SARCOS COST Action (CA 15202)

Guide of Participant Research Groups

Book including the posters and proceedings of the Welcome Workshop, Madrid June 2017
Eds: María José Bayarri Clariana and Mercedes Sánchez Moreno

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15. Institute of Ceramics and Glass
    (ICV-CSIC), Spain

16. Institute of Construction Science “Eduardo Torroja”
    (IETcc-CSIC), Spain

17. Institute of Concrete Science and Technology (ICITECH)
    Universitat Politècnica de València (UPV), Spain

18. University of Cambridge
    Cambridge, UK

19. School of Engineering, M4L Research Group
    Cardiff University, UK

B. Presentations

1. Magnel Laboratory for Concrete Research
   Ghent University, Belgium

2. University Centre for Energy Efficient Buildings
   Czech Technical University in Prague, Czech Republic

3. Helmholtz-Zentrum
   Geesthacht, Germany

4. Institute of Construction Materials
   Technische Universität Dresden, Germany

5. Structural Engineering Department
   Ben Gurion University of the Negev, Beer Sheva, Israel

20. Department of Civil and Environmental Engineering
    Politecnico di Milano, Italy

21. Politecnico di Torino, Italy

22. Cracow University of Technology (CUT)
    Lodz University of Technology (LUT)
    Warsaw University of Technology (WUT), Poland

23. Universidade de Lisboa, Portugal

24. NIRD URBAN-INCERC Cluj-Napoca, Romania

25. Laboratory for Materials in Cultural Heritage
    Department of Materials Engineering
    Faculty of Technology, University of Novi Sad, Serbia

26. Institute of Construction Science “Eduardo Torroja”
    (IETcc-CSIC), Spain

27. Institute of Concrete Science and Technology (ICITECH)
    Universitat Politècnica de València (UPV), Spain

28. University of Cambridge
    Cambridge, UK

29. School of Engineering, M4L Research Group
    Cardiff University, UK

Annex: New incorporations

30. West Pomeranian, University of Technology, Szczecin, Poland

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    Cardiff University, UK

Annex: New incorporations

28. West Pomeranian, University of Technology, Szczecin, Poland

Preface

After SARCOS ("Self-healing As prevention Repair of COncrete Structures") COST Action (CA 15202) started we were aware about the high potential of the network for advancing not only in the knowledge but also in the implementation of innovative preventive repair solutions in the real life. Although SARCOS intends progress beyond the state-of-the-art on the different approaches proposed, we have to be mindful of the necessity to give practical answers to the industry and final users in general.

Thus, a Welcome Meeting for presenting each participating group, the possibilities and interests of the different laboratories in the Action appeared as an excellent way to improve the cohesiveness of the network and to make easier the exchange of experience and knowledge between the involved researchers. Our awareness of the synergies and common interests within the Action groups will improve our efficiency in the use of the COST tools, such as Short-Term Scientific Missions, Training School, etc. With this idea, we organized the 1st Meeting with oral presentations and posters from each research group.

However, in order to reach also another target audience, i.e. the industry and the stakeholders, we decided to prepare this document for consultation, including also information from other groups which joined the Action later, thus giving access to everyone interested in preventive repair of concrete.

The present e-Book aims to be a guide document in which European laboratories experienced in preventive repair methods present themselves, indicating their strengths and interests in order to advance together in the implementation of the most innovative methodologies for concrete repair, being also a practical document to give an overview to stakeholders interested in the topic.

From the SARCOS Action network, we really hope that you can profit from the present e-Book,

Mercedes Sánchez Moreno (Chair of SARCOS)
Nele de Belie (ViceChair of SARCOS)

More information can be found at the Action Website: http://www.sarcos.eng.cam.ac.uk

POSTERS

INSTITUTION

Magnel Laboratory for Concrete Research

FACULTY OF ENGINEERING AND ARCHITECTURE

GHENT UNIVERSITY

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

MAGNEL LABORATORY FOR CONCRETE RESEARCH

Structural behaviour
robustness, structural behaviour after fire, structural assessment, near surface mounted FRP

Concrete technology
SCC, binary and ternary binders, creep and shrinkage, durability, vacuum mixing

Concrete & Environment
Prof. dr. ir. N. De Belie
microbial interactions with mineral building materials, supplementary cementitious materials, durability, recycling, self-healing concrete

RESEARCH LINES

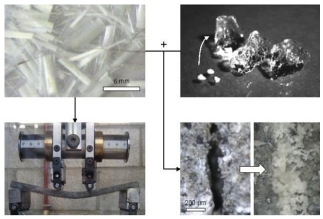
GREEN CONCRETE

- Use of **by-products**: fly ash, slag, silica fume, MSWI ashes, copper slag
- Use of **recycled materials** in Portland clinker production
- **Completely recyclable concrete**

SELF-HEALING CONCRETE

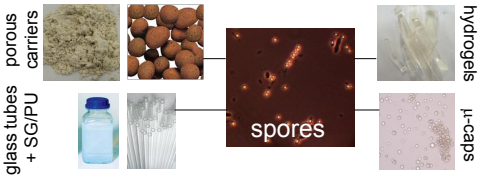
pH-sensitive superabsorbent polymers

Sealing/healing by further hydration & $CaCO_3$ precipitation



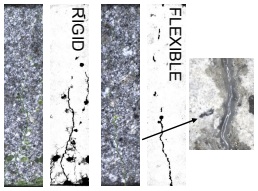
Biogenic healing agents

Encapsulated $CaCO_3$ precipitating bacterial spores

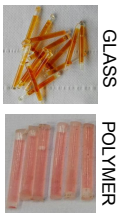


Elastic polymeric healing agents

Precursors of polymers encapsulated in tubular carriers



Behaviour upon reloading

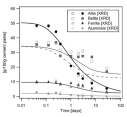


Partner in different national and European projects as HEALCON, CAPDESIGN, LORCENIS

INFRASTRUCTURE

Materials and reactions

Laser diffraction analysis



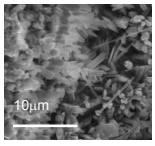
XRD analysis

Isothermal calorimetry

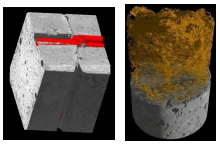
NDT of early-age concrete with US

Microstructure

Air permeability tests



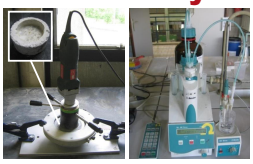
Scanning electron microscope



X-ray tomography

Durability

Accelerated degradation tests



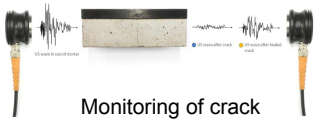
Chloride diffusion tests

Combined chemical-mechanical attack

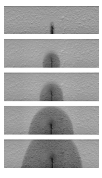
Self-healing

Crack creation

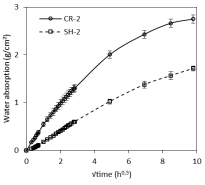
Microscopic observation



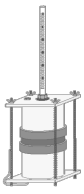
Monitoring of crack creation and closure via evolution of shear waves



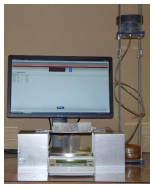
X-ray radiography



Water absorption



Permeability



Water flow

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CSIC Consejo Superior de Investigaciones Científicas — Instituto Eduardo Torroja

1st Internal Workshop SARCOS Action, 26th January 2017, Institute of Construction Sciences "Eduardo Torroja" (Madrid)

COST is supported by the EU Framework Programme Horizon 2020

CZECH TECHNICAL UNIVERSITY in Prague

University Centre for Energy Efficient Buildings

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

INSTITUTION DESCRIPTION:

University Centre for Energy Efficient Buildings (UCEEB) was founded as an independent research institute of the Czech Technical University in Prague under the auspices of four departments – Civil Engineering, Mechanical Engineering, Electrical Engineering and Biomedical Engineering. The Centre's goal is to leverage synergy effects of research activities of the individual departments which are related to energy efficient buildings.

UCEEB is a reaction to one of the European Union's largest priorities aimed at optimisation of energy efficiency of buildings. The centre should also have better opportunities to participate in European scientific projects, such as the Joint Technology Initiative on Energy Efficient Buildings, which is based on the EU's targets for carbon dioxide emissions.

It is clear that sustainable building is not just a trend or fashion, but a necessity. That is why we look at energy efficient buildings as a whole.

RESEARCH GROUP DESCRIPTION:

RESEARCH LINES

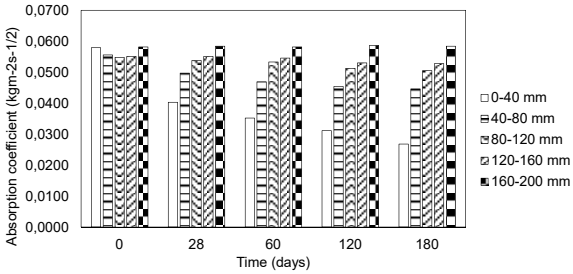
- **Mineral additives in cement and lime based composites**
- **Impact of external conditions on structural materials, durability of contructions**
- **Microstructure of cement based composites**
- **Transport properties of porous materials**
- **Development and testing of new composite materials for severe conditions**

INFRASTRUCTURE

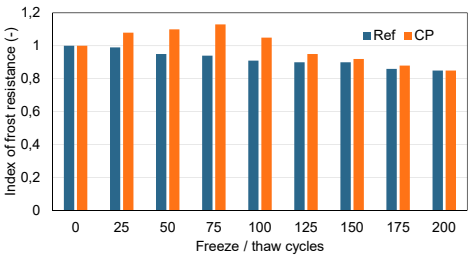
- **Fully equipped mechanical laboratory**
- **Mercury intrusion porosimetry (MIP)**
- **Electron microscopy, x-ray diffraction**
- **Transport properties – high presure permeameter, chloride migration test (NORD Test), ISAT, water penetration test**
- **Climatic laboratory (climatic chambers for controlled cyclic loading)**
- **Thermal analysis (up to 1000°C, DTG/DTA)**

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES:

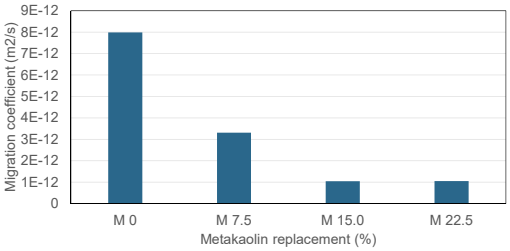
- **Monitoring of the crystalline coating efficiency**

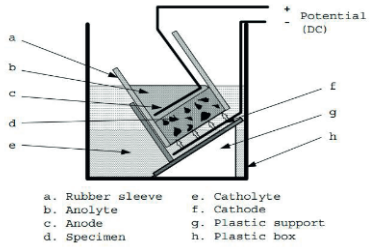


- **Influence of mineral additives on frost resistance**



- **Influence of metakaolin on chloride migration**





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INSTITUTION

"Ss. Cyril and Methodius" University in Skopje, Macedonia, FYR

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

INSTITUTION DESCRIPTION:

First state university
67 years tradition

Faculty of Technology and Metallurgy

Department of Inorganic Engineering, (one of the seven departments)
- Ceramics laboratory

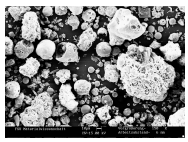
Study programs:
- Inorganic Engineering and Environmental Protection
- Materials Engineering and Nanotechnology
- Food Technology and Biotechnology
- Metallurgy, Design and Management
- Polymers, Design and Management
- Design and Management of Technological Processes
- Design and engineering of clouts

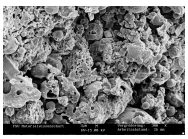
www.tmf.ukim.edu.mk

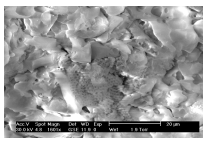
RESEARCH GROUP DESCRIPTION:

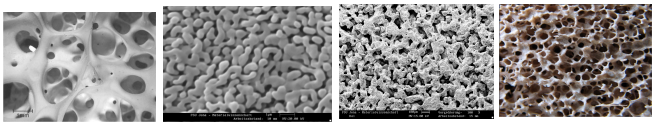
RESEARCH LINES

- Synthesis of powders based on SiO_2, Al_2O_3 and TiO_2 (mono, binary and ternary systems)
- Bioceramics
- Waste (fly ash, metallurgical slags, bottom ash) valorization for ceramics production
- Fabrication of dense and porous ceramics
- Cements (focus on incensement of mechanical properties)
- Dissent experience with geo-polymers


Fly ash


dense ceramics based on fly ash


dense ceramics based on fly ash and clay


a. b. c. d.

Porous structures: a. hydroxyapatite b. nano alumina c. composite slag-glass d. fly ash

INFRASTRUCTURE

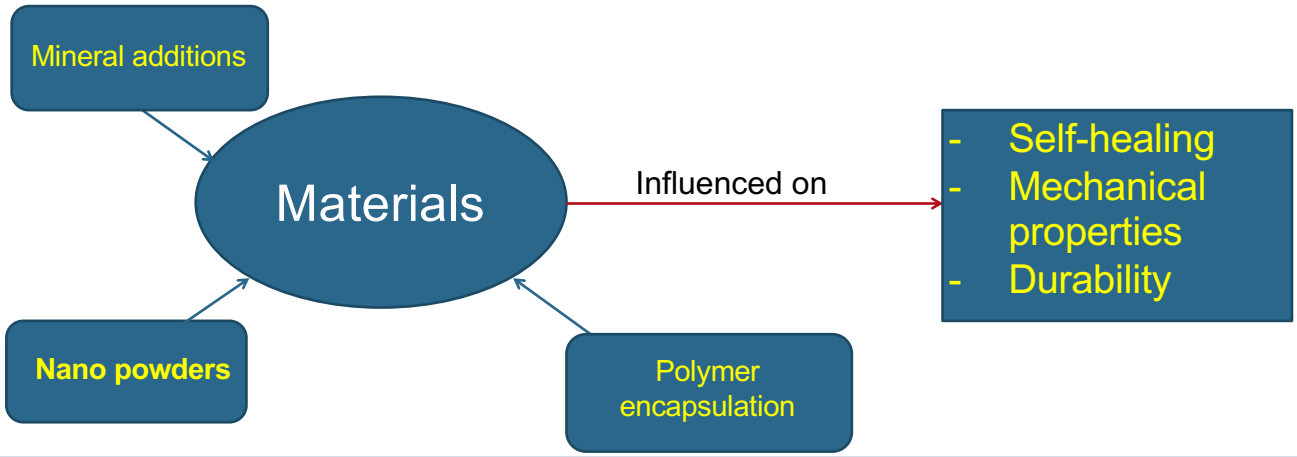
- Top down approach for obtaining nano and micro powders (ball mill, planetary mill and attritor)
- Bottom up approach for synthesis micro and nano powders (sol-gel and hydrolysis methods)
- Consolidation of the powders (Pressing and Sintering)
- Microscopy
- Mechanical properties (bending and compressive strength)
- Non-destructive tester (RFDA MF) for determination E-modulus, G-modulus and Poisson's ratio

Cooperation :
- TITAN Cementarnica USJE (Laboratory for processing and characterization of cements : http://www.usje.com.mk)
- ZIM (Institute for inspection of building materials and development of new technologies: www.zim.com.mk)

Realized projects: EUREKA-294; 158989-TEMPUS-1-2009-1-BE-TEMPUS-JPHES; Fifth Framework program - INCO COPERNICUS; Bilateral: Macedonia- Germany and Macedonia - Bulgaria ;

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES:

Ideas for future cooperation



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COST is supported by the EU Framework Programme Horizon 2020

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Helmholtz-Zentrum Geesthacht
Max-Planck-Straße 1, 21502 Geesthacht, Germany

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

INSTITUTION DESCRIPTION:

The Corrosion and Surface Technology department of the Institute of Materials Research headed by Prof. Mikhail Zheludkevich, studies corrosion mechanisms towards knowledge based surface technology development as well as material design. In this context novel corrosion protection concepts (active and passive) are developed. Specific use of modelling of partial aspects related to corrosion and coating processes supports all the development activities and is available.

Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

RESEARCH GROUP DESCRIPTION:

RESEARCH LINES

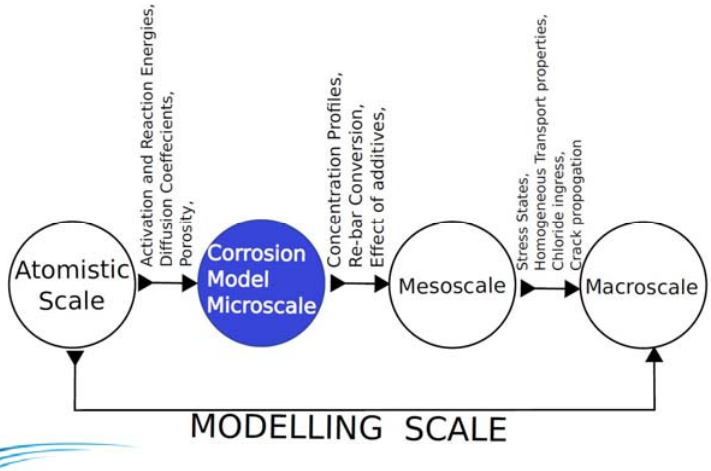
- **Material Modelling**
  - Concrete material modelling
  - Stress & fatigue corrosion cracking
  - State-of-the-art Continuum Corrosion Model (Multi-scale)
- **Corrosion Mechanism**
  - Coating technology
  - Corrosion inhibition techniques
  - Electrochemistry

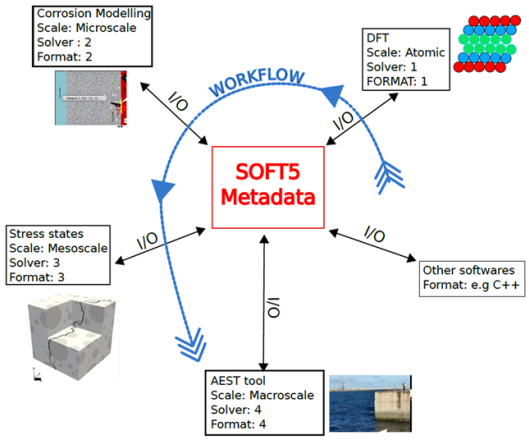
INFRASTRUCTURE

- **Computational**
  - Image based modelling
  - High performance computing
    - Full coupled electrochemical, thermal and transport models.
  - Discrete + continuum infrastructure
- **Experimental**
  - Imaging (Tomography, SEM …)
  - Stress corrosion testing
  - Electrochemical testing

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES:

- Multi scale modelling and service life prediction of reinforced concrete structures under the framework of EU-LORCENIS* Project





Data Exchange Interface
Advanced Engineering Software tool

LORCENIS

***Acknowledgement:** This project has received fundings from the European Union's Horizon 2020 research and innovation Programme under grant agreement No: 685445

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Dr. Sviatlana L. Lamaka sviatlana.lamaka@hzg.de
Website www.hzg.de

INSTITUTION DESCRIPTION: Aristotle University of Thessaloniki, Civil Engineering Department, Laboratory of Building Materials

RESEARCH GROUP DESCRIPTION: Working with lime-based mortars and rcording the re-crystallization phases gave the idea of introducing techniques for self healing agents in cement-based materials in order to provoke crack propagation and increase the durability of concrete's life. The team consists of:

Stefanidou Maria, Associate professor
Eirini-Chrysanthi Tsardaka, Chemist PhD candidate
Fotini Kesikidou, Civil Engineer, PhD Candidate

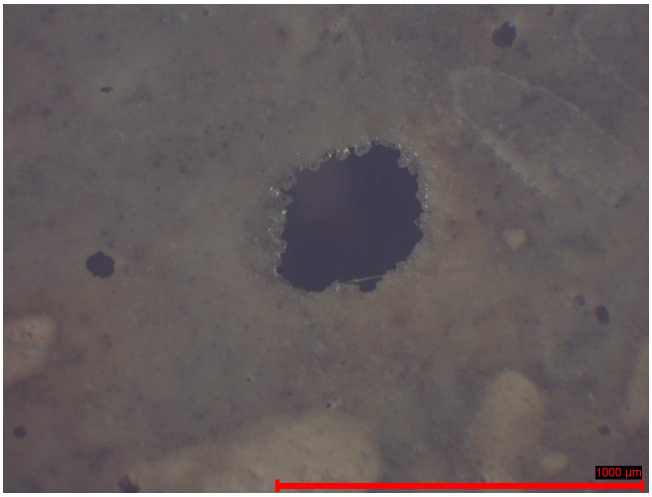
RESEARCH LINES

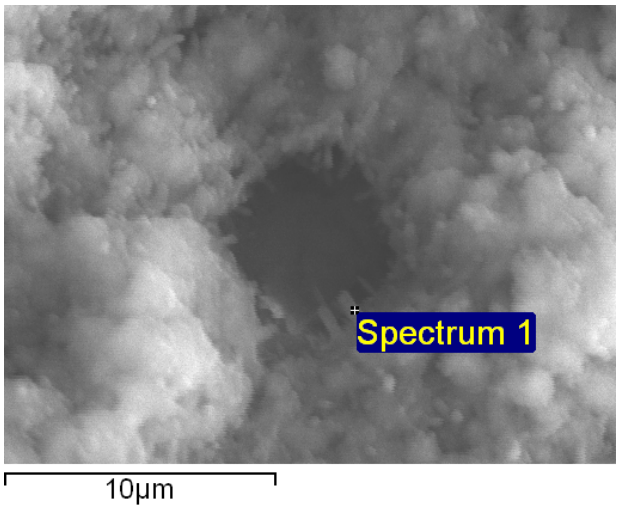
Lime-rich renders with nanoCaO particles in different percentages are tested under different curing regimes.

INFRASTRUCTURE

- Stereoscopic observation
- SEM
- Strength recording
- Porosity evolution
- Capillary absorption

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES:





Development of crystals after healing using nano-CaO particles in cement-based material

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Website
http://www.civil.auth.gr/component/option,com_contact/task,view/contact_id,140/Itemid,61/lang,el/

COST is supported by the EU Framework Programme Horizon 2020

INSTITUTION

Politecnico di Milano
Department of Civil and Environmental Engineering

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

INSTITUTION DESCRIPTION:

Politecnico di Milano, founded in 1863 is one of the leading research institutions in the field of Civil and Structural Engineering (14th in the world according QS World University Ranking, 5th in Europe and 1st in Italy) .
The Department of Civil and Environmental Engineering consists of 102 faculty members, 69 fellows, 89 PhD students and 44 staff people

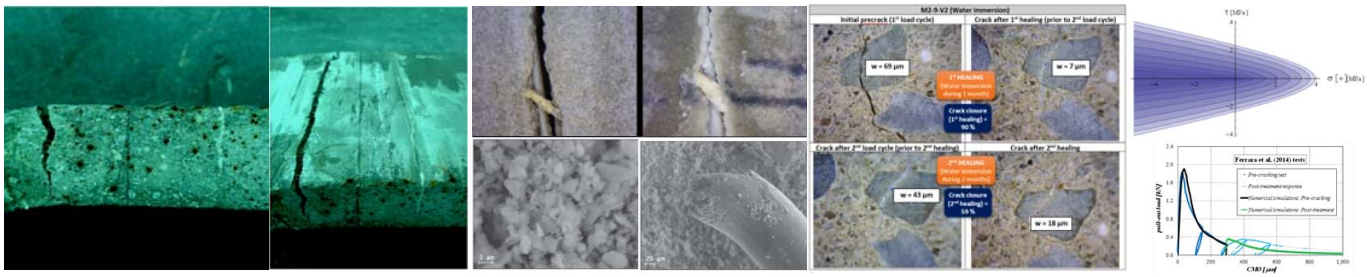
RESEARCH GROUP DESCRIPTION:

RESEARCH LINES

- Advanced cement based materials: characterization and structural applications
- Retrofitting and rehabilitation of existing structures
- Self-healing of cement based materials
- Fracture and damag mechanics
- Micro-mechanical modelling of cement based materials

INFRASTRUCTURE

- 6500 m² Testing Lab for Materials and Structures (25 technicians)
- Rheology lab (Mars III reometer)
- Material testing equipment (INSTRON – 100 kN capacity; SCHENK – 1000 kN capacity)
- Full scale testing equipment (2500 kN MTS + vertical/horizontal reaction frames up to 1000 kN)
- State of art chemical/durability lab



EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES:

- Autogenous and engineered (crystalline admixtures) self-healing of plain concrete (Penetron Italia)
- Autogenous and engineered (crystalline admixtures) self-healing of fiber reinforced concrete and high performance fiber reinforced cementitious composites (IIT Madras, India, and UPValencia, Spain), including “cracking/healing”fatigue (Penetron Italia)
- Natural fibers as facilitators of self-healing in advanced cement based materials (UFRio de Janeiro, Brasil)
- Autogenous and engineered (crystalline admixtures, micro-capsules) of lime mortars (IUAVenice)
- Multi-scale/multi-physics numerical modelling of self-healing in cement based materials (Ubuenos Aires and UNTucuman, Argentina)
- Full scale applications of self-healing fiber reinforced SCC (QUBelfast, Azichem, Penetron It., Banager Precast)

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COST is supported by the EU Framework Programme Horizon 2020

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Politecnico di Torino

Corso Duca degli Abruzzi, 24
10129 Turin (Italy)

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

INSTITUTION DESCRIPTION:

Politecnico di Torino is a technical university active since 1859 in the fields of Education, Research, Technological Transfer and services in all sectors of **Architecture** and **Engineering**. Its research and educational mission is accomplished by eleven departments dealing with coordination, promotion of research, organization and management of the teaching activity. Among them, the following are directly involved in the Cost Action CA15202 SARCOS:

DISAT *– Department of Applied Science and Technology,*

DISEG *– Department of Structural, Geotechnical and Building Engineering.*

POLITECNICO DI TORINO

RESEARCH GROUP DESCRIPTION:

RESEARCH LINES

- Development and optimization of **extruded cementitious hollow tubes** for healing agent encapsulation;
- Development and **mechanical characterization** of materials and structures;
- **Non-Destructive Testing**;
- Development and application of linear and nonlinear **acoustic techniques** for structural monitoring.

INFRASTRUCTURE

- DISAT: LINCE Lab. (Laboratory of Ceramic Technology & Engineering)

  The available equipment includes: Field Emission-Scanning Electron Microscopy (**FE-SEM**), Thermal analysis (Thermogravimetric-Differential Thermal Analysis, **TG-DTA**), **X-Ray Diffraction**, **Mercury porosimetry**, Specific surface area determination (**BET technique**), **Raman spectroscopy**; etc.

- DISEG: Labs. of *Materials and Structures*, *Non-Destructive Testing* and *Bio-Inspired Nano-Mechanics*.

  The available equipment includes: servo-controlled hydraulic or electro-mechanical **universal testing machines**; static and dynamic testing benches; single-point **laser vibrometer**; displacement and acceleration **sensors**; **ultrasonic testing** devices; data acquisition and conditioning units; etc.

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES:

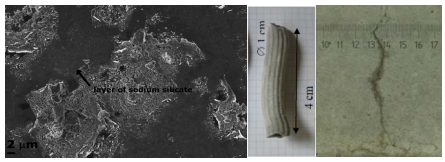
HEALING AGENTS

Selection and evaluation of different healing agents:

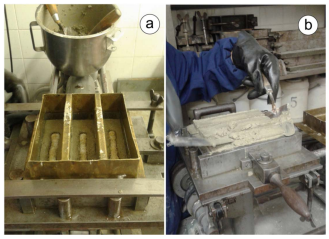
- **mono-component** systems: standard or modified sodium silicates; potassium or lithium silicates; acrylic resin; polyurethane expansive resins.
- **two-component** systems: sodium silicate plus calcium hydroxide or calcium/magnesium chlorides.

ENCAPSULATION

Development of **extruded cementitious hollow tubes** (CHTs) with different sequences of coatings for improved durability:

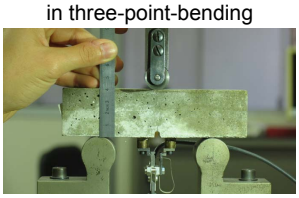


LAB PROTOTYPES

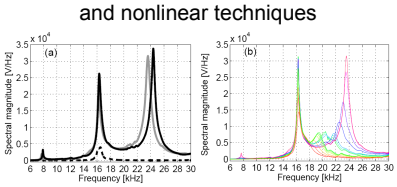


CHARACTERIZATION

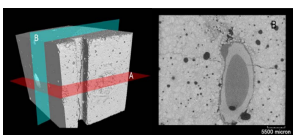
Mechanical performance in three-point-bending

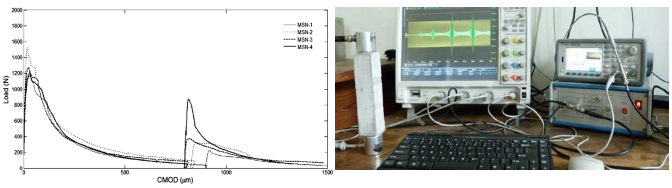


Ultrasonic testing via linear and nonlinear techniques



Micro-structural analysis by X-Ray tomography, etc.





Durability performance through permeability tests

MAIN PUBLICATIONS

A. FORMIA et al., Setup of Extruded Cementitious Hollow Tubes as Containing/Releasing Devices in Self-Healing Systems, *Materials* 2015, 8, 1897-1923.

A. FORMIA et al., Experimental analysis of self-healing cement-based materials incorporating extruded cementitious hollow tubes, *Journal of Intelligent Material Systems and Structures* 2016, 27(19), 2633–2652.

M. AIT OURABI et al., Ultrasonic Monitoring of the Interaction between Cement Matrix and Alkaline Silicate Solution in Self-Healing Systems, *Materials* 2017, 10(46), doi:10.3390/ma10010046

FUNDED PROJECTS

DUALCEM Project (2012-2014)
SHEcrete Project (2015-ongoing)

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CSIC Consejo Superior de Investigaciones Científicas — Instituto Eduardo Torroja

1st Internal Workshop SARCOS Action, 26th January 2017, Institute of Construction Sciences "Eduardo Torroja" (Madrid)

COST is supported by the EU Framework Programme Horizon 2020

INSTITUTION

Riga Technical University
Institute of Materials and Structures
Department of Building Materials and Products

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

INSTITUTION DESCRIPTION:

The research activities of ***Institute of Materials and Structures*** is regarded on development, testing and modelling of new, innovative composite materials with high added value. The Institute has strong impact at the national level with the potential of becoming a full-fledged participant in the international scientific society.

RESEARCH GROUP DESCRIPTION:

RESEARCH LINES

- High-performance and high-strength concrete;
- Alternative binders and building materials;
- High-performance heat insulation materials;
- Monitoring of technical condition of structures;
- Usage of passive energy systems in construction and energy-efficient buildings;
- Waste recycling in production of building materials;
- Eco friendly building materials.

INFRASTRUCTURE

- High efficiency twin shaft mixer, planetary mixers;
- Raw material treatment devices (mills, furnaces)
- Climate chambers;
- Durability testing equipment (freeze-thaw, chloride, sulphate, AAR, etc.);
- Physical properties characterization devices (laser granulometer, BET, SEM, etc.);
- Instruments for chemical analysis (XRD, FTIR, DTA/TG);
- Mechanical testing equipment up to 300 kN.

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES:

- Immobilization of calcium lactate and yeast and/or Bacillus lentus in expanded clay aggregates (FIBO 2/4 mm);
- Lightweight (1700-1800 kg/m^3) expanded clay aggregate concrete (20-30 MPa);
- Sample pre-cracking with different load rates and following healing;
- High strength concrete (up to 150 MPa) with increased silica fume content as autogenous self-healing method (Fig. 2 and 3)
- Pozzolanic materials as internal healing for concrete

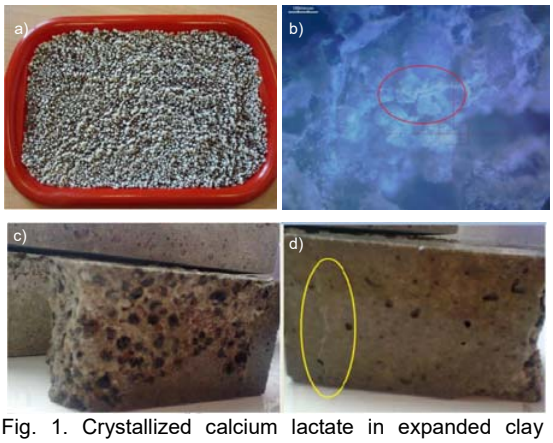

Fig. 1. Crystallized calcium lactate in expanded clay aggregates (a), crack healing in lightweight expanded clay aggregate concrete (b to d)

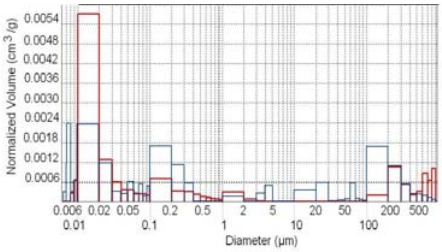

Fig. 2. Pore volume histogram of high performance concrete at 28 days (red line) and 6 months (grey colored volume) initially hardened under pressure of 50 MPa. Reduction of pore size and volume.

Fig. 3. SEM micrographs of high performance concrete at 28 d initially hardened under 50 MPa pressure: round unreacted particles of microsilica, monosulfate hydrate C_4ASH_{18} (C-A-S-H), calcium silicate hydrates (C-S-H).

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COST is supported by the EU Framework Programme Horizon 2020

KAUNAS UNIVERSITY OF TECHNOLOGY, FACULTY OF CIVIL ENGINEERING AND ARCHITECTURE, KAUNAS, LITHUANIA

University has 10,494 students, of which 7,620 are Bachelor's, 2,502 are Master's, 557 are foreign, and 335 are Doctoral students. All of that fits into 9 faculties of KTU.
Faculty of Civil Engineering and Architecture consist of 5 Departments (Department of Building Structures, Department of Building Materials, Department of Construction Technologies, Department of Architecture and Urbanism, Department of Building Energy Systems) and 1 Research Center (Research Center for Building Materials and Construction).

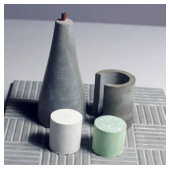
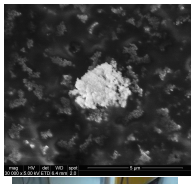
DEPARTMENT OF BUILDING MATERIALS - RESEARCH GROUP DESCRIPTION:

RESEARCH GROUP:

Dr. Algirdas Augonis, Dr. Ernestas Ivanauskas:
Fiber reinforced concrete;
Utilization of Raw Materials (fly ash, biomass etc.);
Alkali Silica Reaction;
Self-compacting and Self-healing of concrete;
Prof. Dr. Vitoldas Vaitkevičius, Dr. Evaldas Šerelis:
Ultra high performance concrete (over 200 Mpa);
Non-autoclaved aerated concrete;
3D concrete printing;
Prof. Dr. Danutė Vaičiukynienė:
Synthesis of crystalline and amorphous zeolites;
Geopolymer binders from Waste Materials;
Prof. Dr. Žymantas Rudžionis, Dr. Audrius Grinys, Dr. Vytautas Sasnauskas, Dr. Arūnas Navickas, Dr. Vidas Kerševičius, Dr. Darius Pupeikis, Dr. Eugenijus Janavičius, Vytautas Bocullo.

Head of Building Materials and Structures Research Centre - *Dr. Ernestas Ivanauskas*.

INNOVATIVE BUILDING MATERIALS


EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES:

Research started 2017 year. As self healing additives, the crystalline powders were used. Crack closes after 14 days of operated through concrete sample with water.



Further research will be carried out with self-healing concrete

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COST is supported by the EU Framework Programme Horizon 2020

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY (VGTU)

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

INSTITUTION DESCRIPTION:

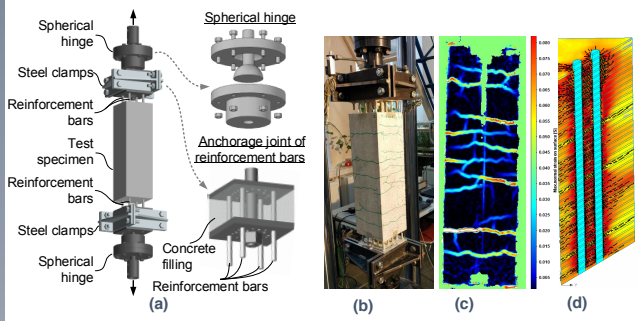
Research laboratory of Innovative Building Structures at VGTU is located in *Sunrise Valley* Science and Technology Park, Vilnius, Lithuania. It is part of National Centre of Physical and Technological Sciences (shown in picture).
Sunrise Valley is a home for:
- **Vilnius University and Vilnius Gediminas Technical University;**
- **Science and Technology park, Business incubator;**
- **Joint center for Life sciences;**
- **National center for Physical and technology sciences;**
- **National center for Scientific communication.**

National Centre of Physical and Technological Sciences

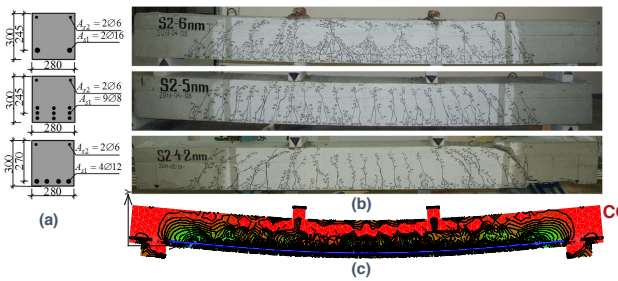
RESEARCH GROUP DESCRIPTION:

RESEARCH LINES

- **Experimental studies and numerical modelling of reinforced concrete elements subjected to short- and long-term loading;**
- **Monitoring of time-depended properties;**
- **Assessing long-term effects and service impacts.**
- **Development of constitutive material models applied in numerical studies;**
- **Application of innovative materials implementing real projects; evaluation of cost-effectiveness and rationale of applied solution; preparation of recommendations.**



Experimental and numerical investigation of tensile elements reinforced with multiple bars: a) patented grips for tensile test; b) test set-up; c) DIC image of the specimen; d) numerical FEM model



Deformation and cracking analysis of beams reinforced with different arrangement of composite bars: a) cross-sections of the beams; b) obtained crack patterns; c) numerical FEM model

INFRASTRUCTURE

SHORT-TERM LOADING
(applying load in reaction or deformation controlled manner)

BEAMS
Load: up to 2000 kN (static or cyclic)
Span: up to 15 m

COLUMNS/ TENSILE ELEMENS
Load: up to 10 000 kN (static)
Load: up to 2 000 kN (static or cyclic)
height: up to 6 m
length: up to 3 m

FRAMES
Load: up to 2000 kN (static or cyclic)
Load: up to 500 kN (static)
height: up to 3 m
Span: up to 15 m

LONG-TERM LOADING
(under controlled temperature and humidity conditions)

BEAMS
Load: up to 200 kN
Span: up to 3 m

COLUMNS/ TENSILE ELEMENS
Load: up to 1000 kN
Load: up to 100 kN
height: up to 2 m
length: up to 1.5 m

Short-term/cyclic loading

Bending specimens (up to 15 m length) can be subjected to static or cyclic load (up to 2000 kN). The equipment also allows testing frames (up to 3 m height). Columns (up to 6 m) can be subjected to monotonically applied compression load (up to 10 000 kN). Specimens (up to 3 m length) can be subjected to axial static tension/compression or cyclic load (up to 2000 kN). All processes are automated applying load in reaction or deformation controlled manner.

