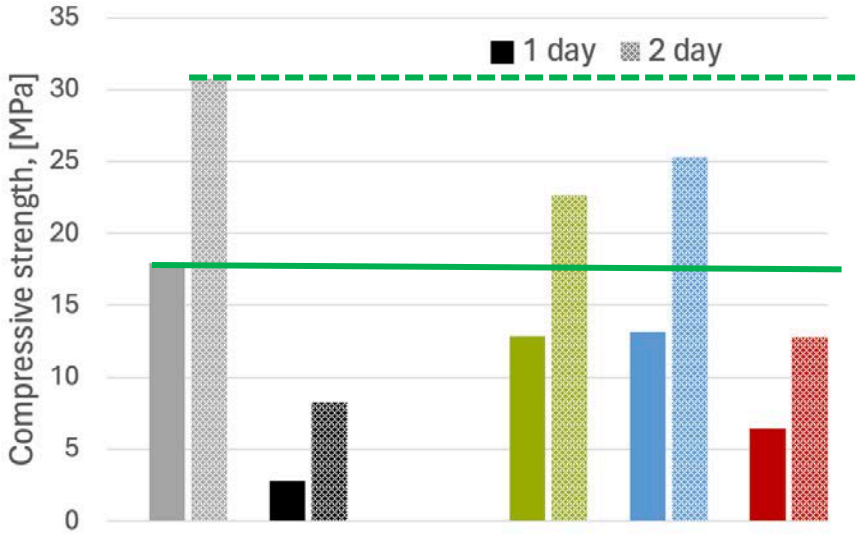
CEM III/B + combinations





CEM III/B

CEM III/B
1% NaOH
3% Na_2CO_3

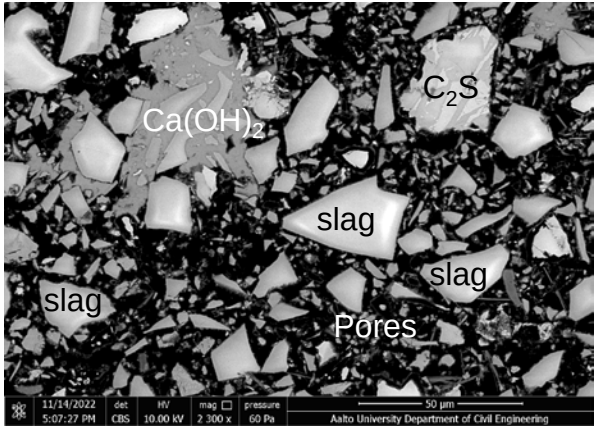
CEM III/B
1% NaOH
3% Na_2CO_3
2% Na_2SO_4

CEM III/B
2% NaOH
2% Na_2CO_3
2% Na_2SO_4

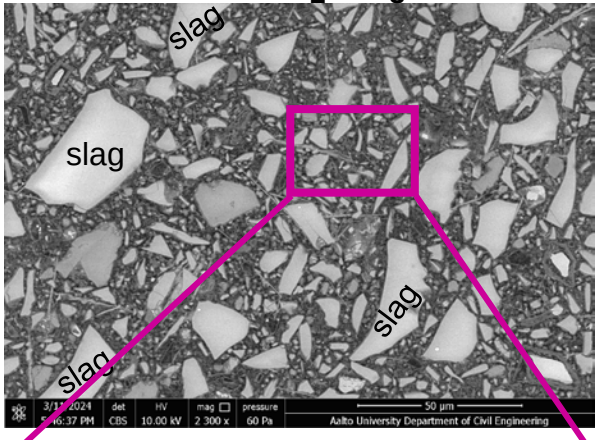
- **Chemical analysis:**
  - Growth of such hydrates as ettringite, AFm and carbonates
- **Compressive strength:**
  - Chemical activation is not enough to reach CEM II/B level

