Sustainable and Innovative Cementitious Materials

The Role of Materials Science and Engineering

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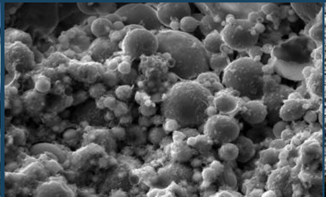



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Questions to discuss

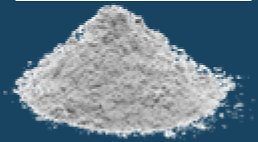
- Are **cement and concrete** regarded as un-sustainable material?

- How does materials science drive **sustainability and innovation** in cementitious materials?

- How can Life Cycle Assessment (LCA) be improved for better **sustainability analysis**?

Topic

Cement



Water

Aggregate

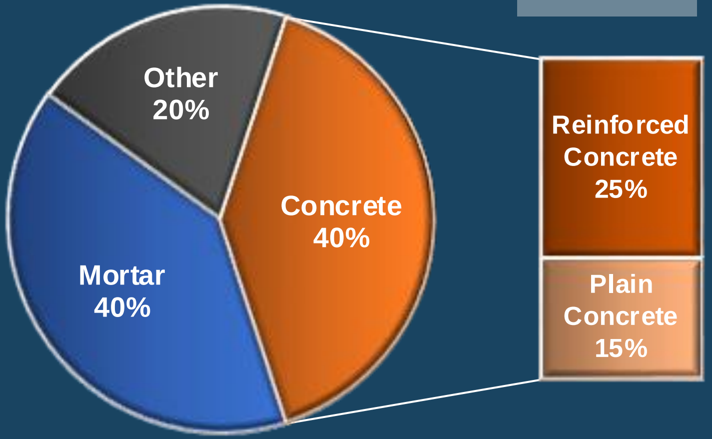
Set (harden) when mixed with water and bind other materials

Concrete

Steel Rebar

Reinforced concrete

Improved tensile strength



Where is it used then otherwise?

Mortars, soil blocks,....

Scrivener, K. L., et al. (2018). Cement and Concrete Research.

History

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Modern societies

Worldwide solutions

Infrastructure requirements

Standards and norms

500 AD

Romans developed a superior form of cement known as "pozzolana," made from volcanic ash and lime, which contributed to the construction of iconic structures like the Colosseum and the Pantheon.

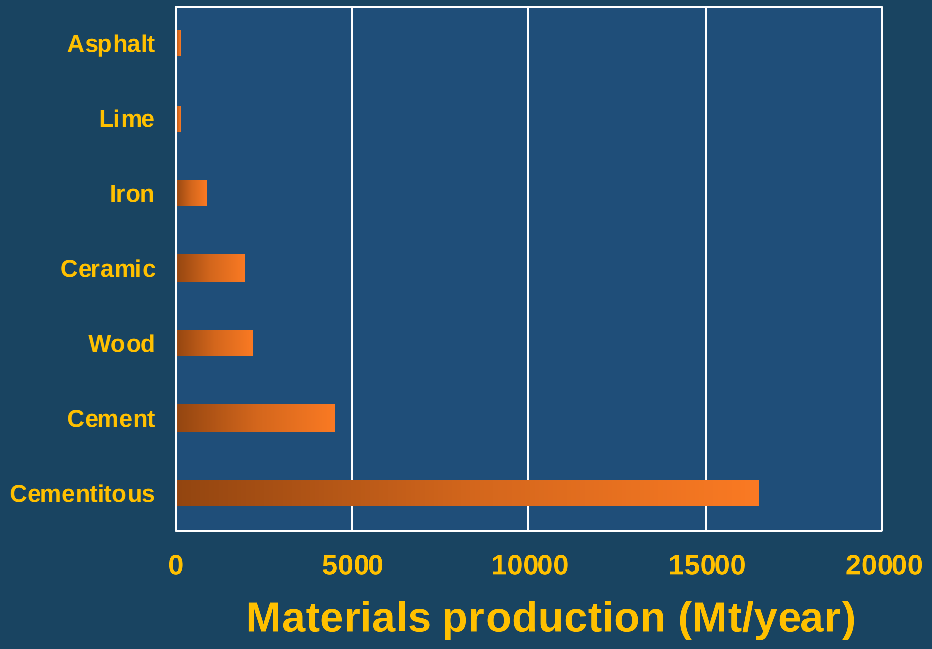
In 1824, Joseph Aspdin patented Portland cement, named after the limestone quarries of Portland, England. This marked the beginning of modern cement production.

1824

Relevance

Why such a topic has a relevance in our society?

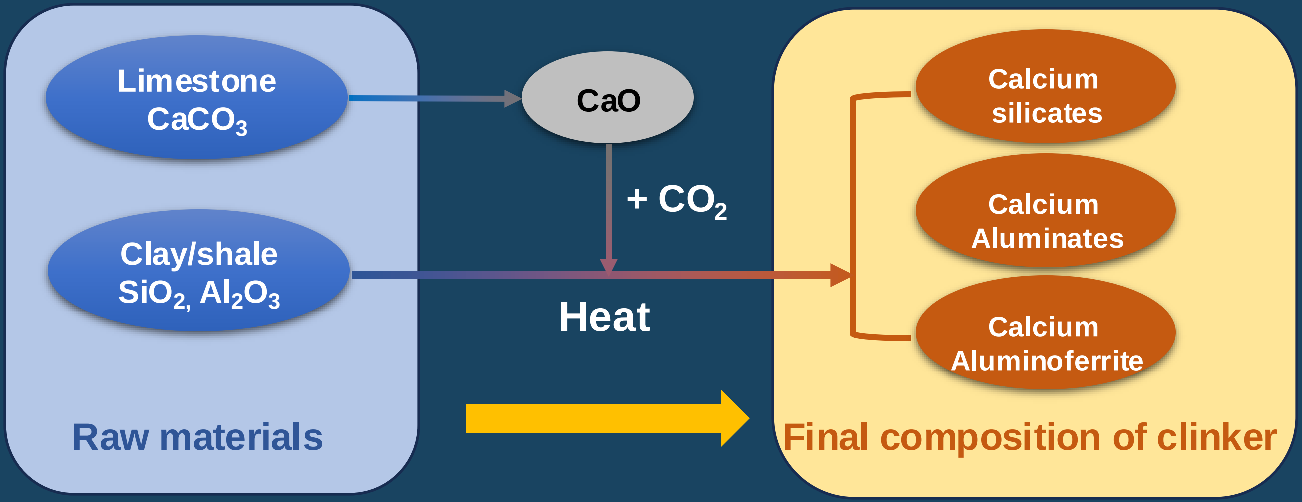
- In 2015, the total mass of cement produced was equivalent to a value higher than the amount of **human food consumption**.
- Cementitious materials are the **second most used substance** in the world after **water.**
- Availability of other materials is not to the level of answering cement needs



