January 2023

Issue 4

DuRSAAM

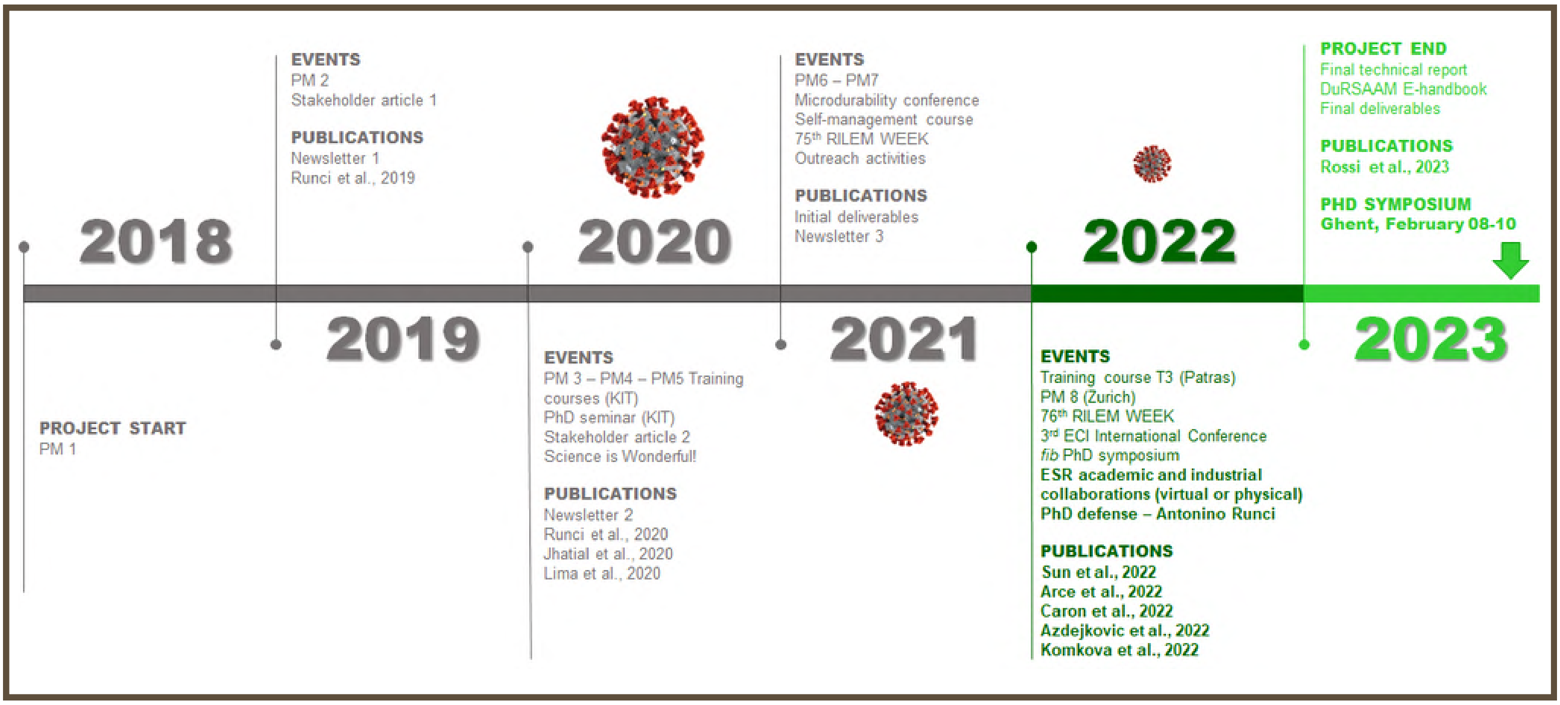
The PhD Training Network on Durable, Reliable and Sustainable Structures with Alkali-Activated Materials

Inside this Issue

4 YEARS OF DURSAAM

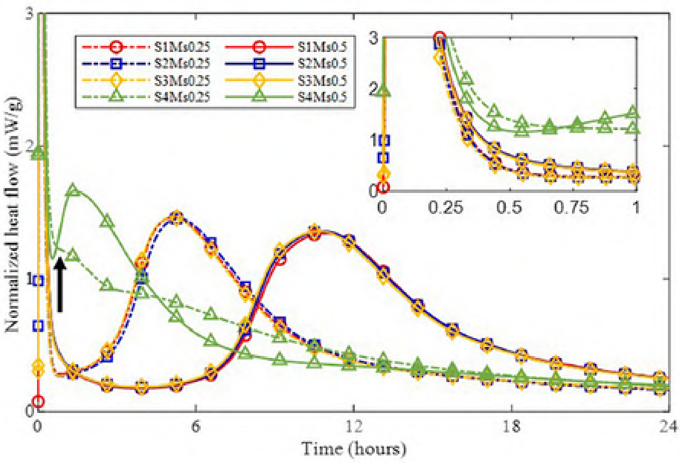
After 4 years, the DuRSAAM project will reach its end in February 2023. Despite the initial challenges - moving to another country, speak a different language, getting familiar with the equipment and the dynamics of the hosting university, facing a pandemic - the ESRs managed to overcome these challenges and achieve outstanding results. Their work narrowed the research gaps in the alkali-activated systems field, providing additional proof of the suitability of this material for field applications.