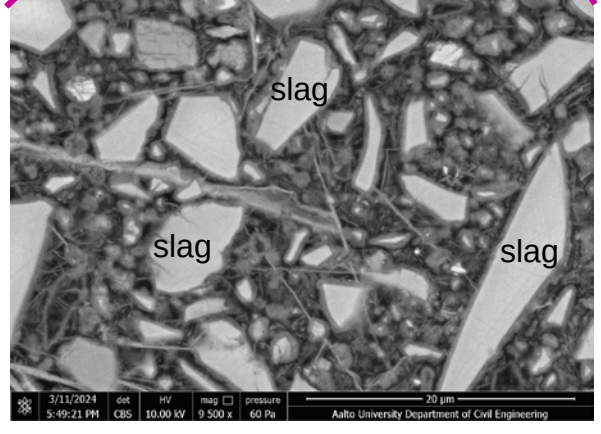
SEM – 1 day of hydration

CEM III/B

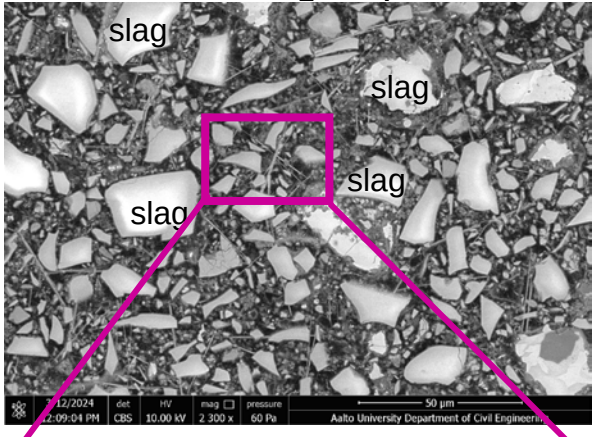


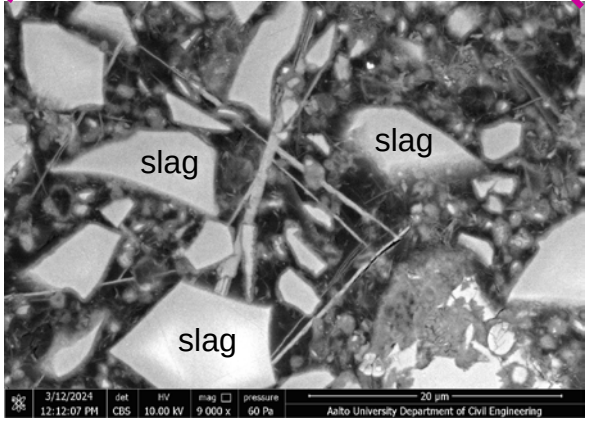
CEM III/B
1 % NaOH
3 % Na_2CO_3





CEM III/B
1 % NaOH
3 % Na_2CO_3
2 % Na_2SO_4





Alkali activation enhances formation of hydrates:

- Decrease in pores and $Ca(OH)_2$
- Formation of needle-like hydrates (AFm/AFt)
- Hydrates rim around slag

Alkali activation of blended concrete: CEM III/B (70% slag)