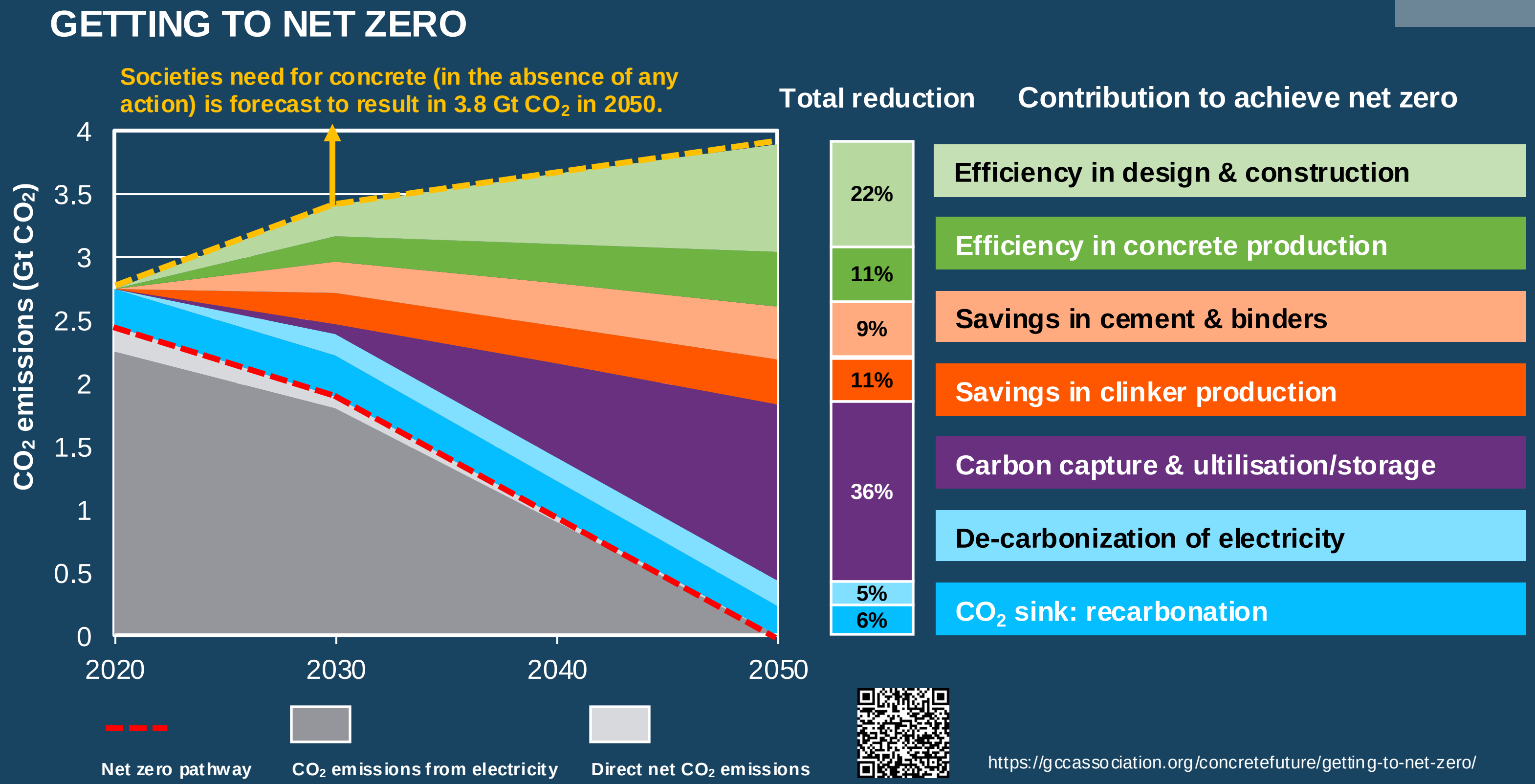
Scrivener, K. L., et al. (2018). Cement and Concrete Research.

Sustainability

- Total global CO_2 emissions from the sector today are in excess of 2.5 Gt (**8% of total emissions**).
- In its Green Deal published December 2019, the European Union sets out its ambition for Europe to be the first **climate neutral continent by 2050**.

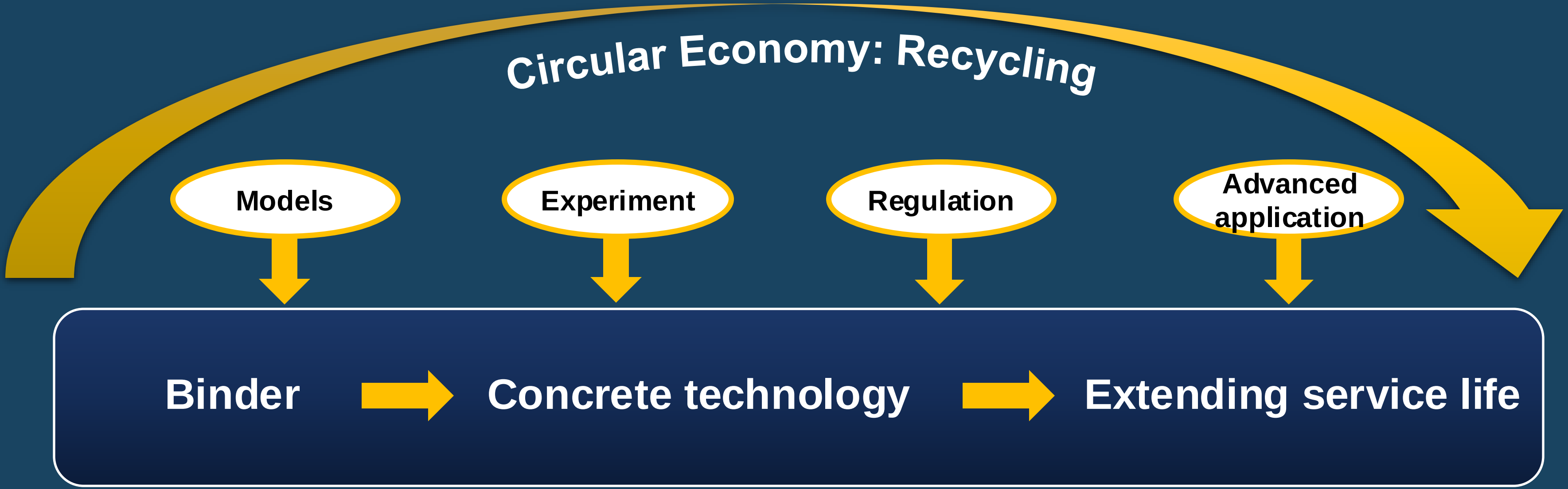


Solution for new production



https://gccassociation.org/concretefuture/getting-to-net-zero/

Focus areas


Circular Economy: Recycling
Models
Experiment
Regulation
Advanced application
Binder
Concrete technology
Extending service life

