Geopolymer as alternative binder for concrete:

Opportunities and challenges

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Concrete Modelling and Materials Behaviour (cmmb)

Focuses on the modelling and design of cement-based materials for the use in concrete structures

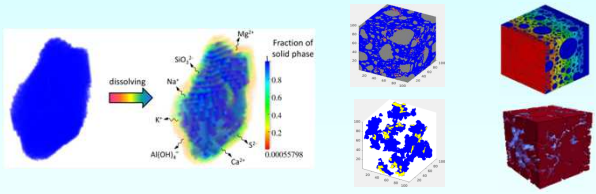
Materials behavior

Mixing and casting, the hydration process, volume changes, transport properties, time-dependent behaviour, durability and service life

Experiments on chemical reaction, characterization, creep and shrinkage

Concrete modelling

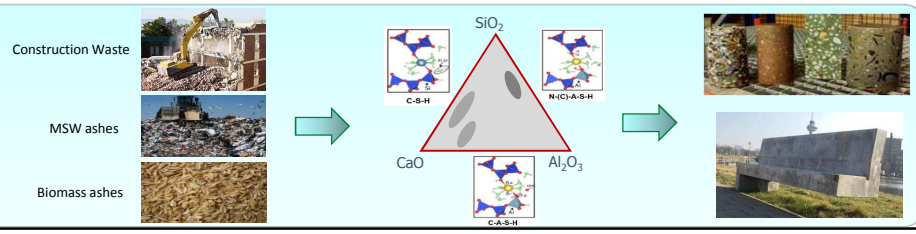
Concrete design based on fundamental materials laws, i.e., thermodynamics, nano-, microstructural development; modelling materials behavior based on multi-scale approach.



Reaction kinetics, thermodynamics, microstructure formation, degradation and transport

Alternative binders for concrete

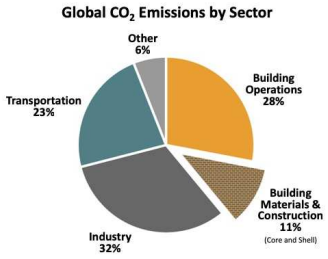
Industrial by-products, wastes to be used as supplementary cementitious materials or alternative binders in concrete.



Opportunities

- In EU level, 40% CO_2 reduction by year 2030
- In the Netherlands CO_2 neutral by year 2050

- Buildings generate nearly 40% of global CO_2 emissions



Cement industry

- Massive natural resource consumption
- 5% - 8% global CO_2 emission and high energy consumption

Reduce CO2 emission in building materials

➡ **Alternative binders for concrete**

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Source: Global alliance for building and construction 2018 GLOBAL STATUS REPORT

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Opportunities

Alkali-activated materials (AAM) are considered as alternative binder for concrete

- ❑ ***AAM*** produces less CO_2
- ❑ ***AAM*** consumes less energy
- ❑ ***AAM*** promotes utilization of industrial by-products and reducing waste materials

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By-products as precursors

Precursors

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Alternative Binder for Concrete: Geopolymer Concrete

Precursors

Alkali activator

Water

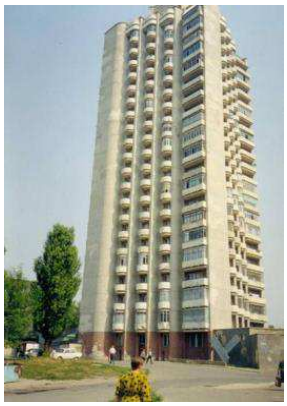
Aggregates

Concrete without OPC

- High strength
- Good durability
- Good fire resistance

Opportunities - experiences

- Russia



The first residential building made of BFS alkali-activated concrete
20-storey residential building, Lipetsk, 1987-1989

Pre-stressed railway sleepers
From Moscow to ST. Petersburg, 1989

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Photo by Ana Fernández-Jiménez

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Opportunities - experiences

- Precast panels, Australia

The building is the first public building with structural Geopolymer Concrete: The University of Queensland's Global Change Institute, 2013

Alkali activated fly ash and BFS concrete. - 3 suspended floors, made of 33 precast panels (10.5 m x 2.4 m)

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https://gci.uq.edu.au/world-first-structural-use-of-earth-friendly-concrete