DURSAAM PROJECT UPDATES

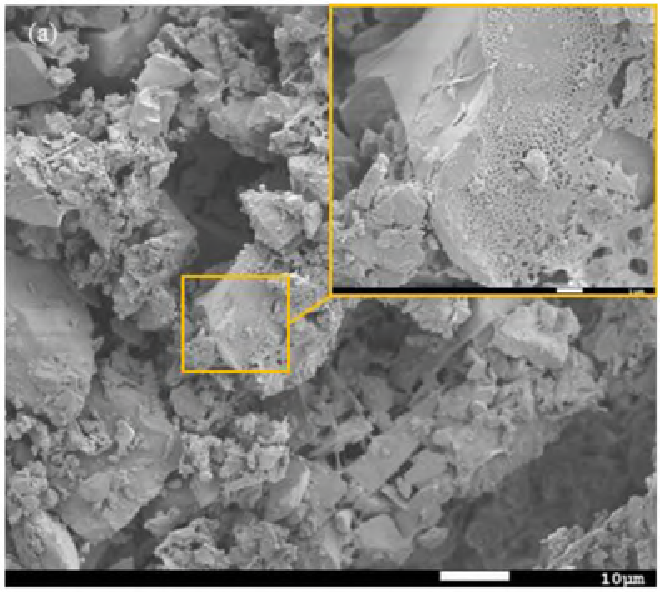


RHEOLOGY OF ALKALI-ACTIVATED SLAG-BASED CONCRETE

This study provides a detailed investigation on the reproducibility of two groups of alkali-activated slag (AAS) mixtures, from both fresh properties and strength development perspectives. Three different commercial sodium silicate solutions and one lab-produced silicate activator (made of silica fume and sodium hydroxide) were used to prepare AAS pastes with the same nominal composition in each group. The reaction process of each AAS mixture was monitored by calorimetry and ultrasonic pulse velocity (UPV) measurements. Meanwhile, mini-slump and flow curve tests measured by rheometer were conducted in the first hour to characterize the evolution of fresh properties. The compressive and flexural strength of hardened AAS mortars were measured at different curing ages. The results revealed that AAS pastes prepared with three different sodium silicate solutions exhibited almost identical reaction kinetics, as well as the evolution of fresh properties and strength development. However, the reaction took place rather fast in AAS pastes made of silica fume. These mixtures showed worse rheology and less strength than the corresponding mixtures prepared with sodium silicate solutions. Furthermore, the present study also showed the feasibility of making the same AAS paste through different class commercial sodium silicate solutions.



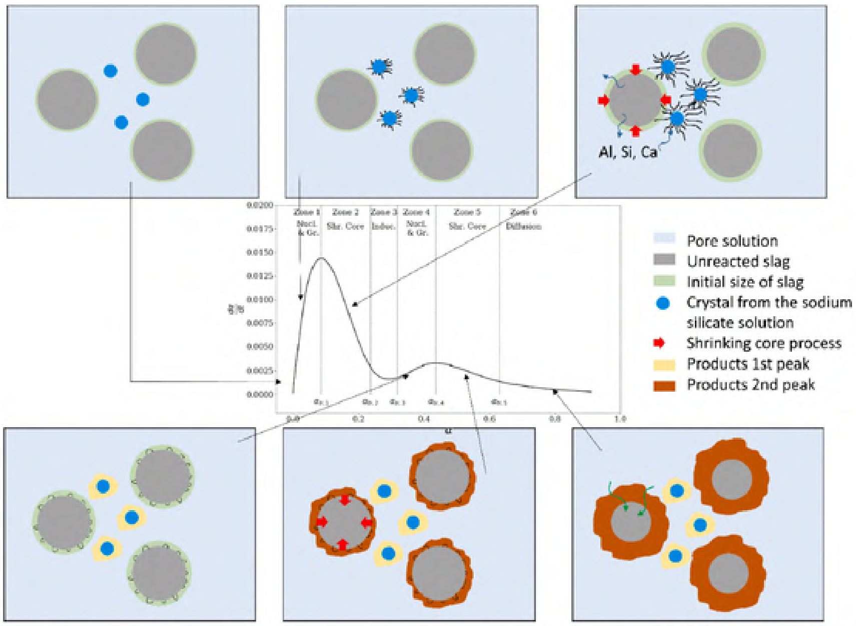
Sun et al. (2022), **Evaluation of rheology and strength development of alkali-activated slag with different silicate sources**, Cement and Concrete Composites 128, https://doi.org/10.1016/j.cemconcomp.2022.104415



Sun et al. (2022), **Rheology of alkali-activated slag pastes: New insight from microstructural investigations by cryo-SEM**, Cement and Concrete Research 157 https://doi.org/10.1016/j.cemconres.2022.106806

This study aims to interpret the early-stage rheology of alkali-activated slag (AAS) paste from microstructure perspectives. The microstructures visualized by cryogenic scanning electron microscopy (cryo-SEM) revealed the essential distinction between hydroxide and silicate-activated slag pastes. The hydroxide-based mixture showed typical suspension features, where slag particles were dispersed in the hydroxide activators. In the hydroxide media, even at very early ages (5 min), the solid grains were attached to each other through rigid connections of reaction products, which resulted in high yield stress. As for the silicate-based mixtures, an emulsion phase has been observed between slag particles, which consists of discontinuous water droplets and continuous silicate gels. Fine emulsions with smaller water droplets were observed as the silicate modulus of activators increased, which dispersed the slag particles but on the other hand improved the viscosity of the paste. With increasing water to binder ratio, both yield stress and viscosity of AAS pastes significantly reduced.