List of the equipment:

•System NS-PA2-DIG.2000 of two universal testing machines with system controller and data acquisition software PROTEUS:
- **vertical static load – up to 2000 kN;**
- **horizontal static load – up to 500 kN;**
- **vertical dynamic load – up to 400 kN (frequency 10 Hz);**
- **data transmission frequency – 8000 Hz;**
- **maximal size of the specimen – 3×15 m;**
- **load/displacement control error – less than 0.5%.**

•Servo-hydraulic testing machine LFV 5000 with system controller and data acquisition software DION 7:
- **vertical static load – up to 5000 kN;**
- **data transmission frequency – 8000 Hz;**
- **maximal size of the specimen – 3 m;**
- **load/displacement control error – less than 0.5%.**

•Servo-hydraulic dynamic testing machine LFV 600-HH with a high temperature furnace, system controller and data acquisition software DION 7:
- **vertical static load – up to ±600 kN;**
- **vertical dynamic load – up to ±500 kN (frequency 30 Hz);**
- **data transmission frequency – 8000 Hz;**
- **maximal size of the specimen – 1 m;**
- **ambient temperature of test specimen – 20-1000°C;**
- **load/displacement control error – less than 0.5%.**

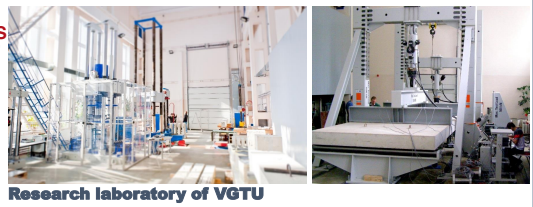
• Universal electromechanical testing machine LFM 100 with system controller and data acquisition software DION STAT:
- **vertical static load – up to ±100 kN;**
- **vertical dynamic load – up to ±500 kN (frequency 30 Hz);**
- **data transmission frequency – 8000 Hz;**
- **maximal size of the specimen – 0,8 m;**
- **ability to operate in slow mode – up to 0,01 mm/min;**
- **contains additional equipment for tensile, compression, bending and shear tests;**
- **load/displacement control error – less than 0.1%.**

Long-term loading

tension tests (up to 100 kN), bending tests (up to 200 kN), and compressive tests (up to 1000 kN) under controlled temperature and humidity conditions.

Durability tests of building structures and materials. Cyclic freezing-thawing conditions can be attributed to samples stored in aggressive environment:
- **area of the chamber – 12,5 m3;**
- **maximal length of the specimen – 3,5 m;**
- **maximal weight of the specimen – 1 t;**
- **operating temperature – from -35°C up to +35°C.**

Production of concrete samples. Available equipment allows producing 3,5×0,5 m specimens. Equipment allows pre-stressing of the bar reinforcement.
- **planetary mixer – 4 m3**
- **planetary mixer for production of the concrete with high amount of fibers – 0.8 m3;**
- **size of the shaking table with push-button magnet system – 8×4 m;**
- **vibrating frequency – 0-100 Hz**



Research laboratory of VGTU

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES:

Research laboratory of Innovative Building Structures at VGTU specializes in experimental and analytical analysis of reinforced concrete (RC), fiber reinforced concrete (FRC) and composite structures. The research group have developed innovative methods for deformation and cracking analysis of RC elements.

After completion of PhD studies in 2015, one member of the research group R. Jakubovskis has turned his attention to the concept of self-healing concrete. By the time limited theoretical knowledge about the methods of self-healing has been obtained. Nevertheless, the existing knowledge and experience in structural behavior of RC may contribute to the development and upscaling of self-healing concrete structures.

The cooperation with the Department of Molecular Microbiology and Biotechnology from the Joint center for Life sciences (shown in Figure) has already been initiated for possible development of biological concrete.

Research laboratory of Department of Molecular Microbiology and Biotechnology

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CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS
INSTITUTO EDUARDO TORROJA

1st Internal Workshop SARCOS Action, 26th January 2017, Institute of Construction Sciences "Eduardo Torroja" (Madrid)

COST is supported by the EU Framework Programme Horizon 2020

cost
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

POLAND INSTITUTIONS

Cracow University of Technology (CUT)
Lodz University of Technology (LUT)
Warsaw University of Technology (WUT)

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR
OF CONCRETE STRUCTURES

INSTITUTIONS DESCRIPTION (POLAND):

Cracow University of Technology (CUT), Faculty of Civil Engineering - address: Warszawska 24, 31-155, Cracow

Institute of Building Materials and Structures (L-1)
Teresa Stryszewska (tstryszewska@pk.edu.pl), **Andrzej Winnicki** (andrzej@hypatia.l5.pk.edu.pl), **Tomasz Zdeb** (tzdeb@pk.edu.pl)

Institute of Structural Mechanics (L-4)
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Institute for Computational Civil Engineering (L-5)
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Lodz University of Technology (LUT), Faculty of Biotechnology and Food Sciences - address: Wólczańska 171/173, 90-924, Łodz

Institute of Fermentation Technology and Microbiology
Anna Otlewska (anna.otlewska@p.lodz.pl)

Warsaw University of Technology (WUT), Faculty of Civil Engineering - address: Armii Ludowej 16, 00-637, Warsaw

Department of Building Materials Engineering
Andrzej Garbacz (a.garbacz@il.pw.edu.pl), **Paweł Łukowski** (p.lukowski@il.pw.edu.pl) - MC

RESEARCH GROUPS DESCRIPTION:

RESEARCH LINES

CUT (L-1)
- *Durability of mineral materials: ceramic brick, mortar and concrete (modern and historical)*
- *Chemical environmental corrosion (salt solution, ocean water and alkali)*
- *Determination* of mechanical, chemical and physical properties of mineral materials
- Structural tests of porosity structures (mercury intrusion porosity) and microstructures (scanning microscope)

CUT (L-4)
- Durability of bonding materials in thermal aspect: epoxy resins, polyurethanes
- Reduction of stress concentrations and stress redistribution in brittle materials
- Repair and strengthening of structures using Polymer Flexible Joints (PFJ)

CUT (L-5)
- Computational mechanics of materials (description of nonlinear phenomena)
- Different aspects of modeling in concrete and concrete structures
- Simulation of cracking using regularized continuum models
- numerical analysis of effects of corrosion in RC structures
- Digital Image Correlation (DIC) method

LUT
- Role of microorganisms (bacteria and fungi) in deterioration of building materials
- Impact of environmental conditions (temperature, relative humidity, salinity level, pH) on microbial growth and proliferation and mechanisms of biodeterioration process
- Detection and identification of microorganisms involved in biodeterioration bacterial strains for biomineralization and bioconsolidation purposes

WUT
- Sustainable building composites (polymers and mineral wastes as components)
- Sustainable concrete technologies
- Shaping and evaluation of durability of concrete (including self-repair ability)
- Diagnostics (including non-destructive methods)
- Designing and evaluation of new generation concretes

INFRASTRUCTURE

CUT
- Electron microscope Zeiss EVO 10 equipped with the SE, VPSE detector and EDS (observations in variable pressure using BSD or VPSE detector and in high pressure using SE and BSD detector, Q150T Turbo-Pumped Sputter Coater/Carbon Coater/Gold Coater in case of non-conducting or poorly conducting specimens)
- Quantachrome Poremaster mercury intrusion porosimeter (range 3nm÷300000nm)
- Chamber for cyclic corrosion tests Corrosionbox 400
- Testing machine for mechanical properties Zwick 1200, Zwick Z 100, Zwick 1455 20kN
- Spectrophotometer V-630 (content of sulphate and chloride ions and pH)
- Vibration measurement system (accelerometers PCB 393B12, aquisition ESAM Traveller Plus, conditioning PA16000 EC Electronics, analyzer LMS SCADAS Mobile)
- DIC system (Digital Single-Lens Reflex cameras -16Mpx and 24 Mpx, CivEng Vision software program)
- 6 multiprocessor computation servers (Linux or MSWindows, 10/1 GB Ethernet)
- Software: ABAQUS, AceGEN/AceFEM for Mathematica, ANSYS, FEAP, hp3d, Mathcad, Matlab, Midas FEA/Gen, Revit, Robot, Tekla Structures, Visual Studio.
- 3D printer (Stratasys uPrint SE) - validation and calibration of porous materials models

LUT
- Climatic chamber (Binder) - controlled temperature and relative humidity
- Accelerated aging chamber (aggravated conditions of heat, humidity, oxygen, sunlight, vibration, etc., controlled standard test methods)
- Luminometer HY-LiTE® System (Merck) - easy, fast and reliable ATP residue rapid detection system for assessing viability of bacteria
- Thermocycler MJ Mini (Bio-Rad), gel imaging system Bio-Doc-It Imaging System (UVP), electrophoresis equipment (Bio-Rad), NanoDrop spectophotometer Pearl (Implen) for molecular identification of microorganisms
- Spectrophotometer UV-Vis (LaboMed, Inc.)
- Light microscopes (Olympus)

WUT
- Laser particle sizer HORIBA LA-300 (range 0-600 μm)
- Testing machine for mechanical properties INSTRON 5567 30 kN
- FORM+TEST lab stand for testing water-tightness of concrete
- GERMAN INSTRUMENTS set for Impact-echo testing

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES:

CUT (L-1) Using of the hardness testing for assessing effectiveness of concrete self-healing is considered, as well as scanning microscope observations, particularly focused on the contact zone between the old and new concrete (repair).

CUT (L-4) Self-repair and strength increase of concrete elements were reached by closing of micro-cracks around cracks in damaged structures, after using of Polymer Flexible Joints, which reduce stress concentrations and redistribute stress more evenly.

CUT (L-5) The main goal in considered research is to formulate and implement efficient models and computational methods for self-healing in reinforced concrete structures, based on damage-plasticity.

LUT The research is focused on identification of microbially induced mineralization mechanisms in of building materials, bacterial strains application to self-heal of different types of building surfaces by precipitation of calcium carbonate and bioconsolidation of sand.

WUT Some self-repair ability of concrete was achieved by adding epoxy resin without chemical hardener into the concrete mix; at present, the use of crystalline admixtures is also considered for this aim; methodology of assessing self-repair ability of the using, among others, a high-precision computer controlled strength machine was developed.

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CSIC Consejo Superior de Investigaciones Científicas — Instituto Eduardo Torroja

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COST is supported by the EU Framework Programme Horizon 2020

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

UNIVERSIDADE NOVA DE LISBOA

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

INSTITUTION DESCRIPTION:

UCIBIO-REQUIMTE

The Research Unit on Applied Molecular Biosciences, UCIBIO, is a team of researchers from the Universities of Porto and NOVA of Lisbon. UCIBIO combines key expertise in Chemistry and Biological Sciences with an ambitious strategic plan to maximize its national and international impact in terms of scientific productivity, advanced training and translation to society.

Civil Engineering Department, Faculty of Sciences and Technology, University NOVA of Lisbon (DEC FCT NOVA)

The DEC FCT NOVA is located at Faculty of Science an Technology from University NOVA of Lisbon. The department main goals are being a reference in education and investigation in Civil Engineering in Portugal; create, develop and diffuse science and technology on the Civil Engineering field; and to serve the community through competent professionals.

RESEARCH GROUP DESCRIPTION:

RESEARCH LINES

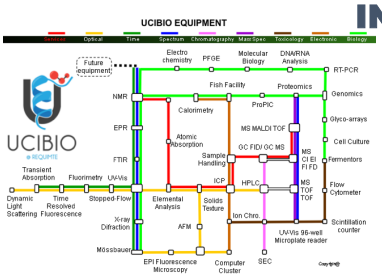
UCIBIO-REQUIMTE

Researchers of the **Structural Molecular Biology Group** have a long-standing interest in a variety of topics, namely environment impact. The different methodologies available provide a characterization of different biomolecular research topics: protein structures, spectroscopic, biophysical and biochemical characterization; enzyme structures and catalytic mechanisms; structural and functional analysis of protein-protein, protein-ligand and protein-glycan interactions.

DEC FCT NOVA

Researchers of **Materials and Structures Group** have been working on new eco-efficient materials and techniques, with a growing concern for the conservation of built environment and improved durability of construction materials and structures. Research at DEC FCT NOVA covers vernacular materials like earthen construction, gypsum-based plasters, lime-based mortars, stone, but also bio-based materials and cementitious grouts, mortars and concretes.

INFRASTRUCTURE



The group has access to all necessary infrastructures for Structural Biology either in-house or within the scope of National or International Networks (PT NMR Network, ESRF and other SR labs (X-ray and SAXS)).

There is access to several necessary infrastructures for the characterization of Granular Materials, formulation and fresh and hardened state characterization of Grouts, Mortars and Concretes, as well as other solid construction materials (e.g. TGA/DTG, MIP, Flow table, Air content, Drying shrinkage, durability to salts, hygroscopicity, water absorption, adsorption and desorption, mechanical properties, NMR for moisture front progress). *In situ* characterization and outdoors controlled weathering is also performed (e.g. Thermal conductivity, Superficial cohesion, Superficial resistance, …)

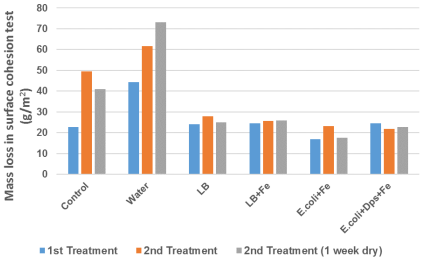
SELF-HEALING OF EARTH PLASTERS:

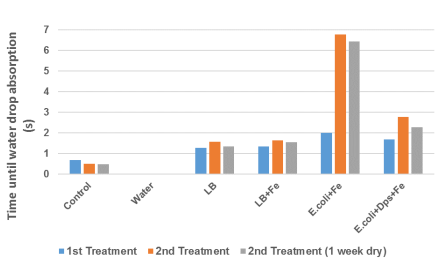
Bio-based treatment of earth mortars

A screening was performed in order to understand how an iron bio-based superficial treatment could improve earth mortars durability. 5 different treatments were tested: Water; Luria Broth (LB) medium; LB with iron; *Escherichia coli* culture with iron; and *Escherichia coli* culture with iron and Dps, an iron scavenger protein.

In a first stage 1 mL of treatment was applied, followed by 5 days of feeding with LB medium. On the second stage, the treatment was re-applied with 1 day feeding.

Surface hardness was performed with PCE Shore A durometer. Surface cohesion was performed by detaching a tape from the treated surface and weighing the tape. Water drop absorption was performed by dropping a water drop on the surface and measuring the time until total absorption.





The results from surface hardness and surface cohesion suggest that, despite the slight surface damage due to the application of the liquid treatment, surface hardness is maintained and higher cohesion can be obtained.

The most promising results were obtained on the water drop absorption test, where the treatment with *E. coli* culture and iron stands out, demonstrating an increased resistance towards water absorption.

Bio-based formulation of earth mortars

Earth mortars were produced with 3 different liquids: a control (water); two with bio-based liquid (LB medium and *E. coli* culture supplemented with ferrous iron). Mortars with bio-based liquid were more fluid, more fluffy and with lower density in comparison with control mortar. Fresh state characteristics seemed appropriated for mechanical application as plasters. Further characterization is now ongoing…..

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CSIC Consejo Superior de Investigaciones Científicas — Instituto Eduardo Torroja

1st Internal Workshop SARCOS Action, 26th January 2017, Institute of Construction Sciences "Eduardo Torroja" (Madrid)

COST is supported by the EU Framework Programme Horizon 2020

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

MINISTRY OF RESEARCH AND INNOVATION
National Institute for Research and Development in Construction, Urban Planning and Sustainable Spatial Development "URBAN-INCERC"

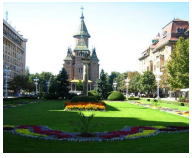
COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

NIRD URBAN-INCERC strategical fields of interests: research and development in construction, urban planning and sustainable territorial development.

The institute contains several branches, placed in Romania's most important cities:

Bucharest ***Cluj-Napoca*** **Timișoara** **Iași**





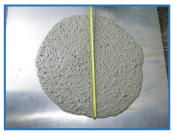

ensuring a complete national covering

NIRD URBAN-INCERC Cluj-Napoca Branch

Material and Structural Elements Research & Testing Laboratory - IME
European Notified Body No 1841, Acreditation Certificate No 320 (RENAR), Autorization Certificate No 2300 (ISC)

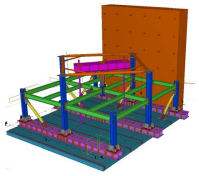
Research on building materials

- Structural and insulating light weight concrete – (*New Romanian Code: C 155-2013 "Norms for lightweight concrete production"*)
- Waste and industrial by-products recycling
- Self-compacting concrete for precast elements industry




Structural Elements & Building Structures Testing



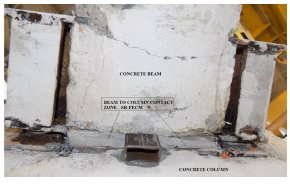



In situ tests, Non-destructive site testing Constructions Monitoring



SELF-HEALING OF CONCRETE STRUCTURES:

Self-Sealing – the prismatic specimens showed partial crack-closing under visual analyses
Self-Repairing (distinct failure path when retesting)



Hybrid spatial joint model after testing - critical interface zone, bottom view: good performance of SH-FECM, no spalling or large visible cracks

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COST is supported by the EU Framework Programme Horizon 2020

Laboratory for Materials in Cultural Heritage

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cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

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Snežana Vučetić

Helena Hirschen-berger

Ana Vidaković

John Milan van der Bergh

PROJECTS, REFERENCES

COORDINATION OF INTERNATIONAL PROJECTS:

- **Horizon 2020** PolyBioSkin (2017-2020)
- **FP7 project HEROMAT** "Protection of Cultural Heritage Objects with Multifunctional Advanced Materials" (2011-2015)
- **Eureka Programme E! 5861** "Multifunctional layers for the protection of mineral substrates" (2010-2013)
- **FP7 project RP DEMATEN** "Reinforcement of research potential of the Department of Materials Engineering in the field of processing and characterization of nanostructured materials", (2008-2011)
- **Eureka Programme E! 3969** "Clean Tile Development of Self-cleaning clay roofing tiles"(2007-2009)
- Bilateral scientific cooperation with **Italy**: "Sviluppo locale incentrato sulla valorizzazione del patrimonio culturale"(2006-2008)
- Bilateral scientific cooperation with **Slovenia**: "Degradation processes of building materials - Frost actions" (2003-2004, 2005-2006)
- **WUS project** "Methods of materials characterization", World University Service Austria (2005)

PARTICIPATION IN INTERNATIONAL PROJECTS:

- **Eureka Programme E! 4964** "Development of lightweight aggregate from waste material and further processing into thermal insulation concrete" (2010-2012)
- **TEMPUS**: "COMPETENCE - Matching competences in higher education and economy: From competence catalogue to strategy and curriculum development" (2009-2012)
- **COST Action 540**: Photocatalytic technologies and novel nanosurfaces materials –critical issues ("Phonasum") (2006-2010)

COORDINATION OF NATIONAL PROJECTS FINANCIED BY SERBIAN MINISTRY OF EDUCATION, SCIENCE AND TECHNOLOGICAL DEVELOPMENT:

- III45008 "Development and application of multifunctional materials using domestic raw materials in upgraded processing lines" (2011-2016)
- TR 19005 "Nano composites based on silicate materials in design of improved and new ceramic materials" (2008-2010)
- TR 6735 "Design of physico-mechanical characteristics of ceramic roof tiles and ceramic tiles resistant to frost and biocorrosion" (2005-2007)
- TR 3200 "Design of texture of brick elements resistant to frost and biological agents" (2002-2004)

EXPERTISE

- **Examination** of building materials (historical and modern)
- **Design and processing** of new functional materials for cleaning and protection of tangible cultural heritage
- **Development of new methods** for materials characterization (*in situ* and laboratory), functionality, compatibility, durability

PROPOSALS FOR SELF-HEALING CONCRETE STRUCTURES

I

Self-healing using the phenomena from the nature: Use of microorganisms which produce natural polymers (biopolymers) as a metabolic product – **direct application**

II

Self-healing using the phenomena from the nature: Use of microorganisms which produce natural polymers (biopolymers) as a metabolic product – **deposition by electro-spinning**

III

Electro-spinning deposition of proven bacterial cultures for self-healing of concrete structures – **production of biofibers**

Challenges:

The pH value of concrete can be rather high which could be a problem for the bacterial growth. However, in damaged and previously infected areas of the concrete structures, the pH values are reduced. This effect has been observed by investigations on culture heritage objects and could be used for the self-healing pre-treatment. The idea is to create environmental possibilities for reduction of the pH value and good start for the self-healing processes proposed above.

CAPACITIES

Mobile equipment:

X-Ray Fluoresence Spectrometer – Bruker Artax µXRF 200

Fourier Transformed Infra-Red Spectrometer – Bruker Alpha

Infra-Red Thermal Camera – FLIR T660

UV/Vis Spectrophotometer – Konica Minolta CM 700d

Drilling Resistance Measurement System – SINT Technology

Light Stereo Microscope – OMANO OMXTL/V7

Laboratory equipment:

- **UV/Vis Spectrophotometer** – Thermo Scientific Evolution 600
- **X-Ray Diffractometer** – Philips PW 1710
- **Scanning Electron Microscope** with **Energy Dispersive Spectroscope** - JEOL JSM 6460 LV and Oxford INCA
- **Polarizing Light Microscope** – Carl Zeiss AxioScope A1
- **Surface Roughness Meter** – Taylor/Hobson precision Surtronic 25
- **Vicker's Microhardness Meter** – ZZV Precision Tool Supply HVS 1000 A
- **Surface and Energy Evaluation System** – Advex Instruments
- **Low Temperature Gas Adsorption Porosimeter** – Thermo Scientific SURFER
- **Mercury Intrusion Porosimeter** – Micromeritics AutoPore IV 9500
- **Growth/Aging Chamber** – Binder KBWF 240
- **Sample Preparation System**: Diamond Cut-off Machine, Vacuum Impregnation Unit, Grinding and Polishing Unit – Struers
- **DTA/TG Analyzer** – Bähr STA 503
- **Electro-spinning Deposition System**

COST is supported by the EU Framework Programme Horizon 2020

COOPERATION

- Lafarge Holcim
- Potisje Kanjiža – Tondach Wienerberger AG
- Polet Novi Bečej – NEXE Group
- Provincial Institute for the protection of cultural monuments – Vojvodina
- Central Institute for Conservation – Belgrade, Serbia
- Slovenian National Building and Civil Engineering Institute
- SMEs in Serbia – Companies for the production of building materials
- Faculty of Chemistry and Chemical Technology – University of Ljubljana, Slovenia

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

INSTITUTION

Institute of Ceramics and Glass (ICV-CSIC)

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

INSTITUTION DESCRIPTION:

The Institute of Ceramics and Glass (ICV) in Madrid (Spain) belongs to the Agencia Estatal Consejo Superior de Investigaciones Científicas (CSIC)

GlaSS group: Glasses, Glass-ceramics and Sol-gel materials for a Sustainable Society

Personnel involved in this COST action: Dr. Mario Aparicio, Dra. Jadra Mosa, Miguel Gómez, Desiré Ruiz

RESEARCH GROUP DESCRIPTION:

RESEARCH LINES

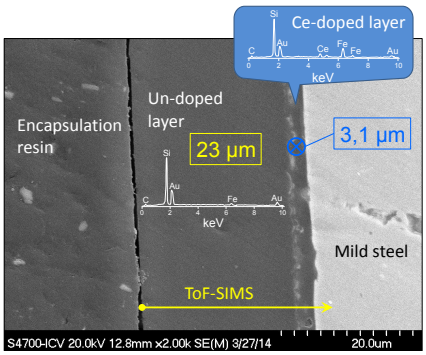
1. Active corrosion inhibition by siloxane-methacrylate Ce-doped sol–gel coatings
2. Corrosion protection based on organic–inorganic Melting Gel coatings

INFRASTRUCTURE

- Electrochemical characterization: AC/DC measurements
- Structural characterization: Confocal Micro-Raman, ToF-SIMS, FT-IR, SEM-TEM, etc.
- Sol-gel Processing: Dip-coating, Automatic Spray-coating, Spin-coating, etc.

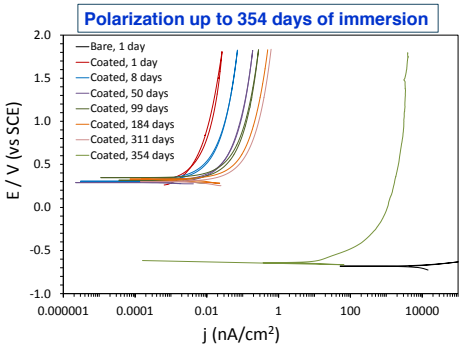
EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES:

1 Active corrosion inhibition by siloxane-methacrylate Ce-doped sol–gel coatings



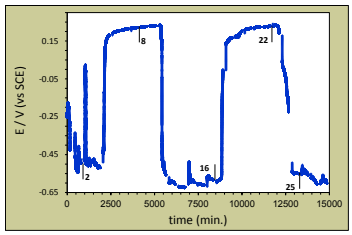
Substrate: Mild steel
Electrolyte: 3.5 wt.% NaCl (RT)

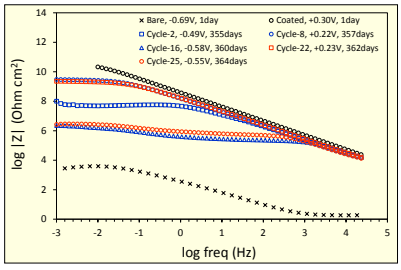
Polarization up to 354 days of immersion



Self-healing activated

Immersion time above 354 days of immersion





2 Corrosion protection based on organic–inorganic Melting Gel coatings

Melting Gels are hybrid organic-inorganic non-porous materials, which are:

- solid at room temperature,
- become fluid at a temperature T1,
- again become solid, and no longer soften after thermal treatment at consolidation temperature T2 (T2 >T1)
- at T2, cross-linking becomes complete.

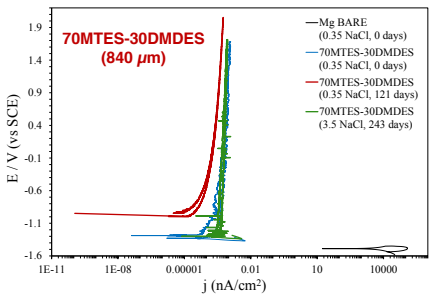
Methyltriethoxysilane (MTES)
CH_3-Si$(OC_2H_5)_3$
mono-substituted alkoxysilane/tri-functional

Dimethyldiethoxysilane (DMDES)
$(CH_3)_2$-Si$(OC_2H_5)_2$
di-substituted alkoxysilane/di-functional

Processing methods allow coatingsThickness between 2 µm and 1 mm

After consolidation (T_2)

Substrate: Magnesium Alloy AZ31B
Electrolyte: 3.5 wt.% NaCl (RT)



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COST is supported by the EU Framework Programme Horizon 2020

cost
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

INSTITUTION

Spanish National Research Council (CSIC)

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR
OF CONCRETE STRUCTURES

INSTITUTION DESCRIPTION: CSIC (IETcc)

Spanish National Research Council (CSIC)

The largest public research organization in Spain and the 3rd in Europe.

125 centers in 8 scientific-technical areas

Scientific and Technological research.
Advancing knowledge.
Economic, social and cultural development.

Institute of Construction Science "Eduardo Torroja" (IETcc-CSIC)

Research on Construction & building materials, structural engineering, roads, energy saving.

Technical support to the construction sector
ETA / UEATC, RILEM,etc.
Elaboration of Spanish& European Standards.

Dissemination of Scientific & Technical Knowledge

RESEARCH GROUP DESCRIPTION:

RESEARCH LINES

Safety and Risk Management (GRS)

Innovative solutions for high performance material & structures in extreme risk conditions:
- *Natural disasters*
- *Environmental*
- *Technologic*

Diagnosis of damage
Models for structural analysis

Nanotechnology & functional materials
- *Risk reduce & manage due to loss of performances*
- *Implementation of new functionalities in materials & components, including self-properties*

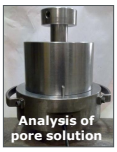
Eco-efficient construction materials (MECONS)

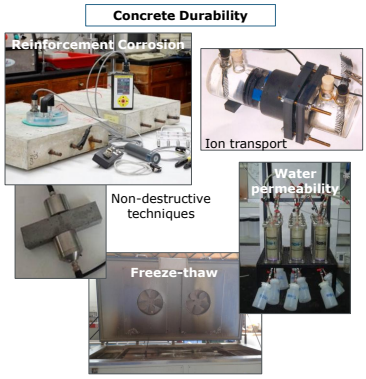
Activation and valorisation of waste products
- *Activation of wastes through hydrothermal treatment.*
- *Valorisation of wastes in eco-efficient cement-based materials.*
- *New eco-efficient cements: low emissions and low energy.*

Development of eco-efficient cement-based materials with advanced functionalities
Self-healing concrete based in autonomous and autogenous strategies
Smart mortar for thermal coating of buildings based in eco-efficient thermocromic cements

INFRASTRUCTURE

SEM/XRD/TG/AFM
MIP/BET-N_2...

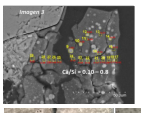


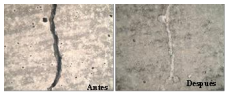


EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES:

External sealing of cracks

Penetration of colloidal nanosilica: several application methods
Sealing coating due to the reaction with cementitious matrix



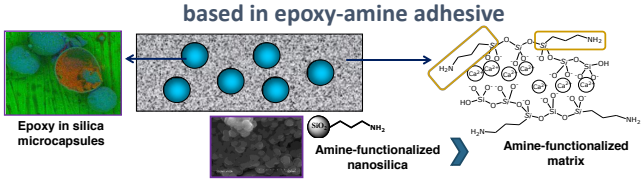


Current results
Sealing up to 300 µm width.
Increased resistance upon agressive agents.
Electrochemical methods enhances versatility.

Future objectives
Regain of mechanical properties
Innovative functionalities: **self-healing**

National funding through ProjectBIA 2014-56825-J IN (2015 – 2018)
Main Researcher: **Mercedes Sánchez**

Autonomous self-healing concrete based in epoxy-amine adhesive



Current results
Sealing up to 300 µm crack-width.
Increased durability (freeze-thaw/salt spray).

Future objectives
Scalability and prototipes.

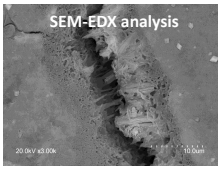
National funding through Project BIA 2011-29234-C02-01 (2012 – 2015) in collaboration with **Tecnalia.**
Main Researcher: **Ana Guerrero**

Engineered Cementitious Composites (ECC) incorporating local waste products

Substitution of fly ashes by biomass ashes from Spanish paper industry.

Current results
Tightness increase with curing time after cracking with 70% biomass ash-30% fly ash.

Future objectives
Complete characterisation of ECC with biomass ashes.
Substitution of PVA fibers by nanofibers from residues.
Search National/European funding.



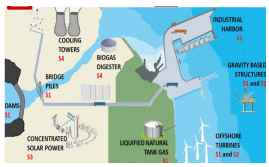
Contact Researcher: **Gloria Pérez**

Long Lasting Reinforced Concrete for Energy infrastructures under Severe Operating Conditions (LORCENIS)

https://www.sintef.no/projectweb/lorcenis/

Goal: multifunctional self-responsive strategies integrated in **bulk reinforced-concrete** for manufacturing energy structures under **Severe operating conditions**:

Self-diagnosis Self-healing Self-curing Self-protection



European funding: H2020 NMP-19-2015 LORCENIS-685445. 17EU Countries, 2016–19
Main Researcher CSIC: **M. Cruz Alonso**

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MECONS group
Mercedes Sánchez mercesanc@ietcc.csic.es
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COST is supported by the EU Framework Programme Horizon 2020

Universitat Politècnica de València (UPV)

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

INSTITUTION DESCRIPTION:

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

- UPV is a young institution. Its history dates back to the early 70s although some schools are +100 years: School of Design Engineering, the Higher Polytechnic School of Alcoi and the Faculty of Fine Arts.
- UPV today has three campus: Vera (main campus in València), Alcoi and Gandia.
- UPV is the only technological university in Spain featured in all the world university rankings.

Some numbers:

Students:	37800
Teaching and research staff:	2600
Administrative and services staff:	1700
Erasmus received 2009-2010:	1783
Erasmus sent 2009-2010:	1147
Area	> 600,000 m^2
Green Areas	> 125,000 m^2

RESEARCH GROUP DESCRIPTION:

RESEARCH LINES

Development of Special Concretes and New Technologies
- Self Compacting Concretes and High Strength Concretes
- Fiber-Reinforced Concretes and Ultra High Performance
- Recycled Concretes
- Self-healing Concretes
- 3D Printing of Concrete Structures
- Cold forming of Concrete

Development of New Test Methodologies and Standardization
- ECADA – BOND
- CREEP of FRC – RILEM TC 261 CCF
- PUSH-OFF – SHEAR of FRC
- SELF-HEALING of Concrete

Monitoring Corrosion: Durability Measurement in Structures

Analysis of Special Concretes Mechanical Behavior
- CFRP – Reinforcements
- Shear on FRC
- Bond Concrete - Reinforcement

Recycling everything for Concrete

Thinking on Real Applications





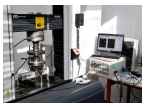
INFRASTRUCTURE

ICITECH
CIENCIA Y TECNOLOGÍA DEL HORMIGÓN

Institute of Concrete Science and Technology

- **Concrete and mortar mixers** of different capacities: 1, 30, 50, 150 and 300 liters (one of high energy)
- **Testing equipment**: INSTRON 10 kN, Ibertest 3000 kN, Universal Testing Machine 600 kN, ICON, …
- **Reaction Wall and Floor** 12x6 m^2
- **Load frames** of different sizes
- Frames and rooms for long-time testing (creep)
- **Permeabilimeter:** high pressures (1-10 bars)
- **Several Humidity Chambers,** water tanks
- **Optical microscope**
- **Accesories** for concrete testing: gauges, LVDTs…

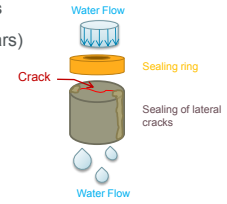


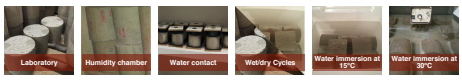


EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES:

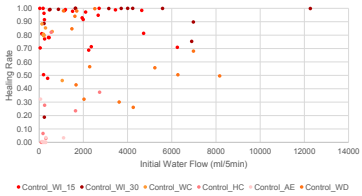
WATER PERMEABILITY TESTS

- **Main work on self-healing concrete with crystalline admixtures (CA)**
- **Comparison for several healing conditions**
- **Own methodology** using high pressure (2 bars)
- **Collaborations in this work:**
  - Prof. Liberato Ferrara
  - MEng. Simone Moscato
  - MEng. Francesco Pirritano

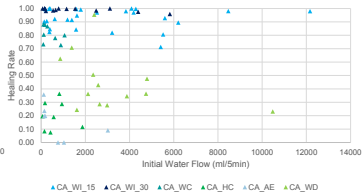




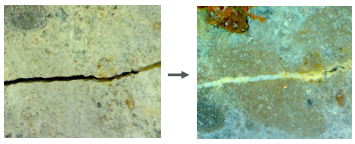
Autogenous healing



Crystalline Admixtures



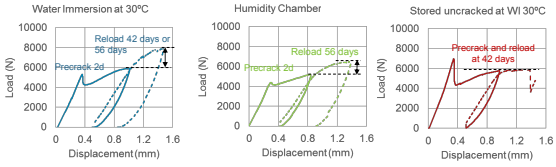
CRACK CLOSURE



- As secondary evaluation method
- Comparisons with permeability results
- Determination of "healable" cracks

MECHANICAL RECOVERY

- **Status:** further analyses on-going
- **Collaborations in this work:**
  - BEng. Laura Rubio (UPV)



SORPTIVITY

- **On-going → COST STSM**
- **Collaborations in this work:**
  - Prof. Abir Al-Tabbaa
  - Dr. Chrysoula Litina

UNIVERSITY OF CAMBRIDGE

MAIN INTERESTS

SARCOS-WG1:
- Autogenous
- Crystalline Admix.

SARCOS-WG2:
- Durability methods (water permeability, sorptivity,…)
- Mechanical recovery
- Crack closure
- Standardisation
- Scaling up

Contact details:

Pedro Serna Ros
pserna@cst.upv.es

Marta Roig Flores
marroifl@cam.upv.es

Websites
www.upv.es / www.icitech.upv.es

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1st Internal Workshop SARCOS Action, 26th January 2017, Institute of Construction Sciences "Eduardo Torroja" (Madrid)

COST is supported by the EU Framework Programme Horizon 2020

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

UNIVERSITY OF CAMBRIDGE

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

INSTITUTION DESCRIPTION:

UNIVERSITY OF CAMBRIDGE

- One of the oldest universities in the world - c.1209
- One of the largest universities in the UK
- World-wide reputation for teaching and research
- Collegiate university, 31 colleges

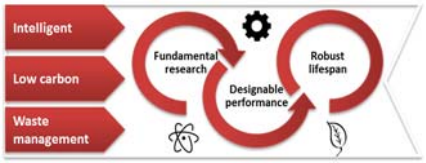
Numbers:

- Engineering Department is 12% of University: 160 faculty, 200 postdocs, 600 PhD students,1100 undergrads
- Civil Engineering Division: Structural, Geotechnical, Environmental engineering research and facilities: 25 academics, 130 PhD students, 50 undergrads/year
- Centre for Doctoral training in Future Infrastructure & Built Environment: 50 students, 19 industry partners, 4 year programme

RESEARCH GROUP DESCRIPTION:

RESEARCH LINES

- Contaminated land remediation
- Ground improvement
- Development of green cements
- Magnesia cements
- Carbon capture materials
- Mineral sequestration
- Self-healing cementitious systems
- Soils, soil-cement, grout, mortar, concrete, pervious concrete

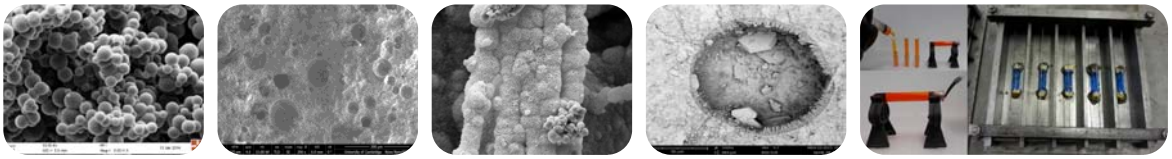


INFRASTRUCTURE

- Production of soils and cementitious systems
- Characterisation studies
- Mechanical, hydraulic, durability
- Analysis of metals and organics
- Environmental testing/fume cupboards
- Microindentation, DMA, calorimeter, zeta meter, rheometer
- Microfluidics dispersion cell, membrane emulsification systems

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES:

- Development of self-healing microcapsules & vascular systems
- Expansive minerals for self-healing applications
- Characterisation of self-healing systems
- Production and testing of self-healing cementitious systems
- Evolution of self-healing process & self-healing compounds
- Mechanical, hydraulic, durability & microstructural testing
- Scale up of self-healing systems and field trials
- Self-healing repair and new concrete systems.