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Opportunities - experiences

- Geopolymer concrete floors, The Netherlands

Acid-resistant concrete floor in a milk factory in Gorinchem, 400 m^3 geopolymer concrete (C53/C60) from Van Nieuwpoort Betonmortel was casted, 2015

http://www.innovatievematerialen.nl/index.php/Eerste_grootschalige_toepassing_geopolymeerbeton?id=241

Problems/challenges in using geopolymer concrete in engineering practise

- Insufficient raw materials for geopolymer concrete production.
- Limited knowledge about the materials related properties of geopolymer concrete.
- **Large scatter in material properties when geopolymer concrete made of different kind of precursors and activators.**
- Lack of information on short-term and time-dependent structural behaviour of reinforced geopolymer concrete, and long term behaviour (durability of structural components, mainly corrosion and freeze/thaw actions)
- No regulation/standard with regarding to the geopolymer concrete mix design, the fresh, hardened properties and the durability design of geopolymer concrete as structural materials.

Geopolymer Concrete Research in TU Delft

Aim: to promote geopolymer concrete use as building materials for structural application

- New resources
- High value building materials
- Degradation and durability
- Volume stability
- Structural application

Sustainable and Green Buildings

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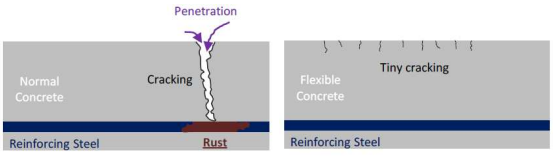
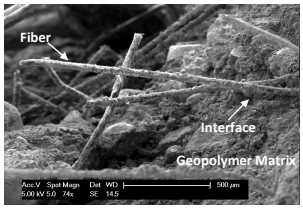
Strain-hardening Geopolymer Composite (SHGC)

Concrete made flexible and sustainable

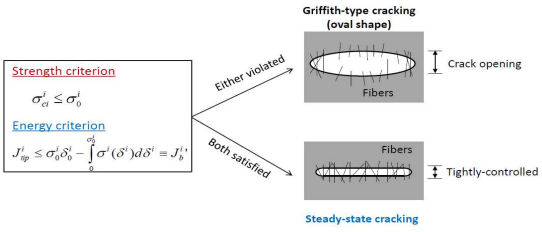


Localized damage

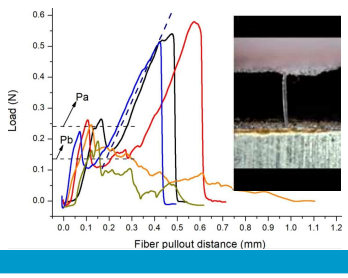
Distributed damage

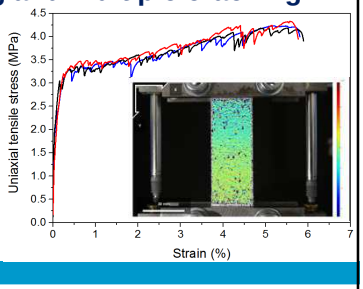


Micromechanics-guided mixture design



Strain-hardening and multiple cracking





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S. Zhang et. al, Submitted to CCC, 2019

*NWO-NSFC project

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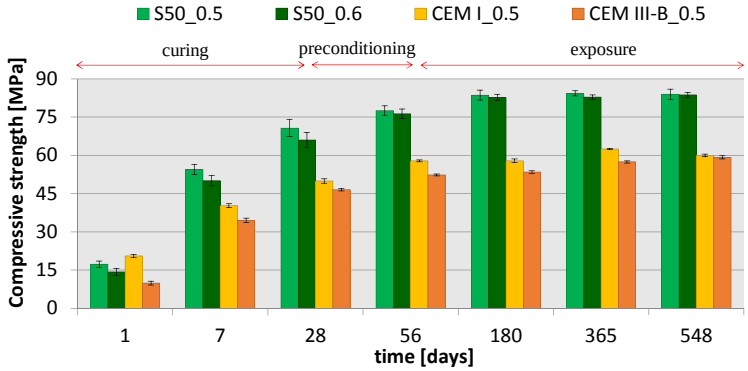
Degradation and durability of geopolymer concrete