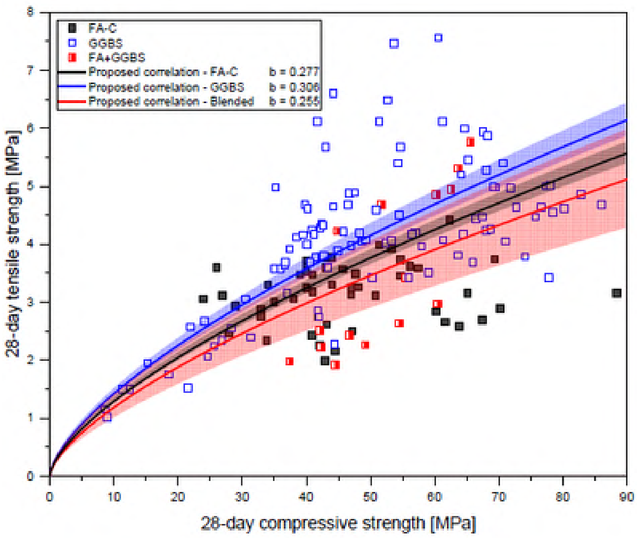
DISSOLUTION PROCESS OF ALKALI-ACTIVATED SLAG



Caron et al. (2022), **Activation kinetic model and mechanisms for alkali-activated slag cements**, Construction and Building Materials 323, https://doi.org/10.1016/j.conbuildmat.2022.126577

A new model for reaction kinetics of waterglass-activated slag cements based on calorimetry results has been proposed. It accounts for the different mechanisms during alkali-activation of slag with waterglass considering successive application of single-particle models. The process of alkali-activation of slag with waterglass typically consists of two accelerated periods, separated by an induction period. The first accelerated period is described by the succession of a nucleation and growth process and a contraction volume process and the second accelerated period is described by the succession of a nucleation and growth process, a contraction volume process and a diffusion process. The induction period is described by zero-order kinetics signifying that the dissolution of slag does not stop during this period. The model is found to successfully describe a wide range of experimental data with R-square values greater than 0.95 for all datasets. Finally, correlations between mix characteristics and parameters of the model are proposed. Interpretations of these correlations seem to be pertinent with experimental observations such as the importance of the pH of the solution on the kinetics, the role of silicon ions as nucleation sites and low apparent activation energies for the diffusion governing step.

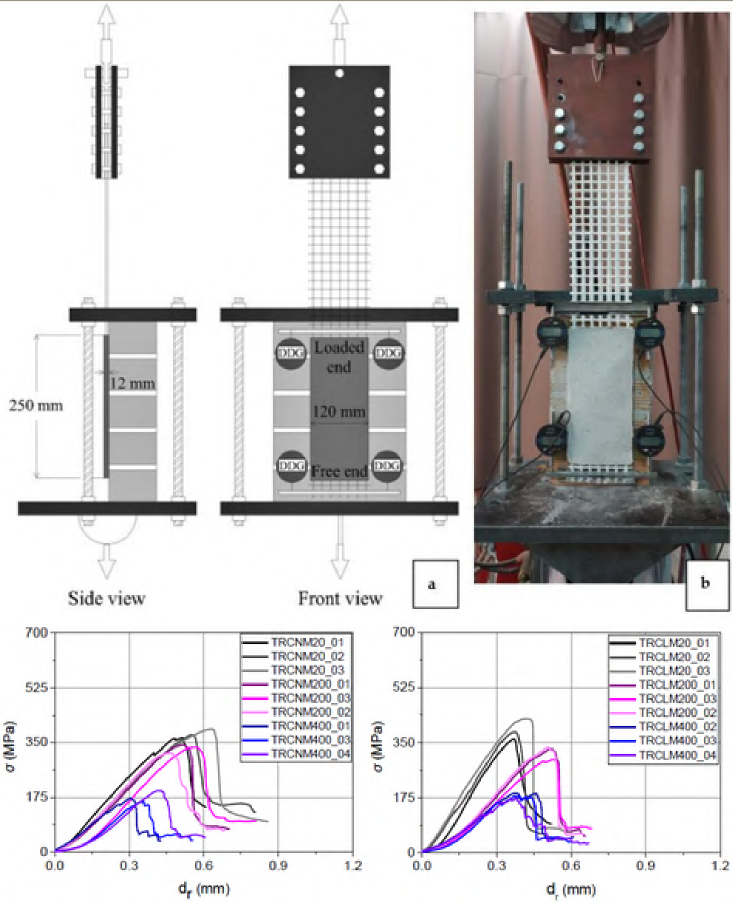
FUTURE PERSPECTIVE OF ALKALI-ACTIVATED CONCRETE



Rossi et al. (2023), **Future perspectives for alkali-activated materials: from existing standards to structural applications**, RILEM Technical Letters, https://doi.org/10.21809/rilemtechlett.2022.160

Successful applications of AACs can be found in Europe since the 1950s and more recently in Australia, China and North America, proving their potential as construction materials. However, their utilisation is limited presently by the lack of normative and construction guidelines. Raw materials' non-uniform global availability and variable intrinsic properties, coupled with the lack of specific testing methods, raise questions regarding reproducibility and reliability. Although a wide amount of studies demonstrated that AACs could meet and even exceed the performance requirements provided by European design standards, a classification of these broad spectra of materials, as well as new analytical models linking the chemistry of the system components to the mechanical behaviour of the material, still need further development. This report gives an overview of the potential of alkali-activated systems technology, focusing on the limitations and challenges still hindering their standardisation and wider application in the construction field.