Contact details:

Prof Abir Al-Tabbaa
aa22@cam.ac.uk

Website
http://www-geo.eng.cam.ac.uk/

COST is supported by the EU Framework Programme Horizon 2020

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Cardiff University
School of Engineering
M4L Research Group

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

INSTITUTION DESCRIPTION:

CARDIFF UNIIVERSITY

Elite Russell Group UK University (1 of 24)
28,500 students
- 21,000 undergraduates
- 7500 postgraduates
- ~1500 permanent academic staff

SCHOOL OF ENGINEERING

Staff : 100 academic staff
200 research and support staff
Turnover: £33m per year
Students: 1,200 undergraduate,
400 postgraduate

RESEARCH GROUP DESCRIPTION:

RESEARCH GROUP & COLLABORATIONS

M4L research group in Cardiff

R Davies D Gardner M Harbottle T Jefferson R Lark I Mihai

PARTNERS ON M4L PROJECT

Cambridge University (Abir Al-Tabba) & Bath University (Kevin Paine)

INFRASTRUCTURE

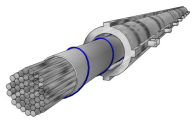
Extensive laboratory facilities for
- Mechanical testing of small & large scale specimens
- Static and dynamic tests
- Different environments
- Durability parameters
- Chemical analysis

EXPERIENCE: SELF-HEALING CONCRETE

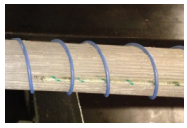
SMP CRACK-CLOSURE SYSTEM

- SMP tendons for crack closure
- Developed electrical activation system
- Investigated long term performance
- Full-scale site trials

Shape memory polymer sample

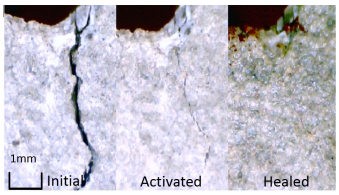


SMP tendon assembly

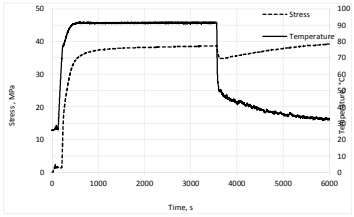


Activation system

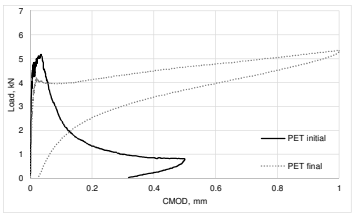
SMP tendons insitu



Crack closure and healing



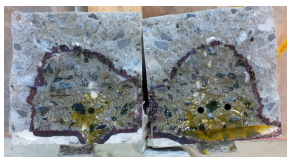
Restrained shrinkage stress



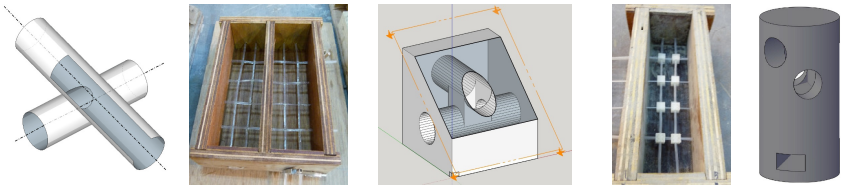
Response of a notched beam test

VASCULAR NETWORKS

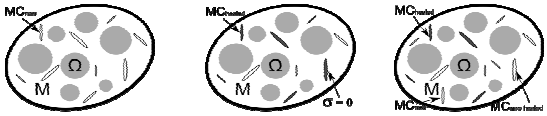
- Flow networks in cementitious materials
- Methods for creating interconnected channels
- Characterisation of capillary flow properties



Studying the flow of healing agents in cracks



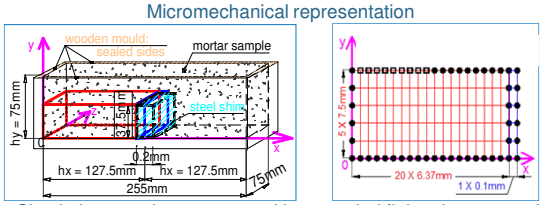
Creating interconnected networks in concrete



Micromechanical representation

MODELLING WORK

- Micro-mechanical model for micro-cracking and healing in concrete *(Davies & Jefferson, 2017)*
- Coupled thermo-hygro-chemo model for early age healing in cementitious materials *(Chitez & Jefferson, 2016)*
- Time dependent simulations of a cementitious-SMP healing system *(Hazelwood et al, 2015)*
- Modelling the flow of capillary healing agents in discrete cracks *(Gardner et al, 2014)*



Simulating reactive transport with a coupled finite element model

Contact details: **Tony Jefferson** JeffersonAD@Cardiff.ac.uk
Bob Lark Lark@Cardiff.ac.uk
Website lhttp://www.cardiff.ac.uk/research/explore/research-units/materials-for-life

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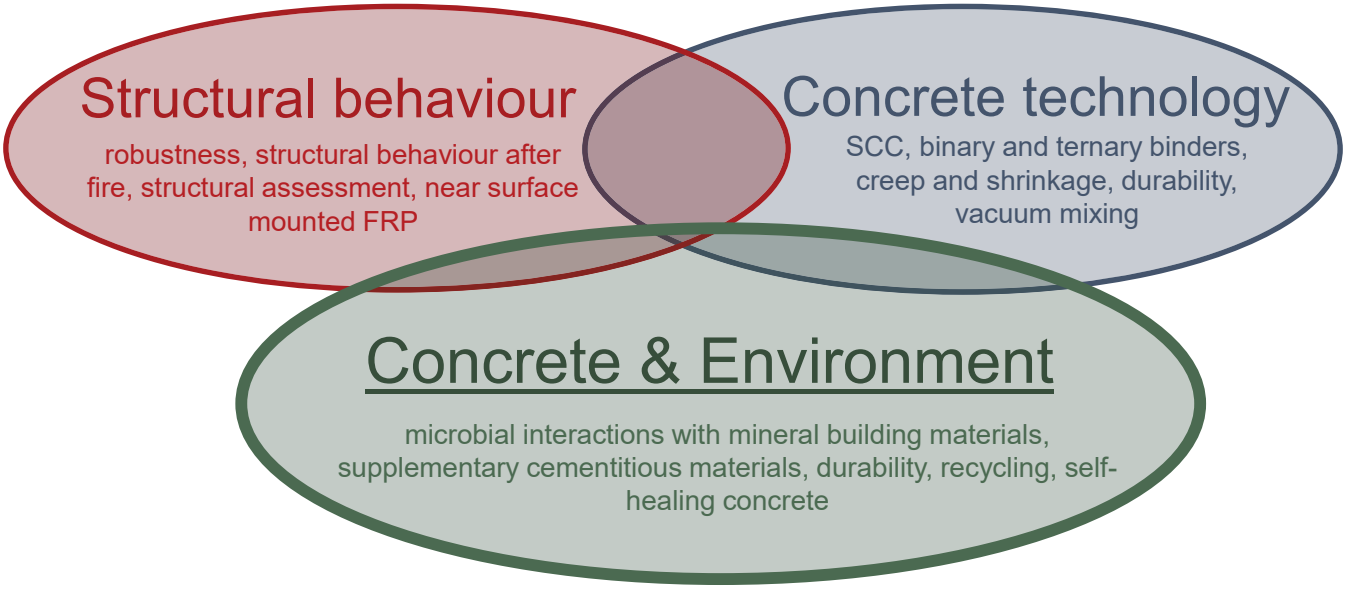
PRESENTATIONS

MAGNEL LABORATORY FOR CONCRETE RESEARCH

GHENT UNIVERSITY

BELGIUM

MAGNEL LABORATORY FOR CONCRETE RESEARCH



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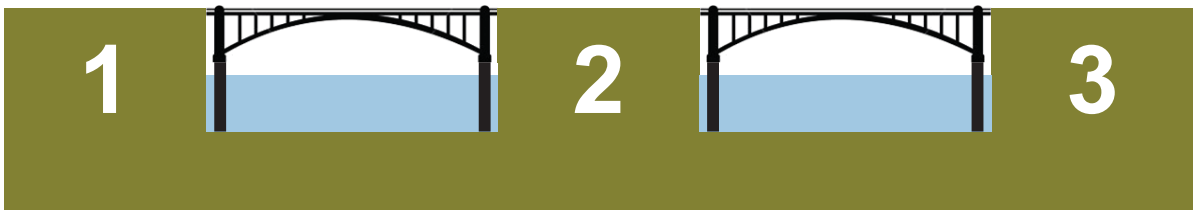
GHENT UNIVERSITY
COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

Research lines CONCRETE AND ENVIRONMENT GROUP

GREEN CONCRETE

- Use of **by-products**: fly ash, slag, silica fume, MSWI ashes, copper slag

Strength + durability assessment | **Service Life Prediction** | **Life Cycle Assessment (LCA)**



Research lines CONCRETE AND ENVIRONMENT GROUP

GREEN CONCRETE

- Use of **recycled materials** in Portland clinker production

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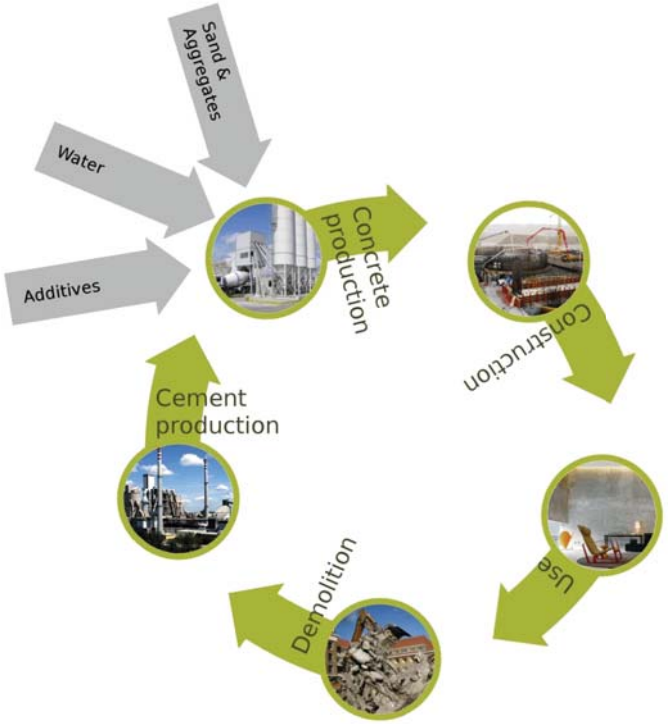
Research lines CONCRETE AND ENVIRONMENT GROUP

GREEN CONCRETE

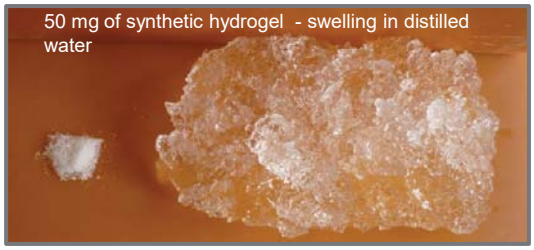
- **Completely recyclable concrete**

*"a concrete **designed to** have a **chemical composition equivalent to** those of **general cement materials**, so that concrete can **be recycled** after demolition **as a material for cement without any modification**."*



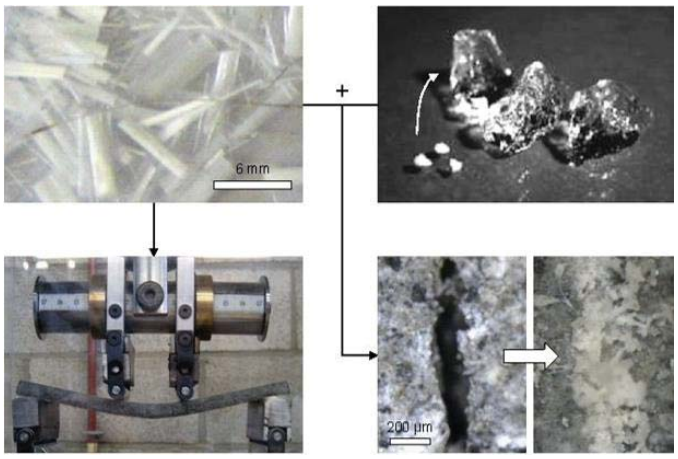
pH-sensitive superabsorbent polymers

Sealing/healing by further hydration & $CaCO_3$ precipitation



High swelling capacity

self-sealing self-healing



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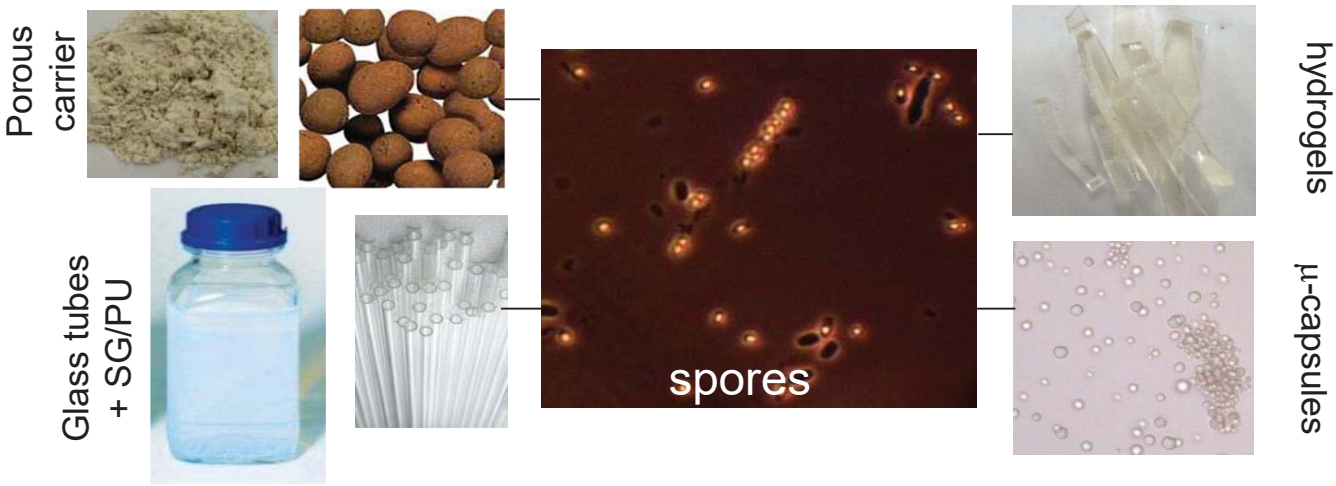
Research lines CONCRETE AND ENVIRONMENT GROUP
SELF-HEALING CONCRETE

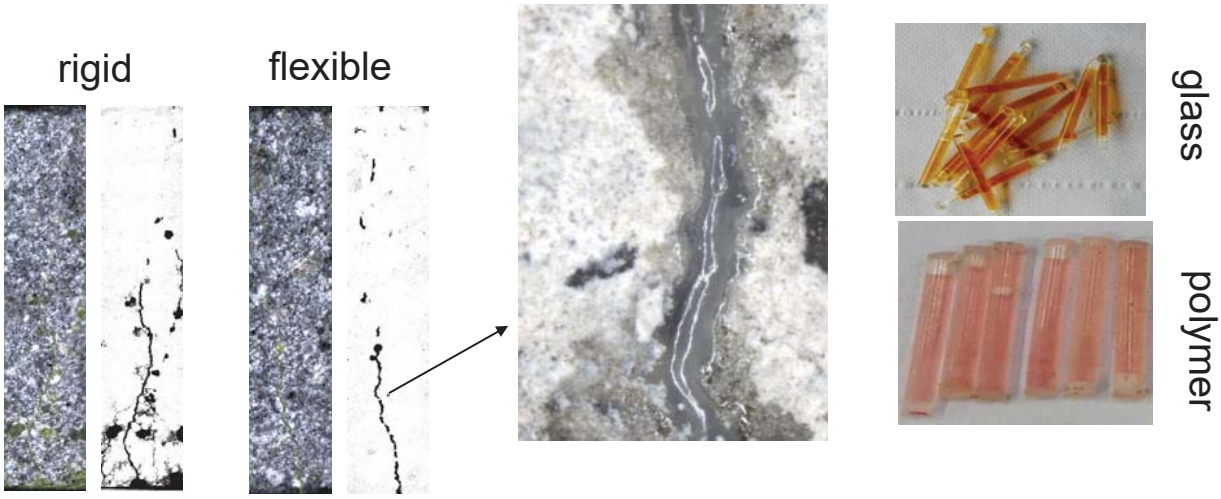
Biogenic healing agents

Encapsulated $CaCO_3$ precipitating bacterial spores



Elastic polymeric healing agents

Precursors of polymers encapsulated in tubular carriers



Behaviour upon reloading

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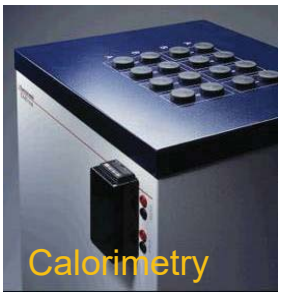
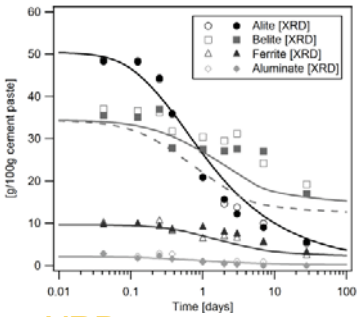
Research lines CONCRETE AND ENVIRONMENT GROUP
SELF-HEALING CONCRETE

Magnel Laboratory is partner in several national and European projects related to self-healing: e.g. HEALCON, CAPDESIGN, LORCENIS

Infrastructure CONCRETE AND ENVIRONMENT GROUP

Materials and reactions





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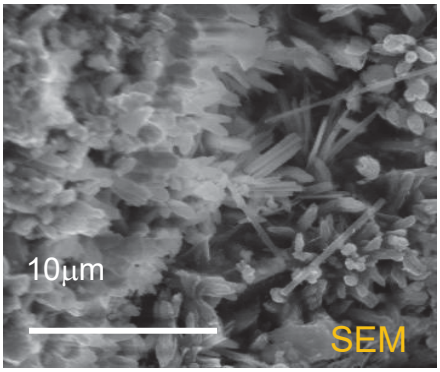
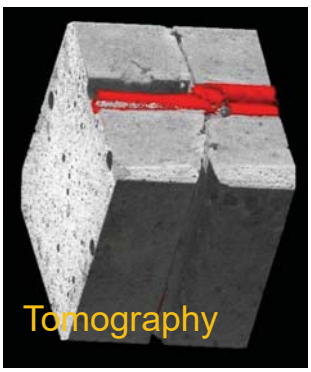
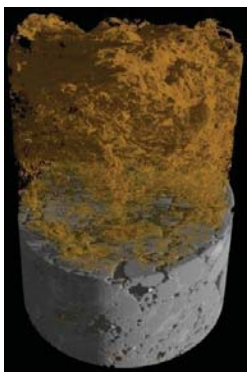
Infrastructure CONCRETE AND ENVIRONMENT GROUP

Microstructure – pore structure







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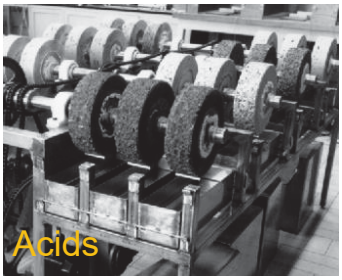
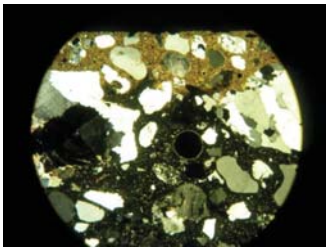
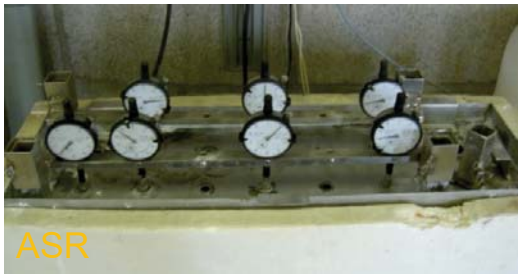
Durability







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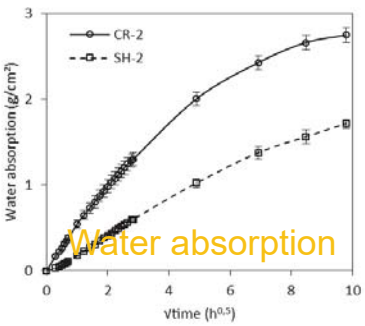
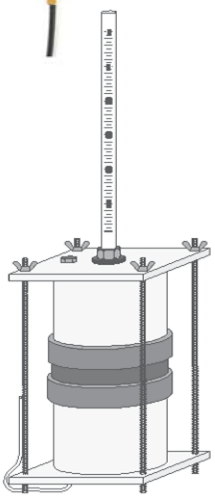
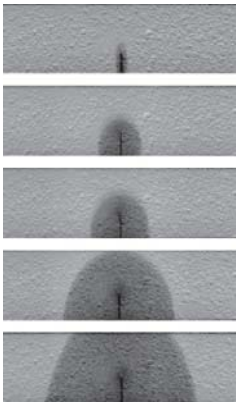
Self-healing







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CZECH REPUBLIC

INSTITUTION DESCRIPTION

University Centre for Energy Efficient Buildings (UCEEB) was founded as an independent research institute of the Czech Technical University in Prague under the auspices of four departments – Civil Engineering, Mechanical Engineering, Electrical Engineering and Biomedical Engineering. The Centre's goal is to leverage synergy effects of research activities of the individual departments which are related to energy efficient buildings.

UCEEB is a reaction to one of the European Union's largest priorities aimed at optimisation of energy efficiency of buildings. The centre should also have better opportunities to participate in European scientific projects, such as the Joint Technology Initiative on Energy Efficient Buildings, which is based on the EU's targets for carbon dioxide emissions.

It is clear that sustainable building is not just a trend or fashion, but a necessity. That is why we look at energy efficient buildings as a whole.

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
CZECH TECHNICAL UNIVERSITY in Prague
University Centre for Energy Efficient Buildings
COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

RESEARCH GROUP DESCRIPTION

Research lines

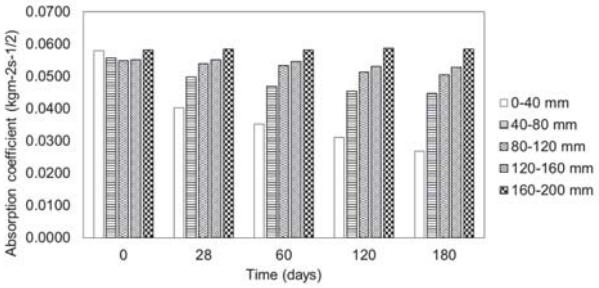
- **Mineral additives in cement and lime based composites**
- **Impact of external conditions on structural materials, durability of contructions**
- **Microstructure of cement based composites**
- **Transport properties of porous materials**
- **Development and testing of new composite materials for severe conditions**

Group infrastructure

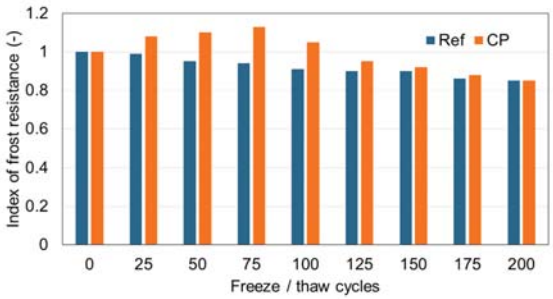
- **Fully equipped mechanical laboratory**
- **Mercury intrusion porosimetry (MIP)**
- **Electron microscopy, x-ray diffraction**
- **Transport properties – high presure permeameter, chloride migration test (NORD Test), ISAT, water penetration test**
- **Climatic laboratory (climatic chambers for controlled cyclic loading)**
- **Thermal analysis (up to 1000°C, DTG/DTA)**

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

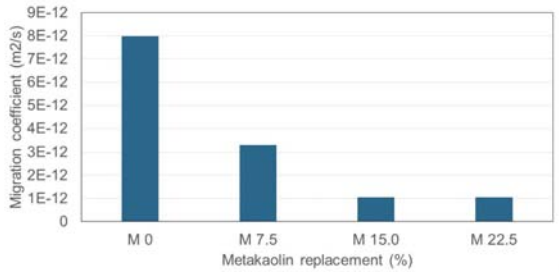
- **Monitoring of the crystalline coating efficiency**

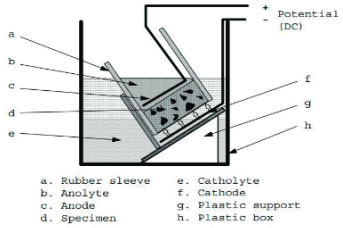


- **Influence of mineral additives on frost resistance**



- **Influence of metakaolin on chloride migration**





EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
CZECH TECHNICAL UNIVERSITY in Prague
University Centre for Energy Efficient Buildings
COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

THANK YOU FOR YOUR ATTENTION

Pavel Reiterman

HELMHOLTZ-ZENTRUM GEESTHACHT

GERMANY

Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
Helmholtz-Zentrum Geesthacht
Max-Planck-Straße 1, 21502 Geesthacht, Germany
COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

INSTITUTION DESCRIPTION

Department: Corrosion and Surface Technology
Institute of Materials Research
Helmholtz-Zentrum Geesthacht

Head: Prof. Dr. Mikhail L. Zheludkevich

Location: 30 mins from Hamburg Center

Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

Description: The Corrosion and Surface Technology department of the Institute of Materials Research headed by Prof. Mikhail Zheludkevich, studies corrosion mechanisms towards knowledge based surface technology development as well as material design. In this context novel corrosion protection concepts (active and passive) are developed. Specific use of modelling of partial aspects related to corrosion and coating processes supports all the development activities and is available.

RESEARCH GROUP DESCRIPTION

Research lines

- **Material Modelling**
  - Concrete material modelling
  - Stress & fatigue corrosion cracking
  - State-of-the-art Continuum Corrosion Model (Multi-scale)
- **Corrosion Mechanism**
  - Coating technology
  - Corrosion inhibition techniques
  - Electrochemistry

Group infrastructure

- **Computational**
  - Image based modelling
  - High performance computing
    - Full coupled electrochemical, thermal and transport models.
  - Discrete + continuum Infrastructure
- **Experimental**
  - Imaging (Tomography, SEM …)
  - Stress corrosion testing
  - Electrochemical testing

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Helmholtz-Zentrum Geesthacht
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RESEARCH PROJECTS:

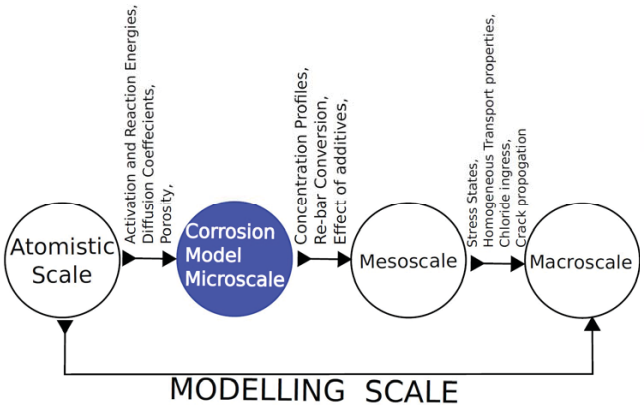
- LORCENIS**: Continuum corrosion model for performance concrete (HPC) : Service life prediction (A multi-scale approach)
- EMMC: European Material Modelling Council
- PROAIR: Active protection of multi-material assemblies for aircrafts
- ...

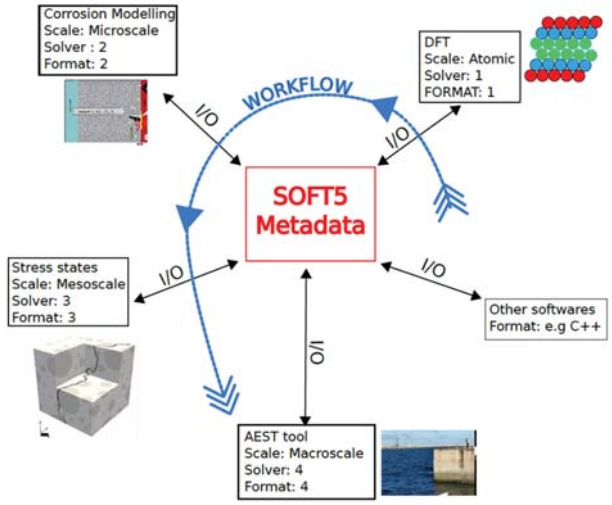
LORCENIS

**Acknowledgement: This project has received fundings from the European Union's Horizon 2020 research and innovation program under grant agreement No: 685445

RESEARCH PROJECTS:

- Continuum Corrosion Model (Micro-scale) under the framework of EU-LORCENIS project





Data Exchange Interface
Advanced Engineering Software tool(AEST)

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
Helmholtz-Zentrum Geesthacht
Max-Planck-Straße 1, 21502 Geesthacht, Germany
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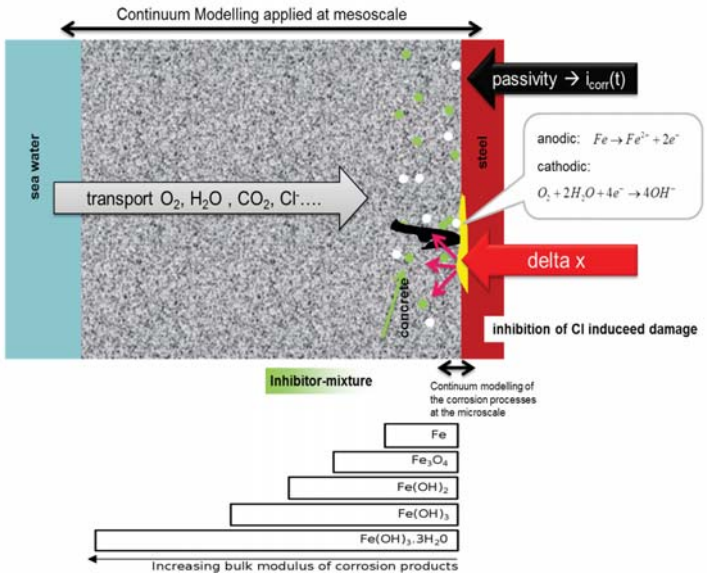
Current research work: **Continuum Modelling of Corrosion Processes in Reinforced Concrete at Microscale**

- Chloride Ingress
- Effect of Inhibitors
- Moisture effect
- Transport properties
- Porosity, permeability and migration parameters
- Rebar radius reduction
- Failure/Service life prediction



Contacts:

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Dr. Daniel Höche	**daniel.hoeche@hzg.de**
Dr. Sviatlana L. Lamaka	**sviatlana.lamaka@hzg.de**
Prof. Dr. Mikhail L. Zheludkevich	**mikhail.zheludkevich@hzg.de**
Website	**www.hzg.de**
Address:	**Max-Planck-Straße 1, 21502 Geesthacht, Germany**

****Acknowledgement:** This project has received fundings from the European Union's Horizon 2020 research and innovation program under grant agreement No: 685445

INSTITUTE OF CONSTRUCTION MATERIALS

TECHNISCHE UNIVERSITÄT DRESDEN

GERMANY

INSTITUTE OF CONSTRUCTION MATERIALS at TU DRESDEN

Univ.-Prof. Dr.-Ing. Viktor MECHTCHERINE — Director
Dr. rer. nat. Christof SCHRÖFL, Dipl.-Chem. — Group leader morphology and characterization of construction materials

https://tu-dresden.de/bu/bauingenieurwesen/ifb?set_language=en

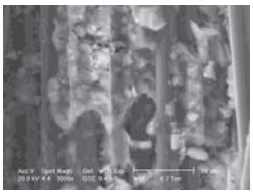
Research areas

- Tailor-made mineral-based composites, material design
- High-performance concretes with fiber reinforcement: Textile reinforced concretes, SHCC, UHPC etc.
  → Design of fiber/matrix bond, interface science
- Mechanics of building materials: Fracture mechanics, shrinkage, creep etc.
- Rheology of fresh concrete: Rheometry, DEM simulation, 3D-printing
- Degradation, durability design → Microstructure analysis FE-ESEM with EDX, quantitative p-XRD etc.
- Structure/efficiency relation and working mechanism of new admixtures and additives for cement-based systems: Superabsorbent polymers for internal curing and rheology tailoring, carbon nanotubes

Workabilty of carbon concrete

Digital fabrication using concrete pump

Strain-hardening cement-based composite after a short-time dynamic tension test



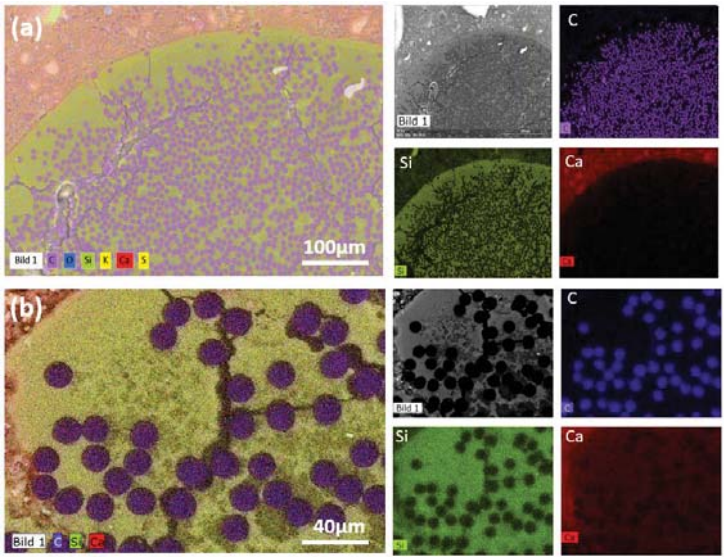
Ageing behavior of fiber-matrix Bond in TRC

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

CONCRETE TECHNOLOGY – MICROSTRUCTURE ANALYSIS

Infrastructure and equipment

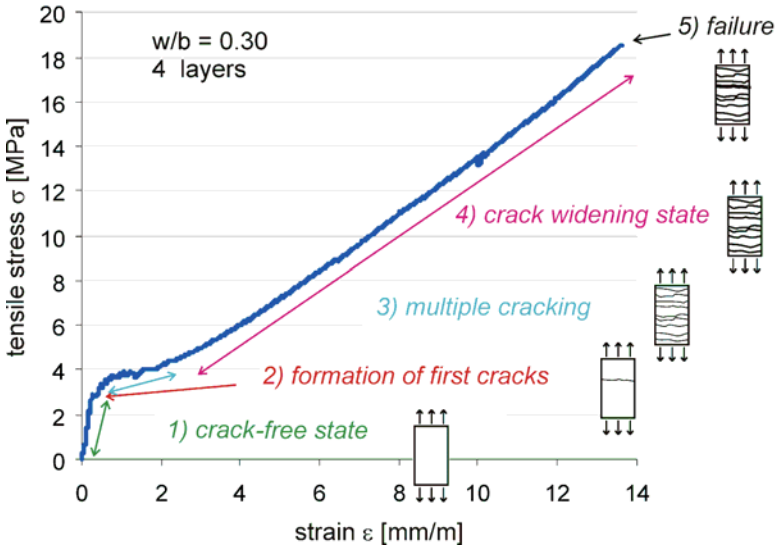
- Various mixers for (cement) pastes, mortars and concretes
- Concrete viscometer ConTec 5, viscometer Haake Mars II, flow table tests
- Various mechanical concrete test machines
- Ultrasonication of pastes and solids
- Zeta potential (electro-acoustic method)
- CDF, CIF, fog chamber (40 °C, >99 % r.h.)
- Air voids analyser
- Laser diffractometer
- Thin sections and micro-sections
- FE-ESEM Quanta 250 (FEI), EDX (Bruker Quantax 400), µ-RFA (IfG iMOXS)
- p-XRD, RIETVELD quantification
- Thermogravimetry, differential scanning calorimetry DSC/TG
- FT-IR incl. IR microscope
- Gas adsorption (BET), Helium pycnometer
- MIP up to 4000 bar



EDX-ESEM elemental mapping of (a) low and (b) high magnification of polished sample cross-sections containing carbon yarn coated with micro-silica. The C, Si and Ca are indicated by purple, green and red, respectively. Left panel: element superposition. This high-magnification image indicates the presence of both Ca and Si between the fibers of the multifilament yarn.
Nadiv, Peled, Mechtcherine, Hempel, Schröfl: Composites Part B 111 (2017) 179-189

CRACK-WIDTH LIMITATIONS BY COMPOSITE DESIGN to PROMOTE AUTOGENOUS SELF-HEALING

Textile reinforced concrete (TRC) – mechanical characteristics



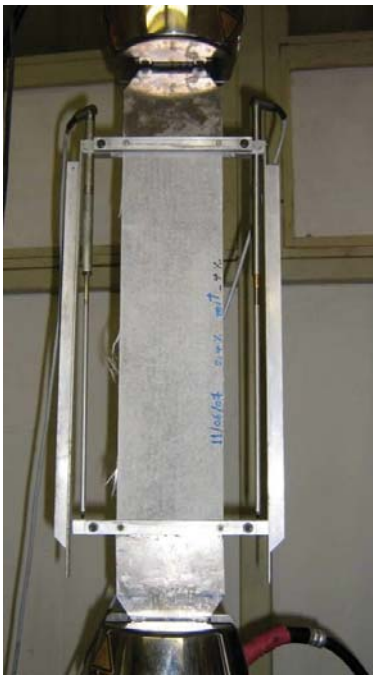


Diagram and image: TU Dresden, Institute of Construction Materials

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TECHNISCHE UNIVERSITÄT DRESDEN
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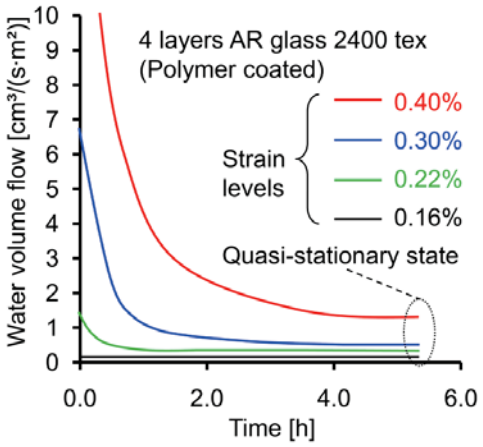
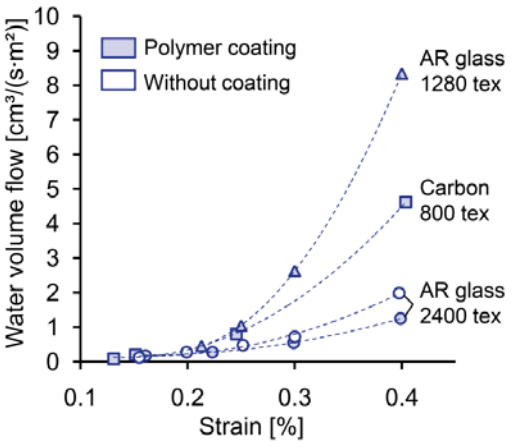
CRACK-WIDTH LIMITATIONS BY COMPOSITE DESIGN to PROMOTE AUTOGENOUS SELF-HEALING

Textile reinforced concrete (TRC) – water permeability test *in situ*

Time dependent



Strain dependent

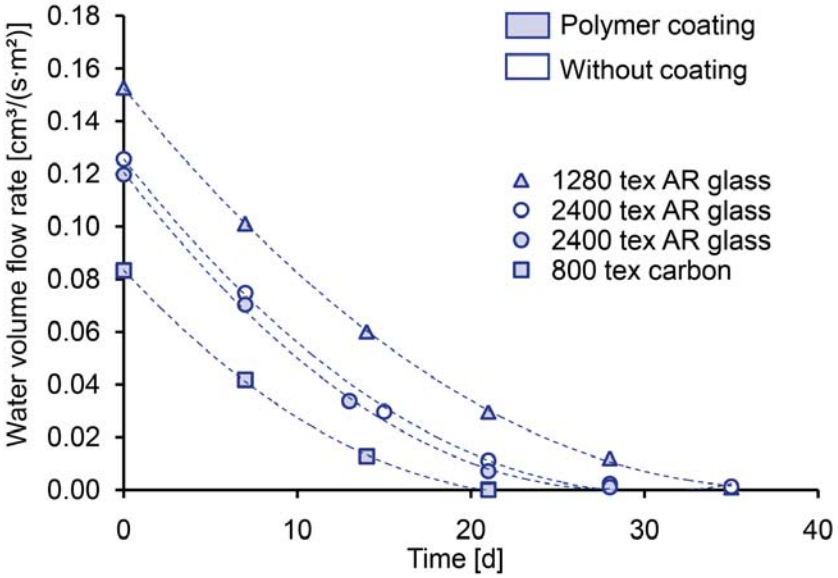


TRC specimens solely (d = 14 mm, 4 textile layers)
Water pressure 100 kPa (14.5 psi)

Mechtcherine, Lieboldt: Cement and Concrete Composites 33 (7) (2011) 725-734

CRACK-WIDTH LIMITATIONS BY COMPOSITE DESIGN to PROMOTE AUTOGENOUS SELF-HEALING

Textile reinforced concrete (TRC) – water permeability test *in situ*



TRC specimens solely
(d = 14 mm, 4 textile layers)

Stored water-saturated but without differential pressure and tensile load

Reduction really caused by self healing – or by matrix swelling ?