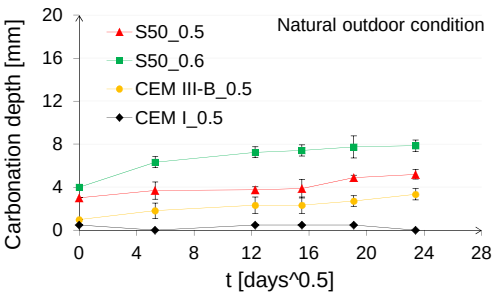
- Compressive strength development



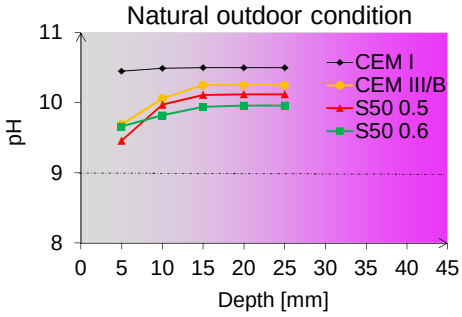
Compressive strength development in cement-based and alkali-activated concretes (samples (150×150×150 mm^3) were cured in the curing room for 28 days, preconditioned for additional 28 days (28-56 days) at 55% RH and then exposed to natural outdoor sheltered conditions (56-548 days)). (S50.0.5 = 50%BFS+50%FA, w/s 0.5 geopolymer concrete)

Degradation and durability of geopolymer concrete

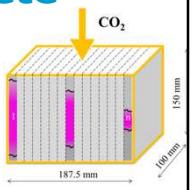
- Carbonation resistance



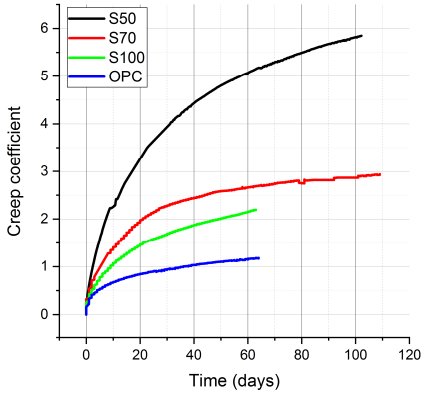
Carbonation depth versus time in natural outdoor (sheltered) carbonation conditions
(S50 = 50%BFS+50%FA)



pH along carbonation path measured after 548 days of exposure in natural outdoor (sheltered).
Pink colour indicates noncarbonated zone and grey colour indicates the carbonated zone.



Creep of Geopolymer Concrete

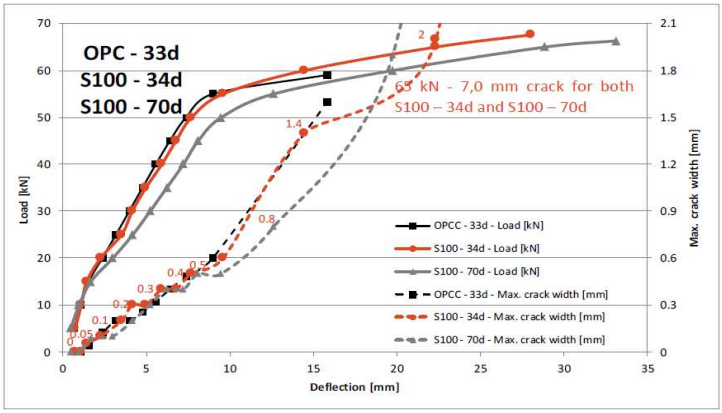


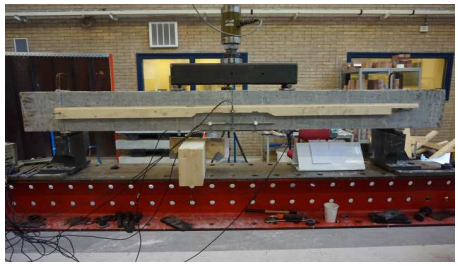
(S0 = 100%FA, S30 = 30%BFS+70%FA……., S100=100%BFS)