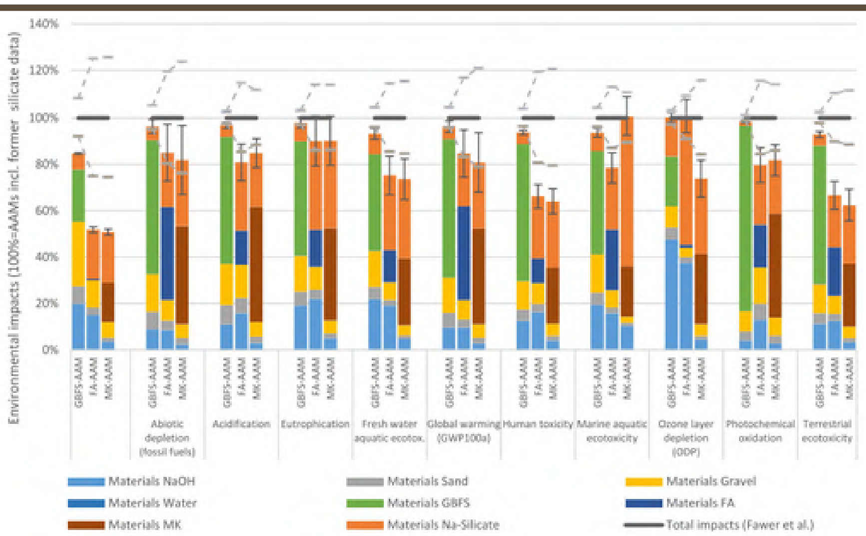
STRUCTURAL APPLICATIONS OF ALKALI-ACTIVATED CONCRETE



In this study, masonry prisms that were furnished with double-layered TRM strips were tested under shear bond conditions after their exposure to 200 °C and 400 °C for 1 h using the single-lap/single-prism setup. A total of four TRM systems were applied sharing the same type of textile –a dry AR glass fiber one– and different matrices: two cementitious matrices and two counterpart alkali-activated matrices based on metakaolin and fly ash. Specimens' exposure to elevated temperatures did not alter their failure mode which was due to the sleeve fibers' rupture along with core fibers' slippage from the mortar. The residual bond capacity of the TRM systems decreases almost linearly with increasing exposure temperature. The alkali-activated textile reinforced mortars outperformed their cement-based counterparts in terms of bond strength at every temperature. Per the type of binder, lightweight matrices resulted in either comparable (cement-based systems) or better (alkali-activated systems) heat protection at the TRM/masonry interface

Azdejkovic et al. (2022), **Experimental Investigation of the TRM-to-Masonry Bond after Exposure to Elevated Temperatures: Cementitious and Alkali-Activated Matrices of Various Densities**, Material 2022, 15 (1), 140, https://doi.org/10.3390/ma15010140

ENVIRONMENTAL IMPACT OF ALKALI-ACTIVATED CONCRETE

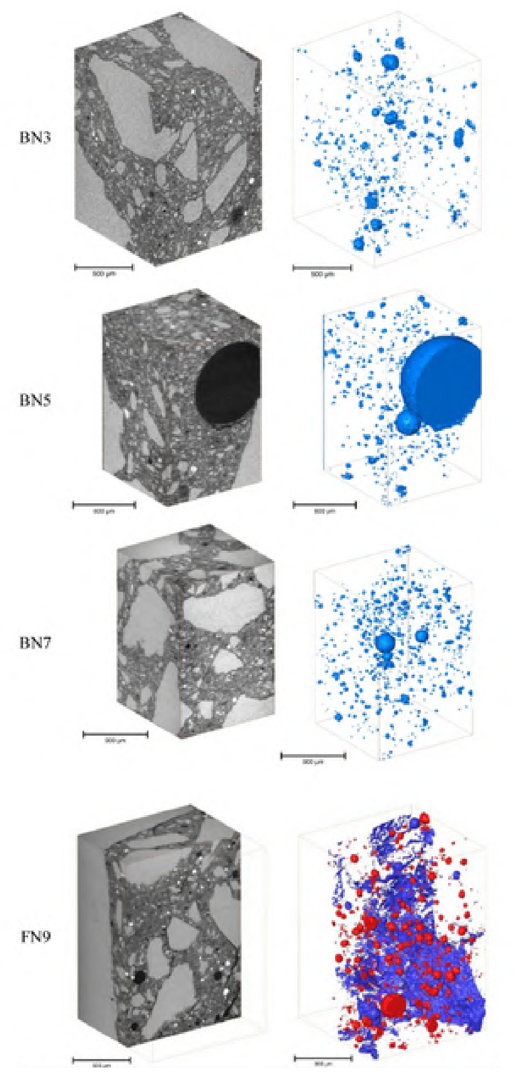


Komkova et al. (2022), **Environmental impact assessment of alkali-activated materials: Examining impacts of variability in constituent production processes and transportation**. Construction and Building Materials, 363, https://doi.org/10.1016/j.conbuildmat.2022.129032