Iiro Vähälä Master thesis

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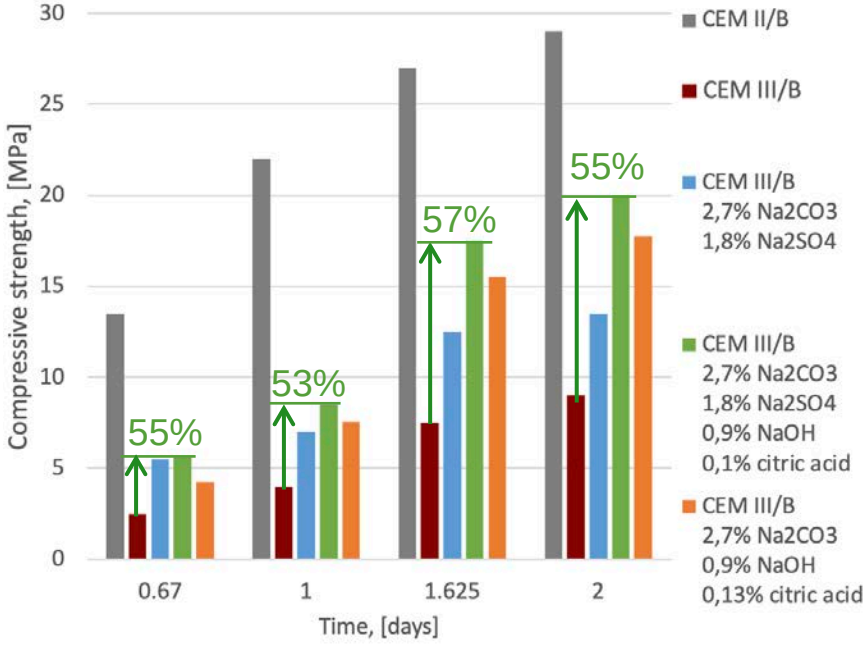
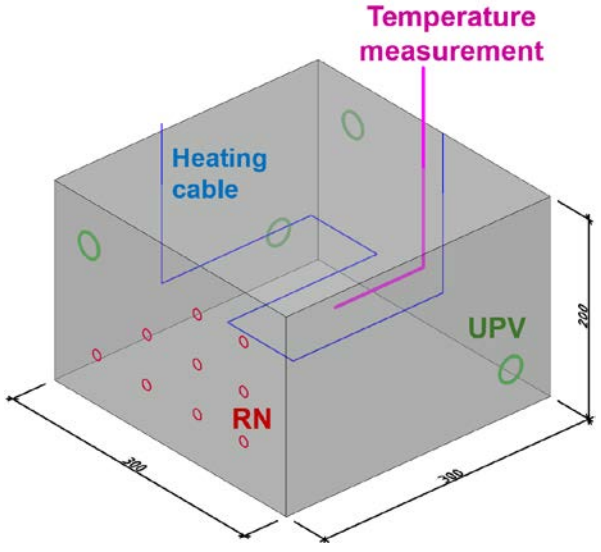
Activation of CEM III/B concrete

- Chemical combinations were optimized to ensure workability of concrete





- Both thermal and chemical activation were used to accelerate CEM III/B to the levels of CEM II/B