Focus areas

Supplementary cementitious materials (SCM)

Portland cement clinker → Process optimization CO_2 (↓ CCS/CCU) → SCM / Clinker → Hydration H_2O → Calcium silicate hydrates

Alternative cements

			Hydration H_2O	
Supersulfated cement	Granulated blast furnace slag +$CaSO_4$+ alkline activator	SSC	*Calcium silicate hydrates*; *Calcium sulfo-aluminate hydrates (Ettringite)*	*Very low*
Belite Ye'elimite Ferrite cement	Made from up to 100% recycled industrial waste	BYF-BCSA	*Calcium sulfo-aluminate hydrates (Ettringite)*; *Calcium silicate hydrates*	*Very fast*
MgO-based cement	MgO+H_2O+different salts	MgO cement	*Magnesium Silicate Hydrate*	*Durability issues*

Focus areas

Possibilities

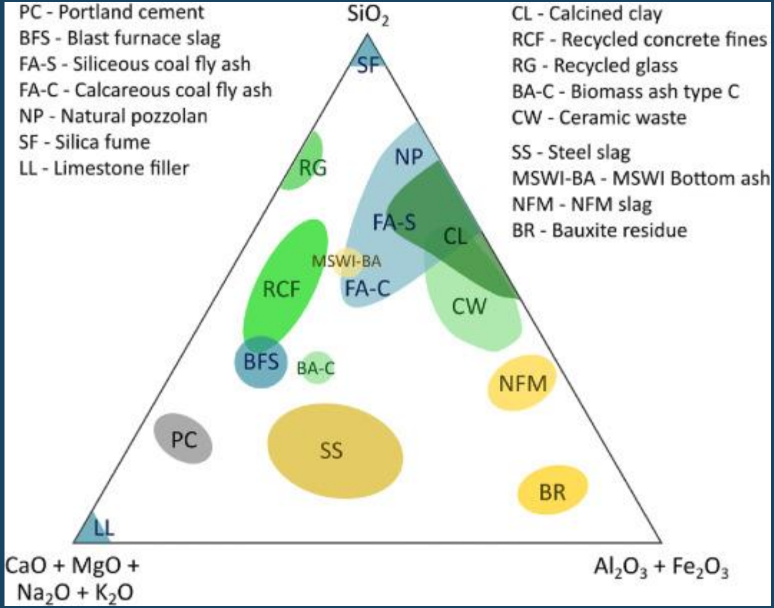
Available oxides in earth crust

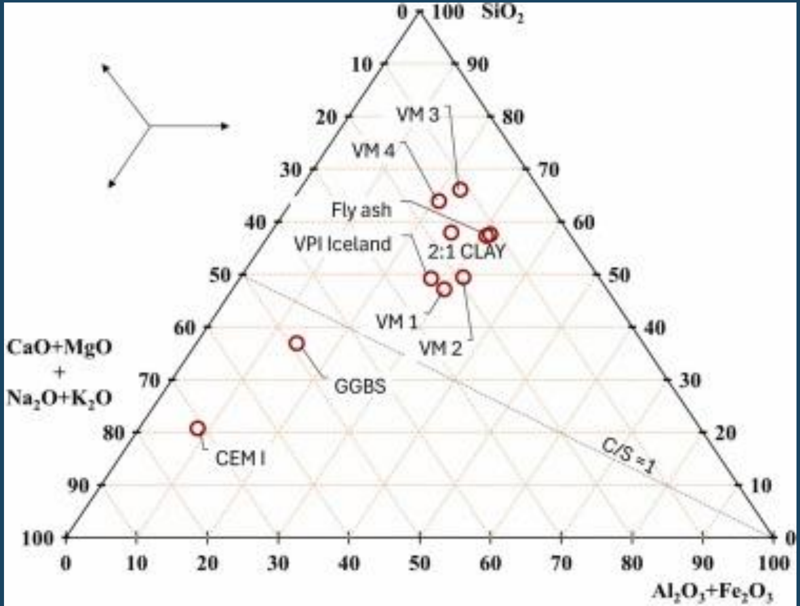
SiO_2, Al_2O_3

Na_2O, K_2O Fe_2O_3, MgO

soluble?

low mobility?



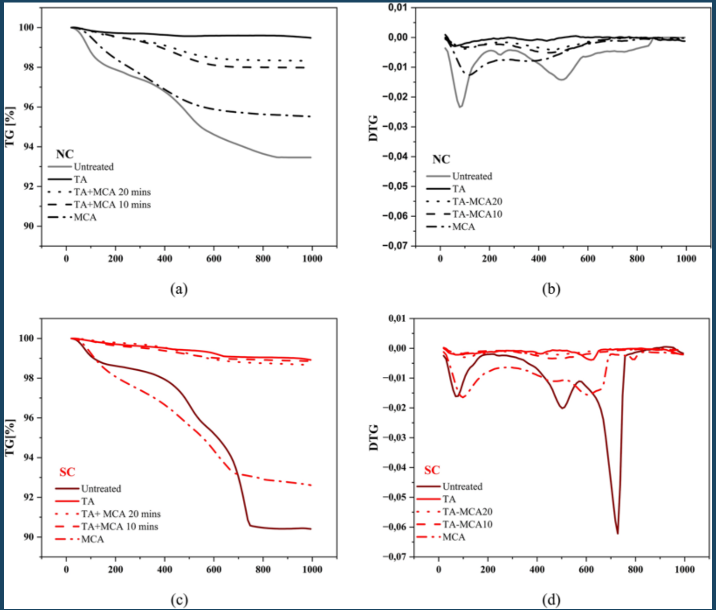


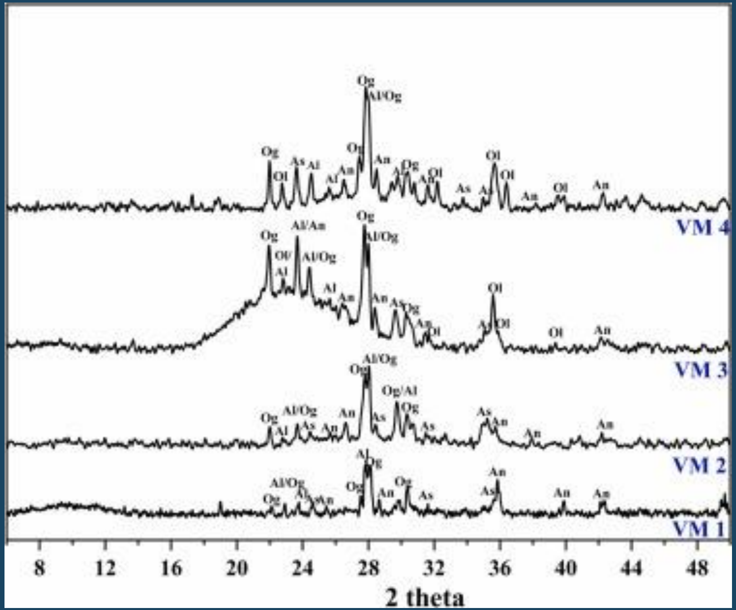
Snellings, R., et al. (2023). Cement and Concrete Research.
Hazarika, A., et al. (2025). Case Studies in Construction Materials.