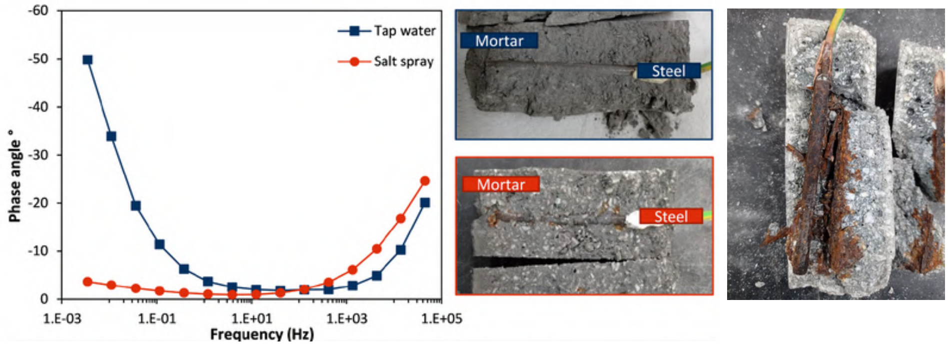
This study compares the environmental impacts of blast furnace slag-, fly ash-, and metakaolin-based alkali-activated concretes with Portland cement (PC) concretes using life cycle assessment methodology. Results show that alkali-activated materials have up to 57 % lower CO2 eq. emissions than PC concretes, while activators contribute between 13 % and 33 % to the total GWP of AA concrete mixes, depending on mix design. This paper concludes that taking into account variability in production technologies of precursors and activators, as well as of PC, alkali-activated materials still have lower CO2 eq. emissions than PC concretes

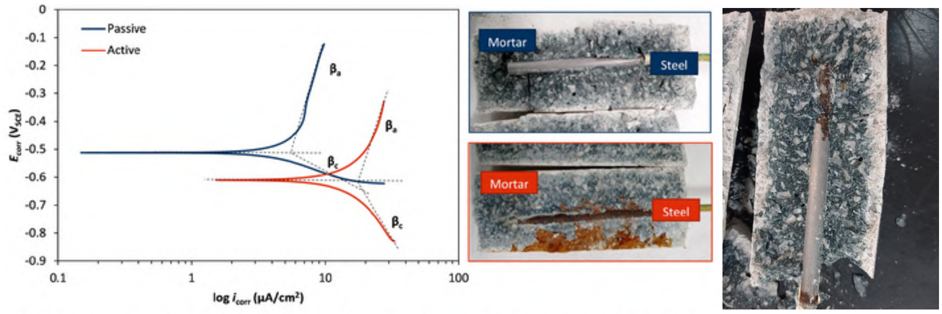
CHLORIDE INGRESS AND CORROSION OF STEEL IN ALKALI-ACTIVATED MATERIALS
PHD DEFENSE - ANTONINO RUNCI

Antonino Runci was the first ESR of the DuRSAAM project to defend his PhD at the University of Zagreb on May, 31st 2022. The work of Antonino (ESR 8) investigates from different angles the chloride intrusion and the resulting corrosion of the reinforcement in alkali-activated materials. The chemical composition and microstructural properties of different alkali-activated mortars were correlated with the apparent chloride diffusion coefficient according to the main standard developed for Portland cement. In addition, the long-term behaviour of reinforced alkali-activated mortars was studied to identify the passivation process and the electrochemical parameters of corrosion.



Runci et al. (2022), **Microstructure as a key parameter for understanding chloride ingress in alkali-activated mortars**, Cement and Concrete Composites 134, https://doi.org/10.1016/j.cemconcomp.2022.104818

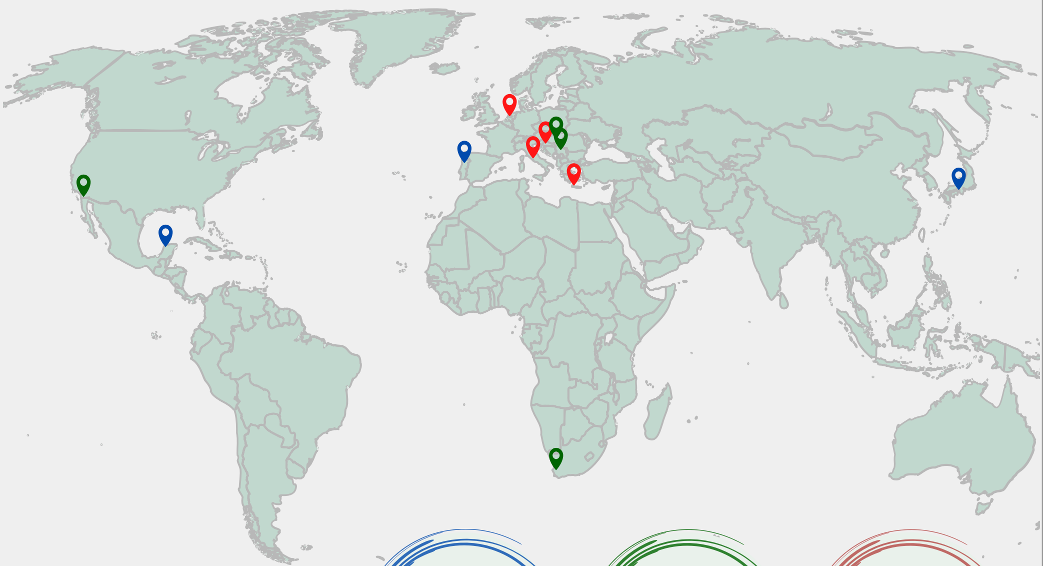




The long-term corrosion behaviour of reinforcing steel embedded in alkali-activated mortars (AAMs) prepared with three different binder compositions was monitored over a 360-day period by cyclic wetting/drying and spraying with chloride solution. Corrosion potential and polarisation resistance were determined by linear polarisation, individual resistance of mortar and steel by electrochemical impedance spectroscopy, and Tafel slopes by potentiodynamic anodic polarisation. The results were validated by correlating the electrochemical mass losses with the gravimetric mass losses. Based on the time evolution of the corrosion parameters, the study proposes new limits for passive and active corrosion conditions for reinforcing steel in AAMs.