A. Kostiuchenko et al. (15th ICCC and 73th RILEM week, 2019)

*NWO project

Cracks and load-deflection behaviour





Four-point bending test

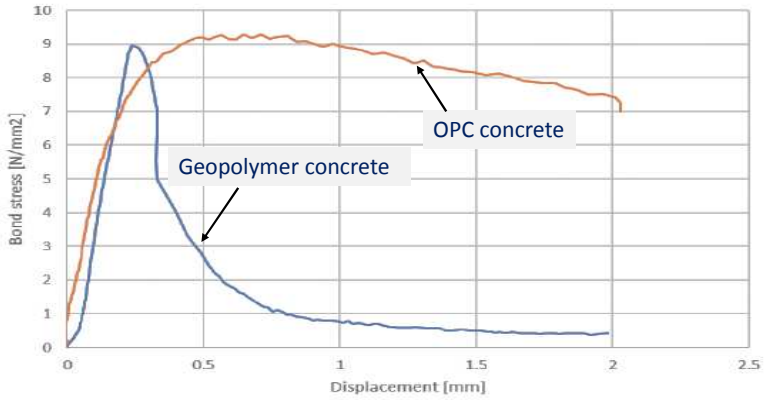
Alkali activated concrete
w/b=0.52,
S100 = 100% BFS

S. Prinsse, D. A. Hordijk, G. Ye, P. Lagendijk and M. Luković, Time-dependent material properties and reinforced beams behaviour of two alkali-activated types of concrete. Structural Concrete, 2019

*4TU project

Bonding properties Pull-out test

Geopolymer concrete shows more brittle than OPC concrete



Geopolymer concrete:
w/b = 0.45, 90%BSF and 10%FA

OPC concrete: w/c=0.52

Bonding properties Pull-out test

Geopolymer concrete failed due to splitting of concrete

Geopolymer concrete:
w/b = 0.45, 90%BSF and 10%FA

OPC concrete: w/c=0.52

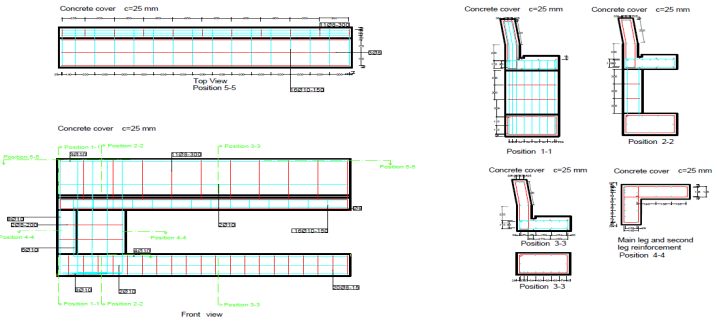
Low risk structural application

- To study the current design codes whether fit geopolymer concrete design, to demonstrate engineering application

Steel reinforced geopolymer concrete bench

Geopolymer concrete C50, 50%BFS+50%FA, NaOH +Na_2SiO_3 w/s = 0.52

Geopolymer concrete bench reinforcement design



Low risk structural application

Steel reinforced geopolymer concrete bench

Geopolymer concrete C50, 50%BFS+50%FA, NaOH +Na_2SiO_3 w/s = 0.52

The geopolymer concrete bench was placed at G.J. de Jonghweg, Rotterdam, the Netherlands