Materials Science

Composition | Activation | Reactivity | Simulation | Hazardousness

Chemical composition and Mineralogy



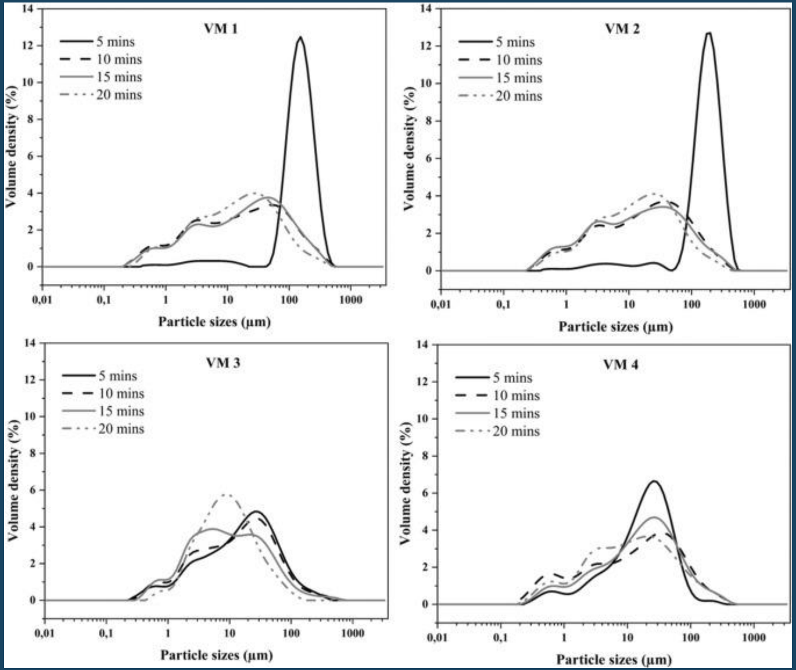


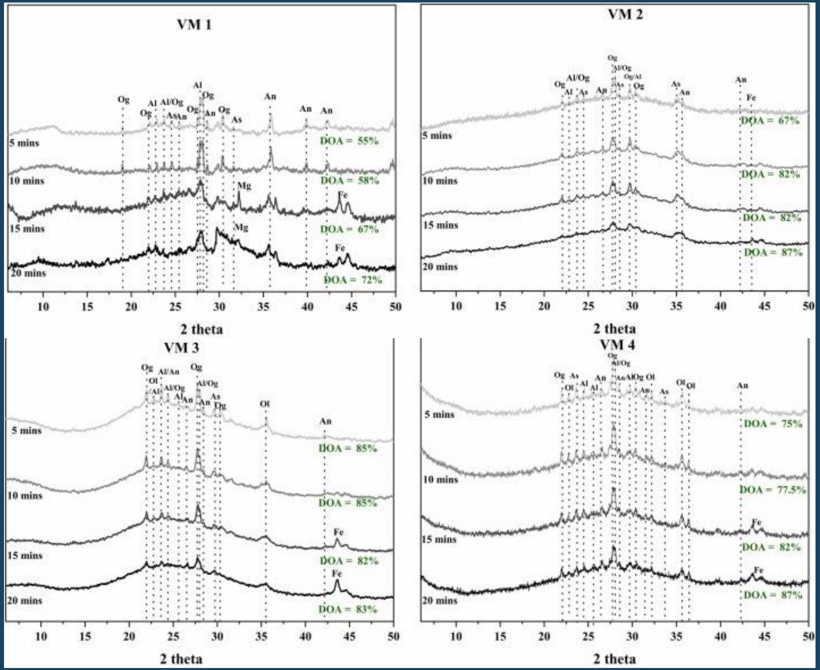
Hazarika, A., et al. (2024). Materials and Structures.
Hazarika, A., et al. (2025). Case Studies in Construction Materials.

Materials Science

Composition | **Activation** | Reactivity | Simulation | Hazardousness

Particle engineering





Hazarika, A., et al. (2025). Case Studies in Construction Materials.