Runci et al. (2023), **Revealing corrosion parameters of steel in alkali-activated materials**, Corrosion Science 210, https://doi.org/10.1016/j.corsci.2022.110849

CONFERENCES



International conferences
RILEM events
Symposiums

4 continents

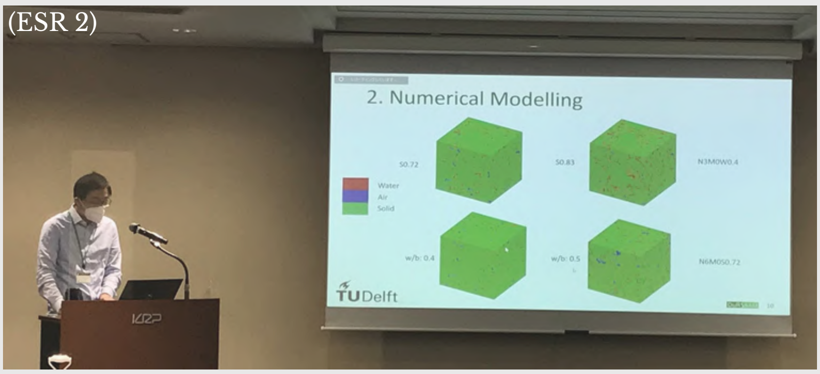
13 conferences

33 presentations

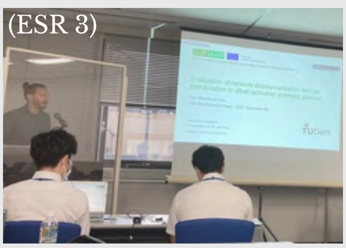
In the past 4 years, the DuRSAAM ESRs participated in several international conferences, RILEM events and symposiums all around the world, with 33 publications and poster presentations. During the pandemic, the majority of the presentations were held online. Once the COVID-19 restrictions were lifted and travelling again permeitted, it was possible to discuss the research work and share knowledge in person at conferences across and beyond Europe.

76th RILEM Annual Week (Kyoto, 2022)

The **76th RILEM Annual Week** took place in Kyoto, Japan, in September 2022. **Zhiyuan Xu** (ESR 2), **Luiz Miranda de Lima Junior** (ESR 3), **Antonino Runci** (ESR 8), **Olivera Bukvić** (ESR 9), **Tamara Chidiac** (ESR 12) and **Anastasija Komkova** (ESR 13) presented their research in the fields of numerical modelling, life cycle analysis, microstructure and durability of alkali-activated materials.



(ESR 2)


(ESR 3)


(ESR 9)


(ESR 13)

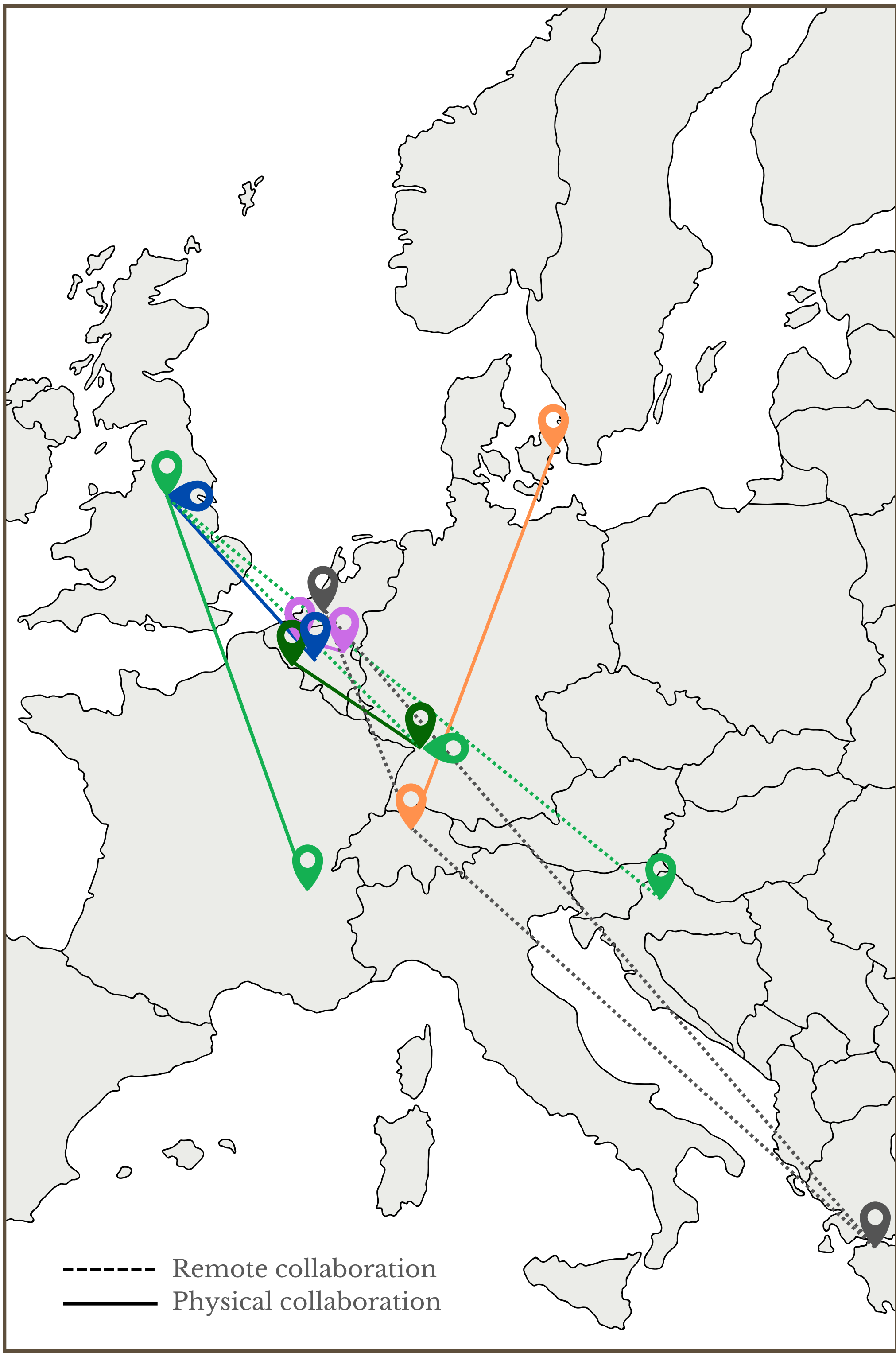
14th *fib* PhD Symposium (Rome, 2022)