Mechtcherine, Lieboldt: Cement and Concrete Composites 33 (7) (2011) 725-734

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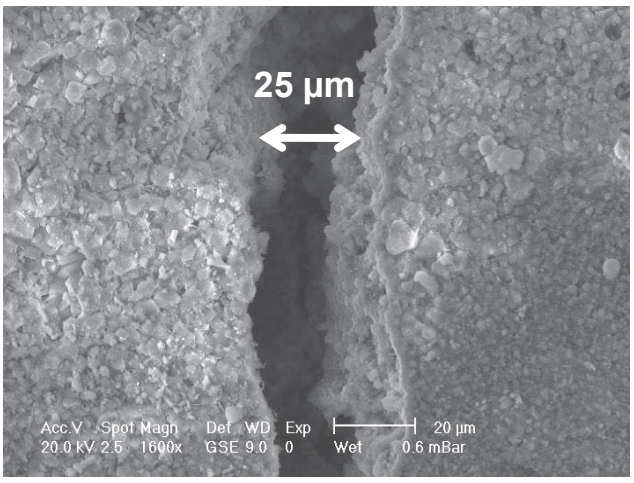
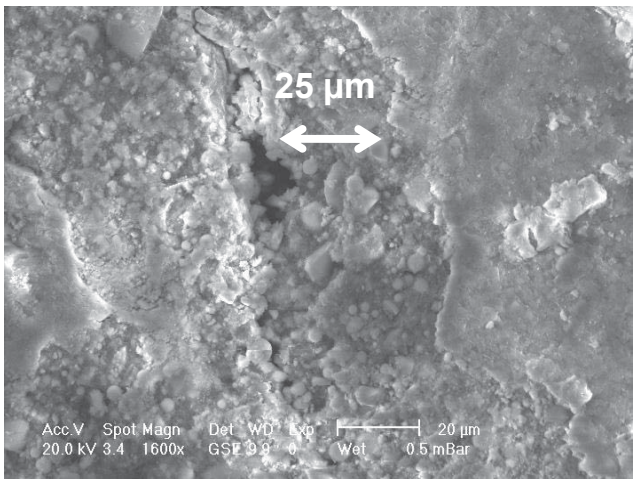
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

SELF-HEALING OF FINE CRACKS

Before permeability tests



After permeability tests
calcite precipitation



Lieboldt: Dissertation, TU Dresden, Institute of Construction Materials, 2012

STRUCTURAL ENGINEERING DEPARTMENT

BEN GURION UNIVERSITY OF THE NEGEV, BEER SHEVA, ISRAEL

INSTITUTION DESCRIPTION

Ben Gurion University of The Negev, Beer Sheva, Israel

Structural Engineering Department

Prof. Alva Peled

RESEARCH GROUP DESCRIPTION

Research lines

- Construction and building materials
  - Cement-based
    - UHPC
  - Geopolymers
    - Metakaolin - based
    - Fly ash - based
- Mineral additives -
  - Limestone, basalt, dolomite – material type and particle size
- Cement-based composite materials
  - Textile reinforced concrete – TRC
    - Bonding
    - Hybrid
    - Repair and retrofit
- Nano-fillers
  - Nano particles
  - CNT
  - Graphene

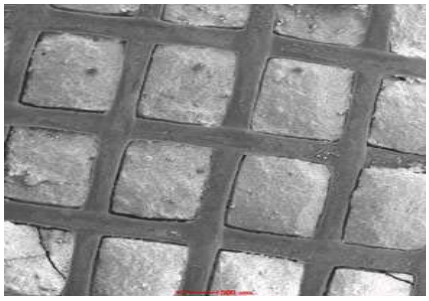
RESEARCH GROUP DESCRIPTION

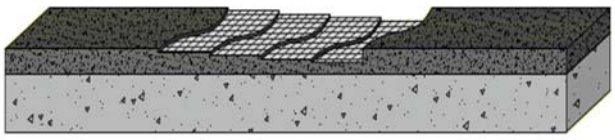
Group infrastructure

- Microstructure and chemical analysis:
  - SEM, EDS, XRD, TGA
  - Calorimetry, vicat needle
- Durability:
  - Aging
  - Leaching
  - Dimension change
- Mechanical performance:
  - Tensile
  - Bending
  - Compression
  - Impact
  - Pullout
- Cracking:
  - Image analysis
  - Acoustic emission

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

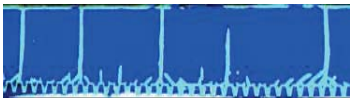
Textile reinforced concrete



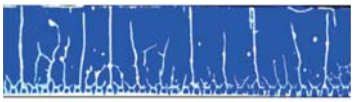


Cracks control

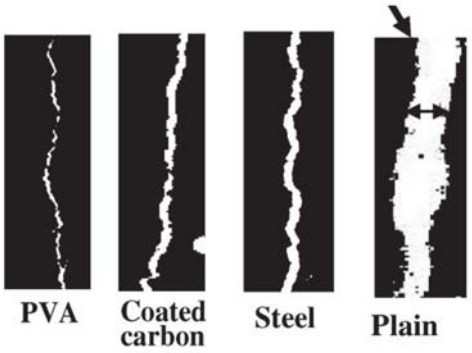
Fabric materials

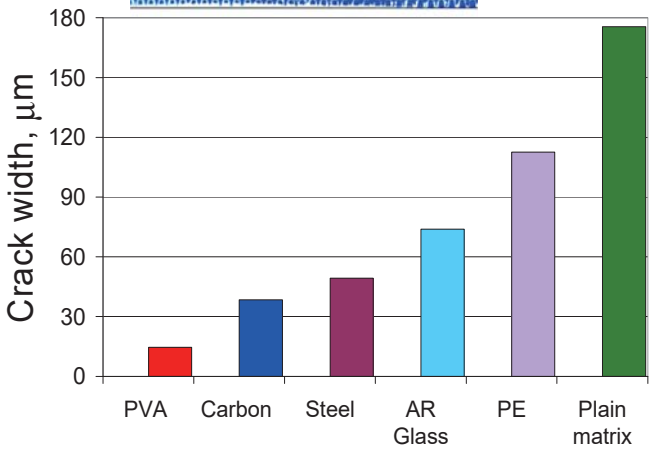


Plain matrix



TRC-PVA fabric

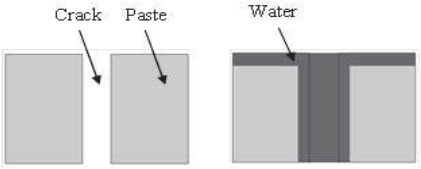




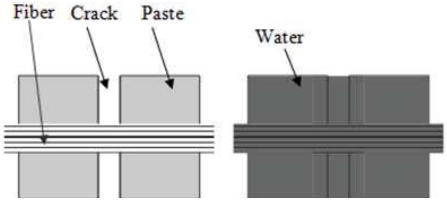
Pourasee, Peled and Weiss, J. of materials in civil engineering, ASCE / August 2011

Cracks control

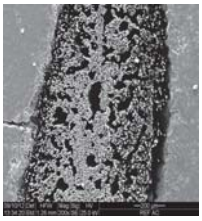
Carbon fabric

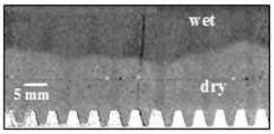


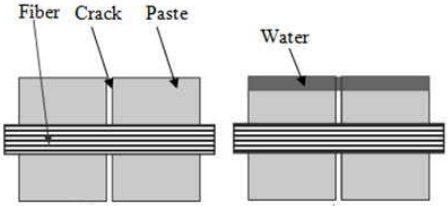
Cement paste



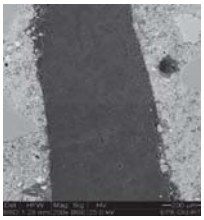
Non coated carbon







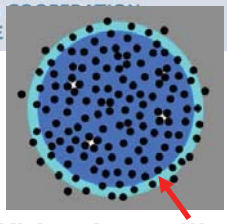
Coated carbon



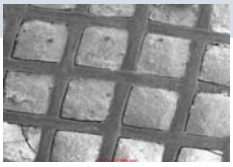
Coated carbon bundles do not exhibit rapid fluid ingress along the bundles.

Pourasee, Peled and Weiss, J. of materials in civil engineering, ASCE / August 2011

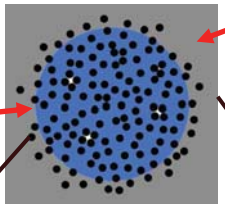
TRC

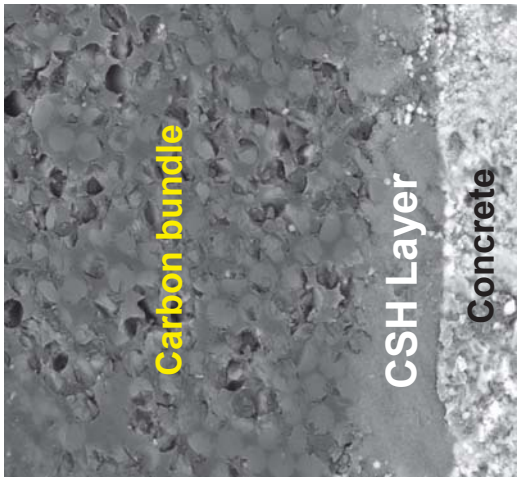


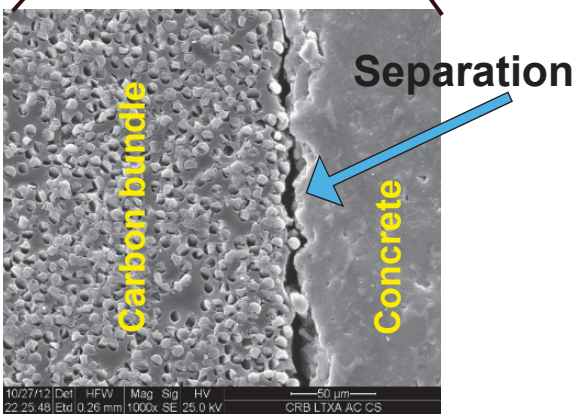
With micro-silica



Cross section view



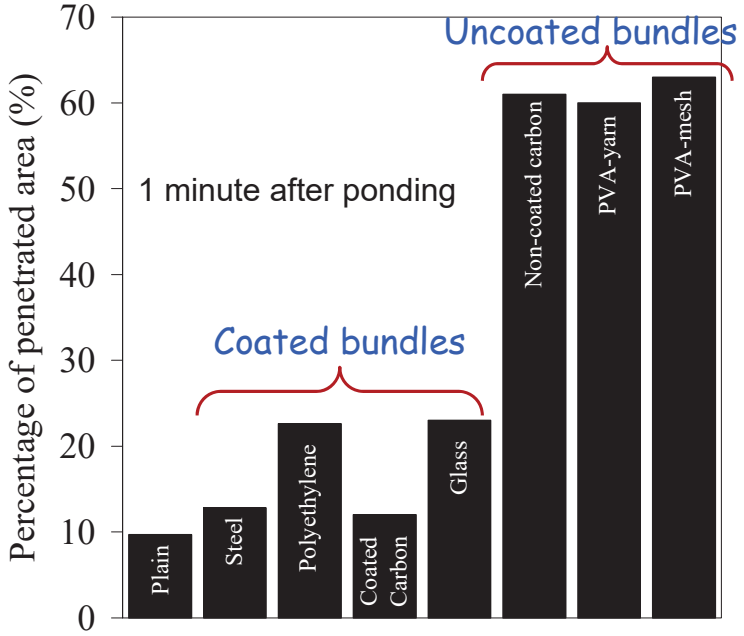




Zamir, Dvorkin Peled, SHCC3, November 2014

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR
OF CONCRETE STRUCTURES

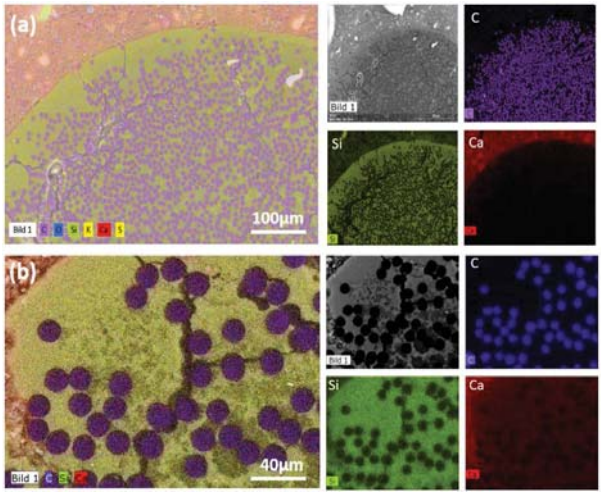
Penetrated area – water

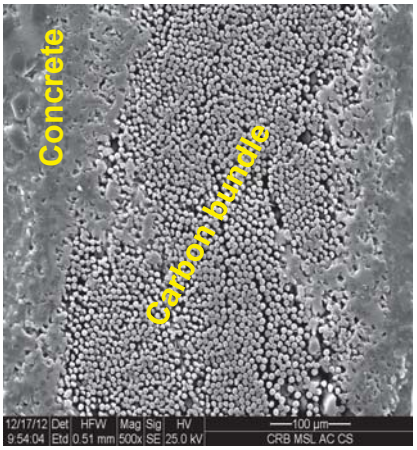


Pourasee, Peled and Weiss, J. of materials in civil engineering, ASCE / August 2011

1st Internal Workshop SARCOS Action, 26th January 2017,
Institute of Construction Sciences "Eduardo Torroja" (Madrid)

Carbon bundle filled with microsilica





Nadiv, Peled, Mechtcherine, Hempel and Schroefl, Composites Part B, 2017

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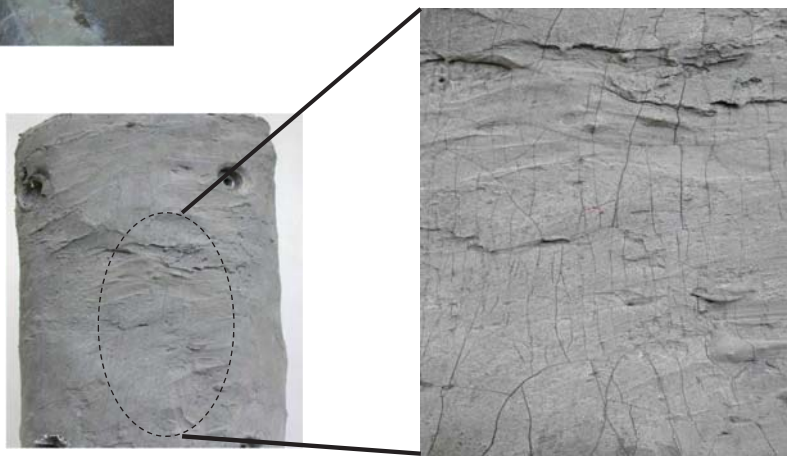
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

Textile reinforced concrete

Repair, retrofit, strengthening



PVA fabric impregnated in cementitious matrix

CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS
1st Internal Workshop SARCOS Action, 26th January 2017, Institute of Construction Sciences "Eduardo Torroja" (Madrid)

Thank You

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

POLITECNICO DI MILANO

ITALY

INSTITUTION DESCRIPTION

Politecnico di Milano, founded in 1863 is one of the leading research institutions in the field of Civil and Structural Engineering
(14th in the world according QS World University Ranking, 5th in Europe and 1st in Italy)

The Department of Civil and Environmental Engineering consists of 102 faculty members, 69 fellows, 89 PhD students (2 PhD programs) and 44 staff people.
Research groups: Mechanics of Materials and Structures; Environmental Engineering, Geodesy and Geomatics, Transport Infrastructures and Geosciences, Structures and Environment, Design, Diagnosis and Structural Rehabilitation, Water Science and Engineering, Hydraulic Engineering.

INSTITUTION
Politecnico di Milano
Department of Civil and Environmental Engineering
COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

RESEARCH GROUP DESCRIPTION

Prof. L. Ferrara (coordinator), prof. G. di Luzio, prof. P. Bamonte, prof. M. Carsana (Department of Chemistry, Materials and Chemical Engineering), dr. E. Cuenca Asensio (post-doc), dr. V. Krelani (post-doc, now at UBT, Prishtine, Kosovo), MArch. Cristina De Nardi (PhD student – cosupervised with prof. A. Cecchi - IUAVenice)

Research lines

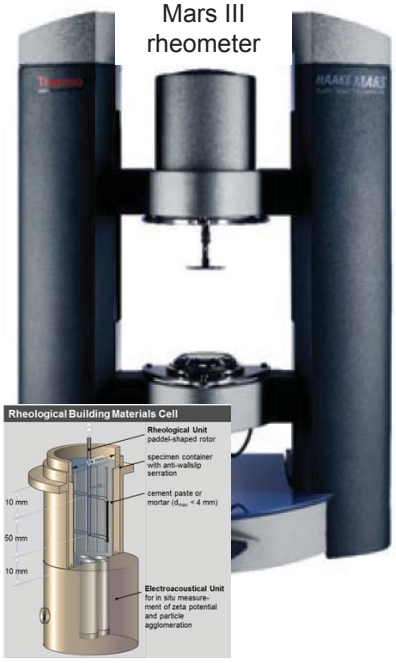
- Advanced cement based materials: characterization and structural applications
- Retrofitting and rehabilitation of existing structures
- Self-healing capacity of cementitious composites
- Fracture and damage mechanics of cement based materials
- Micro-mechanical modelling of cement based materials

Group infrastructure

- 6500 m^2 Testing Lab for Materials, Buildings and Structures
- Rheology lab (Mars III reometer)
- Material mechanical testing lab (INSTRON – 100 kN capacity; SCHENK – 1000 kN capacity)
- Full scale testing equipment reaction frames (vertical/horizontal)
- Fully equipped chemical lab

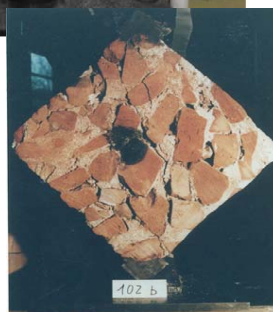
GROUP INFRASTRUCTURE

Mars III rheometer



Schenk 1000 kN

INSTRON electro-mechanical 100 kN t/c



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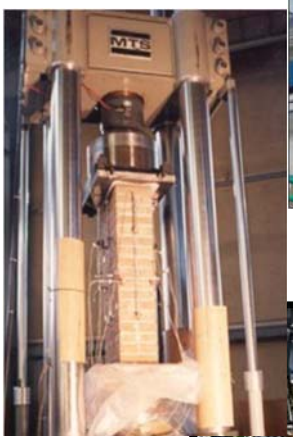
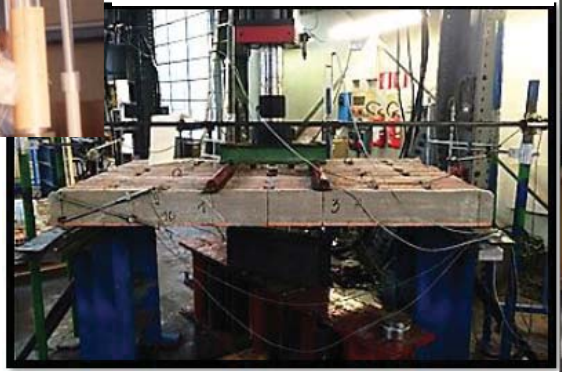
COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

GROUP INFRASTRUCTURE



MTS 2500 kN t/c

Reaction frames and actuators for full scale testing (250, 500, 1000 kN static and 250/500 kN dynamic)



EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

- Autogenous and engineered (crystalline admixtures) self-healing of plain concrete
- Autogenous and engineered (crystalline admixtures) self-healing of fiber reinforced concrete and high performance fiber reinforced cementitious composites (in cooperation with IIT Madras, India, and UPValencia, Spain)
- Natural fibers as facilitators of self-healing in advanced cement based materials (in cooperation with UFRio de Janeiro, Brasil)
- Autogenous and engineered (crystalline admixtures, micro-capsules) of lime mortars (in cooperation with University of Venice Ca' Foscari and IUAVenice)
- Multi-scale/multi-physics numerical modelling of self-healing in cement based materials (in cooperation with UBuenos Aires and UNTucuman, Argentina)
- Full scale applications of self-healing fiber reinforced SCC (in cooperation with QUBelfast, Azichem, Penetron It., Banager Precast)

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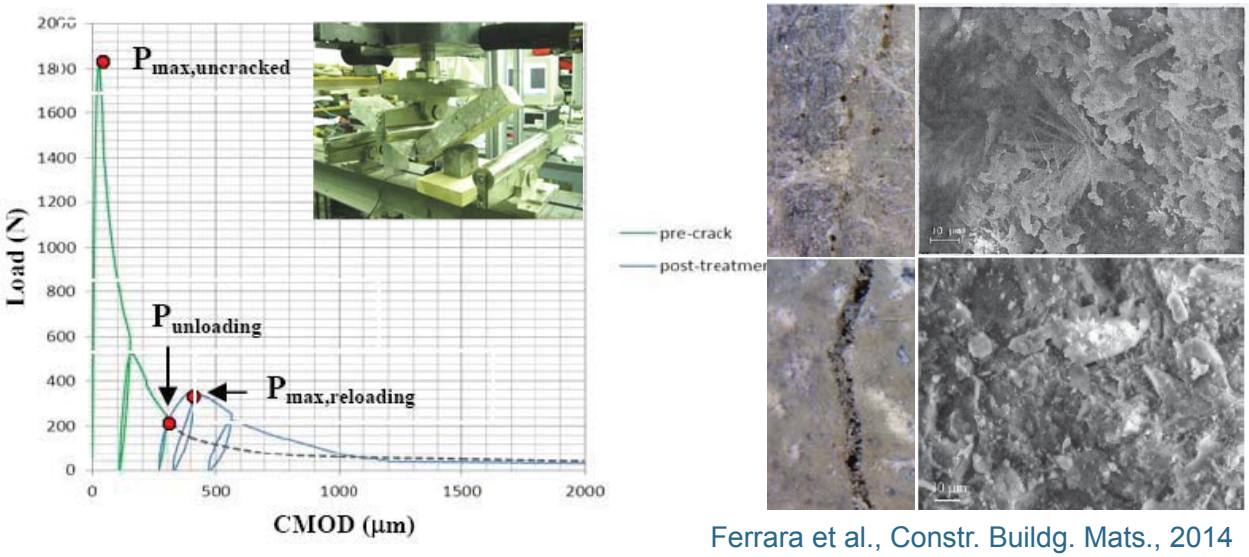
EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

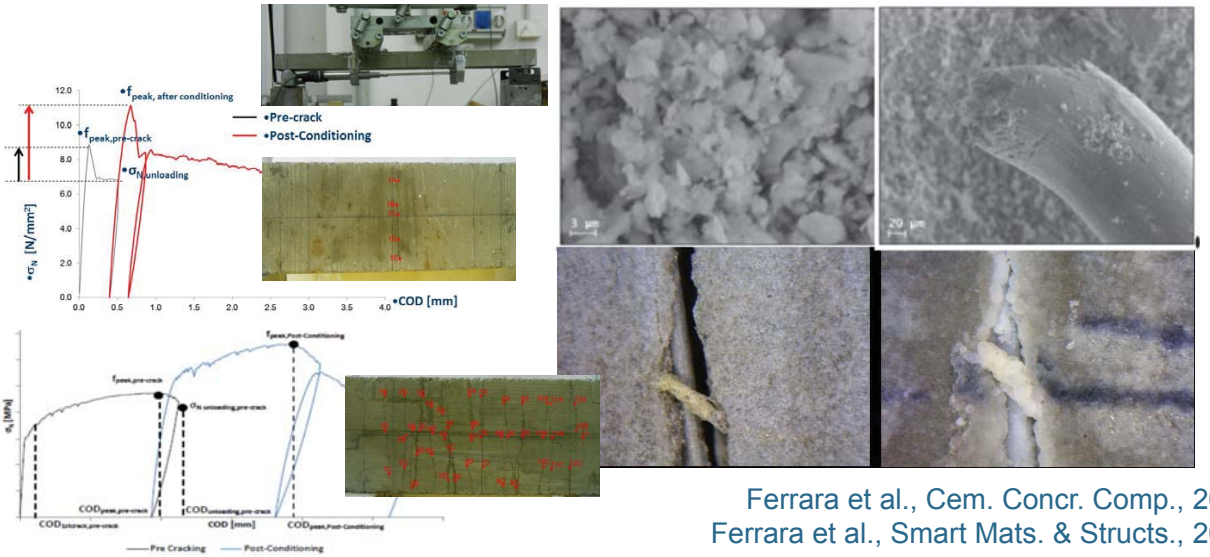
Autogenous and engineered (crystalline admixtures) self-healing of plain concrete (Penetron Italia)



Ferrara et al., Constr. Buildg. Mats., 2014

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

Autogenous and engineered (crystalline admixtures) self-healing of FRC and HPFRCCs (IIT Madras, India, UPValencia, Spain, Penetron Italia)



Ferrara et al., Cem. Concr. Comp., 2016
Ferrara et al., Smart Mats. & Structs., 2016

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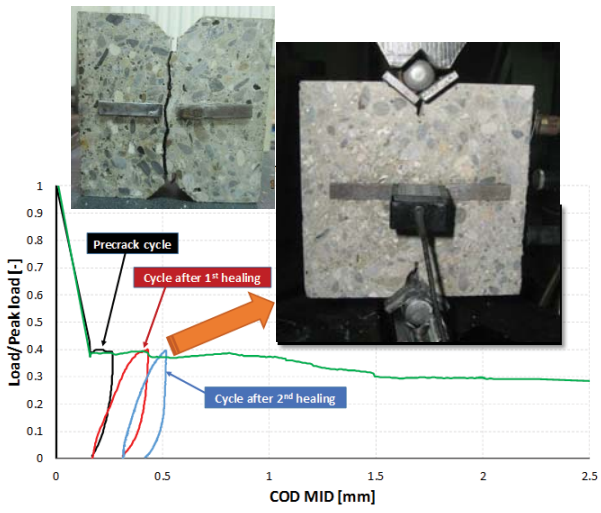
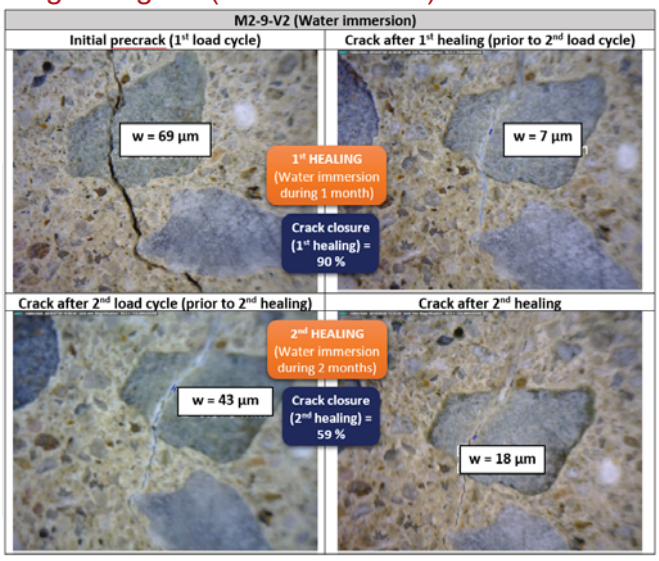
EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

Autogenous and engineered (crystalline admixtures) self-healing of FRC and HPFRCCs – cracking/healing fatigue (Penetron Italia)

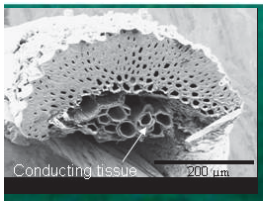




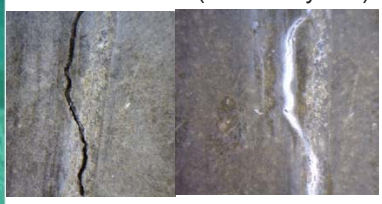
Cuenca and Ferrara, ACI SP, 2017 accepted

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

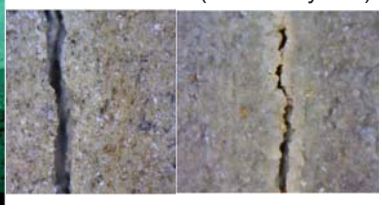
Natural fibers as facilitators of self-healing in advanced cement based materials (in cooperation with UFRio de Janeiro, Brasil – EnCORe project)



with sisal fibers (3m w/d cycles)



w/out sisal fibers (3m w/d cycles)



Ferrara et al., ACI SP 305, 2015
Ferrara et al., CCC, 2017, submitted

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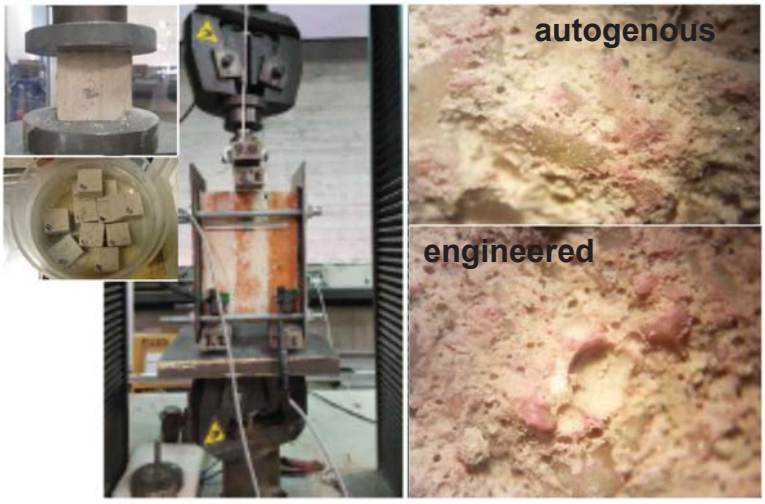
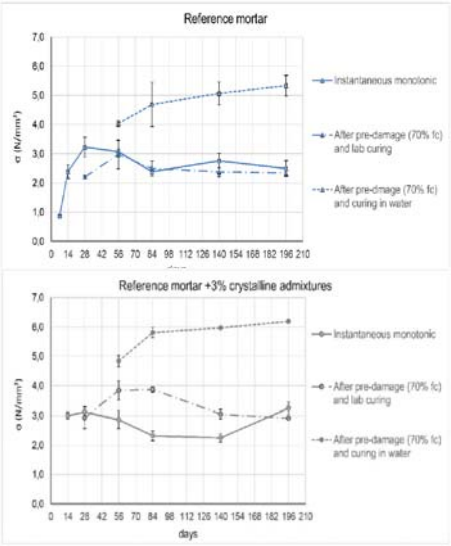
EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

Autogenous and engineered (crystalline admixtures, micro-capsules) of lime mortars (in cooperation with UVenice Ca' Foscari and IUAVenice)

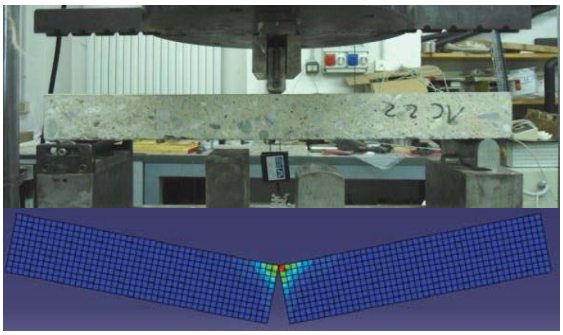


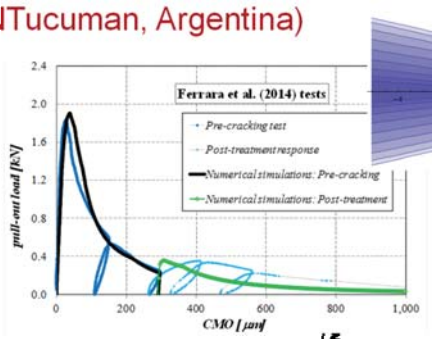


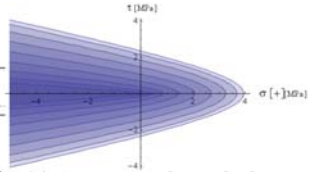
De Nardi et al., M&S. 2017, submitted

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

Multi-scale/multi-physics numerical modelling of self-healing (in cooperation with UBuenos Aires and UNTucuman, Argentina)

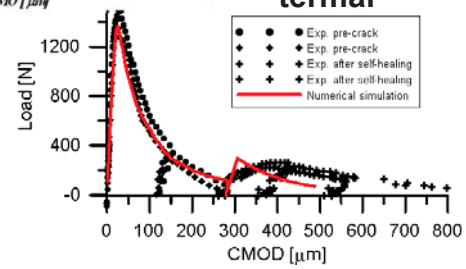






poroplasticity

Hygro-chemo-termal



Caggiano et al., Comp.&Structs., revisions
di Luzio et al., Comp&Structs., submitted

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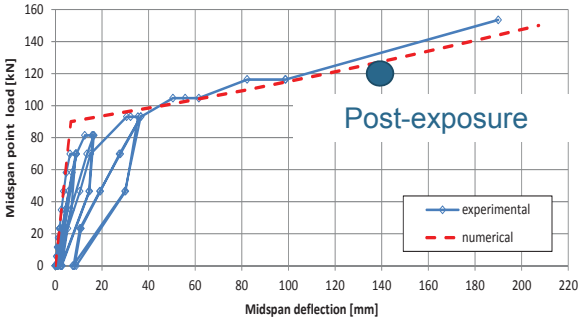
EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

Full scale applications of self-healing FR-SCC (in cooperation with QUBelfast, Azichem, Banager, Penetron It)

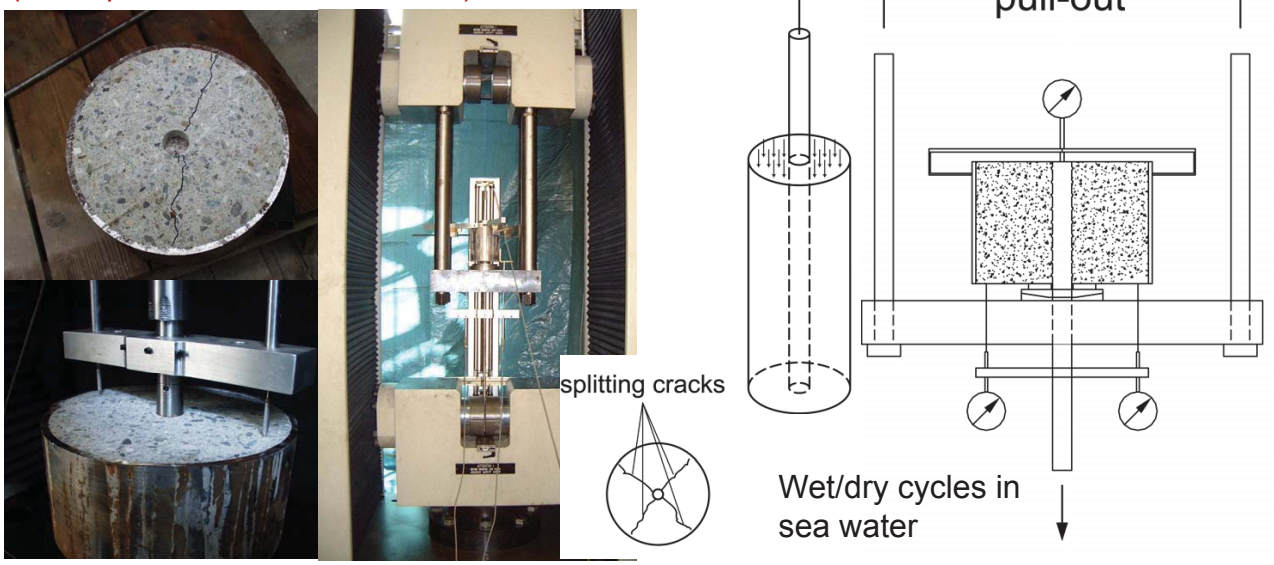
Fiber Reinforced SCC slab
Pre-stressed with basalt FRP bars
+ crystalline admixture
(≅«failure» test + 9 months open air + failure test)



Dal Lago et al., CompB, 2017, submitted

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

... on going work: effect of self-healing on bond in chloride environment (in cooperation with Penetron It.)