Material Science

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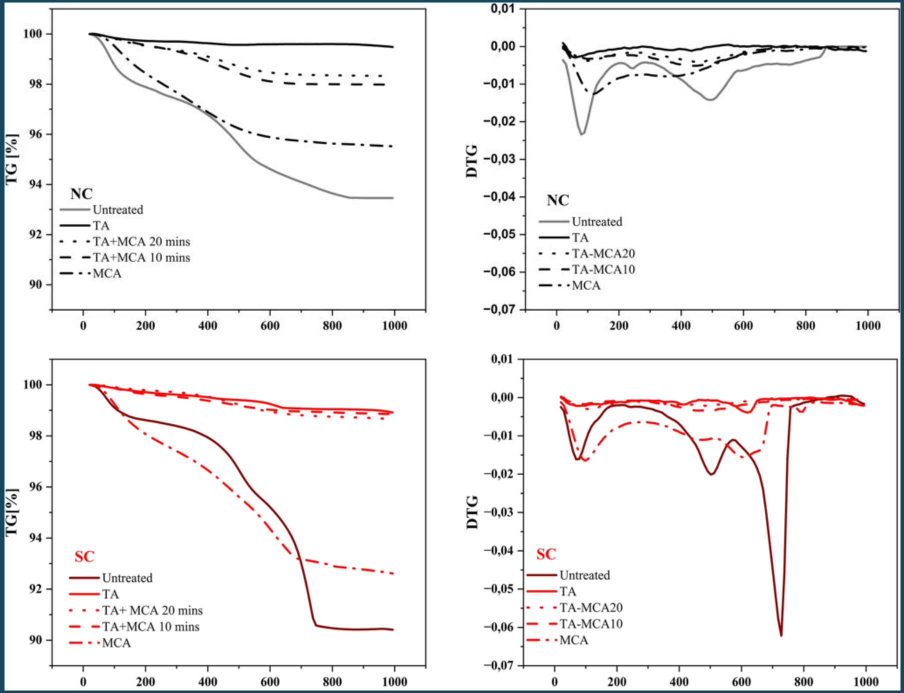
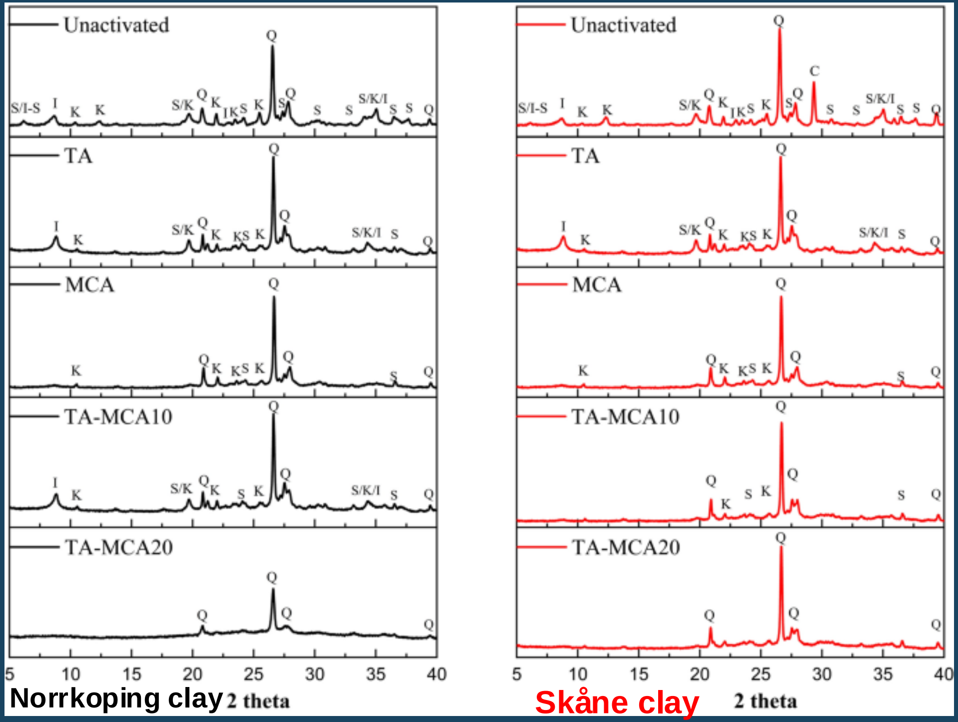
Composition | **Activation** | Reactivity | Simulation | Hazardousness

Thermal treatments



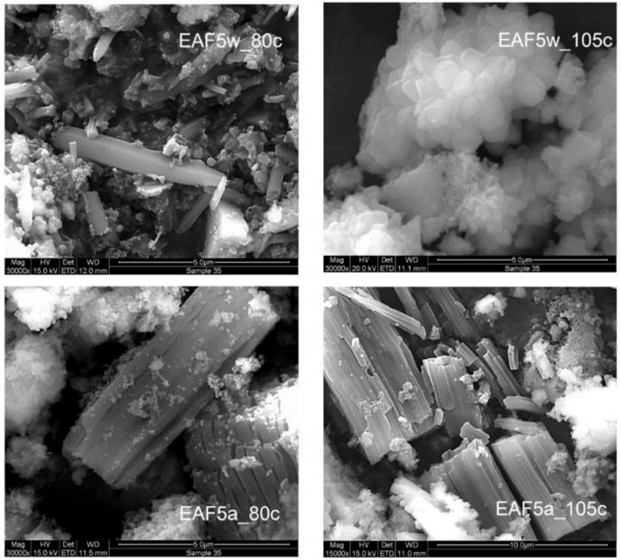


Hazarika, A., et al. (2024). Materials and Structures.

Material Science

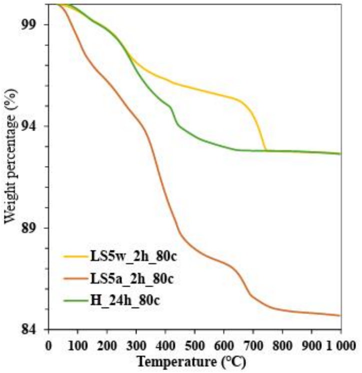
Composition | **Activation** | Reactivity | Simulation | Hazardousness

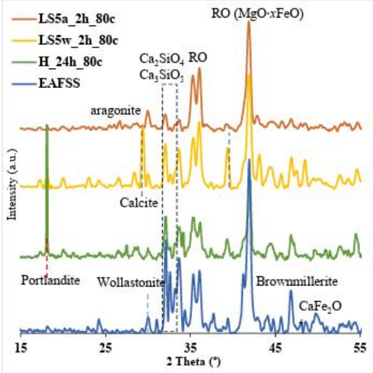
CO_2 mineralization

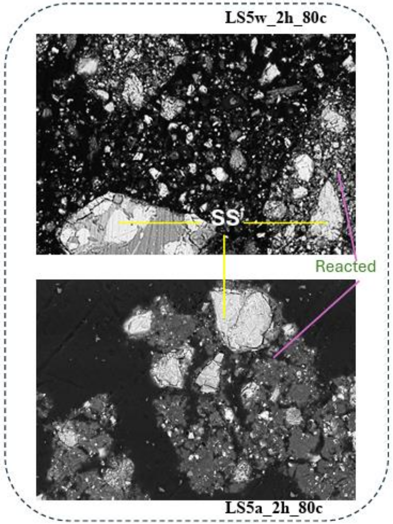


Chemical composition of EAF slag

Chemical composition	Fe_2O_3	CaO	SiO_2	MgO	MnO	Al_2O_3	Cr_2O_3	TiO_2	SO_3	P_2O_5	V_2O_5	Nb_2O_5
Weight percent	37.70%	29.10%	9.71%	6.32%	6.20%	4.92%	2.24%	0.40%	0.35%	0.30%	0.20%	0.12%