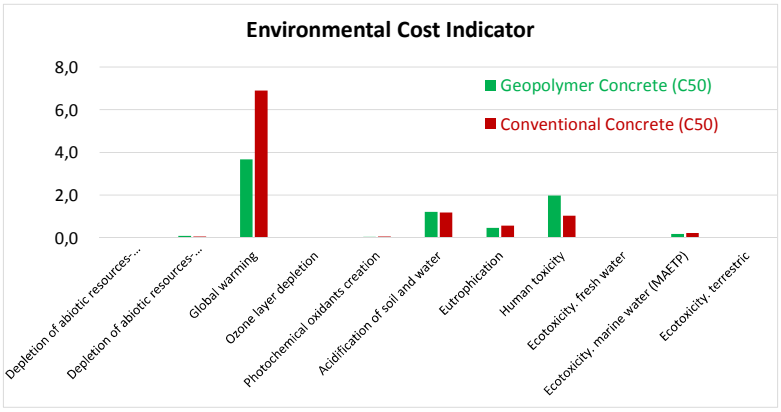
Place date: September 2017

Steel reinforced geopolymer concrete bench

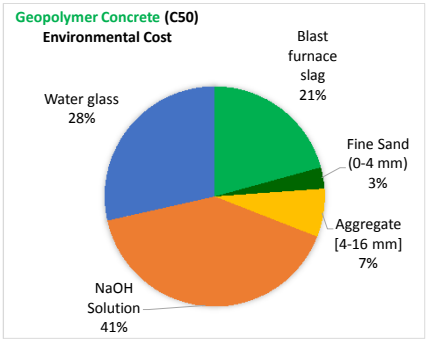
After half year exposure
Photo on 21 March 2018

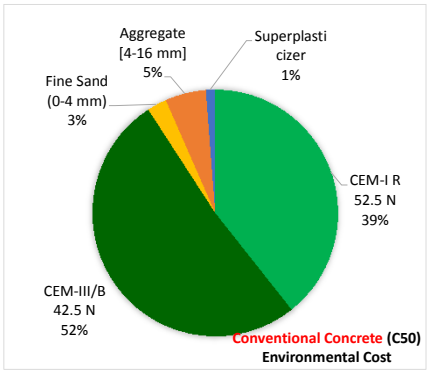
After two years exposure
Photo on 24 Aug 2019

Life cycle analysis



Shizhe Zhang 2019, unpublished data

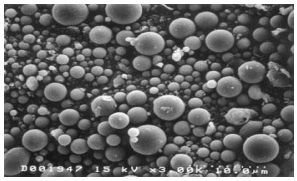




Prospects for the future

– Insufficient raw materials

We have to find alternative solution



Coal fly ash
Production: 1 Mt/yr in NL

Blast furnace slag
Production: is 0.35Mt/yr in NL

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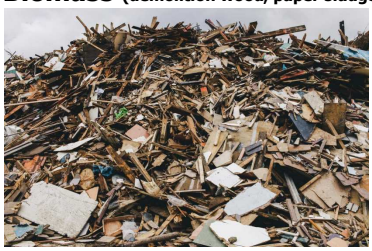
By-products/wastes to Resources

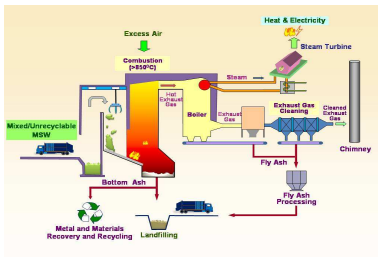
Municipal Solid Waste (MSW)

7,57 MT in the Netherlands

Biomass (demolition wood, paper sludge…)



2,50 MT in the Netherlands



Incineration (waste to energy)

Lamers, Cremers et al. 2018

MSWI bottom ash: 1,5 MT/year

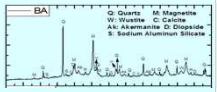
Biomass ash: 0,5 MT/year

By-products/wastes to Resources

Searching by-products/wastes

- Building up waste database in the Netherland

Digging Minerals



$CaO\ SiO_2\ Al_2O_3$

- Minerals
- Reactivity
- Chemical

*XRF, XRD, TGA

Improving reactivity

Crashing/grinding

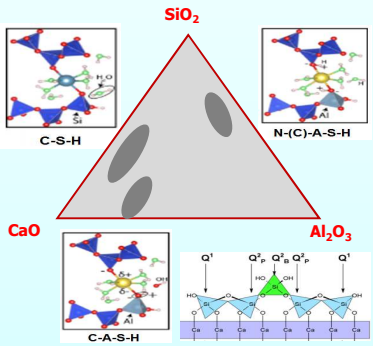
Thermal treatment

Reactive mineral

- Reactivity
- Dissolution kinetics

*EDTA, FTIR, EDX, XRD

Activating as SCMs or as Alterative binder



Gel Formation

- Stoichiometry
- Thermodynamics
- Molecular structure

*FTIR, NMR, SEM, EDX

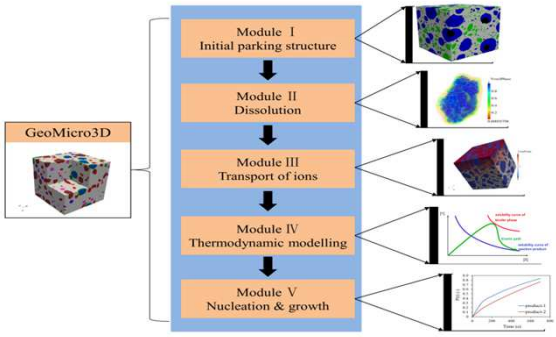
Producing building materials

Performance

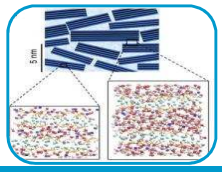
- Mechanical properties
- Durability
- Volume stability