Our researchers **Laura Rossi** (ESR 4) and **Richard Caron** (ESR 10), accompanied by their supervisor, Prof. Dr.-Ing. Frank Dehn, presented their work at the **14th *fib* PhD Symposium** organised in Rome in Septemeber 2022. During the conference, the paper of Richard Caron - *Applicability of the fib Model Code 2010 for predicting strength and shrinkage behaviour of alkali-activated slag concrete* - was awarded with a "**Mention as best paper**". **Congratulations!**


(ESRs 4 and 10)


(ESR 10)

ACADEMIC AND INDUSTRIAL COLLABORATIONS



During the last 4 years, the DuRSAAM project enabled the collaboration between researchers, professors and industrial partners all around Europe.
Despite COVID-19, the ESRs managed to collaborate with the other ESRs and the industrial partner involeved in the project in a virtual way. Through regular email exchange and online meetings, the ESRs implemented their research work and network. The collaborations between ESRs resulted in several joint publications, such as:

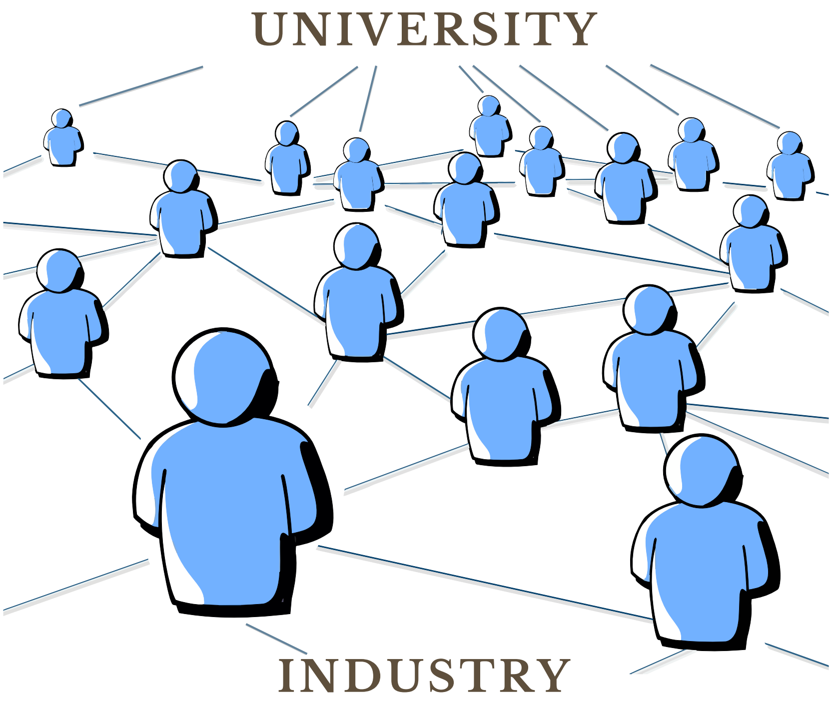
- ESR11 - ESR13: **Arce, Komkova** et al. (2022), Optimal Design of Ferronickel Slag Alkali-Activated Material for High Thermal Load Applications Developed by Design of Experiment, doi:10.3390/ma15134379

- ESR11 - ESR6 - ESR3: **Arce, Azdejkovic, Miranda de Lima** et al. (2022), Mechanical behavior of textile reinforced alkali-activated mortar based on fly ash, metakaolin and ladle furnace slag, doi:10.5281/zenodo.6461340

After evaluating the mechanical performance of textile reinforced alkali-activated mortar, **Lazar Azdejkovic** (ESR6) and **Luiz Miranda de Lima** (ESR3) are currently working together on the durability of AR-glass textile reinforced alkali-activated mortars (AAM-TRM). The effect of the AAM mortar on coated alkali-resistent glass fibers is studied over a time span of six months. The mechanical tests are being carried out at University of Patras (ESR6) while the microscopic testing is done at TU Delft (ESR3) lab facilities.