POLITECNICO DI TORINO

ITALY

INSTITUTION DESCRIPTION

Founded in 1859, Politecnico di Torino is the oldest technical university in Italy.

Professors and researchers: 890.
Administrative /technical staff: 880.
Ca 32,000 students, 780 Ph.D. students.

Departments involved in the Cost Action SARCOS:

DISAT – Department of Applied Science and Technology, Jean-Marc Tulliani (jeanmarc.tulliani@polito.it).

DISEG – Department of Structural, Geotechnical and Building Engineering, Paola Antonaci (paola.antonaci@polito.it).

Politecnico di Torino
COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

RESEARCH GROUP DESCRIPTION

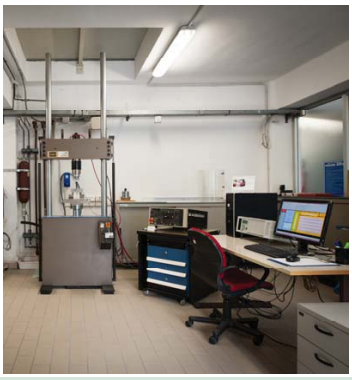
Research lines

- Optimization of extruded cementitious hollow tubes for healing agent encapsulation;
- Development and mechanical characterization of materials and structures;
- Non-Destructive Testing;
- Development and application of linear and nonlinear acoustic techniques for structural monitoring.

Group infrastructure

Field Emission-Scanning Electron Microscopy (FE-SEM), Thermal analysis (Thermogravimetric-Differential Thermal Analysis, TG-DTA), X-Ray Diffraction, Mercury porosimetry, Specific surface area determination (BET technique), Raman spectroscopy, etc.

Servo-controlled hydraulic or electro-mechanical universal testing machines; static and dynamic testing benches; single-point laser vibrometer; displacement and acceleration sensors; ultrasonic testing devices; data acquisition and conditioning units; etc



RESEARCH GROUP DESCRIPTION

People involved in self-healing cementitious materials

1 Associate professor,

1 Assistant professor,

1 Technical Lab assistant,

1 Post-doc researcher,

1 Ph.D student,

2 Graduating students.

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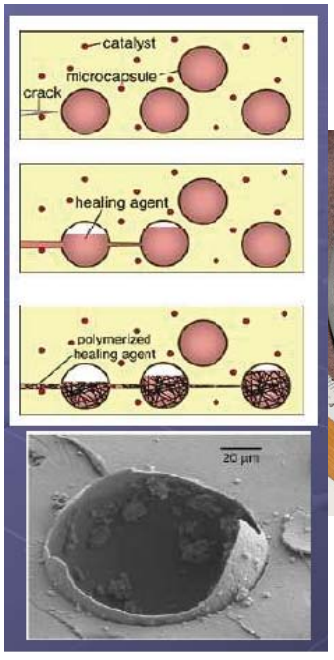
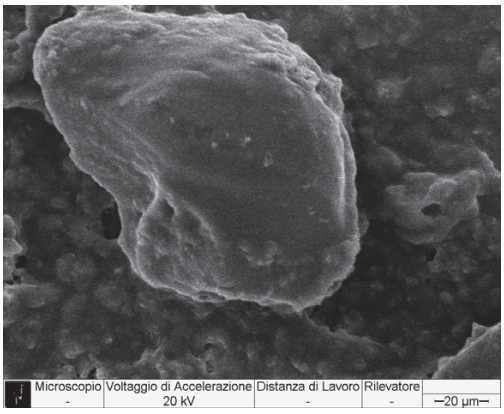
EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES



Production of microcapsules

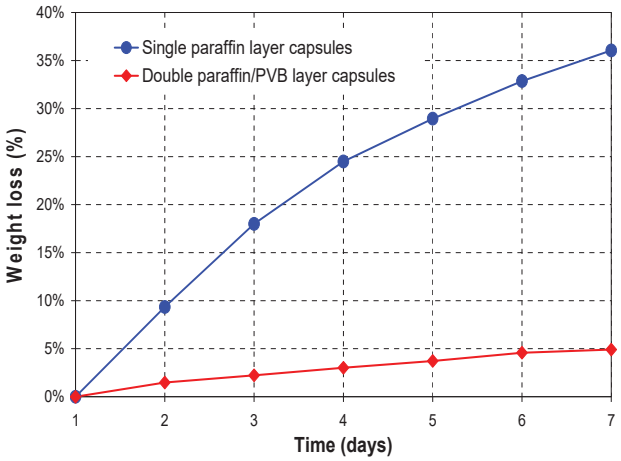


- Water/$Ca(OH)_2$ encapsulation
- MK encapsulation

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

Capsules characterization

- Liquid-core capsules (grid spacing: 3 mm)



- Evolution of liquid-core capsule weight

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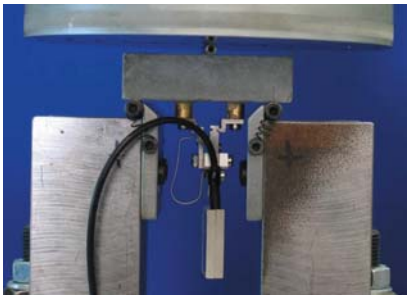
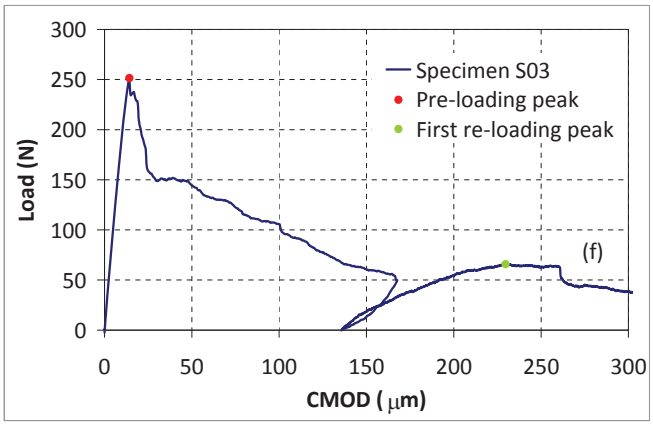
EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

Samples testing



- Set-up for three-point-bending tests



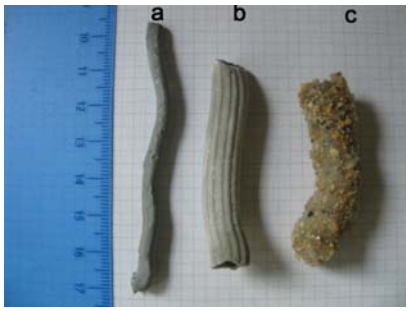
- Results of mechanical characterization tests for sample S3.

$$LRI_n(\%) = \frac{P_n - P_u}{P_p - P_u} \cdot 100$$

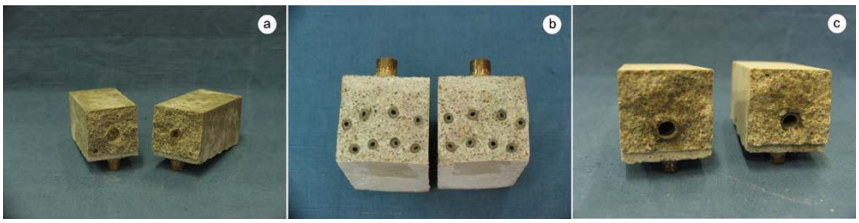
- Best result for S3: LRI_1 = +8.1%

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

- „High tech“ extruder...



- Cementitious hollow tubes w/o and w final coating



- Prisms for 3-point bending tests w cementitious hollow tubes

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EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

Evaluation of big hollow tubes durability

- Simulation of concrete mixing

- Cementitious hollow tubes survived mixing...

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

Mechanical testing

- Set-up for three-point-bending tests: mortar specimens (16x4x4 cm^3, w/c = 0.5, cement-to-sand ratio of 1:3 by wt)

$$SRI_n(\%) = \frac{S_n}{S_p} \cdot 100$$

$$LRI_n(\%) = \frac{P_n - P_u}{P_p - P_u} \cdot 100$$

- Self-healing agent diffusion

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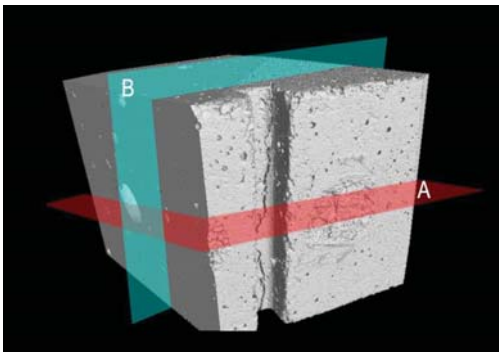
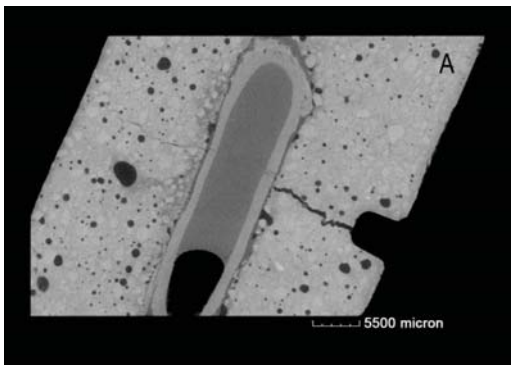
3-D visualization of the portion of the cracked prism

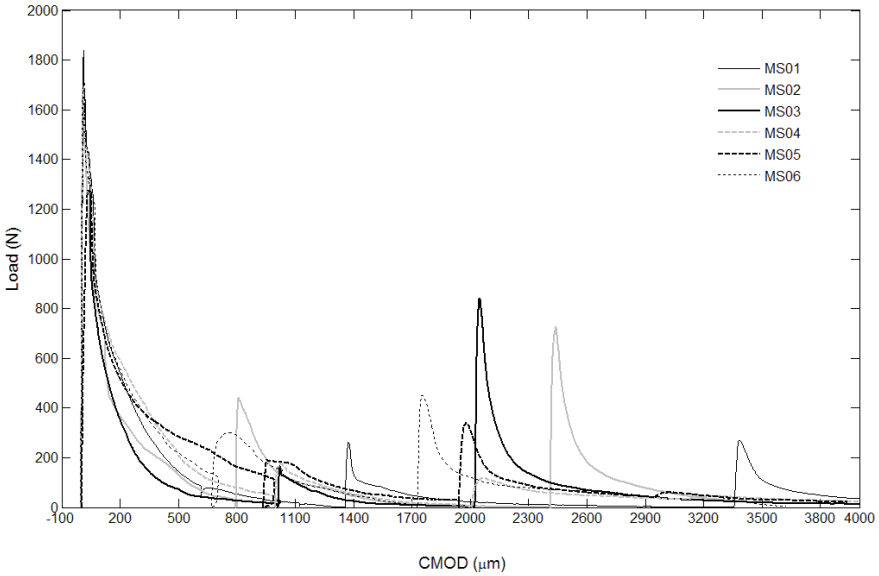




- X-Ray tomography for healing agent (Na_2SiO_3) diffusion monitoring after sample damaging

- Cracks partially filled w Na_2SiO_3

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES



- Load vs. CMOD curves for specimens with big hollow tubes (MS series) reassembled after complete failure and re-loaded after the second self-healing process

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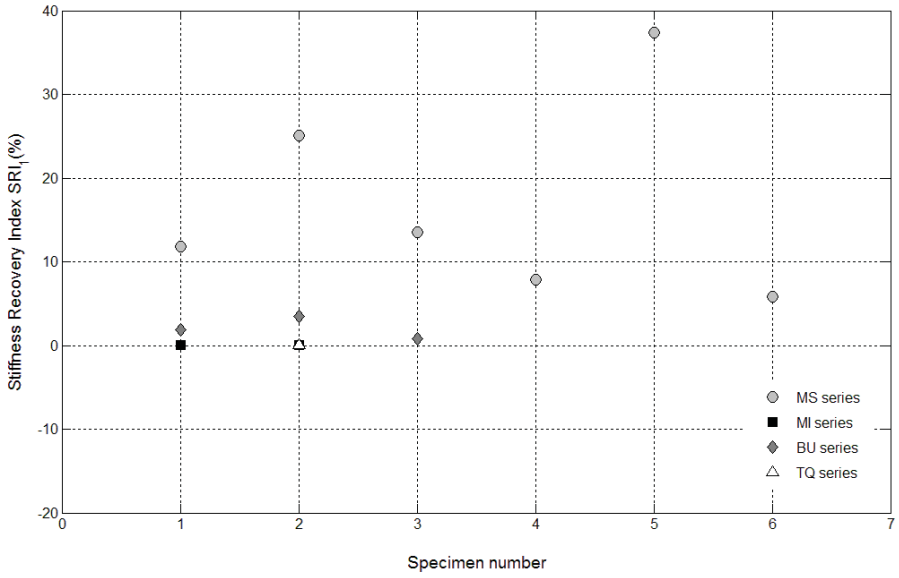
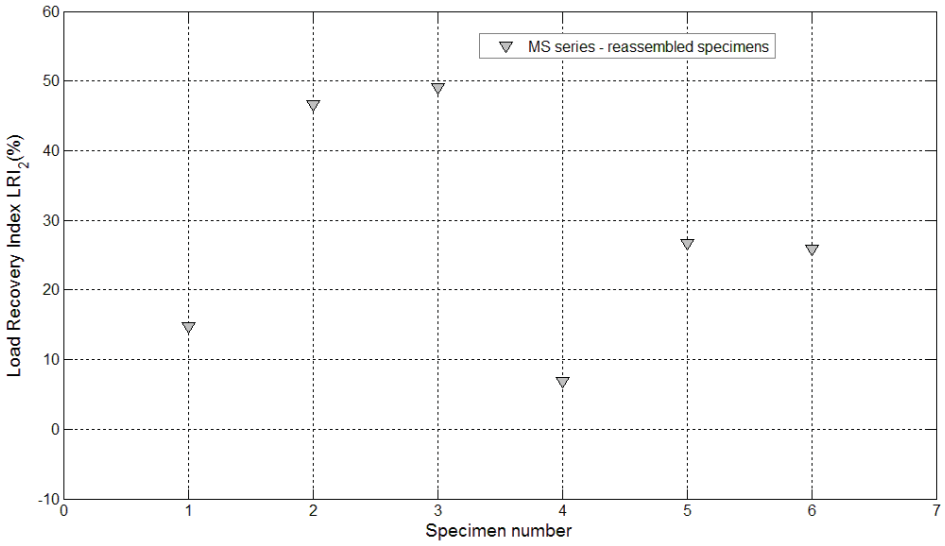


- Stiffness Recovery Indices SRI_1 for control specimens (TQ series and MI series) and self-healing specimens (MS series and BU series)
- The Stiffness Recovery Indices ranged from +5.8% to +25%

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES



- Load Recovery Indices up to nearly 50% and Stiffness Recovery Indices up to 33% were recorded after the second re-loading stage

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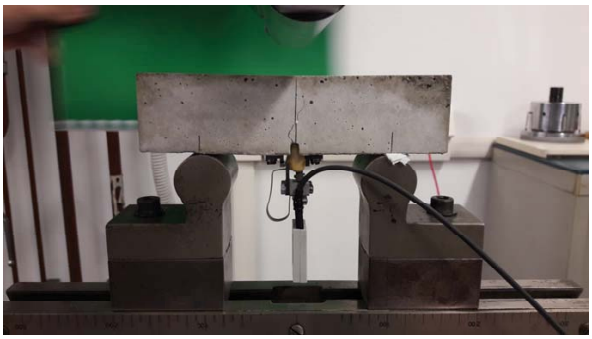
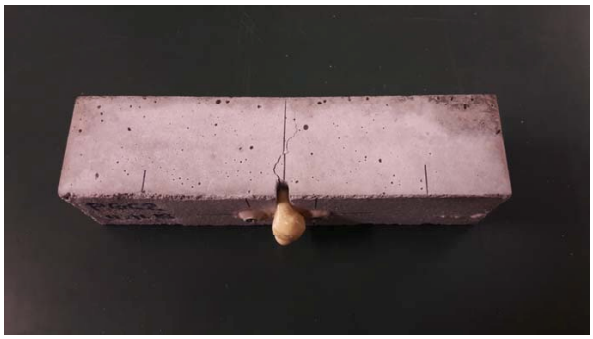
EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES





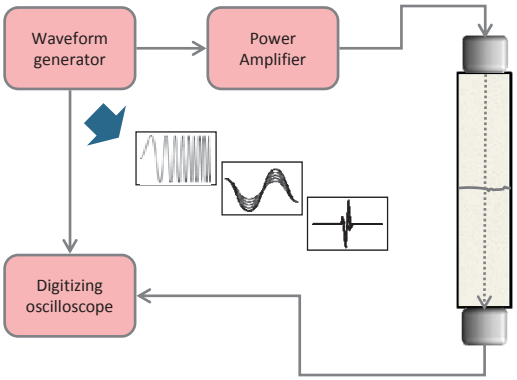
EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

Ultrasonic testing via linear and non linear techniques

Approach

- Defining a simplified system
  - Reducing the testing variables
  - Preserving the essential peculiarities
- Performing a nondestructive investigation
  - Observing the evolution of the system during the healing process by means of linear and non linear ultrasonic techniques
- Assessing the mechanical performances
  - Before damage and at the end of the healing process

General settings



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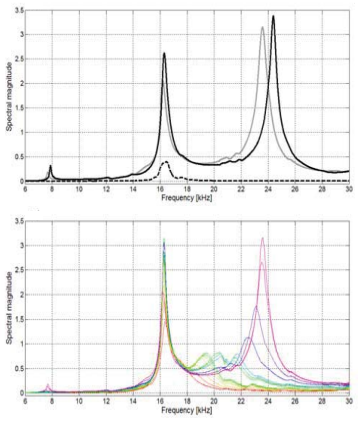
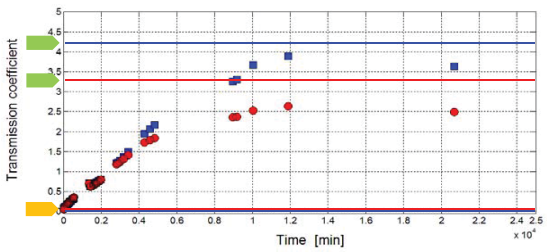
EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

Ultrasonic testing via linear and non linear techniques

Eperimental evidence

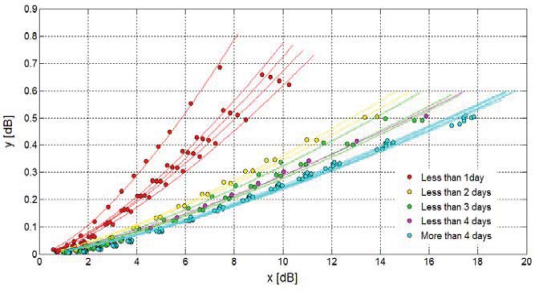
Spectral evolution and peak shift in resonance





Progressive recovery of the transmission properties in linear experiments

Evolution of the nonlinear parameters according to Scaling Subtraction Method (SSM) and Nonlinear Elastic Wave Spectroscopy (NEWS)



Thank you for your attention!

We are happy to collaborate…

CRACOW UNIVERSITY OF TECHNOLOGY (CUT)

LODZ UNIVERSITY OF TECHNOLOGY (LUT)

WARSAW UNIVERSITY OF TECHNOLOGY (WUT)

POLAND

INSTITUTION DESCRIPTION

Cracow University of Technology (CUT) – Arkadiusz Kwiecień (MC)
Lodz University of Technology (LUT)
Warsaw University of Technology (WUT) – Paweł Łukowski (MC)

INSTITUTION DESCRIPTION

Cracow University of Technology (CUT)
Faculty of Civil Engineering
Institute of Building Materials and Structures (L-1)
Institute of Structural Mechanics (L-4)
Institute for Computational Civil Engineering (L-5)
Warszawska 24, 31-155, Cracow, Poland; www.wil.pk.edu.pl

Institutes L-1, L-4 and L-5 provides the knowledge about constructing physical, mathematical and computational models of real-world phenomena, including civil engineering problems of structures and building materials. The particular subjects of our studies are: determination of properties of mineral materials in aspect of durability and their modification, developing of innovative repair and strengthening methods, mechanics of materials and modelling of materials and structures. We cooperate with many scientific and industrial institutions in Poland and abroad.

RESEARCH GROUP DESCRIPTION

Research lines

L-1 (Teresa Stryszewska, Andrzej Winnicki, Tomasz Zdeb): Structural tests of porosity structures (mercury intrusion porosity) and microstructures (scanning microscope), durability of mineral materials; determination of mechanical, chemical and physical properties of mineral materials;

L-4 (Arkadiusz Kwiecień, Bogusław Zając, Łukasz Zdanowicz): Durability of bonding materials in thermal aspect; reduction of stress concentrations and stress redistribution in brittle materials; repair and strengthening of structures using Polymer Flexible Joints (PFJ)

L-5 (Marcin Tekieli, Adam Wosatko): Computational mechanics of materials (description of nonlinear phenomena); modelling of concrete and concrete structures; simulation of cracking using regularized continuum models; numerical and Digital Image Correlation analysis

Group infrastructure

- Electron microscope Zeiss EVO 10 equipped with the SE, VPSE detector and EDS
- Quantachrome Poremaster mercury intrusion porosimeter (range 3nm÷300000nm)
- Chamber for cyclic corrosion tests Corrosionbox 400
- Testing machine for mechanical properties Zwick 1200, Zwick Z 100, Zwick 1455 20kN
- DIC system (Digital Single-Lens Reflex cameras -16Mpx and 24 Mpx, CivEng Vision software)

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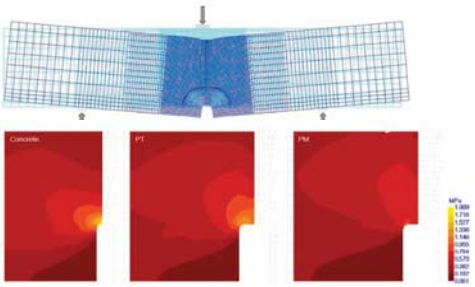
CRACOW UNIVERSITY OF TECHNOLOGY
COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

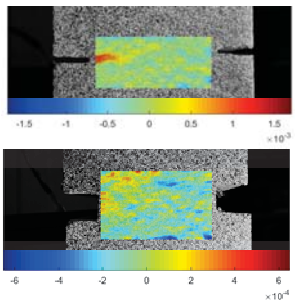
EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

(L-1) Hardness testing for assessing effectiveness of concrete self-healing is considered, scanning microscope observations, focused on the contact zone between the old and new concrete (repair).

(L-4) Self-repair and strength increase of concrete elements were reached by closing of micro-cracks around cracks in damaged structures, after using of Polymer Flexible Joints, which reduce stress concentrations and redistribute stress more evenly.

(L-5) The main goal in considered research is to formulate and implement efficient models and computational methods for self-healing in reinforced concrete structures, based on damage-plasticity.





INSTITUTION DESCRIPTION

Lodz University of Technology
Faculty of Biotechnology and Food Sciences
Institute of Fermentation Technology and Microbiology
Wolczanska 171/173, 90-924 Lodz, Poland; http://binoz.p.lodz.pl

Institute of Fermentation Technology and Microbiology conducts research concerning the role of microorganisms (bacteria and fungi) in deterioration of building materials. We analyse the impact of environmental conditions (temperature, relative humidity, salinity level, pH) on microbial growth and proliferation, as well as mechanisms of biodeterioration process; we develop modern and fast methods for detection and identification of microorganisms involved in these phenomenon. We apply bacterial strains, naturally occurring in building materials, for biomineralization and bioconsolidation purposes.

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SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES SA COS

RESEARCH GROUP DESCRIPTION

Research lines (Anna Otlewska)

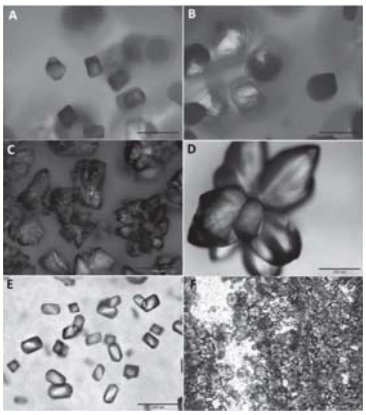
- Role of microorganisms (bacteria and fungi) in deterioration of building materials
- Impact of environmental conditions (temperature, relative humidity, salinity level, pH) on microbial growth and proliferation and mechanisms of biodeterioration process
- Detection and identification of microorganisms involved in biodeterioration
- Bacterial strains for biomineralization and bioconsolidation purposes

Group infrastructure

- Climatic chamber for incubation and storage of material samples
- Accelerated aging chamber to help determine the long-term effects of expected levels of stress within a shorter time
- Luminometer HY-LiTE® System - ATP residue rapid detection system for assessing viability of bacteria
- Gel imaging system Bio-Doc-It (UVP)
- Electrophoresis equipment (Bio-Rad)
- NanoDrop spectophotometer Pearl (Implen) for molecular identification of microorganisms

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

- Identification of microbially induced mineralization mechanisms
- Bacterial strains application to self-heal different types of building surfaces and bioconsolidation of sand
- Studies on biomineralization (by bacteria) phenomenon
- Analysis of molecular and biochemical mechanisms of biomineralization and optimizing conditions of bioconsolidation of building materials



Selected bibliography related to the COST subject:

1. *Otlewska A., Gutarowska B.: Environmental parameters conditioning microbially induced mineralization under the experimental model conditions. Acta Biochimica Polonica 63, 2016, 343-351*
2. *Adamiak J., Otlewska A., Gutarowska B.: Halophilic microbial communities in deteriorated buildings. World Journal of Microbiology and Biotechnology, 31, 2015, 1489-1499*
3. *Otlewska A., Adamiak J., Gutarowska B.: Clone-based comparative sequence analysis of 16S rRNA genes retrieved from biodeteriorating brick buildings of the former Auschwitz II–Birkenau concentration and extermination camp. Systematic and Applied Microbiology, 38, 2015, 48-55*

INSTITUTION DESCRIPTION

Warsaw University of Technology (WUT)
Faculty of Civil Engineering
Department of Building Materials Engineering
Armii Ludowej 16, 00-637 Warsaw, Poland; www.il.pw.edu.pl

Research and didactic activity of Department of Building Materials Engineering (ZIMB) covers all types of building materials. The particular subjects of our studies are shaping and evaluation of durability of concrete (including self-repair ability), its material modification towards sustainable building composite (including use of polymers and mineral wastes as components), diagnostics of building materials and structures (including non-destructive methods). Our research projects are conducted as a part of international collaboration with such centers as University of Liege, Belgium; RWTH Aachen, Germany, Laval University, Canada and others.

RESEARCH GROUP DESCRIPTION

Research lines (Andrzej Garbacz, Paweł Łukowski)

- material designing and optimization of building composites, including ordinary cement concrete, polymer-cement concrete (PCC) and polymer concrete (PC),
- evaluation of usefulness of building materials and systems, including NDT methods,
- materials and technologies of repair and protection of building structures, including scientific and engineering aspects of the European Standard EN 1504 as well as possibilities of self-repairing and self-healing of concrete,
- sustainable building composites as an element of sustainable development in construction, including utilization of mineral wastes like fly ashes, blast furnace slag, perlite powder etc. as the components of building materials.

Group infrastructure

- Laser particle sizer HORIBA LA-300 (range 0-600 μm)
- Testing machine for mechanical properties INSTRON 5567 30 kN
- FORM+TEST lab stand for testing water-tightness of concrete
- Carbonization chamber FEUTRON KPK800
- GERMAN INSTRUMENTS set for Impact-echo testing

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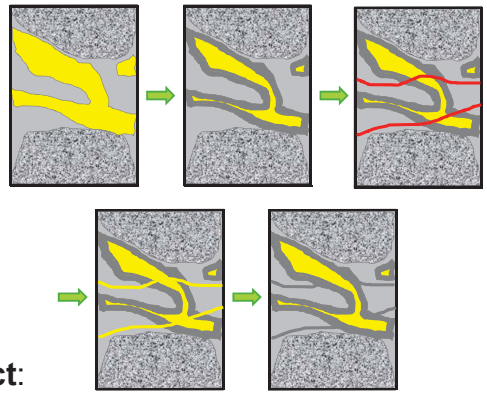
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

- Some self-repair ability of concrete can be achieved by adding epoxy resin without chemical hardener into the concrete mix.
- At present, the use of crystalline admixtures is also considered for this aim.
- Methodology of assessing self-repair ability by using high-precision computer controlled strength machine was developed.



Selected bibliography related to the COST subject:

1. *Łukowski P., Adamczewski G.: Self-repairing of polymer-cement concrete. Bulletin of the Polish Academy of Sciences – Technical Sciences, 61 (1), 2013, 195-200*
2. *Łukowski P., Adamczewski G.: Evaluation of the properties of self-repairing epoxy-cement composite. International Journal Restoration of Buildings and Monuments, 3/4, 2012, 169-175*
3. *Łukowski P., Adamczewski G.: Evaluation of possibility of self-repairing of epoxy-cement composite. 7th Asian Symposium on Polymers in Concrete "ASPIC'2012", Istanbul, 2012, 369-376*
4. *Bissonnette B., Courard L., Garbacz A.: Concrete Surface Engineering, series Modern Concrete Technology, CRC Press Taylor & Francis Group, 2015, 258 pages*

FACULTADE DE CIÊNCIAS E TECNOLOGIA

UNIVERSIDADE NOVA DE LISBOA

PORTUGAL

Paulina Faria[1], Alice S. Pereira[2], Ricardo Velez da Silva[3]

[1]paulina.faria@fct.unl.pt; [2]masp@fct.unl.pt; [3]rc.silva@campus.fct.unl.pt

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INSTITUTION DESCRIPTION

Universidade NOVA de Lisboa – Located in Lisbon and Caparica – 9 Faculties - http://www.unl.pt/en/

Faculty of Sciences and Technology (FCT NOVA) – Located Caparica
14 Departments - http://www.fct.unl.pt/en

FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

Dep. Civil Engineering - http://www.dec.fct.unl.pt/ - Paulina Faria
- Ricardo Silva

Dep. Chemistry - http://www.dq.fct.unl.pt/en - Alice Pereira

Others related Departments: Materials Science, Environmental Sciences and Engineering, Earth Sciences, Conservation and Restoration

INSTITUTION DESCRIPTION

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INSTITUTION DESCRIPTION (related with SARCOS)

FCT FACULDADE DE CIÊNCIAS E TECNOLOGIA UNIVERSIDADE NOVA DE LISBOA

Department of Civil Engineering

The researchers of the Department combine construction and structural skills on the characterization of construction materials, not only cement-based but also other, more vernacular, materials

UCIBIO-REQUIMTE (NOVA and Oporto Universities)

The Research Unit combines key expertise in Chemistry and Biological Sciences

UCIBIO REQUIMTE

CERis (Univ. Lisboa)

The Research Unit operates in the Built and Natural Environment sector

CERIS Civil Engineering Research and Innovation for Sustainability

RESEARCH GROUP DESCRIPTION

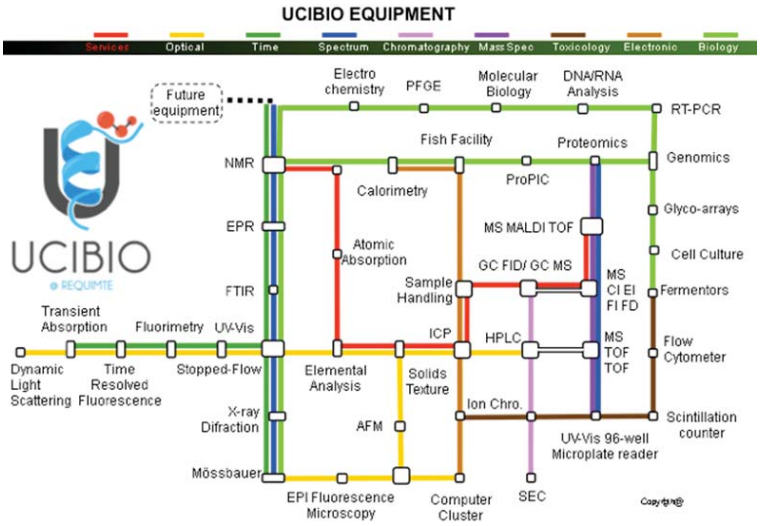
Research lines

Structural Molecular Biology Group → long-standing interest in a variety of topics, namely environment impact

Different methodologies → characterization of different biomolecular research topics:

- protein structures
- spectroscopic
- biophysical and biochemical
- enzyme structures and catalytic mechanisms
- structural and functional analysis of protein-protein, protein-ligand and protein-glycan interactions

Group infrastructure



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SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

RESEARCH GROUP DESCRIPTION

Research lines

Researchers of the **Construction Materials and Structures Group** → long-standing interest in a variety of topics, namely materials characterization, durability and eco-efficiency

Group infrastructure

Granular materials characterization
TGA
MIP
Particle size distribution
Loose bulk density
Organic material
Presence of salts
Moisture
Blaine
Pozzolanic reactivity
…..

Fresh grouts, mortars and concretes
Consistency by penetrometer and flow table
Abrams cone
Marsh cone
Injectability in porous media
Viscosimeter
Exsudation
Segregation
Bulk density
Air content
Drying shrinkage
Water retention
….

RESEARCH GROUP DESCRIPTION

Group infrastructure

Solid materials

Porosimetry (by MIP)
Bulk density
Humid front in real time (by NMR)
Binocular glass observation
Durability to salts (chlorides, sulphates)
Durability to freeze-thaw
UV acelerated weathering
Salt fog acelerated weathering
Water absorption under low pressure
Capillary water absorption
Drying capacity
Hygroscopicity (adsorption and desorption)
Moisture content
Hygroscopic moisture content
Dry abrasion
Wet flux abrasion
Drop water abrasion
Mechanical properties (dynamic elasticity modulus, flexural , compressive, diametral, …)
…..

In situ

Thermography
Thermal conductivity
US velocity
Superficial cohesion
Carbonation
Superficial resistance by pendular sclerometer
Superficial resistance by durometer
Mechanicl behaviour by flat jacks
Resistance of sphere impact, deformability and resilience
Water absorption by Karsten tubes
Real time monitoring of T and RH indoor cell and outdoors
Natural weathering
…..

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SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES
SA COS

SELF-HEALING OF EARTH PLASTERS

Bio-based treatment of earth mortars

Bio-based formulation of earth mortars

SELF-HEALING OF EARTH PLASTERS

Bio-based treatment of earth mortars

How can an iron bio-based superficial treatment improve earth mortars durability ?

5 different "treatments" were tested:

- Water
- Luria Broth (LB) medium
- LB with iron
- *E. coli* culture with iron
- *E. coli* culture with iron and Dps, an iron scavenger protein

Control specimens had no treatment applied

First stage: 1 mL of "treatment" was applied, followed by 5 days of feeding with LB medium (or water)

Second stage: the "treatment" was re-applied with 1 day feeding

The "treatment" was applied on a central point of the upper surface of each mortar specimen, allowing percolation throughout the specimen

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SELF-HEALING OF EARTH PLASTERS

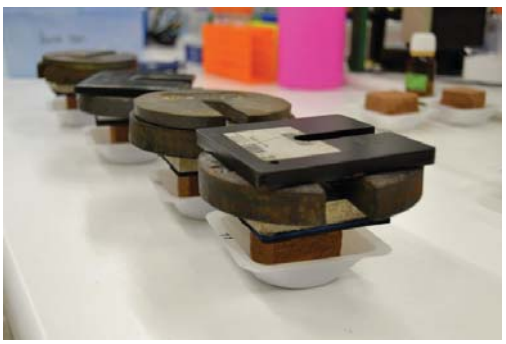
Bio-based treatment of earth mortars – Tests

Surface hardness: assessed with PCE Shore A durometer

1	2		3
4	5	6	9
	7	8	
10	11		12

Surface cohesion: test was performed by detaching a tape from the treated surface and weighing it

Equal pressure was applied to all specimens: 1.5kg weights were positioned on top of the tape for 5 minutes, before it was detached

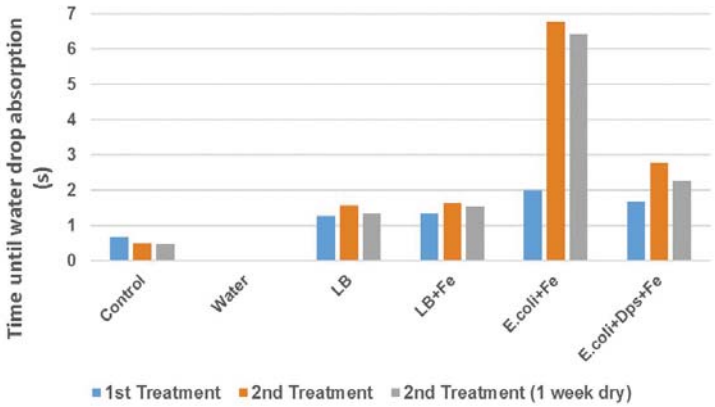


SELF-HEALING OF EARTH PLASTERS

Bio-based treatment of earth mortars – Tests and Results

Water drop absorption: dropping a water drop on the surface and measuring the time until total absorption

The test was video recorded in order to achieve a more accurate time measurement



After first treatment: an increase of water drop absorption time is observed in all bio-treated specimens

After the second treatment: absorption time of *E. coli* with iron treated specimens have a considerable increase

A high resistance towards water absorption is achieved !