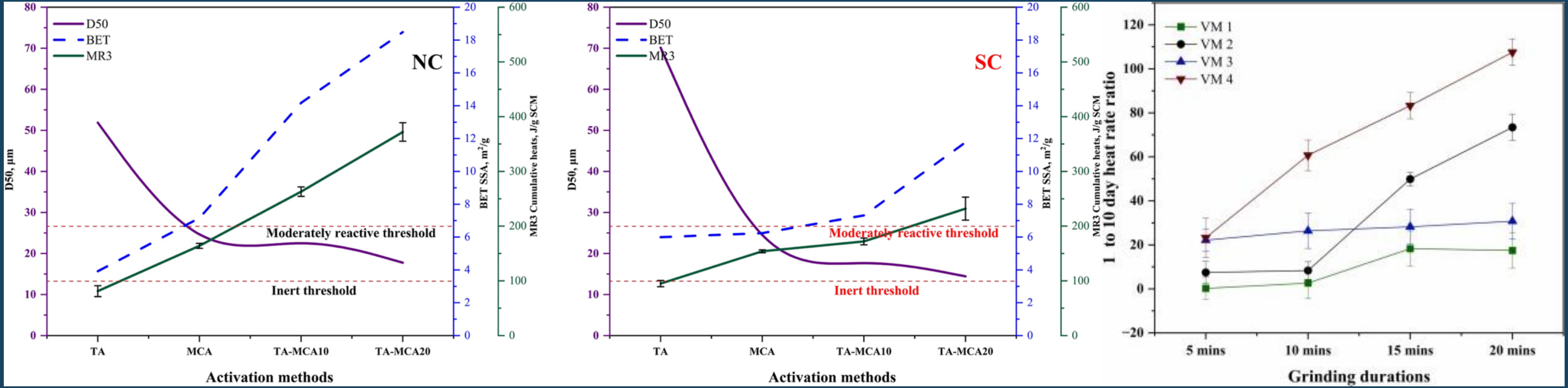




Material Science

Composition | Activation | **Reactivity** | Simulation | Hazardousness

Hydration Kinetics



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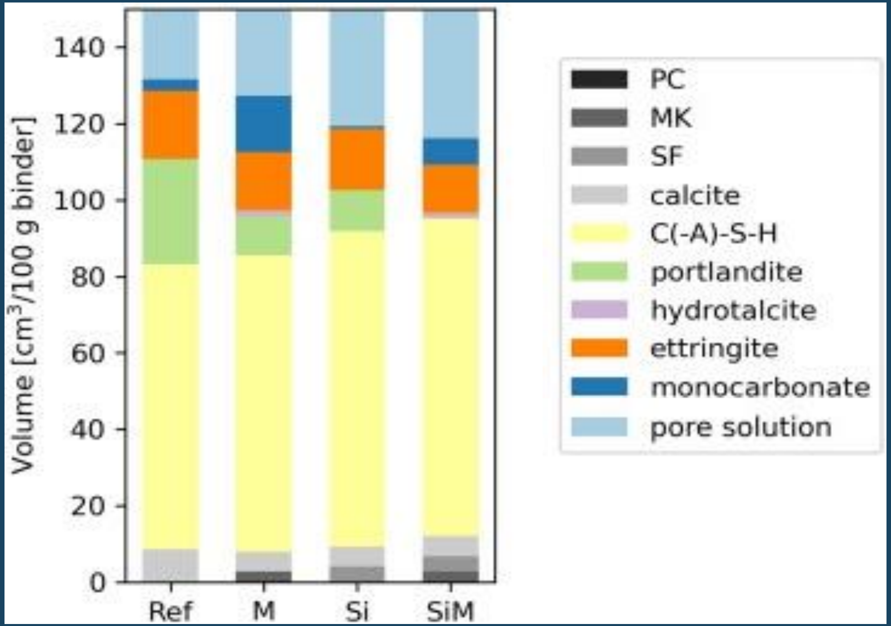
Hazarika, A., et al. (2025). Case Studies in Construction Materials.

Material Science

Composition | Activation | **Reactivity** | Simulation | Hazardousness

Thermodynamics

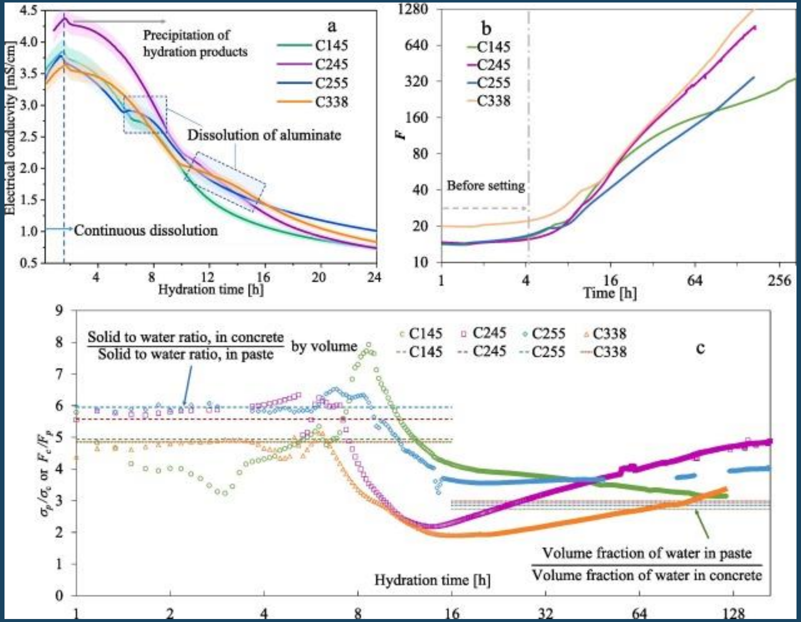


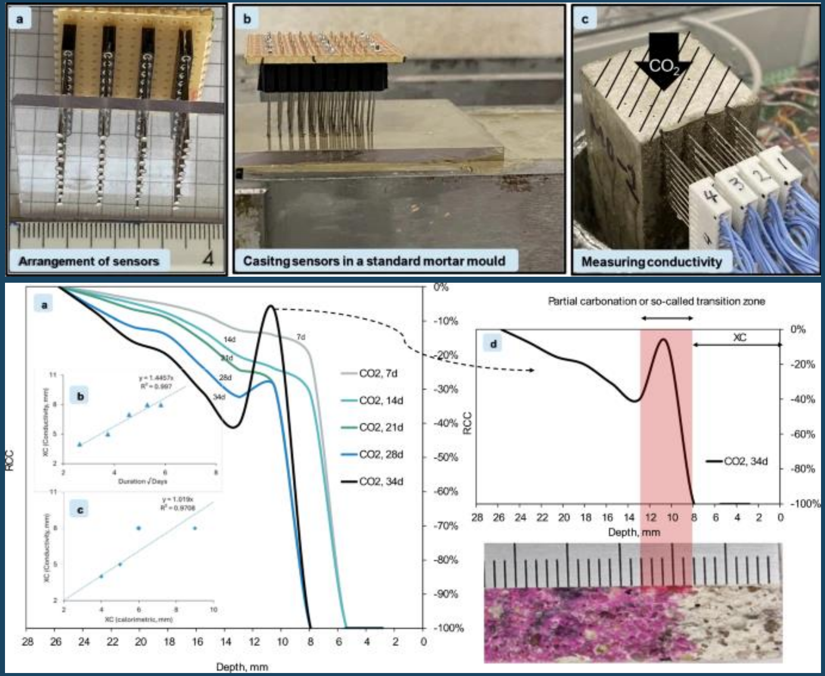
Babaahmadi, A., et al. (2022). Cement and Concrete Research.