ACADEMIC AND INDUSTRIAL COLLABORATIONS

To understand the impact of carbonation on steel fibres in alkali activated concrete, a collaborative project between **Laura Rossi** (ESR4) and **Cassandre Le Galliard** (ESR7) was designed and conducted. The specimens were casted at Karlsruhe Insitute of Technology (ESR4) and shipped to Sheffield where they were exposed to natural and accelerated carbonation. SEM-EDS and XRD were performed on the samples before and after the carbonation at the University of Sheffield laboratories (ESR7).



The collaboration between universities and industries was a great opportunity for the ESRs. Being able to spend time in the industries laboratories helped them understand how research is applied to marketable products.

Laura Rossi (ESR4) had the possibility to collaborate with ResourceFull BVBA and NV Bekaert SA, both located in Belgium, to evaluate the effect of the incorporation of steel fibres.

Yubo Sun (ESR1) spent six months at Mobiliteit en openbare werken (Mobility and public works) sector of the Flamish government where he investigated the properties of AAM concretes produced with local materials.

Fig. 1. Tamara Chidiac at SANACON

The industrial secondment of Tamara Chidiac (ESR 12) was carried out at SANACON (see Fig. 1). With the data from real service conditions and the support of the SANACON team, Tamara managed to calibrate her service life model.

Fig. 2. Ivana Krajnovic during her industrial secondment at Owens Corning

Ivana Krajnovic (ESR 5) had an opportunity to do part of her testing campaign in the laboratory of the Owens Corning company in Chambery, France (see Fig.2).

During her stay with great help of the laboratory team she produced and tested 70 alkali-activated and Portland cement mortar pull-out specimens and demonstrated potential use of alkali-activated mortar with FRP rebars in new structures and for strengthening of existing structures.

THE DURSAAM PROJECT SEEN BY THE ESRS

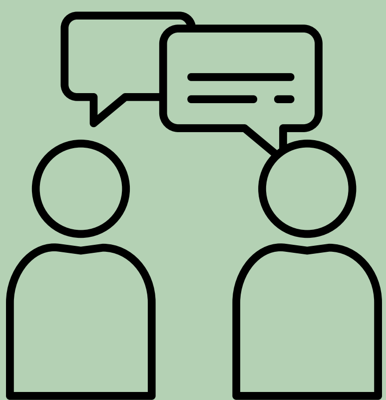
"Being a student during the pandemic has been difficult not only physically but especially mentally. The project board has provided us with the help needed to continue our work in the best way possible."

"The DuRSAAM project was definitely a challenge but also a great opportunity for professional and personal growth."

"Working in an international environment improved not only my problem-solving skills, but also adaptability and teamwork. The DuRSAAM project built an international network of researchers and promoted the collaboration between universities and industries."

"Despite the travel restrictions, the project online meetings and the remote collaborations have strengthened the relationships between ESRs and universities, resulting not only in joint publications but also nice friendships."

"Personally, I hope that the professional network established in the last 3 years will continue existing and expanding. It would be nice to keep contact with the ESRs, meet each other and have a nice time also outside of the DuRSAAM project."



"Despite the difficulties along the way, we finally made it to the finish line!"

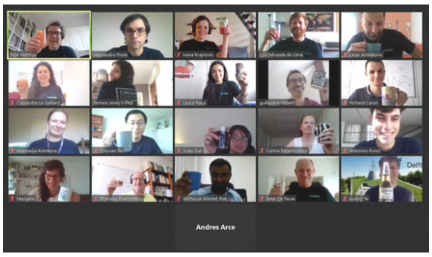
THE DURSAAM PROJECT IN PICTURES

2018 Kick-off meeting (Ghent)

2019 PM2 (Delft)

2020 PM3 (Karlsruhe)

2020 Science is wonderful!



PM4-PM5 (Online meeting)

ESRs council (online meeting) **2020**

Special session on geopolymer concrete

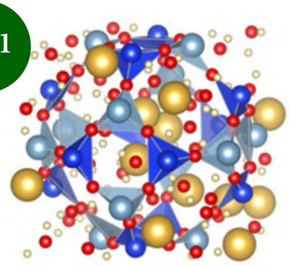
2021 DuRSAAM Midterm Workshop

2022 PM7-Zagreb (hybrid meeting)

PM8 - Zurich **2022**

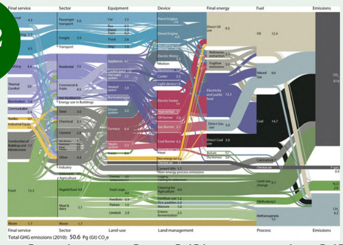
DuRSAAM Training courses

TC1



Introduction to AAM technology
January 2020
ISBN 9789082526813

TC2



Introduction to durability, sustainability and LCA of concrete structures
September 2020
ISBN 9789082526820

TC3

Structural application of alkali-activated concrete
January 2022
Soon available

THANKS TO THE ACADEMIC AND INDUSTRIAL PARTNERS OF THE PROJECT

TU Delft, University of Patras, ETH zürich, KIT Karlsruhe Institute of Technology, The University Of Sheffield, Ghent University, CRH, WARE, T.ΕΠ.ΚΑΤ., LafargeHolcim, gent:, Aurubis, SANACON, Gradmont d.o.o. Gradačac, ARGOS, Mobiliteit en Openbare Werken, FDN, BEKAERT better together, Gemeente Rotterdam, Owens Corning, RESOURCEFULL, ArcelorMittal

https://www.linkedin.com/company/dursaam-itn/ https://www.youtube.com/watch?v=qP-cvcX2Xxs Follow us on Twitter @Du_RSAAM

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