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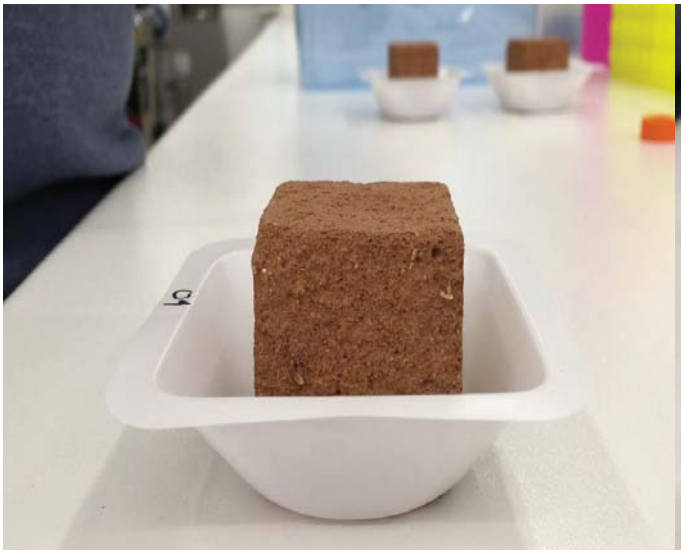
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

SELF-HEALING OF EARTH PLASTERS

Bio-based treatment of earth mortars - Water drop absorption test

Control Specimen (no treatment applied)

***E. coli* with iron**



SELF-HEALING OF EARTH PLASTERS

Bio-based formulation of earth mortars

Earth mortars were produced with 3 different liquids:

- Control (water)
- LB medium
- *E. coli with* iron

Mortars with bio-based liquid were more fluid, more fluffy and with lower density in comparison with control mortar

Fresh state characteristics seemed appropriated for mechanical application of plasters

Further characterization (hardened state) is now ongoing…

An article is being prepared…

NIRD URBAN-INCERC

ROMANIA

NIRD URBAN-INCERC

- research and development in construction
- urban planning
- sustainable territorial development

The institute contains several branches and provides assistance to all its partners in the construction sector and not only, in adopting the optimum solutions for specific issues related to construction materials, housing in urban and rural areas, energy saving and environmental protection, historical heritage and structural safety.

- **European Notified Body pursuant to the Construction Products Regulation** (NB 1841)
- **Acreditation Certificate No 320 (RENAR, National Accreditation Body -NAB)**
- **Autorization Certificate No 2300 (ISC, State Construction Inspectorate)**

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RESEARCH GROUP DESCRIPTION

Research lines

Research on building materials

- Structural and insulating light weight concrete
- Waste and industrial by-products recycling

- Self-compacting concrete for precast elements

- Self-healing capacity of cement based materials

RESEARCH GROUP DESCRIPTION

Research lines

Research on elements and substructures

- New desing concepts for precast RC structures subjected to seismic type loadings
- Behaviour of steel and mix structures subjected to accidental loadings
- Retrofitting solutions for reinforced concrete frame structures and masonry structural walls
- Shear bearing capacity of reinforced concrete beams under seismic loading

Group infrastructure

Material and Structural Elements Research & Testing Laboratory – IME
NIRD URBAN-INCERC Cluj-Napoca Branch

ERRIS (Engage in the Romanian Research Infrastructures System) for Romanian Research Infrastructures, the booking gate for research infrastructures, research & technological services

https://erris.gov.ro/Cluj-Napoca-Branch-NIRD-URBA

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
MINISTRY OF RESEARCH AND INNOVATION
National Institute for Research and Development in Construction, Urban Planning and Sustainable Spatial Development "URBAN-INCERC"
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SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

Main equipments:

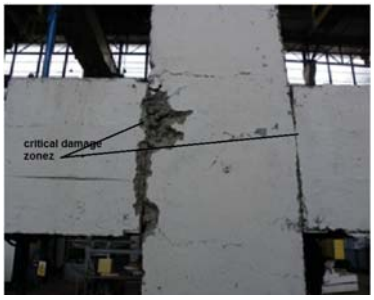
- Servo-hydraulic control console
- Flexural test device for concrete beams
- Extensometer for Elastic Modulus determination
- Apparatus for determination of thermal conductivity
- Data acquisition system (DAQ)
- Load Cell with High Nominal Rated Forces
- Inductive displacement transducer
- Ultrasonic pulse velocity tester
- Test equipment for self-compacting concrete
- Reaction wall with double slab multipurpose PC stand

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

I.THE SEISMIC RESISTANT HYBRID JOINT:– the context for the present study

Starting with 2009 at URBAN - INCERC test laboratory, Cluj-Napoca Branch, there were developed and tested different concepts of reinforced concrete precast frame structures with superior behavior under seismic action: PLANAR HYBRID JOINT & SPATIAL HYBRID JOINT

Planar model of the hybrid joint:
critical damage areas after testing



Spatial model of the hybrid joint:
overall testing assembly

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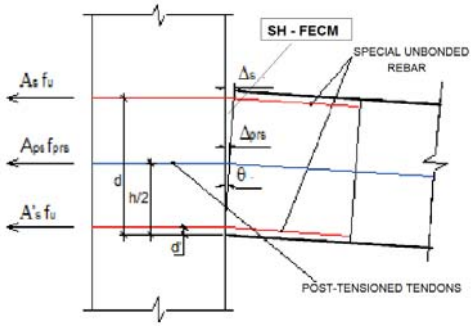
EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

I.THE SEISMIC RESISTANT HYBRID JOINT:– the context for the present study

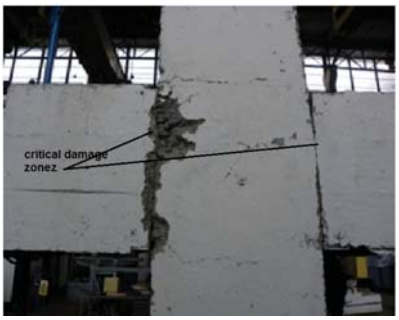


The hybrid joint has the special reinforcement de-bonded along two limited zones situated at the column-beam interface joint, where yielding is expected to occur under seismic loadings

The design concept allows the replacement of the damaged reinforcement, injury induced by a strong earthquake or other high magnitude accidental loading

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

I.THE SEISMIC RESISTANT HYBRID JOINT:– the context for the present study



Planar model: critical damage areas after testing

Spatial model: critical beam to column contact surface

Concentration of high peaks of alternating compressive and yielding stresses during cyclic seismic loadings

Critical damage areas: two limited zones at the interface of column-beam joint, where yield is expected to occur during seismic loading

Advanced Fiber Reinforced Cementitious Composites as **beam – column interface material** for seismic resistant hybrid joint, for improving the vulnerability of critical damage areas

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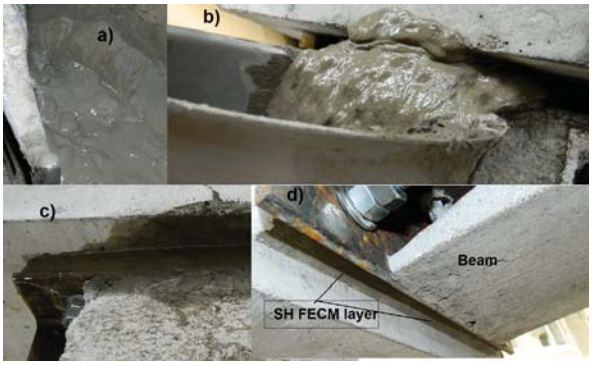
EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

II.THE SEISMIC RESISTANT HYBRID JOINT:– objectives of the research

1. Development of Self-Healing Fiber Engineered Cementitious Materials (SH – FECM), with main fresh and hardened state characteristics similar or close to those of ECCs, including the self-healing (SH) potential, by using local raw materials.

2. SH – FECMs used as beam – column interface material for seismic resistant hybrid joint, for improving the vulnerability of critical damage areas.



EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

III. RESULTS; SH-FECM PERFORMANCES

Good bond strength to the support layer (Pull-off test)

Bond strength > 5 MPa
(Rapture was produced in the support layer)

Good behavior of material under and after seismic loading („Acceptance Criteria for Moment Frames Based on Structural Testing ACI T1.1-01" ; Imposed Displacement – resulting force test)

There was no recorded, during and after testing, crashing of the mortar or large cracking pattern at the beam to column interface

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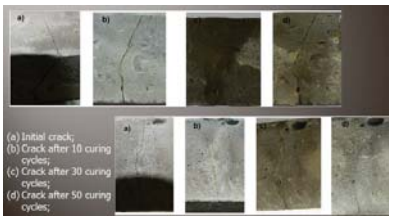
EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

III. RESULTS; SH-FECM PERFORMANCES

1. Prismatic specimens 40x40x160 mm: Three Point Bending Initial Test

Testing specifications
Age of the specimens: 20 days;
Testing method: EN 196;



2. Curing conditions

All three specimens were then exposed to 50 wet and dry curing cycles:
- WET: Tap water, at the temperature of (20±2)°C, for 8 h;
- DRY: Air, T: (21 ± 3)°C; RH: (50 ± 5) %.

3. Evaluation of SH capacity

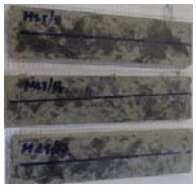
Evaluation of Self –Healing properties was classically performed:
a) Self Sealing: visual analyze of crack self closing;
b) Self Repairing: mechanical (bending) recovery

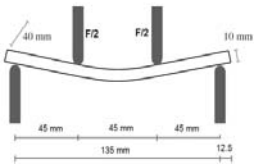
Cracking pattern under reloading

Micro-cracking pattern under compression

IV. Dynamic loading performance of materials and evaluation of their SH performance – Laboratory Magnel, Ugent, Belgium (PhD internship)

1. Test Method: Prismatic specimens 10x40x160 mm: Four Point Bending (4PB) at different loading/strain rates





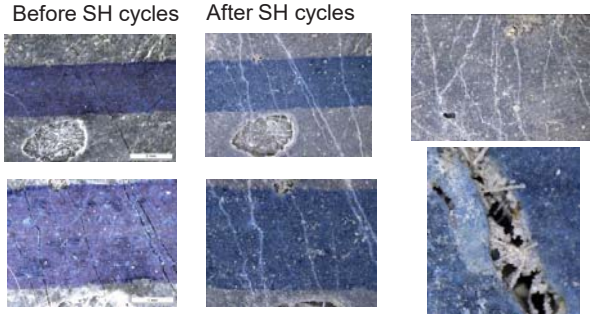
2. Curing conditions

Exposure of SH & R specimens to 28 wet and dry curing cycles:
WET: Tap water, at the temperature of (20±2)°C, for 12 h;
DRY: Air, T: (20 ± 2)°C; RH: (60 ± 5) % for 12 h.

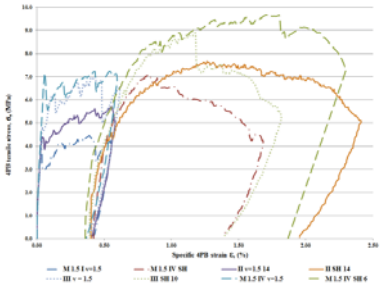
3. Evaluation of SH capacity

a) Self Sealing: visual analyze of crack self closing

Before SH cycles After SH cycles



b) Self Repairing: mechanical 4PB retesting



cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
URBAN INCD INCERC MINISTRY OF RESEARCH AND INNOVATION National Institute for Research and Development in Construction, Urban Planning and Sustainable Spatial Development "URBAN-INCERC"
COST CA15202 SARCOS SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES SA COS

Thank you for your attention!!!

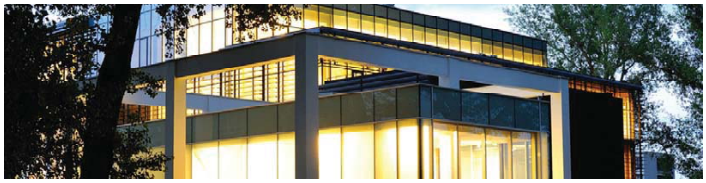
☺

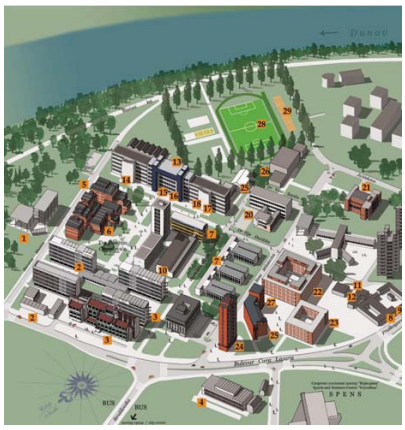
FACULTY OF TECHNOLOGY

UNIVERSITY OF NOVI SAD

SERBIA

INSTITUTION DESCRIPTION





University of Novi Sad

14 Faculties + 2 Institutes
2nd largest in Serbia, 4 cities
Comprehensive university
- 5.000 employees
- 50.000 students

Faculty of Technology

- 8 Departments + 4 Laboratories
- food, chemical, pharmaceutical, materials engineering and biotechnology

web: www.tf.uns.ac.rs

Department of Materials Engineering

- 3 research groups

Laboratory for Materials in Cultural Heritage

Contact us: heritagelab@tf.uns.ac.rs

University of Novi Sad
Faculty of Technology
Department of Materials Engineering
Laboratory for Materials in Cultural Heritage

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR
OF CONCRETE STRUCTURES

RESEARCH GROUP DESCRIPTION

Prof. Dr. Jonjaua Ranogajec
Head of Department and Laboratory

Prof. Dr. Siniša Markov

Dr. Bojan Miljević

Snežana Vučetić

Helena Hirschen-berger

Ana Vidaković

John Milan van der Bergh

EXPERTISE

- **Examination** of building materials (historical and modern)
- **Design and processing** of new functional materials for cleaning and protection of tangible cultural heritage
- **Development of new methods** for materials characterization (*in situ* and laboratory), functionality, compatibility, durability

PROJECTS, REFERENCES

COORDINATION OF INTERNATIONAL PROJECTS:

- **Horizon 2020** PolyBioSkin (2017-2020)
- **FP7 project HEROMAT** "Protection of Cultural Heritage Objects with Multifunctional Advanced Materials" (2011-2015)
- **Eureka Programme E! 5861** "Multifunctional layers for the protection of mineral substrates" (2010-2013)
- **FP7 project RP DEMATEN** "Reinforcement of research potential of the Department of Materials Engineering in the field of processing and characterization of nanostructured materials", (2008-2011)
- **Eureka Programme E! 3969** "Clean Tile Development of Self-cleaning clay roofing tiles"(2007-2009)
- Bilateral scientific cooperation with **Italy**: "Sviluppo locale incentrato sulla valorizzazione del patrimonio culturale"(2006-2008)
- Bilateral scientific cooperation with **Slovenia**: "Degradation processes of building materials - Frost actions" (2003-2004, 2005-2006)
- **WUS project** "Methods of materials characterization", World University Service Austria (2005)

PARTICIPATION IN INTERNATIONAL PROJECTS:

- **Eureka Programme E! 4964** "Development of lightweight aggregate from waste material and further processing into thermal insulation concrete" (2010-2012)
- **TEMPUS**: "COMPETENCE - Matching competences in higher education and economy: From competence catalogue to strategy and curriculum development" (2009-2012)
- **COST Action 540**: Photocatalytic technologies and novel nanosurfaces materials –critical issues ("Phonasum") (2006-2010)

COORDINATION OF NATIONAL PROJECTS FINANCIED BY SERBIAN MINISTRY OF EDUCATION, SCIENCE AND TECHNOLOGICAL DEVELOPMENT:

- III45008 "Development and application of multifunctional materials using domestic raw materials in upgraded processing lines" (2011-2016)
- TR 19005 "Nano composites based on silicate materials in design of improved and new ceramic materials" (2008-2010)
- TR 6735 "Design of physico-mechanical characteristics of ceramic roof tiles and ceramic tiles resistant to frost and biocorrosion" (2005-2007)
- TR 3200 "Design of texture of brick elements resistant to frost and biological agents" (2002-2004)

PARTNERS

- Lafarge Holcim
- Potisje Kanjiža – Tondach Wienerberger AG
- Polet Novi Bečej – NEXE Group
- Provincial Institute for the protection of cultural monuments, Vojvodina, Serbia
- Central Institute for Conservation, Belgrade, Serbia
- Slovenian National Building and Civil Engineering Institute, Slovenia
- SMEs in Serbia - companies for the production of building materials
- Faculty of Chemistry and Chemical Technology, University of Ljubljana, Slovenia

University of Novi Sad
Faculty of Technology
Department of Materials Engineering
Laboratory for Materials in Cultural Heritage

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR
OF CONCRETE STRUCTURES

Coordination of FP7 project HEROMAT – *Protection of Cultural Heritage Objects with Multifunctional Advanced Materials*, visit www.heromat.com

Member of the cluster of 5 FP7 projects in cultural heritage:

- HEROMAT
- IMAT
- NANOFORART
- NANOMATCH
- PANNA

NanomeCH

New applications for Horizon 2020, Danube2020, Adrion, etc.

Intensive networking with similar organizations and laboratories for protection and preservation of tangible cultural heritage.

CAPACITIES

Mobile equipment:

X-Ray Fluoresence Spectrometer – Bruker Artax µXRF 200

Fourier Transformed Infra-Red Spectrometer – Bruker Alpha

Infra-Red Thermal Camera – FLIR T660

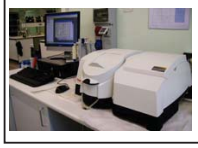
UV/Vis Spectrophotometer – Konica Minolta CM 700d

Drilling Resistance Measurement System – SINT Technology

Light Stereo Microscope – OMANO OMXTL/V7

University of Novi Sad
Faculty of Technology
Department of Materials Engineering
Laboratory for Materials in Cultural Heritage
COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

Laboratory equipment



UV/Vis Spectrophotometer – Thermo Scientific Evolution 600

Vicker's Microhardness Tester – ZZV Precision Tool Supply HVS 1000 A

Mercury Intrusion Porosimeter – Autopore IV 9500 Micromeritics

Scanning Electron Microscope with Energy Dispersive Spectroscopy – JEOL JSM 6460 LV, Oxford INCA

Low Temperature Gas Adsorption Porosimeter – Surfer Thermo Scientific (N_2, He)

Growth/Aging Chamber – Binder KBWF 240

Polarizing Light Microscope – Carl Zeiss AxioScope A.1

Surface Roughness Meter – Taylor/ Hobson Surftronic 25

Surface and Energy Evaluation System – Advex instruments

Sample Preparation System – Diamond Cut-off machine, Vacuum impregnation Unit, Grinding and Polishing Unit, Struers

DTA/TG Analyzer – Bahr STA 503

Electrospinning Deposition System

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

PROPOSALS FOR SELF-HEALING CONCRETE STRUCTURES

I	II	III
Self-healing using the phenomena from the nature: Use of microorganisms which produce natural polymers (biopolymers) as a metabolic product – **direct application**	Self-healing using the phenomena from the nature: Use of microorganisms which produce natural polymers (biopolymers) as a metabolic product – **deposition by electro-spinning**	Electro-spinning deposition of proven bacterial cultures for self-healing of concrete structures – **production of biofibers**

Challenges:

The pH value of concrete can be rather high which could be a problem for the bacterial growth. However, in damaged and previously infected areas of the concrete structures, the pH values are reduced. This effect has been observed by investigations on culture heritage objects and could be used for the self-healing pre-treatment. The idea is to create environmental possibilities for reduction of the pH value and good start for the self-healing processes proposed above.

INSTITUTO DE CIENCIAS DE LA CONSTRUCCIÓN

EDUARDO TORROJA – CSIC

SPAIN

INSTITUTION DESCRIPTION - CSIC

- Autonomous agency within the Ministry of Economy &Competitiveness.
- The largest public research organization in Spain and the 3rd in Europe.

- Main objectives:
  Foster, coordinate, develop and promote Scientific and Technological research.
  Contribute to advancing knowledge and economic, social and cultural development.
  From basic research to technological development.

- Collaborations:
  National and international universities, scientific and technical R&D institutions, large &SMEs enterprises etc.

125 centers in eight scientific-technical areas
Area 6. Materials Science &Technology
Institute of Construction Science "Eduardo Torroja" (IETcc)

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

INSTITUTION
Spanish Research Council (CSIC)

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

INSTITUTION DESCRIPTION - IETcc

➢ **Scientific and Technological Research**
Construction & building materials.
Structural engineering, roads & energy saving.
National & International Projects, private contracts

➢ **Technical support to the construction sector**
"European Technical Assessment" (ETA) for innovative construction products
Active member & co-founder of international bodies: UEATC, EOTA, CEB, CIB, RILEM and ENBRI, UEATC.
Elaboration of Standards. Permanent member of the Spanish construction code (EHE) & EUROCODE

➢ **Dissemination of Scientific and Technical Knowledge** (2 SCI journals)

http://www.ietcc.csic.es/index.php/es/

INSTITUTION DESCRIPTION - IETcc

Specific facilities for research in self-healing concrete

Concrete production

Microstructural Characterisation

SEM/XRD/TG/AFM/MIP/N2...

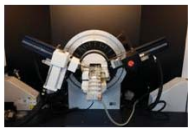
Concrete Durability

Corrosion of reinforcement

Ion transport

Mechanical test labs

Controlled cracking of concrete specimens



Analysis of pore solution

Freeze-thaw

Non-destructive techniques

Water permeability

http://www.ietcc.csic.es/index.php/es/

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

INSTITUTION
Spanish Research Council (CSIC)

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

RESEARCH GROUP DESCRIPTION:

Safety and Risk Management (GRS)

Research in the area of risk & safety in construction. Focused in theoretical-experimental.

Search in new sustainable technologies, efficient and safe around the multiple risks variable in time and dimension.

Research lines

Innovative solutions for high performance material & structures in extreme risk conditions:

- *Natural disasters*
- *Environmental*
- *Technologic*

Nanotechnology & functional materials

- *Risk reduce & manage due to loss of performances*
- *Implementation of new functionalities in materials & components, including self-properties*

Diagnosis of damage

Models for structural analysis

Multidisciplinar Group

- ***Alonso Maria Cruz*** *(Leader, Staff)*
- ***Fernández Alvaro*** *(Dr)*
- ***Flor-Laguna Virtudes*** *(Technician)*
- ***Jimenez Mercedes*** *(PhD student)*
- ***Luna Javier*** *(PhD student)*
- ***Puentes Javier*** *(Dr)*
- ***Rio Olga*** *(Staff)*
- ***Sanchez Mercedes*** *(Dr)*

RESEARCH GROUP DESCRIPTION:
Eco-efficient construction materials (MECONS)

Research in the design and development of cement-based materials for sustainable construction

Multidisciplinar Group

- ***Guerrero, Ana*** *(Leader, Staff)*
- ***Pérez, Gloria*** *(Dr)*
- ***Sánchez, Jose A.*** *(Technician)*
- ***Mota, Carlos*** *(Master student)*

Associate Unit MATCON Tecnalia-CSIC

Research lines

Activation and valorisation of waste products

- *Activation of wastes through hydrothermal treatment.*
- *Valorisation of wastes in eco-efficient cement-based materials.*
- *New eco-efficient cements: low emissions and low energy.*

Development of eco-efficient cement-based materials with advanced functionalities

- *Autonomous self-healing concrete based in epoxy-amine adhesive*
- *Engineered cementitious composites (ECC) incorporating local waste products and natural nanofibers from plant residues.*
- *Smart mortar for thermal coating of buildings based in eco-efficient thermocromic cements*

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

INSTITUTION
Spanish Research Council (CSIC)

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

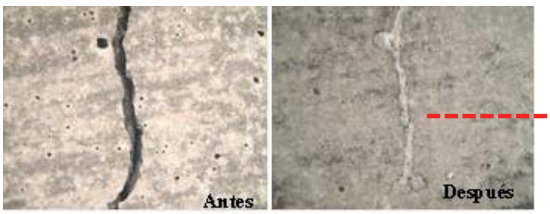
EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES
Safety and Risk Management (GRS)

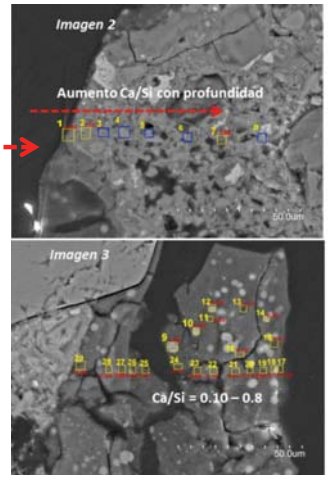
External sealing of cracks

- Penetration of colloidal nanosilica and reaction with cementitious matrix gives rise to formation of a sealing coating.
- Several application methods. Electrochemical methods enhances versatility in coating properties.

➢ Current results

- Sealing up to 300 µm crack-width.
- Increased resistance upon agressive agents .





➢ Future objectives

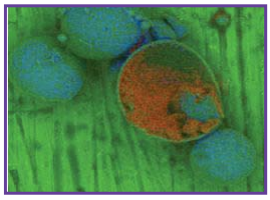
Regain of mechanical properties
Implementation of innovative functionalities

National funding through Project BIA 2014-56825-JIN (2015 – 2018)
Main Researcher: **Mercedes Sánchez (mercesanc@ietcc.csic.es)**

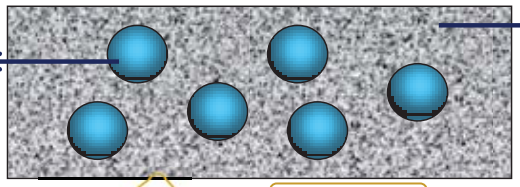
EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

Eco-efficient construction materials (MECONS)

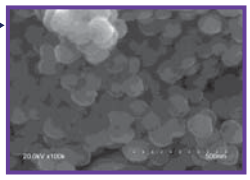
Autonomous self-healing concrete based in epoxy-amine adhesive

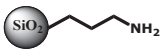


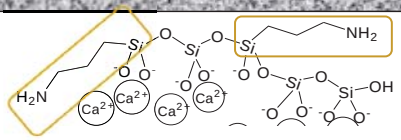
Epoxy in silica microcapsules

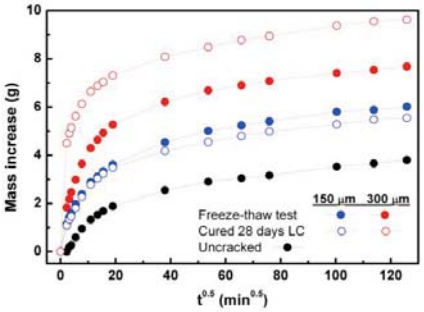


Amine-functionalized nanosilica









➢ **Current results**

Complete sealing up to 150 µm and partial up to 300 µm crack-width.
Increased durability under freeze-thaw cycles and salt spray test.

➢ **Future objectives**

Scalability of self-healing system synthesis and prototipes.

National funding through Project BIA 2011-29234-C02-01: MICROREP (2012 – 2015).
In collaboration with **Tecnalia** Materials Sustainable Construction Division.
Main Researcher **Ana Guerrero (aguerrero@ietcc.csic.es)**

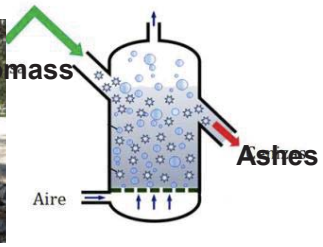
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
INSTITUTION
Spanish Research Council (CSIC)
COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

Eco-efficient construction materials (MECONS)

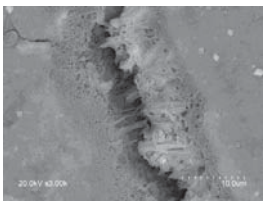
ECC incorporating local waste products

- Substitution of fly ashes by biomass ashes from Spanish paper industry.

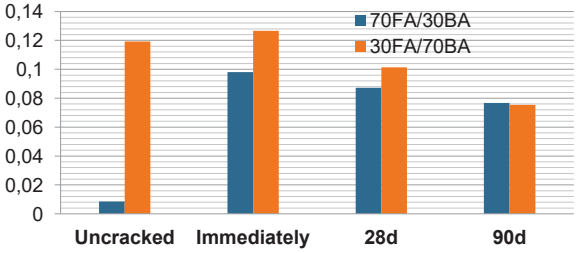


➢ **Current results**

Tightness increase with curing time after cracking with 70% biomass ash-30% fly ash.



SEM-EDX analysis



Water absoption

➢ **Future objectives**

Complete characterisation of ECC incorporating biomass ashes.
Substitution of PVA fibers by natural nanofibers from residues.
Search National/European funding.

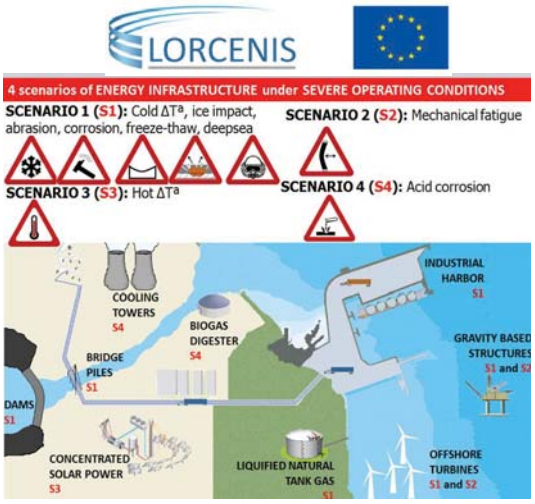
Contact Researcher **Gloria Pérez (gperezaq@ietcc.csic.es)**

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

Safety and Risk Management (GRS) & Eco-efficient construction materials (MECONS)

Long Lasting Reinforced Concrete for Energy infrastructures under Severe Operating Conditions (LORCENIS)

https://www.sintef.no/projectweb/lorcenis/



Goal: multifunctional self-responsive strategies integrated in **bulk reinforced-concrete** for manufacturing of energy structures under **Severe operating conditions**:

Self-diagnosis Self-healing Self-curing Self-protection

➢ **CSIC main contributions:**

- Development of functionalized concrete for high T (S3)
- Leader of Task Laboratory performance functionalities in simulated severe environments

European funding: H2020 NMP-19-2015 LORCENIS-685445, 17EU Countries, 2016–19

Main Researcher CSIC **M. Cruz Alonso**
(mcalonso@ietcc.csic.es)

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

SPAIN

INSTITUTION DESCRIPTION

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

SARCOS Grant Holder

young institution (early 70s), some schools +100 years old

33 Bachelor + 51 Master + 25 PhD Programmes

- Arts
- Engineering and Architecture:
  - Construction
  - Agrifood and Forest
  - Industrial and Aeronautical
  - Information and Communications Tech.
  - Science and Technology for Health
- Sciences
- Social and Legal Sciences

Some numbers:

Students:	37800
Teaching and research staff:	2600
Administrative and services staff:	1700

>125000 m^2 of green space

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

UNIVERSITAT POLITÈCNICA DE VALÈNCIA (UPV)

COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

INSTITUTION DESCRIPTION

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ICITECH Ciencia y Tecnología del Hormigón

Institute of Concrete Science and Technology

Group infrastructure

- **Concrete and mortar mixers** of different capacities: 1, 30, 50, 150 and 300 liters
- **Testing equipment**: INSTRON 10 kN, Ibertest 3000 kN, Universal Testing Machine 600 kN, ICON
- **Reaction Wall and Floor** 12x6 m^2. Several **load frames**.
- **Permeabilimeter:** high pressures (1-10 bars)
- **Several Humidity Chambers** and water tanks
- **Optical microscope**
- **Accesories** for concrete testing: gauges, LVDTs…
- UPV electronic microscopy services

RESEARCH GROUP DESCRIPTION

MC: Prof. Pedro Serna (*group leader*)
MC Subs.: Marta Roig Flores

Research lines

Development of Special Concretes and New Technologies

- Self Compacting Concretes and High Strength Concretes
- Fiber-Reinforced Concretes and Ultra High Performance
- Recycled Concretes
- **Self-healing Concretes**
- 3D Printing of Concrete Structures
- Cold forming of Concrete

Development of New Test Methodologies and Standardization

- ECADA – BOND
- CREEP of FRC – RILEM TC 261 CCF
- PUSH-OFF – SHEAR of FRC
- **SELF-HEALING of Concretes**

Monitoring Corrosion: Durability Measurement in Structures

Analysis of Special Concretes Mechanical Behavior

- CFRP – Reinforcements
- Shear on FRC
- Bond Concrete - Reinforcement

Recycling everything for Concrete

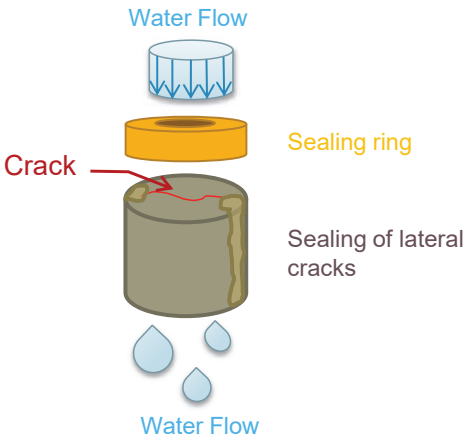
Thinking on Real Applications

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
UNIVERSITAT POLITÈCNICA DE VALÈNCIA (UPV)
COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

EXPERIENCE ON SELF-HEALING CONCRETE

WATER PERMEABILITY TESTS

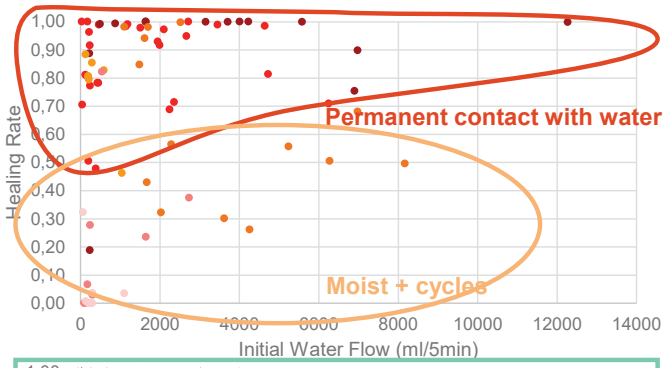
- **Started in 2013** – main work
- Autogenous healing and crystalline admixtures (CA) in **concrete**
- Own methodology using high pressure (2 bars)
- **Collaborations in this work:**
  - Prof. Liberato Ferrara
  - MEng. Simone Moscato
  - MEng. Francesco Pirritano



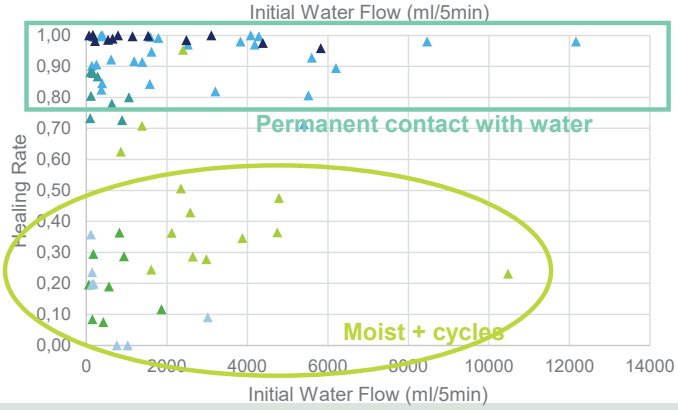
EXPERIENCE ON SELF-HEALING CONCRETE

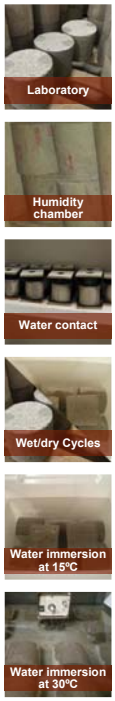
$$Healing\ Rate = 1 - \frac{Final\ Flow}{Initial\ Flow}$$

Autogenous healing



Crystalline Admixtures



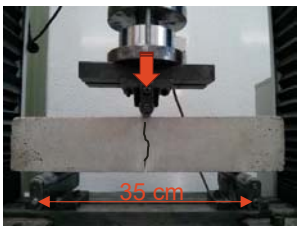


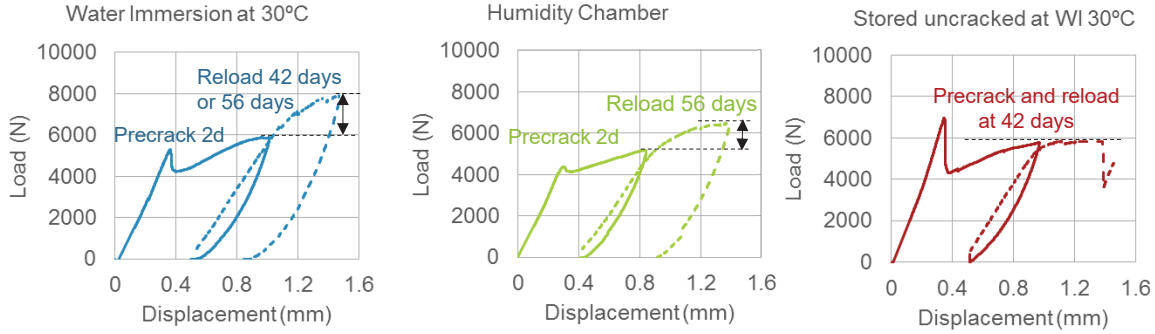
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
UNIVERSITAT POLITÈCNICA DE VALÈNCIA (UPV)
COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

EXPERIENCE ON SELF-HEALING CONCRETE

MECHANICAL RECOVERY

- Autogenous healing and with crystalline admixtures (CA)
- Comparison of methodologies and criteria
- Further analyses on-going
- Collaborations in this work:
  - BEng. Laura Rubio (UPV)



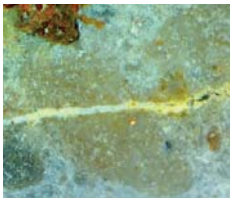


EXPERIENCE ON SELF-HEALING CONCRETE

OPTICAL MICROSCOPE

- As secondary evaluation method
- Comparison with permeability results
- Determination of "healable" cracks



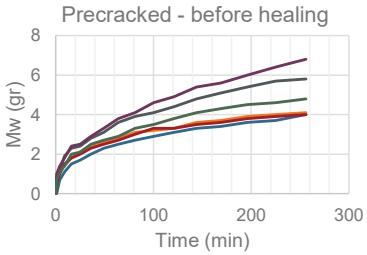


SORPTIVITY TESTS (CURRENT WORK)

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

- **Starting** → COST STSM
- To compare autogenous healing and crystalline admixtures (CA)
- Characterisation at different depths
- **Collaborations in this work:**

UNIVERSITY OF CAMBRIDGE
- Prof. Abir Al-Tabba
- Dr. Chrysoula Litina



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UNIVERSITAT POLITÈCNICA DE VALÈNCIA (UPV)
COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