Material Science

Composition | Activation | Reactivity | **Ageing** | Hazardousness

Development of test-methods



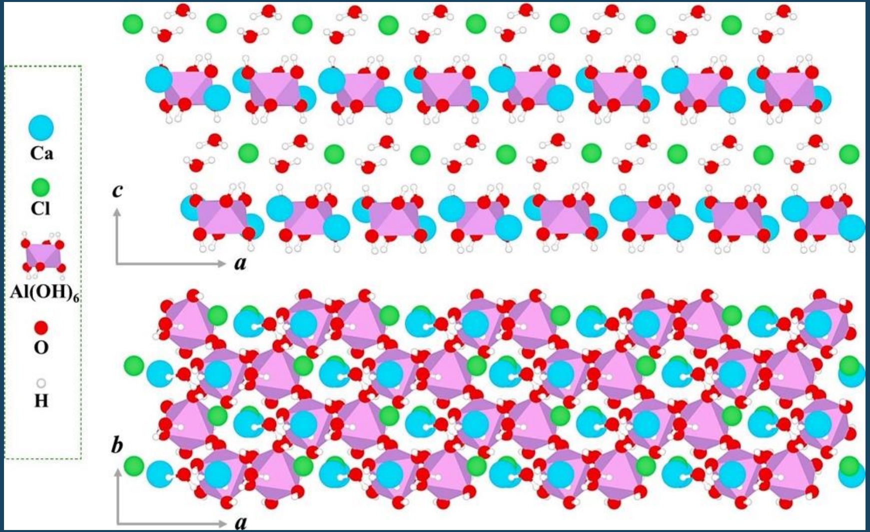


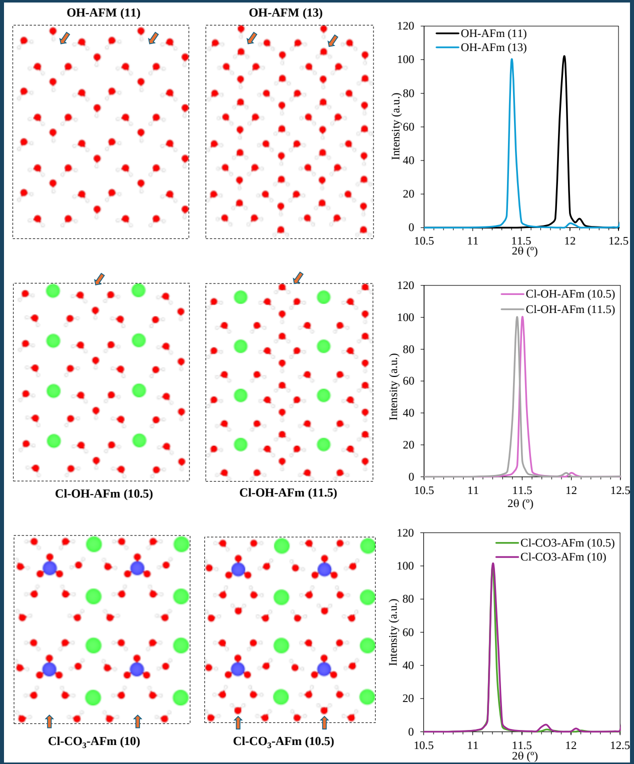
Huang, L., et al. (2023). Construction and Building Materials.
Babaahmadi, A., et al. (2025). Materials and Structures.

Material Science

Composition | Activation | Reactivity | **Ageing** | Hazardousness

Physical and Chemical Changes



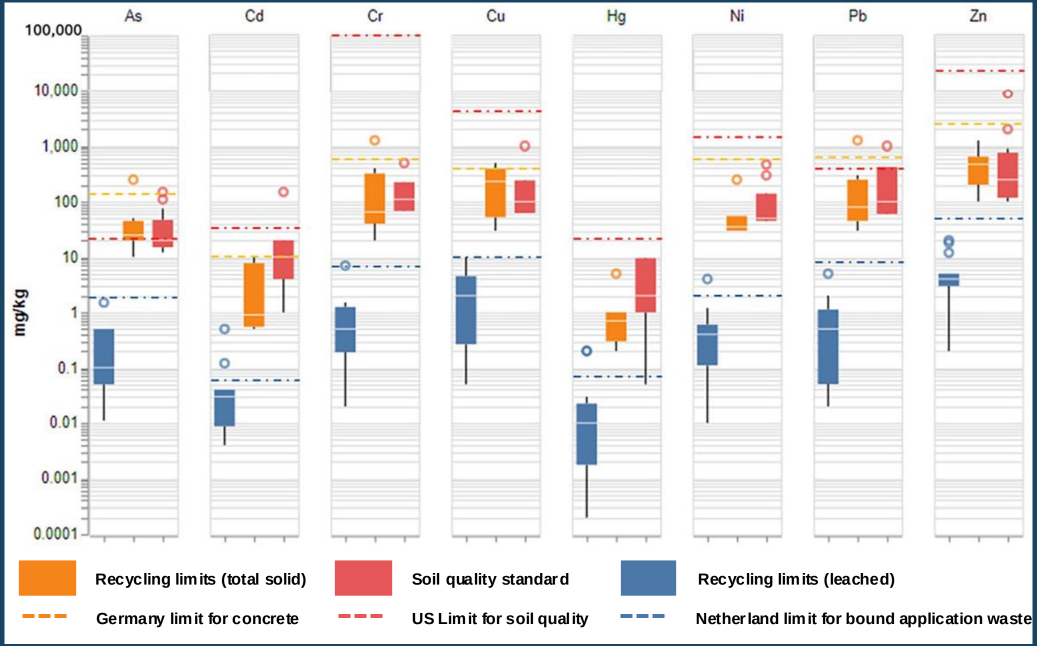


Huang, L., et al. (2025). Cement and Concrete Research.

Material Science

Composition | Activation | Reactivity | Simulation | **Hazardousness**

End of waste criteria and test methods

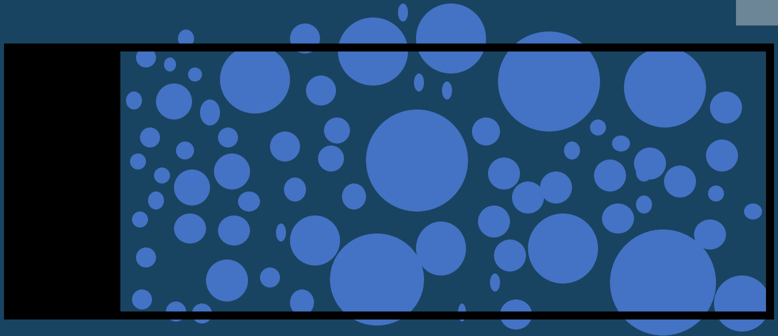


Armistead, S. J. and A. Babaahmadi (2024). Waste Management & Research.