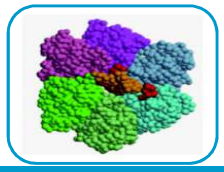
Prospects for the future

- Geopolymer concrete mixture design should based on fundamental reaction and performance requirements – modelling is important.



- Fundamental studies on time-depended behavior (i.e., creep and shrinkage) are needed.





Yibing Zuo, Experimental Study and Numerical Simulation of the Reaction Process and Microstructure Formation of Alkali-Activated Materials, PhD thesis, TU Delft, 2019

Prospects for the future

– It is possible to use geopolymer concrete as structural concrete. But we must gain more confidence via full scale tests. The collaboration between industries, governments and research institutions is important.

http://www.precast.com.cn/index.php/news_detail-id-6166.html

We need international collaboration

DuRSAAM Project (H2020-2018 Marie Curie ITN): Durable, Reliable and Sustainable Structures with Alkali-Activated Materials

- **Partners:** 7 universities, 15 industrial partners or public organisations, 13 PhD researchers.
- **Goals:**
  - to train a new generation of researchers in the optimal use of AAM concrete for a sustainable built environment
  - to provide a critical mass of researchers specifically skilled to address the multi-disciplinary and cross-sectoral challenges
  - to underpin the technological value of AAM as an effective and eco-efficient technology for concrete.

We need international collaboration

URBCON Project (2018-2021): By-products for sustainable concrete in the urban environment

- **Partners:** 2 public organisations, 4 Universities, 7 companies
- **Objectives**:
  - to apply by-products as alternative raw materials for concrete
  - to develop concrete mixes with up to 100% by-product aggregates and low carbon footprint cements (geopolymer binder)
- **Pile projects:** a concrete bridge and office building

We need international collaboration

Wool2Loop Project, H2020 (2019-2022)

- Mineral wool waste back to loop with advanced sorting, pre-treatment, and alkali activation
- **Aim:** to divert mineral wool as construction and demolition waste from landfilling and to develop and enhance its utilization into novel applications and construction products, meanwhile securing the access to sustainable, alternative, non-conventional raw materials for the construction industry in the future.
- **Partners:** 15 partners.

We need international collaboration

New RILEM Technical Committee (TC-MPA): Mechanical Properties of Alkali-activated Materials

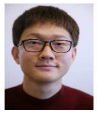
- Chairman: Ye Guang (TU Delft, the Netherlands)
- Deputy chairman: Frank Dehn (KIT, Germany)

- **Welcome new TC members!**
- **Kick off meeting will be in Guimaraes, Portugal, 11 March 2020**

TU Delft Geopolymer Research Group


Dr. Guang Ye

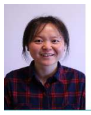

Hua Dong

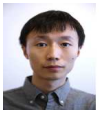

Zhenming Li


Ir. Shizhe Zhang


Albina Kostiuch-enko


Postdr


Ir. Boyu Chen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Former colleagues who have contributed to the TU Delft geopolymer research


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Dr. Kamel Arbi Delta Concrete Consult BV


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MSc. Jiahua Liu Jiangsu, China


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M21 materials innovation institute

SCK•CEN STUDIECENTRUM VOOR KERNENERGIE CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

CHINA SCHOLARSHIP COUNCIL

NSFC 国家自然科学基金委员会 National Natural Science Foundation of China

4TU.Bouw

Gemeente Rotterdam

van Gansewinkel

CRH

HEROS SLUISKIL A COMPANY OF THE REMEX GROUP

Mineralz Part of Renewi

TATA STEEL

Cementbouw

DE RUWBOUW GROEP

AVR.