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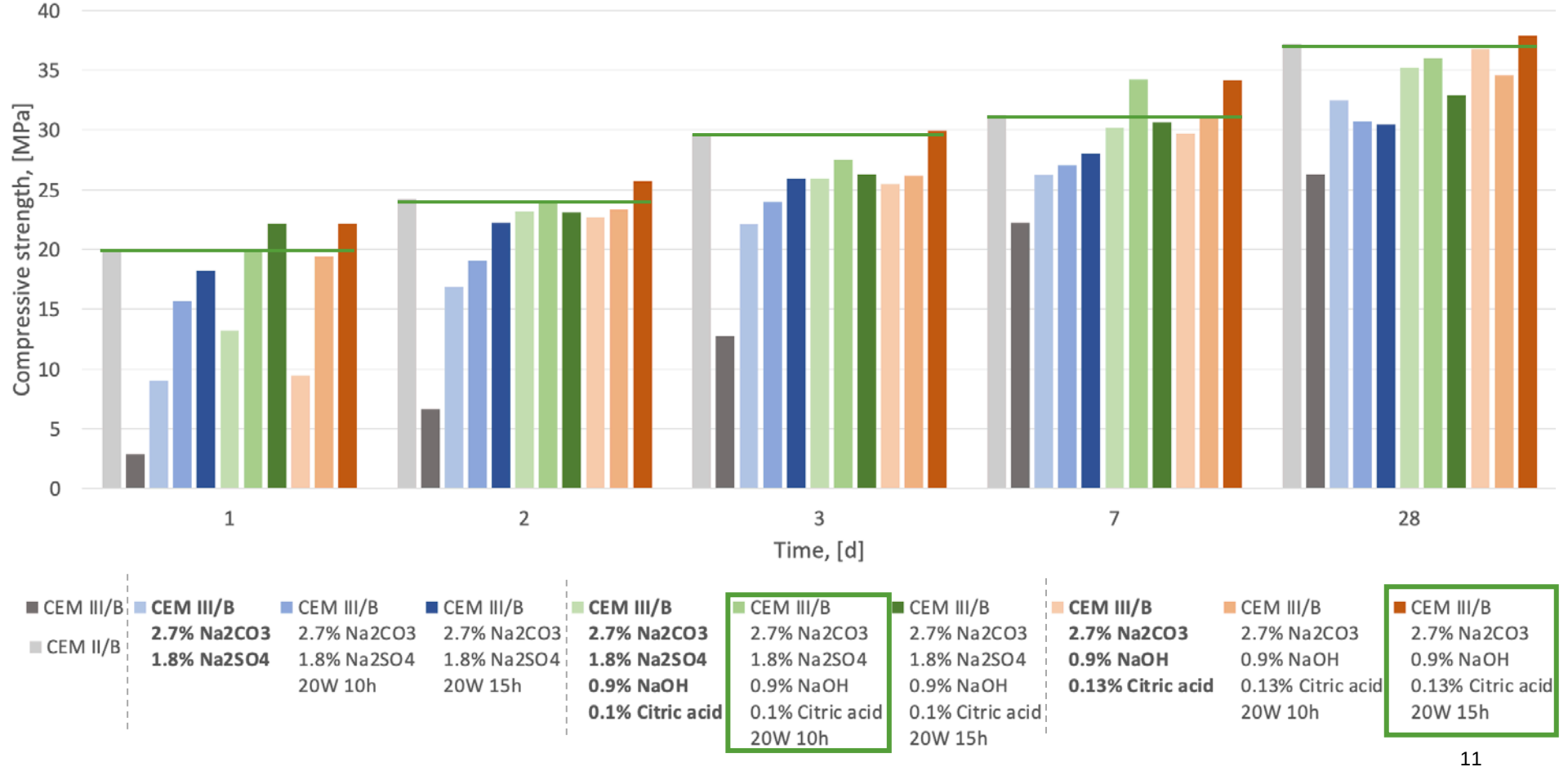
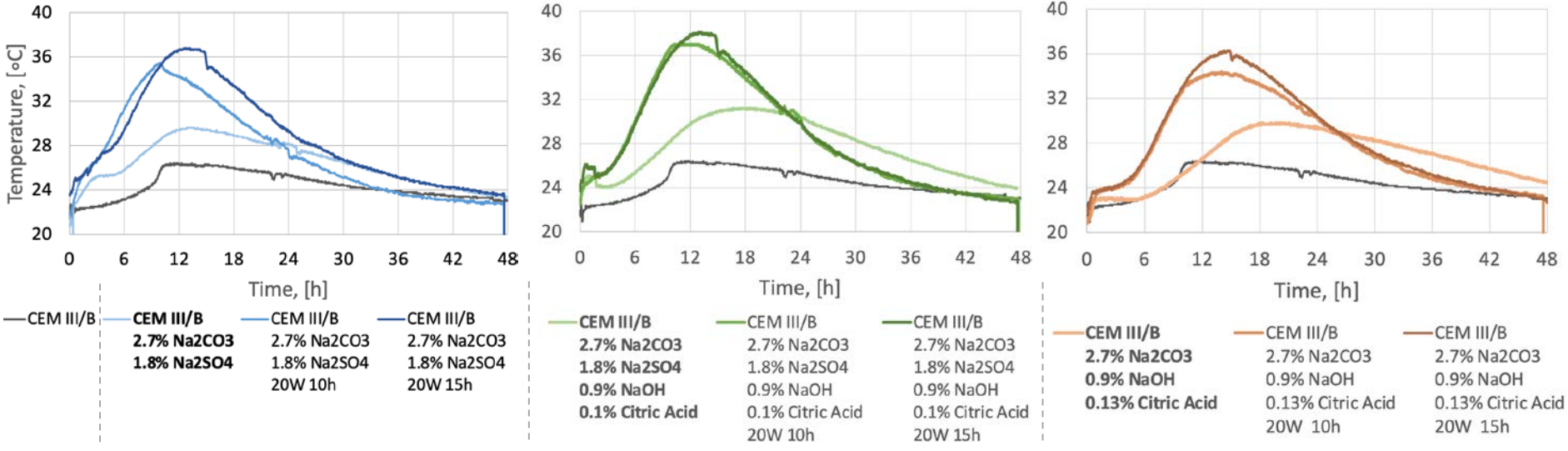
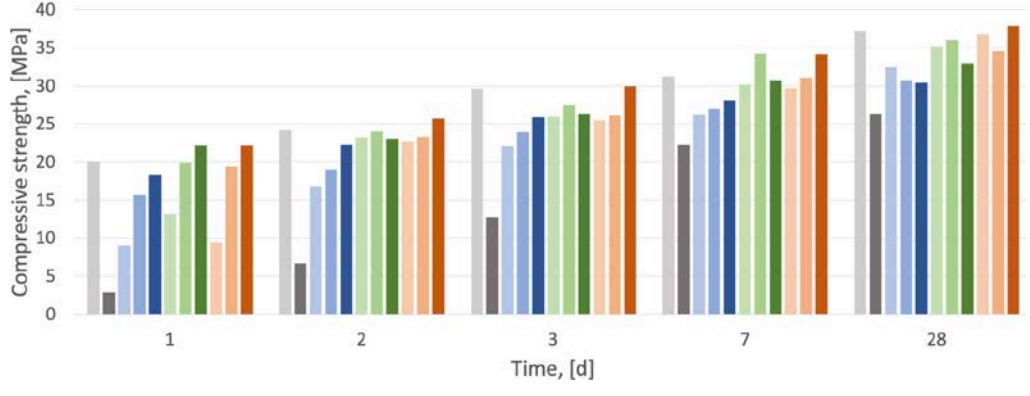
CEM III/B: thermal + chemical activation