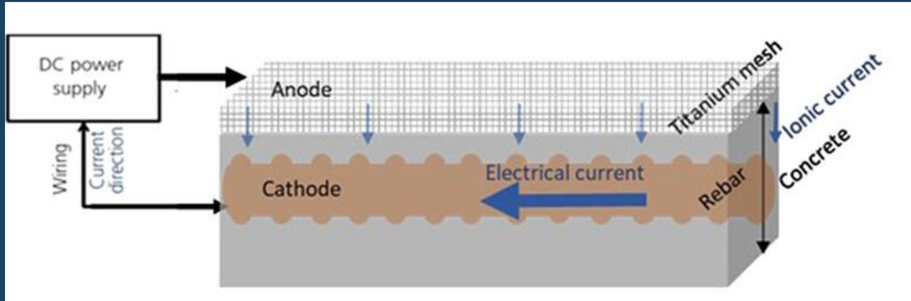
Focus areas

Concrete Technology

- **Fresh properties**
  - Mix design
  - Admixtures
- **Upscaling paste/mortar to concrete**
  - Pore structure changes
  - Modifications in construction
  - Moisture profile/Shrinkage
  - Heat of hydration/thermal cracks
- **Recycling**
  - Recycled and carbonated concrete aggregate
- **Innovative applications**
  - geopolymers
  - 3D printing
  - **Smart applications**



Reconstructed with inspiration from: Scrivener, K. L., et al. (2004). "The Interfacial Transition Zone (ITZ) Between Cement Paste and Aggregate in Concrete." Interface Science **12**(4): 411-421.



Jansson, H., et al. Materials and Corrosion.

Focus areas

Extended Service-Life

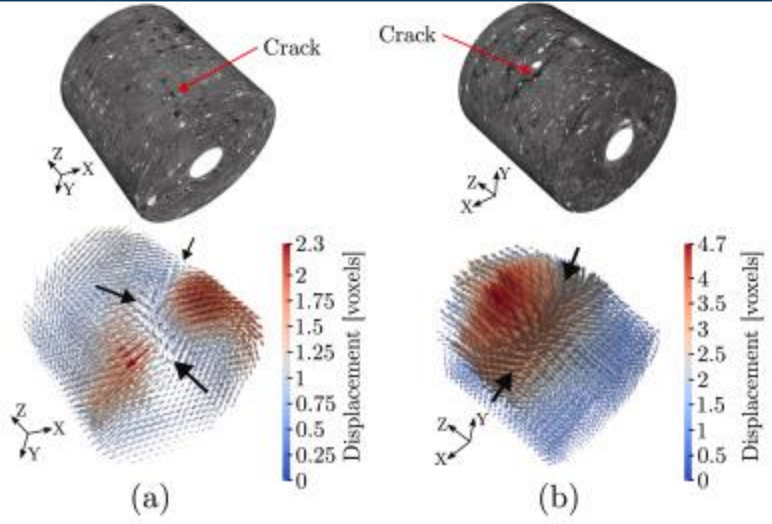
- Steel Corrosion & Matrix Damage:
- Crack Formation & Propagation
- Volumetric Expansion of Corrosion Products
- Transport of Corrosion Products:

✓ **Use of Advanced Imaging (XCT & NCT)**

Non-destructive techniques provided insights into damage progression, aiding predictive durability models.

✓ **Implications for Service Life Modeling**

The study provides crucial data for corrosion modeling, essential for maintenance strategies and extending infrastructure lifespan.



Alhede, A., et al. (2025). Cement and Concrete Research.

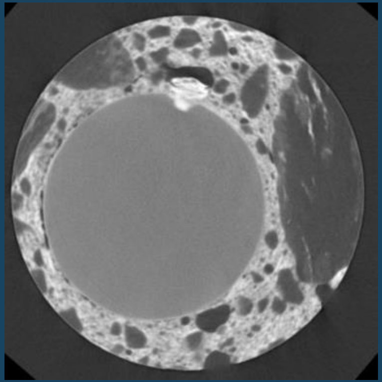
Focus areas

Extended Service-Life

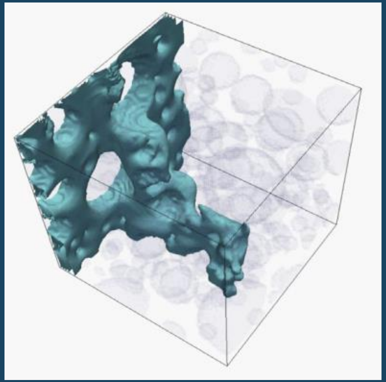
Low carbon binders?

Concrete technology?

→ Materials for the infrastructure of tomorrow



Experimental characterization
Neutron tomography of a rebar with a corrosion pit (white) in concrete



Modelling
Mesoscale model of chloride ingress in cracked concrete

PI: Karin Lundgren
Co-Pi: Arezou Baba Ahmadi
Jelke Dijkstra
PhD candidate: Talles Felix

Focus areas

LCA

Primary data | **Functional unit** | **Boundaries**

Optimize particle engineering

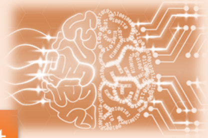
Integrate alternative feedstocks

Processing

Build database

Machine learning

Functional unit



Feedstock

Low reactivity

Leaching risk

Binder

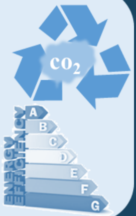
Hydration kinetics

Environment safety

LCA

Energy efficiency

Carbon footprint



Conclusions

- Material research is a major key towards a future sustainable built environment.
- Importance of involvement of industry but also policy makers.

Future insight

- Higher TRLs- field demonstration and lab to reality approach.
- From experimental observations to theoretical physiochemical fundamentals.
- Importance of Education.

Projects and cooperations

CHALMERS
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New-Dur-Cem

Formas

NTNU, RISE

Carbo-Crete

Family Thomas foundation
Geotechnics Research area

Concrete battery

Area of Advance Material
Chalmers Chemistry

2019 — 2020 — 2021 — 2022 — 2023 — 2024 — 2025

New-Soil-Bind

Vinnova
Easy mining, Halosep, VTI, Keller
Gothenburg Energy, Trafikverket,

SCM-Force I

Uppsala University, CemVision

PostNorm-SSC

Tillväxtvrket

CemVision, Vattenfall,

LKAB, RWTH Aachen

SCM-Force II

Formas

Uppsala University, NCC,
CemVision, Trafikverket

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Thanks for your attention

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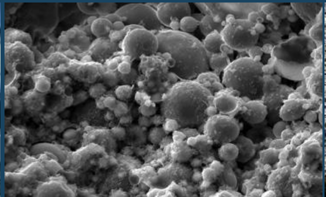



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