EXPERIENCE ON SELF-HEALING CONCRETE

2013
Our starting point

2017

Main outputs:
- 5 BEng, MEng theses
- 2 journal + 5 conference papers
- 1 on-going PhD thesis

Main interests for future work

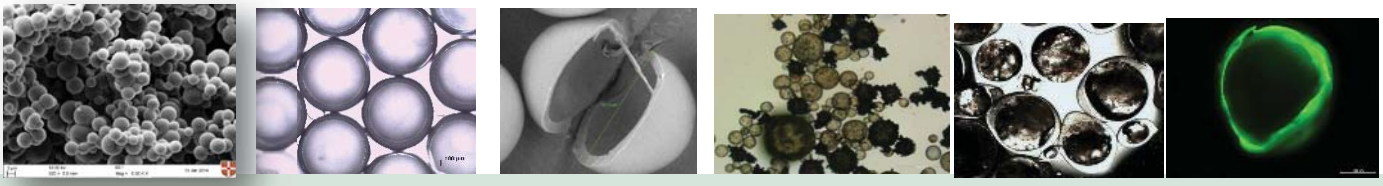
- **Ready-to-mix self-healing agents** (SARCOS-WG1)
- **Tests methods and evaluation** (SARCOS-WG2)
  - Durability
  - Mechanical recovery
- **Standardisation** (SARCOS-WG2)
  - Mainly for concrete but also mortar
- **Scaling up**

UNIVERSITY OF CAMBRIDGE

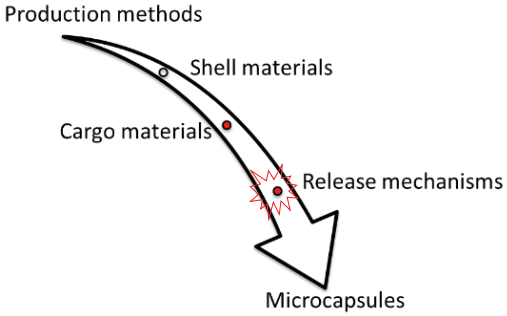
UNITED KINGDOM

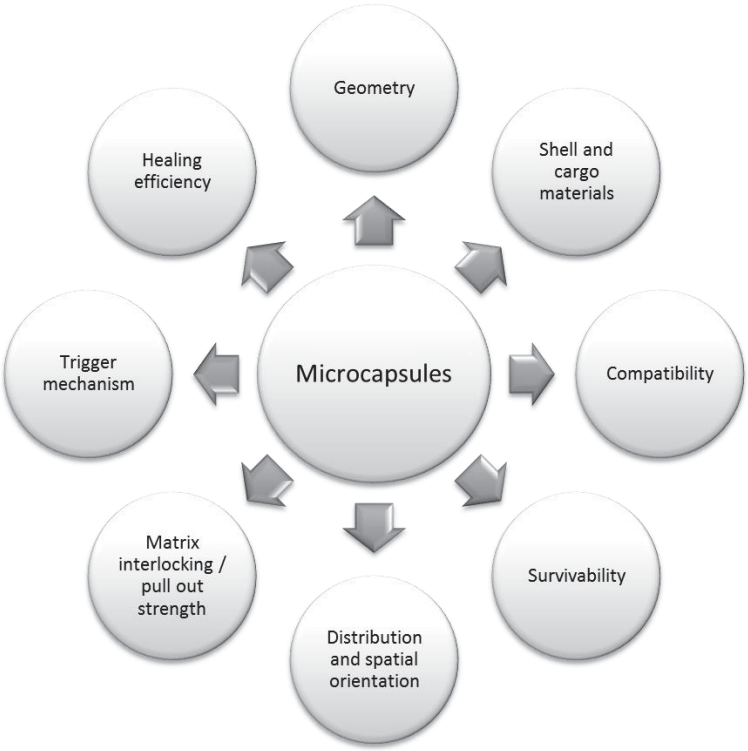
ENCAPSULATION APPROACHES

Abir Al-Tabbaa
University of Cambridge



COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR
OF CONCRETE STRUCTURES





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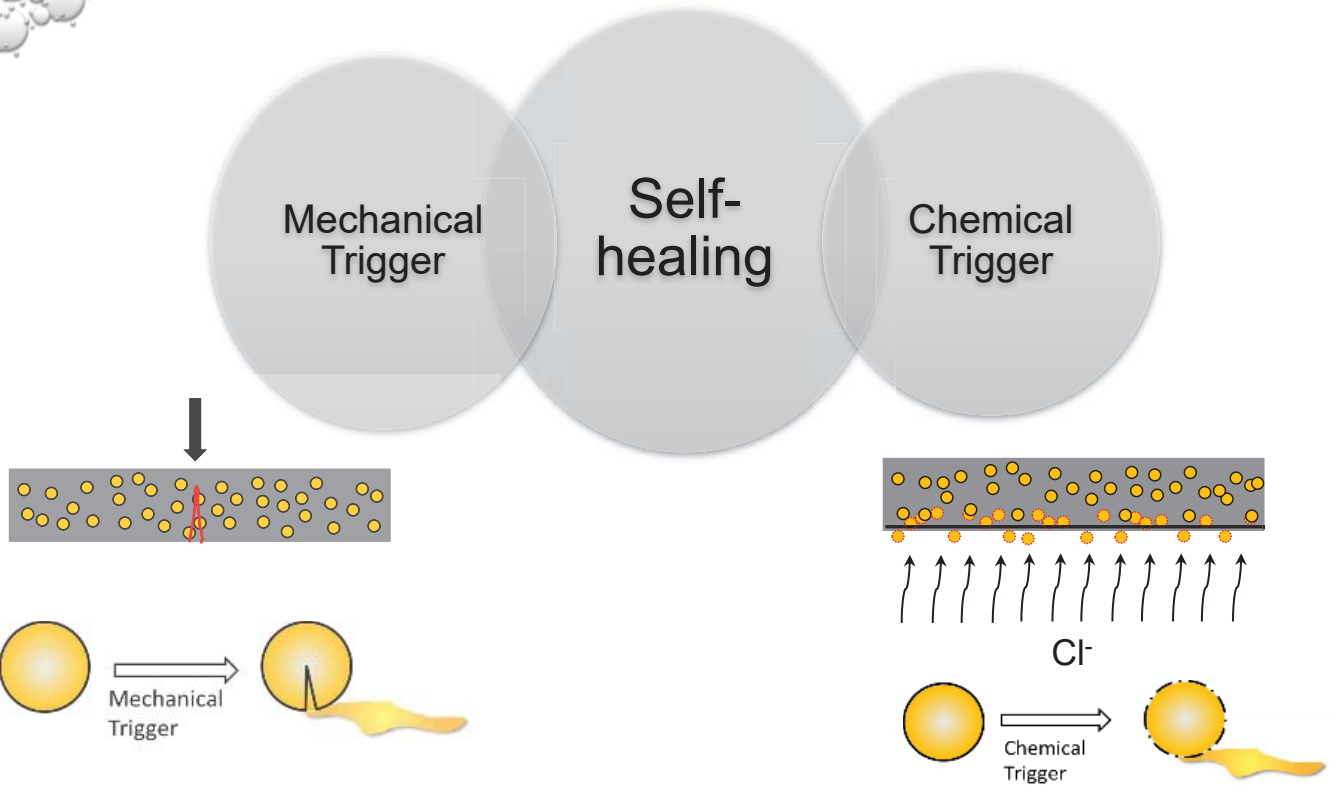

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COST CA15202 SARCOS
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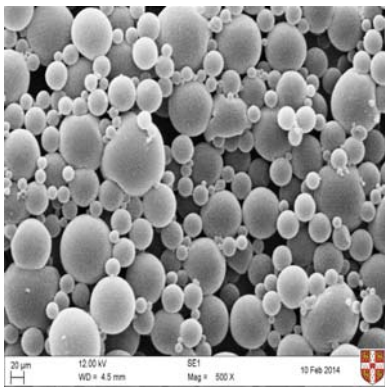
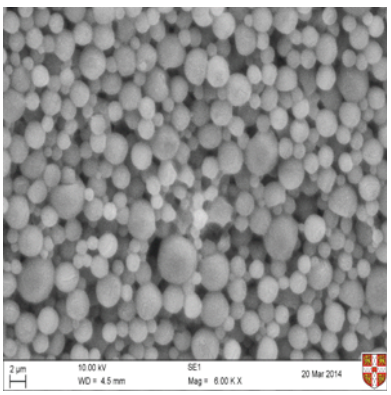
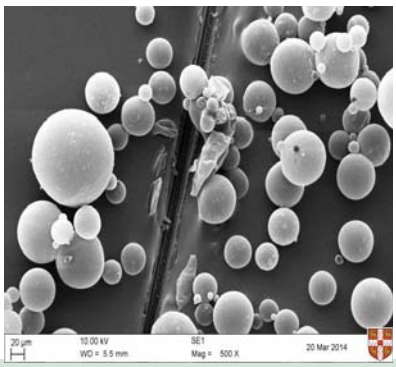


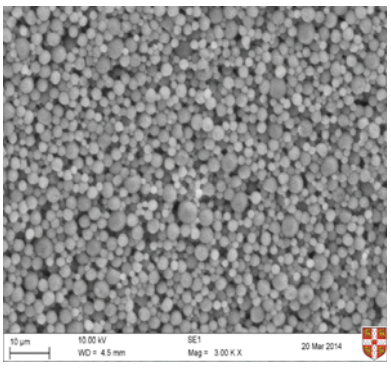
BASF Micronal PCMs

Shell: PMMA
Cargo: Paraffin Wax
Size: 1-5µm





SikaAir
Shell: Polyacrynitril
Cargo: Air
Size: ~75µm



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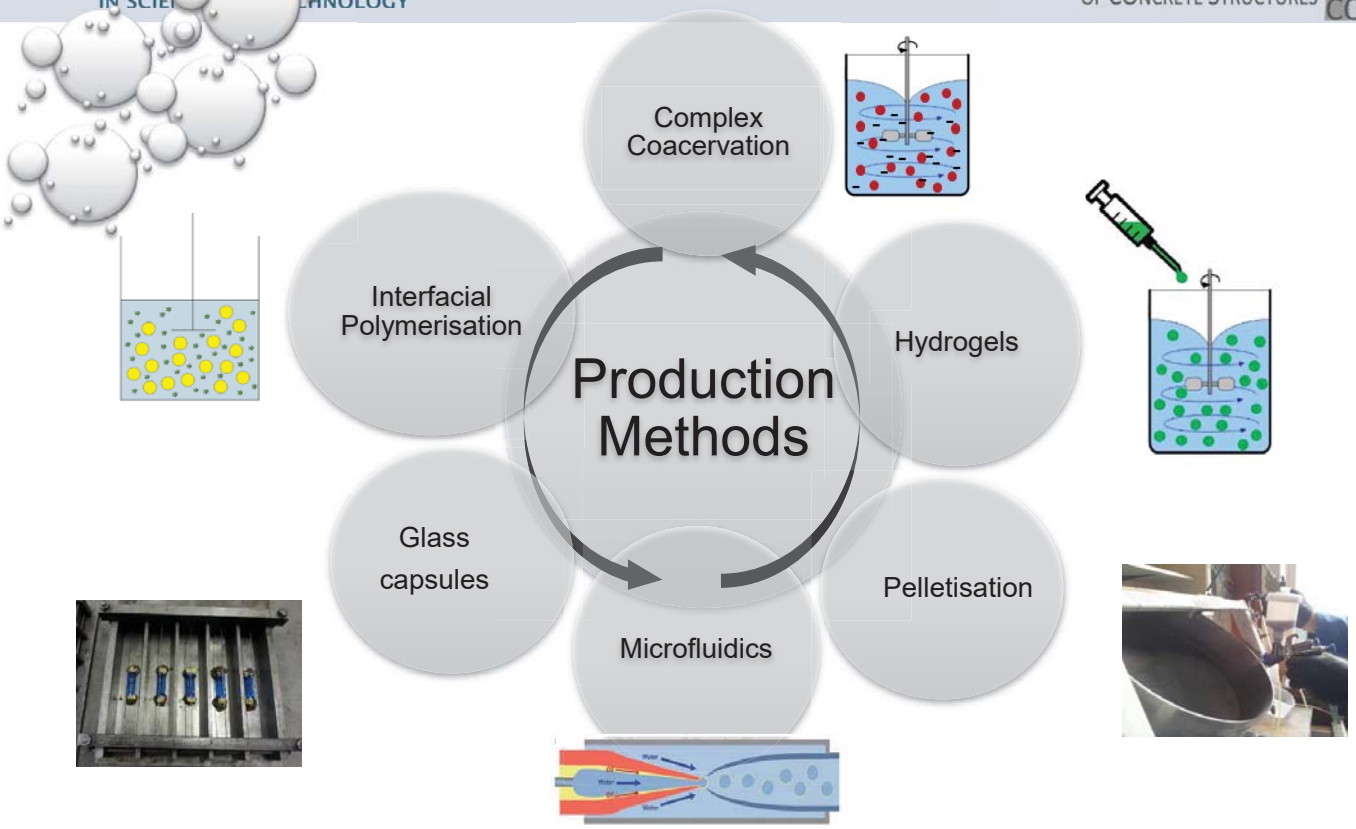
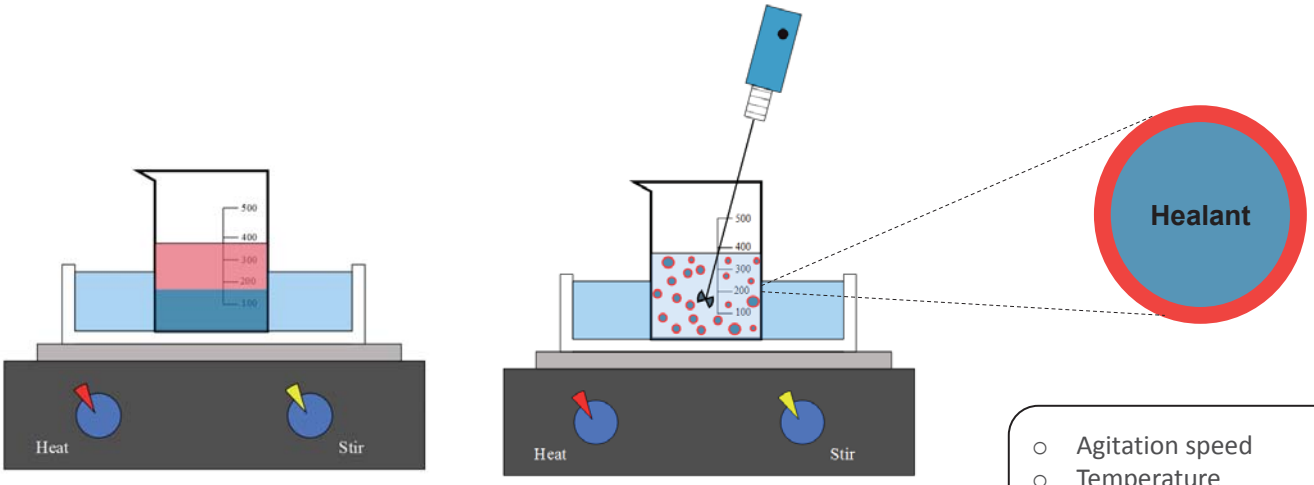
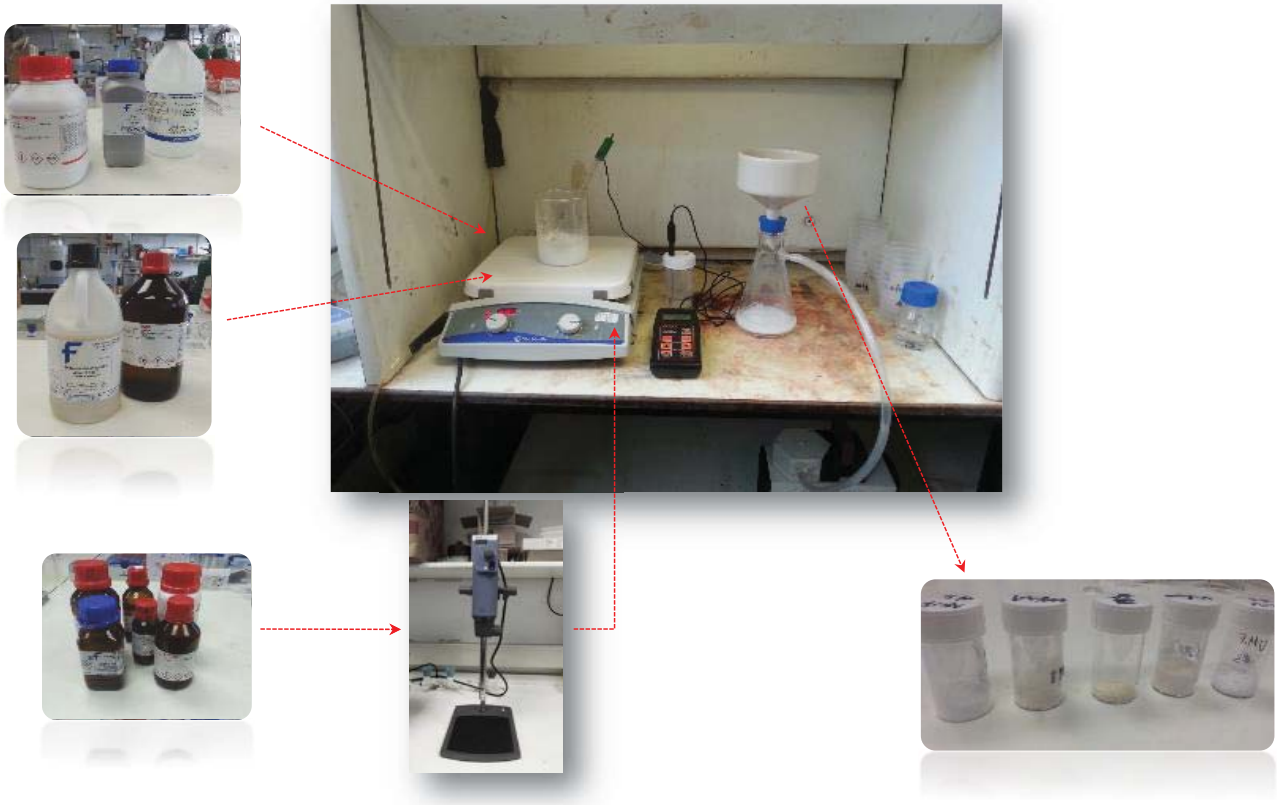
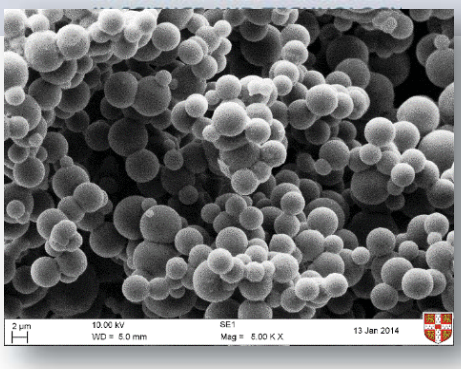


Emulsification/Interfacial Polymerisation



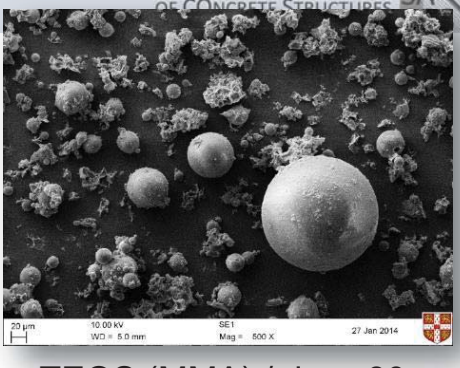
- Agitation speed
- Temperature
- pH
- Flow rate



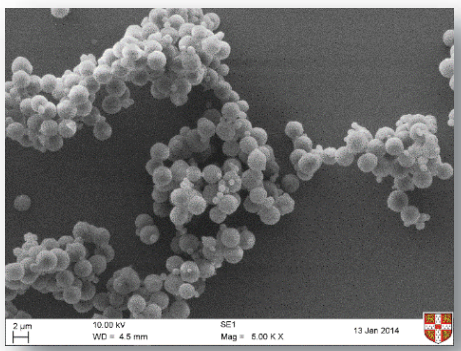


UF (MMA) / d_{av} ≈ 10μm

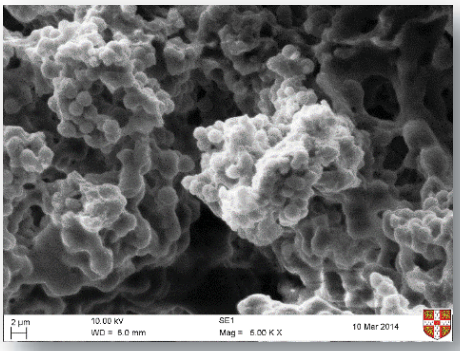
- Production yield varies between few grams to ~ 40 gr
- Size and shape depend upon:
  - Type of materials
  - pH
  - Temperature



TEOS (MMA) / d_{av} ≈ 80μm



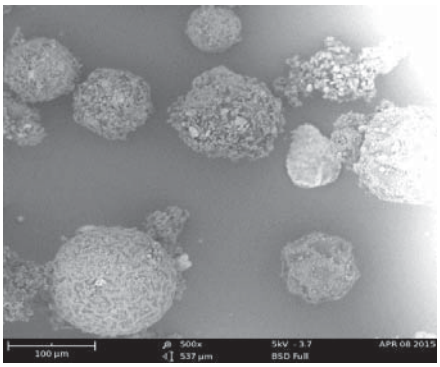
MUF (MMA) / d_{av} ≈ 5μm

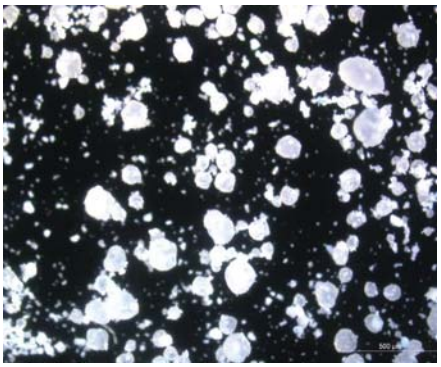


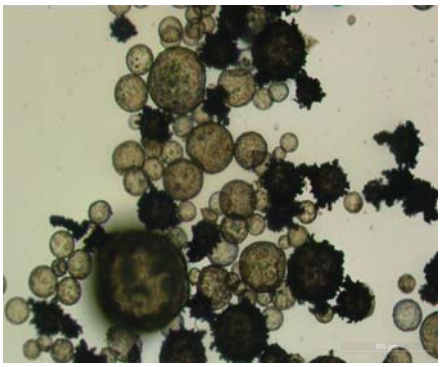
MUF (SiO_2) / d_{av} ≈ 5μm

THIES Microcapsules

Shell: Polyurea – thickness varied resulting in rigid/thick, soft/thin and mixed/intermediate shell stiffnesses
Cargo: Sodium Silicate (semi-crystalline)
Size: 100-130µm

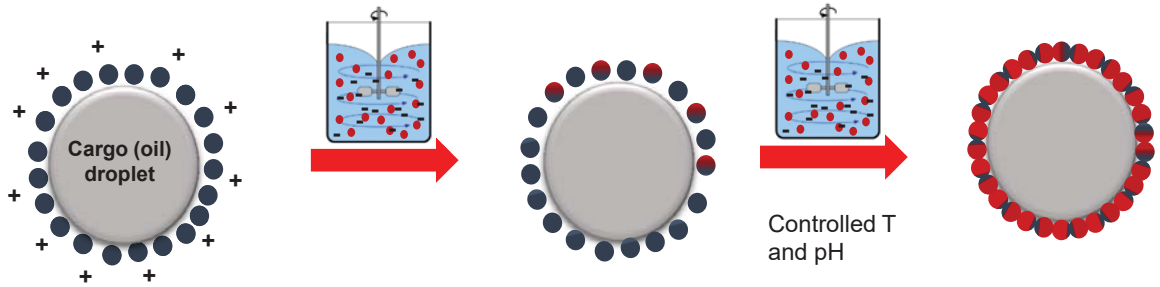






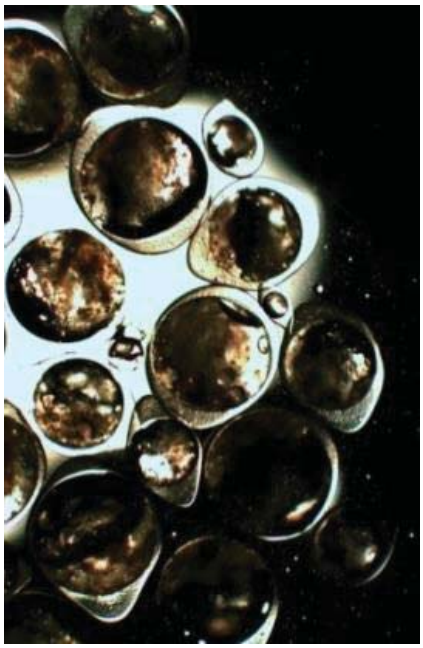
Complex Coacervation

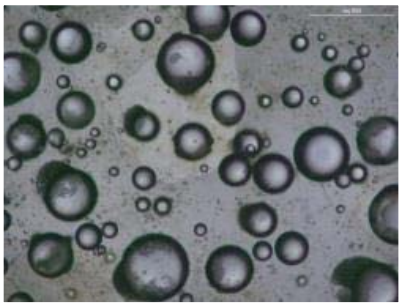
Oil in water / water in oil emulsions

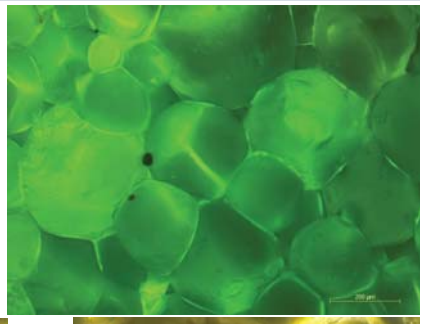


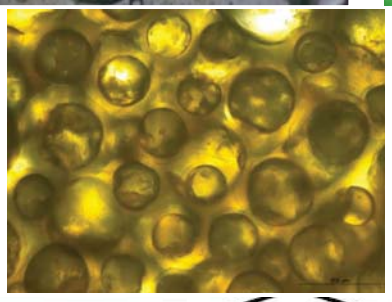
Lambson capsules

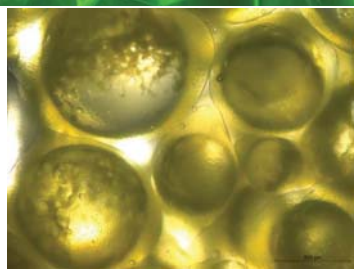
Shell: Gelatin/Arabic-Gum
Cargo: Sodium Silicate solution
Size: ~300-500μm average

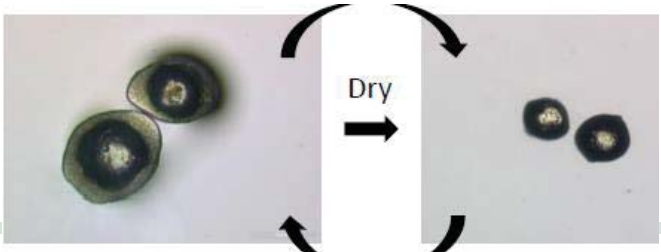




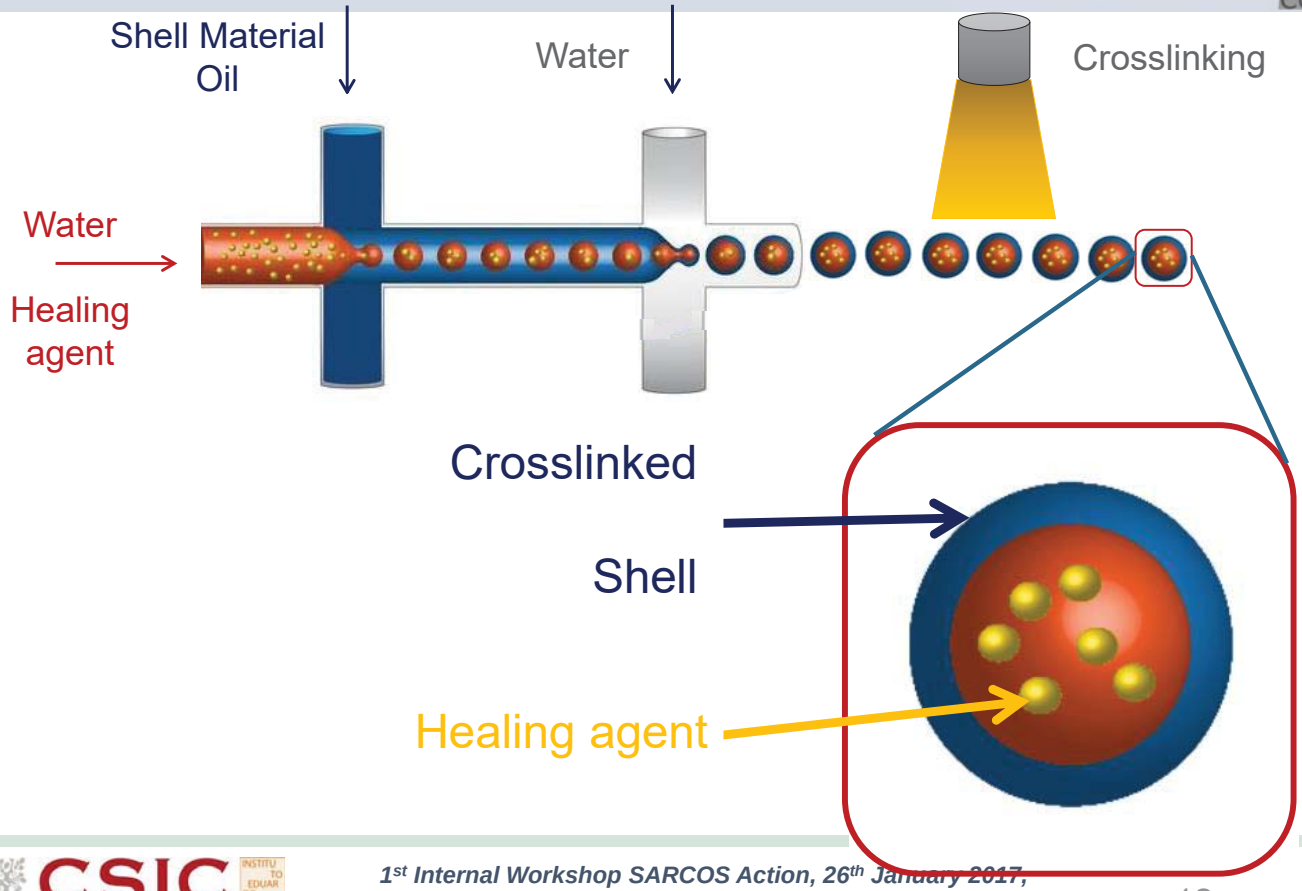


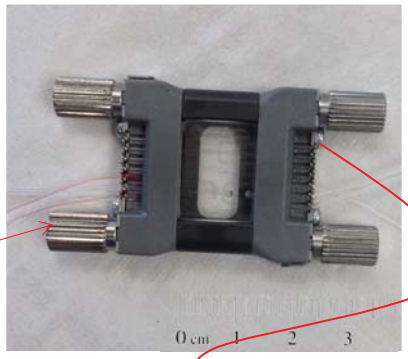






Microfluidics





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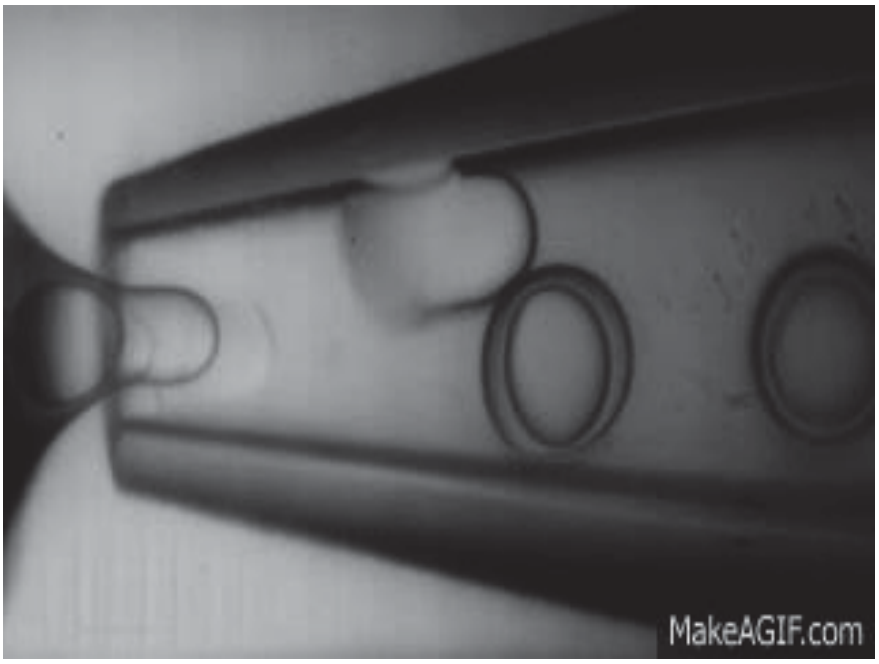
COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES



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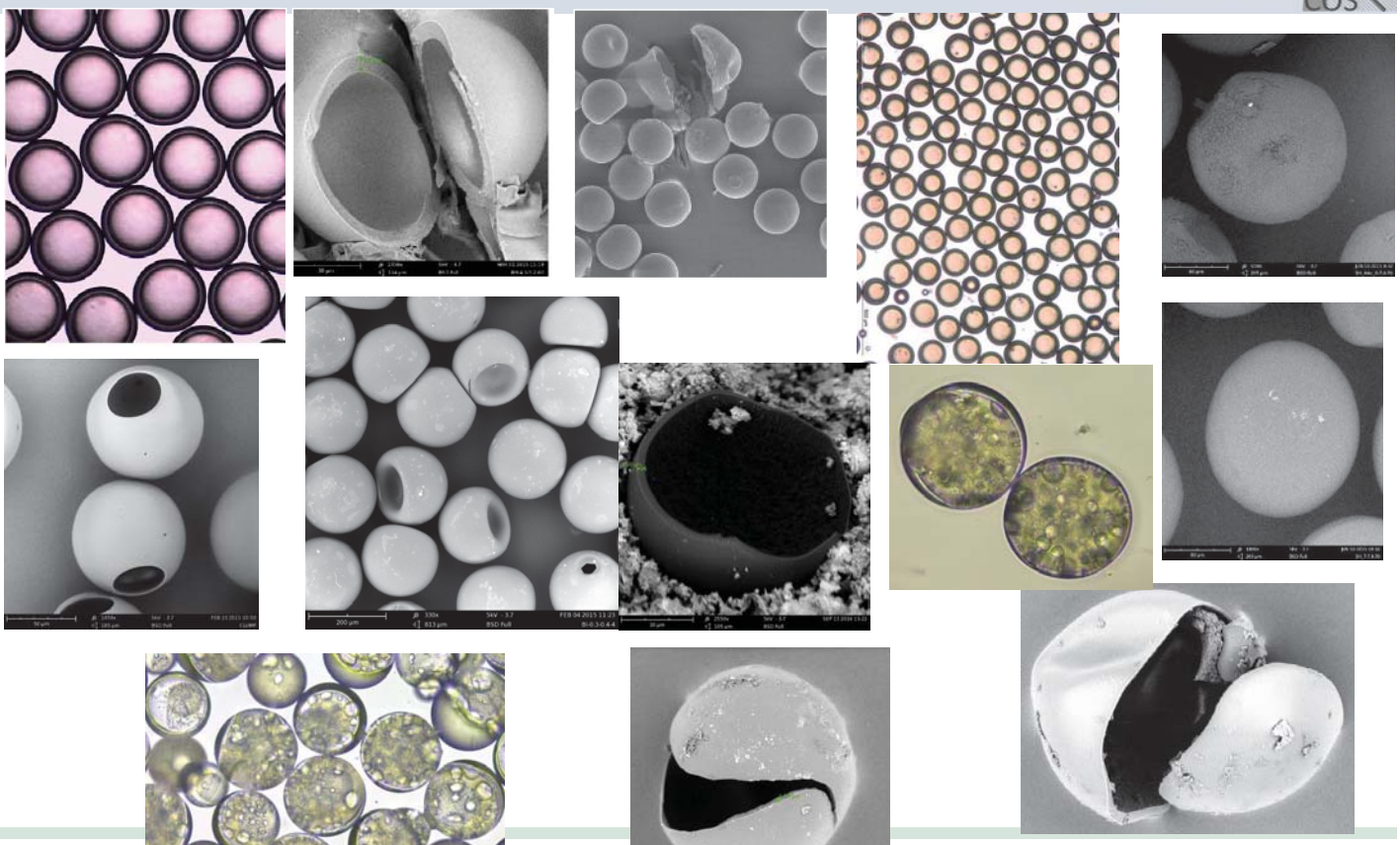
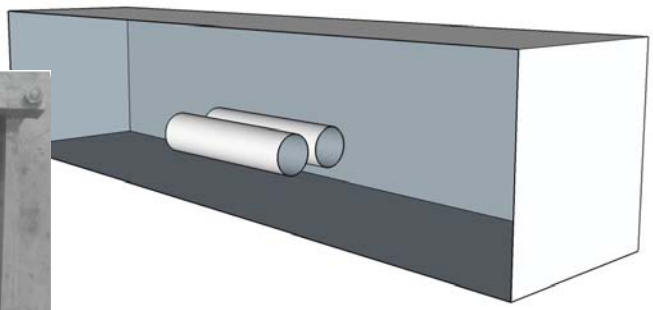
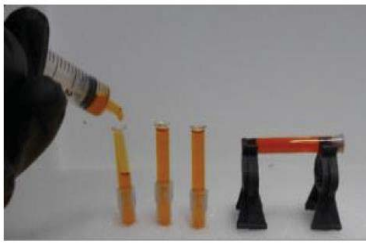
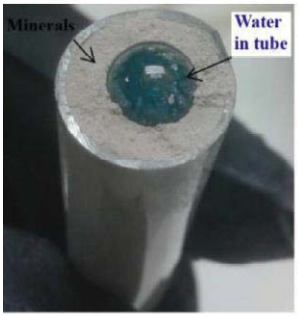