CEM III/B: thermal + chemical activation

Effect of heating on actual temperature of hydration:





- Quarts was used instead of CEM III/B in mix design to evaluate the temperature rise generated by heating.
- The heating temperature was subtracted from ones measured for each mix design → actual hydration temperature was obtained.

Results and targets

Target: Accelerate early strength of concrete with 40% (CEM III/A) and 70% (CEM III/B) slag to the levels of CEM II/B (Oiva).

Results:

- with CEM III/A the target can be achieved using:
  - Chemical activation - *1% Na_2SO_4*

- with CEM III/B target is more challenging:
  - Chemical activation alone is not enough.
  - Combining thermal activation and complex combination of chemical activators gives the same early strength as CEM II/B:
    - *2.7% Na_2CO_3 + 1.8% Na_2SO_4 + 0.9% NaOH + 0.1% Citric acid + 20 W 10 hours (11.1 kWh/m3)*
    - *2.7% Na_2CO_3 + 0.9% NaOH + 0.13% Citric acid + 20 W 15 hours (16.7 kWh/m3)*

Research continuation

- **Ekaterina Illarionova doctoral research:**
  - Understanding chemical processes behind the alkali activation of cement binders with latent hydraulic (different slags) and pozzolanic (ashes) materials.

- **Valtteri Närhi master thesis:**
  - Effect of alkali activation on durability properties (carbonation, shrinkage, capillary suction) of low carbon concrete.

Thank you for your attention!

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