Encapsulated glass tubes

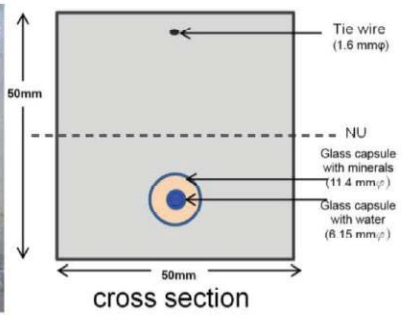






a

b



cross section

c

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Pelletisation

COST CA15202 SARCOS
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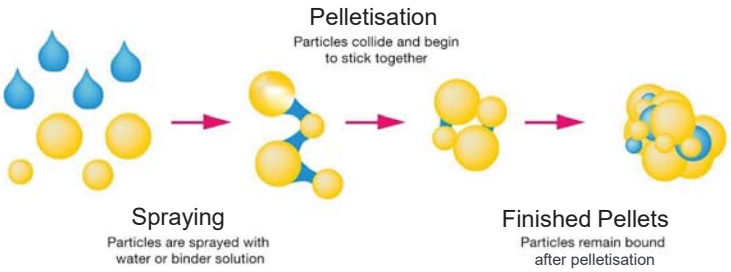
MgO+ Bentonite Pellets



MgO+ SF Pellets

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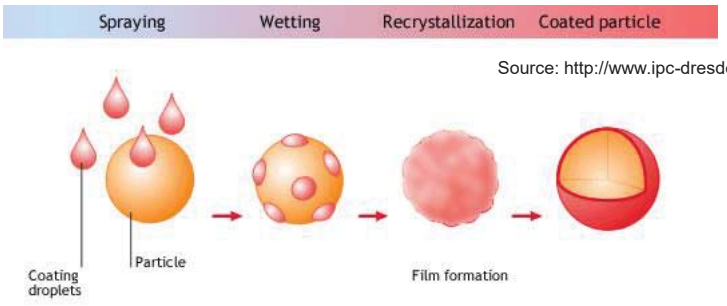
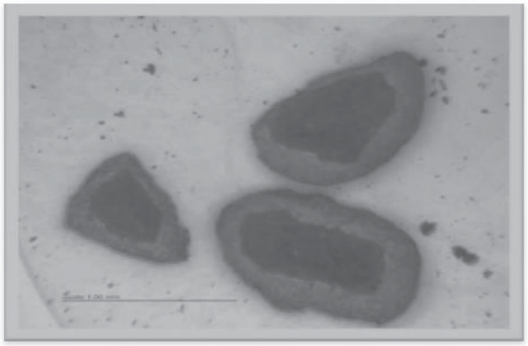


Source: http://www.ipc-dresden.de/



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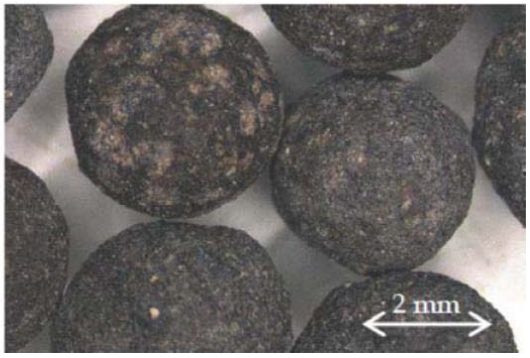
Prototype pellets

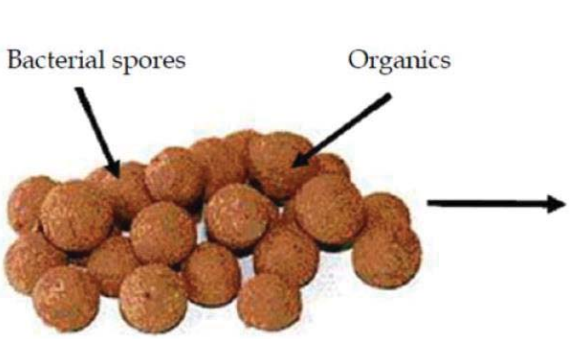
Commercial pellets

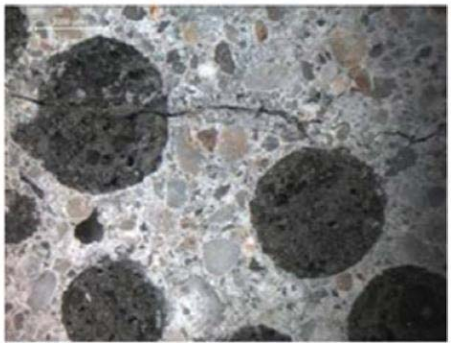
1-2 mm

2-4 mm



Encapsulated lightweight aggregates (clay) before and after (Sisomphon et al, 2011)





Expanded clay particles impregnated with bacterial spores and calcium lactate and (Jonkers, 2010)

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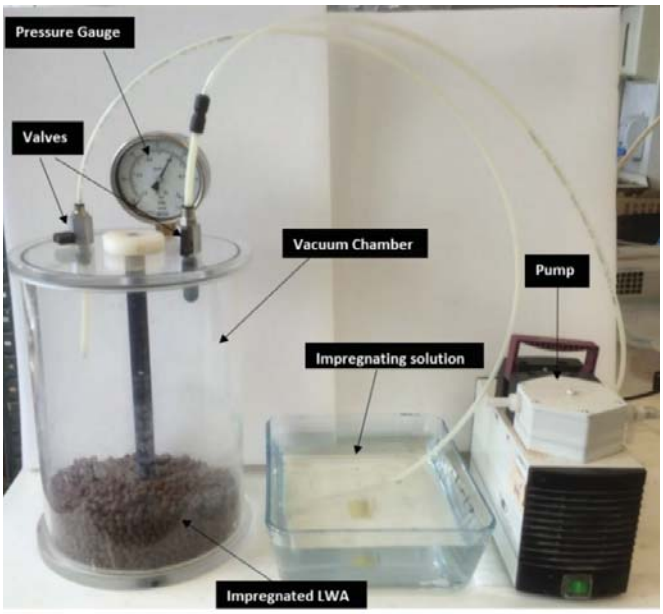
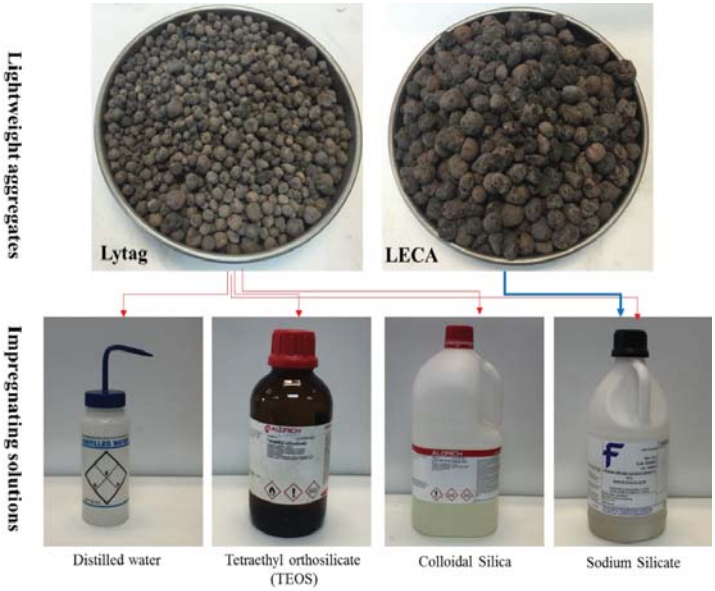
Impregnated Lightweight Aggregates

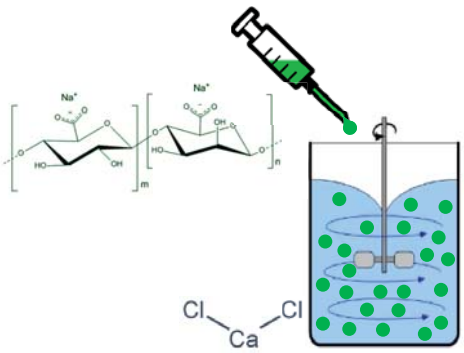


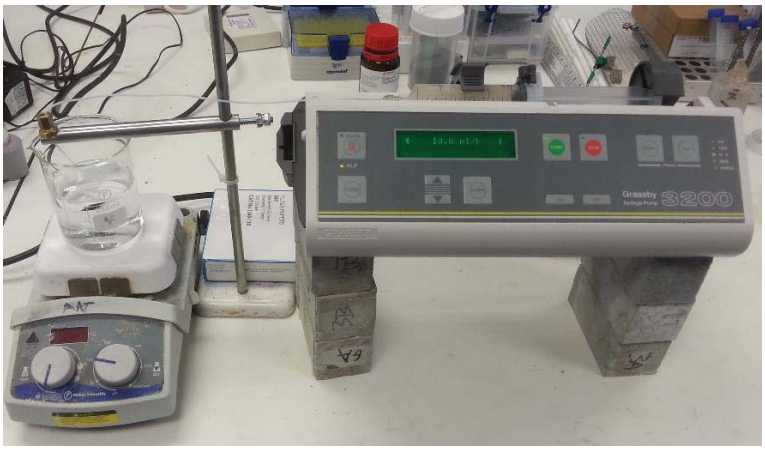
Vacuum impregnation set-up

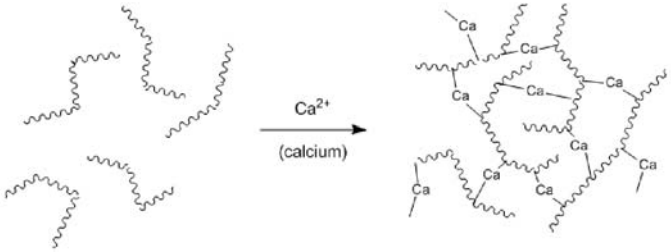


All materials utilised in impregnation LWA

Hydrogels







- Release height
- Sodium alginate concentration
- Crosslinking initiators
- Gelation time
- Degradation mechanisms

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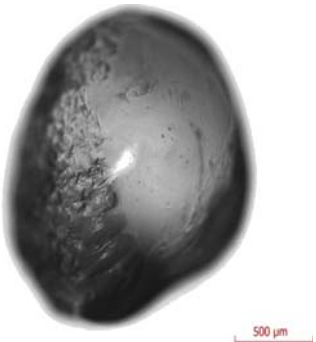
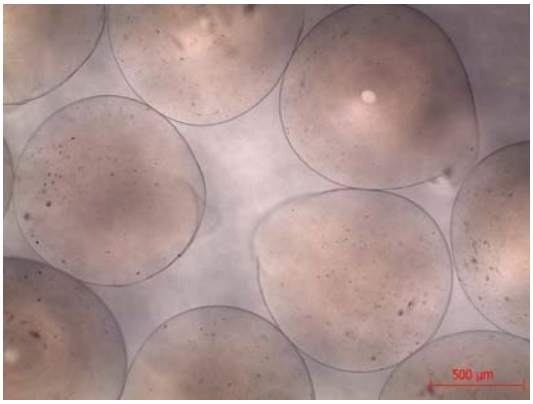
OF CONCRETE STRUCTURES
SA COS

Hydrogel – Delivery tube 0.6 mm

$d_{av} \approx 1.1$ mm



Hydrogel + TEOS – Delivery tube 0.6 mm



Hydrogel – Delivery tube 0.3 mm

$d_{av} \approx 0.9$ mm

- Compatibility
- Cost
- Health and safety

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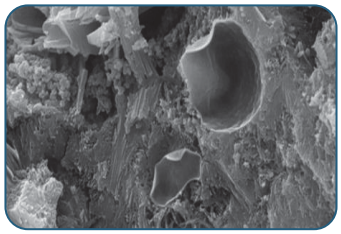
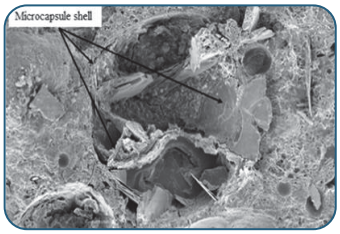
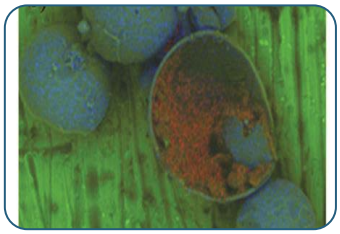
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES
SA COS







Bacteria

$$CO(NH_2)_2 + H_2O \xrightarrow{Bacterial\ urease} CO_3^{2-} + NH_4^+$$

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$$

Minerals

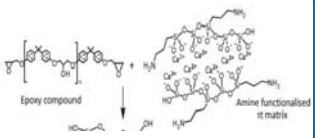
Sodium silicate

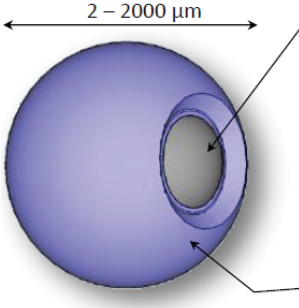
$$Na_2SiO_3 + Ca(OH)_2 \xrightarrow{+H_2O} x(CaO \cdot SiO_2)H_2O + Na_2O$$

Colloidal silica

$$SiO_2 + Ca(OH)_2 \xrightarrow{+H_2O} x(CaO \cdot SiO_2) \cdot H_2O$$

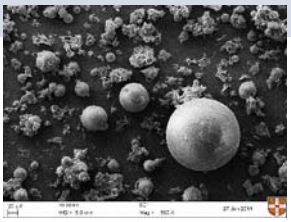
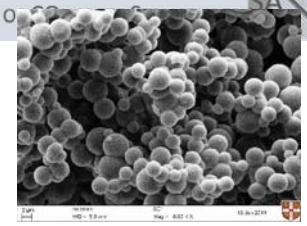
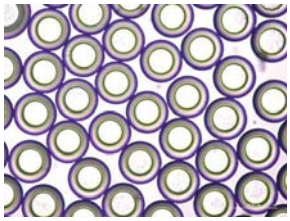
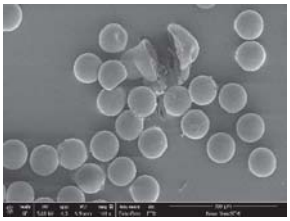
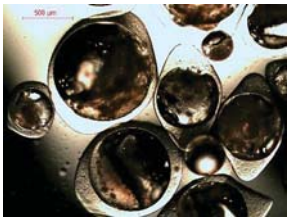
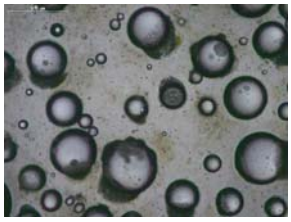
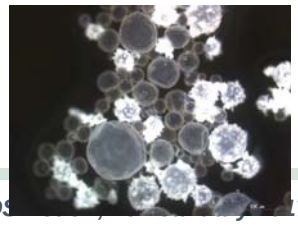
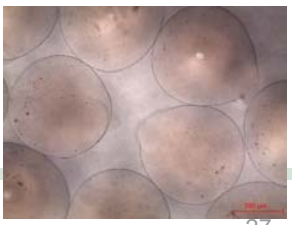
Polymers

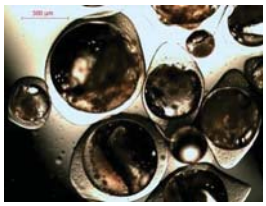
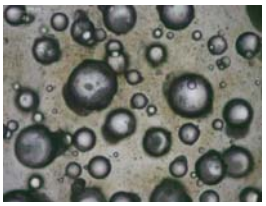
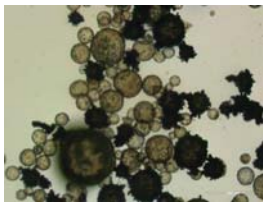
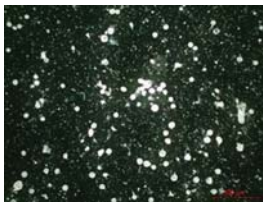




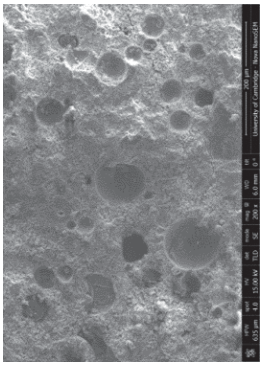
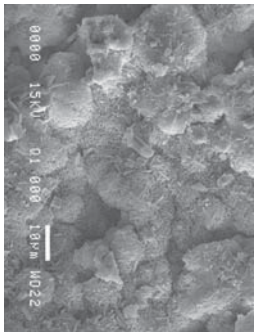
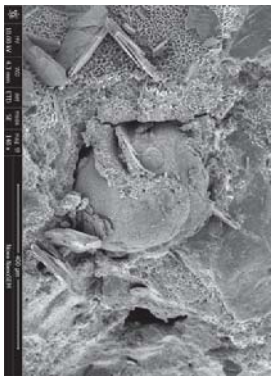
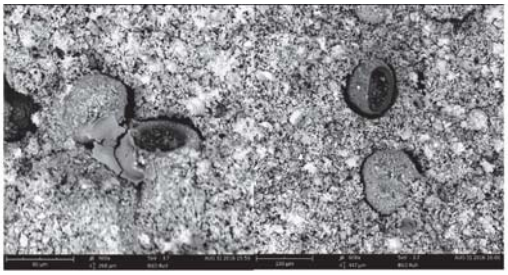
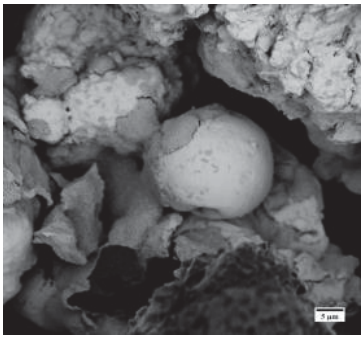
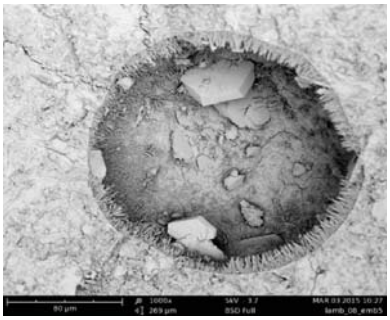
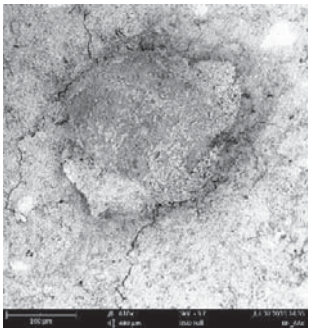
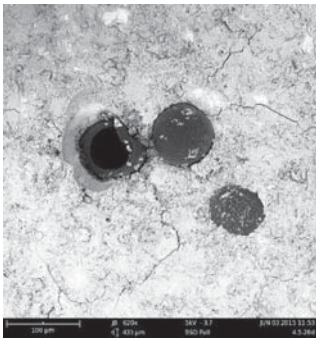
- Mineral: Sodium silicate, silica gel, MgO, CaO, bentonite
- Polymer: glues, MMA, PVA
- Water

- Polymer: Urea: Formaldehyde, Polyurethane, poly-acrylates, PVA
- Gum arabic & gelatine
- Cement coating
- Calcium alginate


Production method	Shell	Cargo	Av. Size (µm)	Supplier
Complex coaccervation	Pig gelatin/ Gum acacia	Sodium silicate emulsion (42% wt. in oil)	700	Lambson Ltd
			300	
Interfacial polymerisation	Polyurea	Sodium silicate semi-crystalline	129	THIES
	Polyuria-urethane	Silica solution (40% wt. in water)	41	Prototype
Microfluidics	Polyacrylate	Sodium silicate solution	80	Prototype

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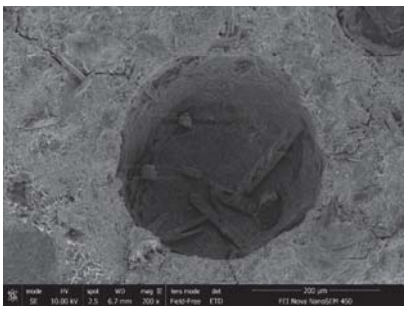
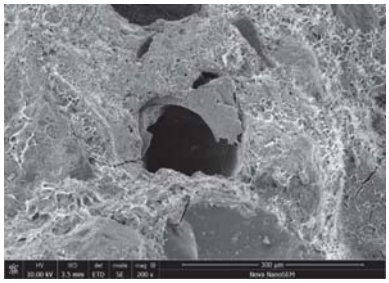
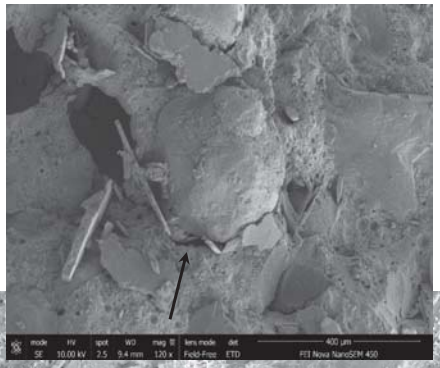
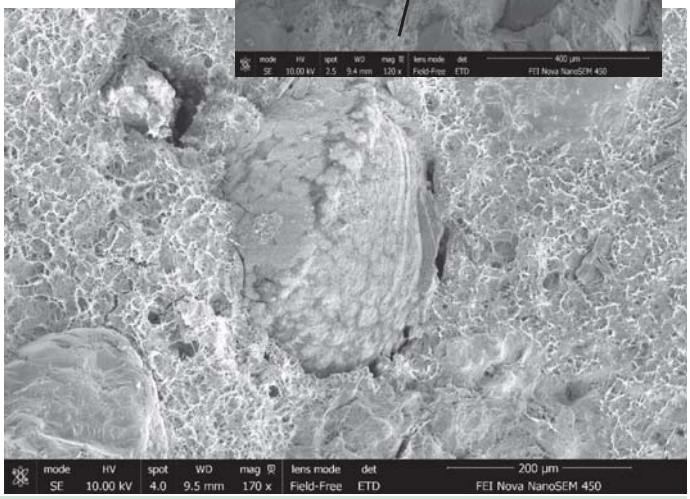
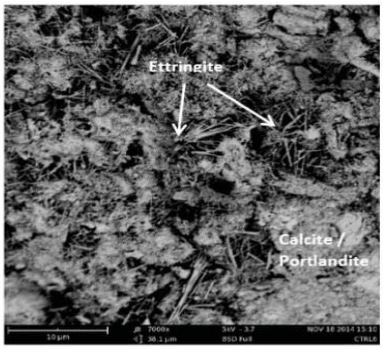





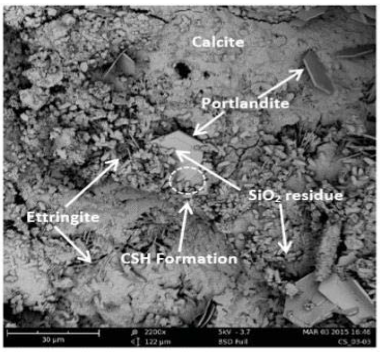

CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

1st Internal Workshop SARCOS Action, 26th January 2017,
Institute of Construction Sciences "Eduardo Torroja" (Madrid)

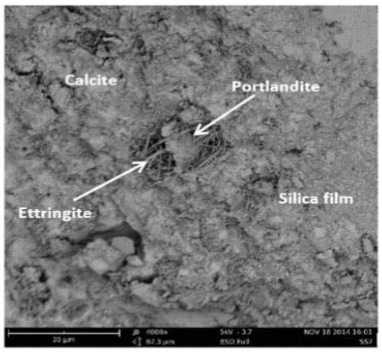
Healing products



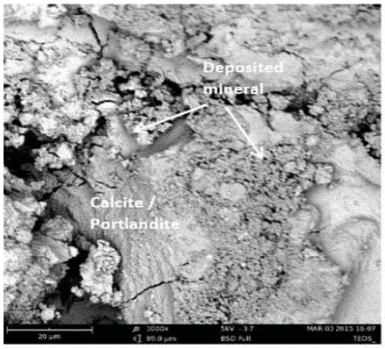
Control



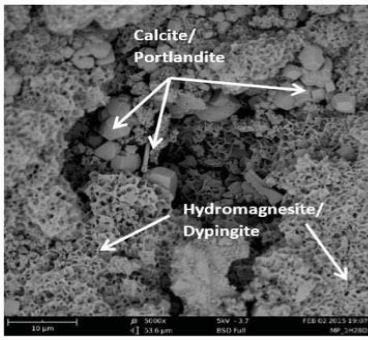
CS



SS



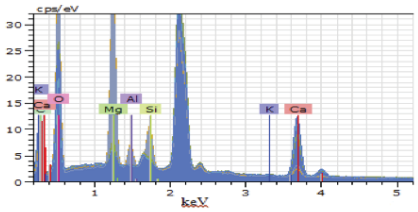
TEOS

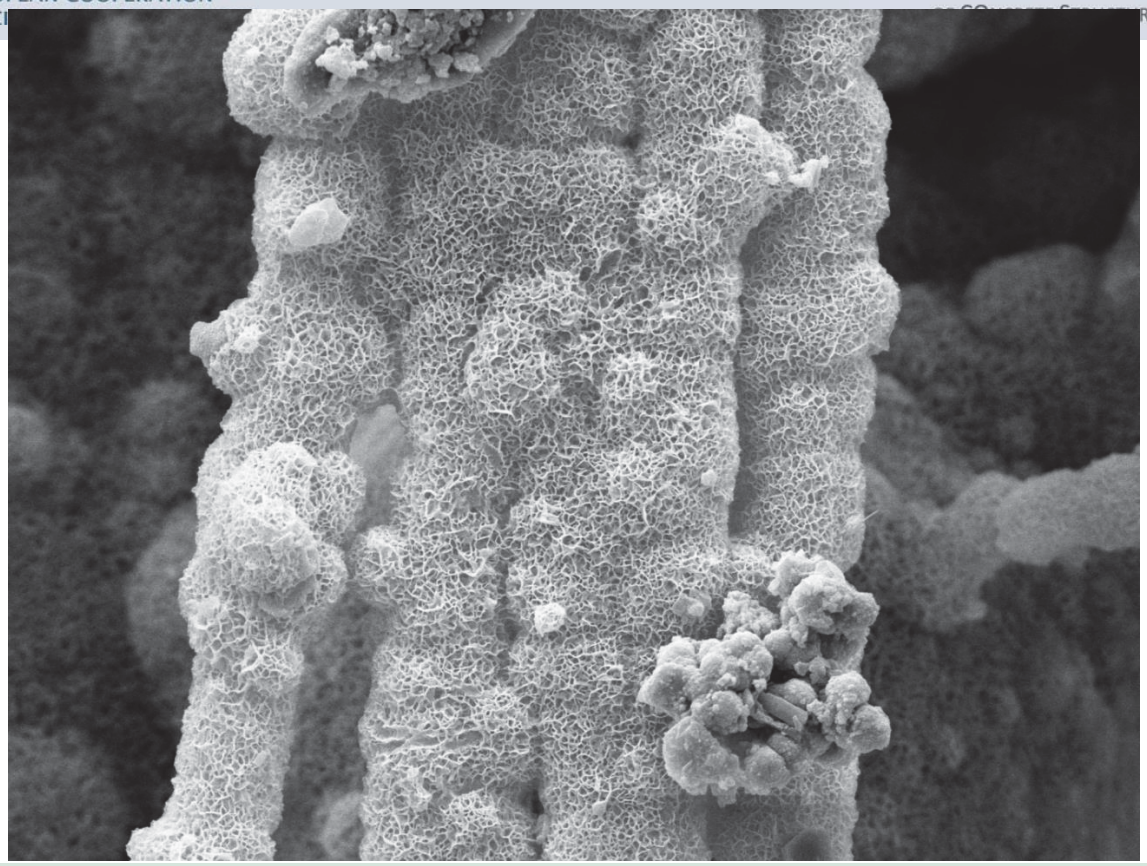


MgO

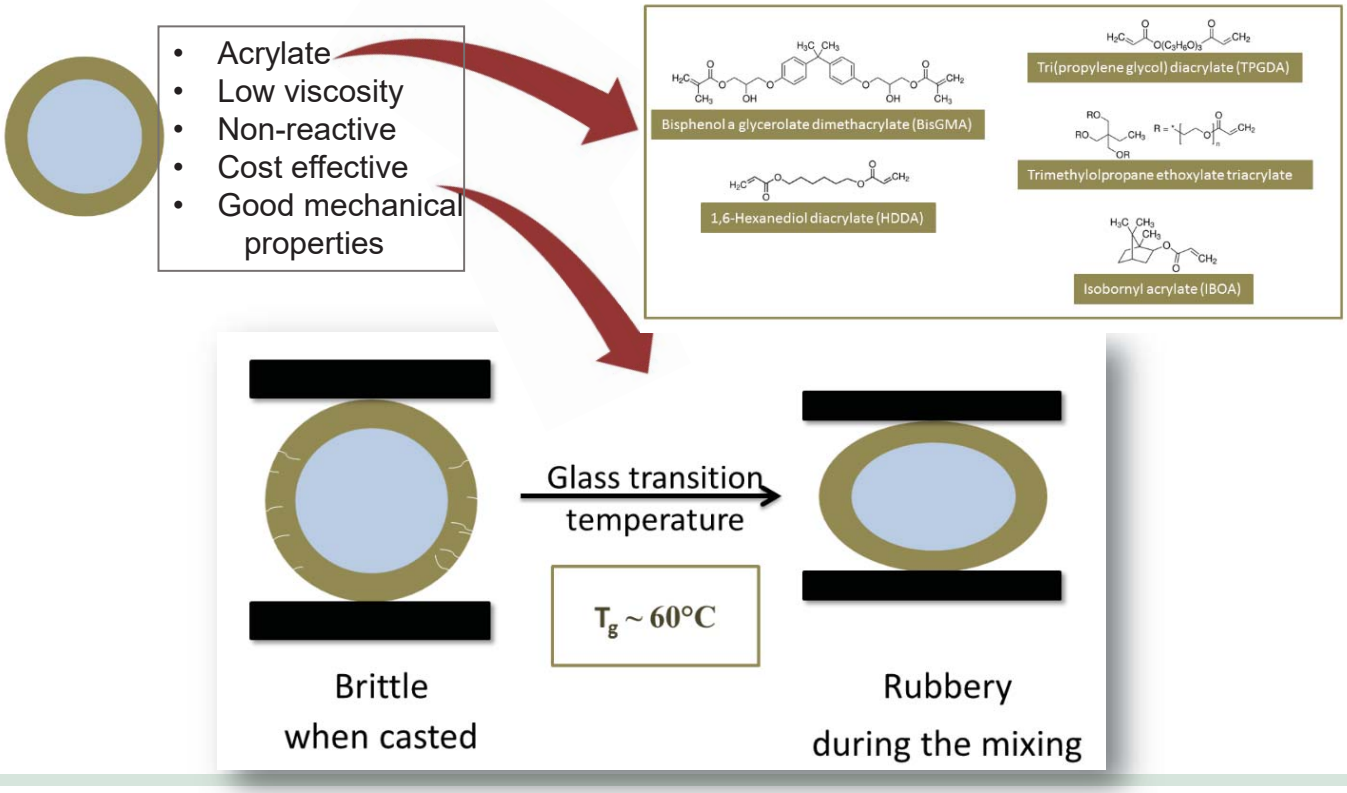
Mass present (%) **Typical EDX investigation.**

Spectrum	C	O	Mg	Al	Si	Ca
Spectrum 1	0.97	12.72	0.29	-	0.13	8.84
Spectrum 2	0.64	11.23	0.72	0.05	0.53	8.05
Spectrum 3	0.98	11.44	0.86	0.04	0.61	5.49
Spectrum 4	0.51	11.86	5.81	0.91	2.37	1.92
Spectrum 5	0.92	12.19	6.11	1.00	2.51	1.24



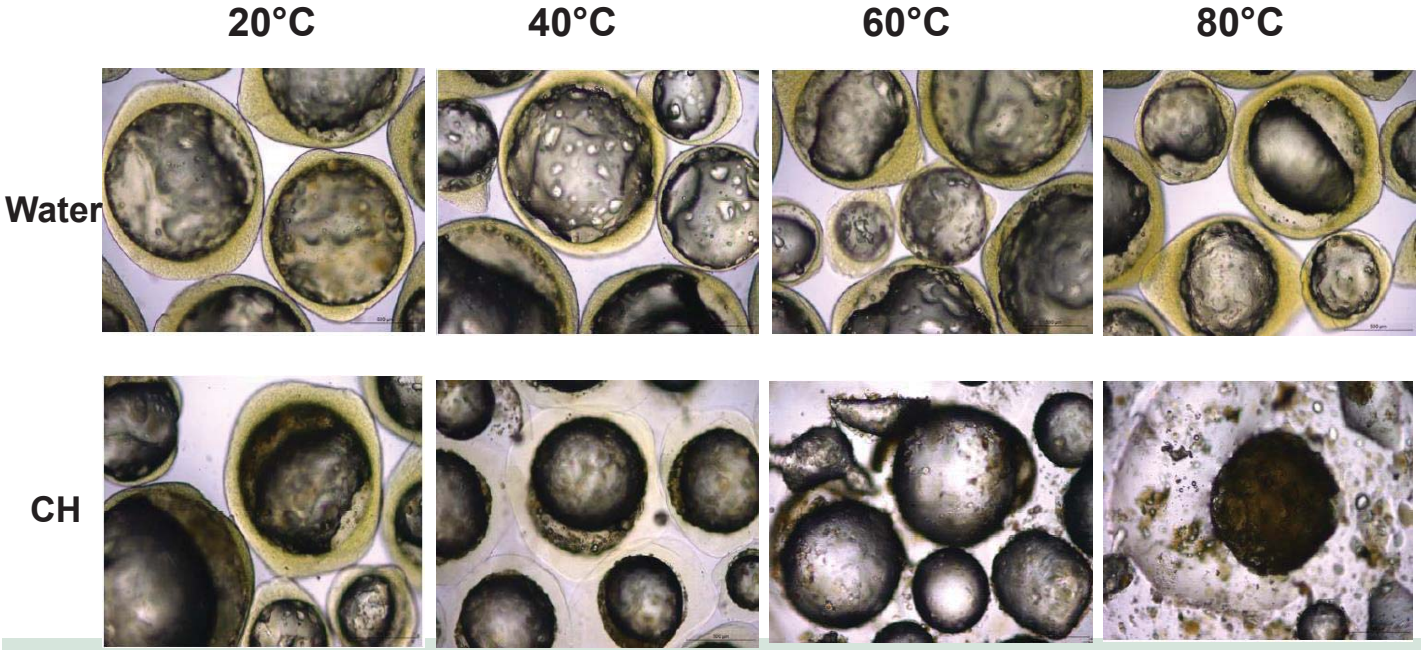


Survivability in mixing



Survivability in high temperatures and high alkalinity

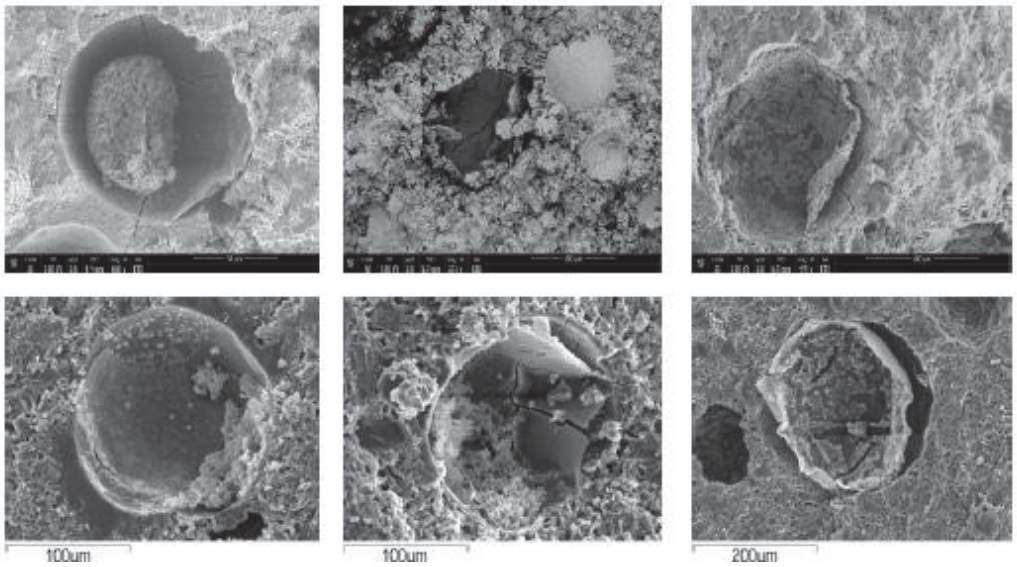
Lambson Microcapsules



Thies microcapsules

20ºC

80ºC



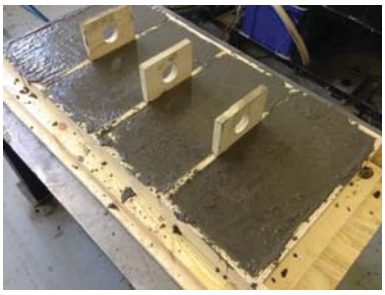
Rigid/thick shell

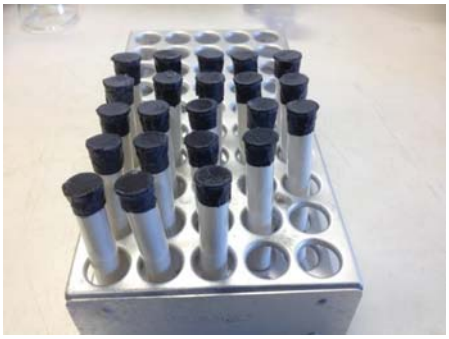
Mixed shell

Soft/thin shell

Scaling up





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Ioanna Papanikolaou

Benyi Cao

+ many undergraduate students

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EPSRC Pioneering research and skills

CARDIFF UNIVERSITY

UNITED KINGDOM

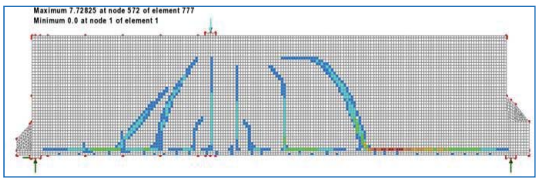
MODELLING SELF-HEALING PROCESSES IN CEMENTITIOUS MATERIALS: A STATE-OF-THE-ART REVIEW

CONTENTS

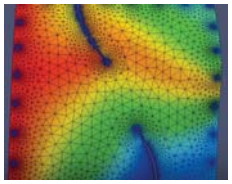
- MODELLING PREREQUISITES
- MODELS FOR MECHANICAL SELF-HEALING
  - Continuum and cohesive-zone damage-healing models
  - Micro-mechanical damage-healing models
- TRANSPORT & COUPLED MODELS
  - Coupled continuum Hygro-Thermo-Chemo model
  - Coupled Hygro-Thermo-Chemo-Mechanical model
- MODELS FOR FLOW OF SH AGENTS IN DISCRETE CRACKS
- OTHER MODELS (Incl. HYMOSTRUC)
- CURRENT DEFICIENCIES and DEVELOPMENT PRIOROTIES

MODELLING PREREQUISITES

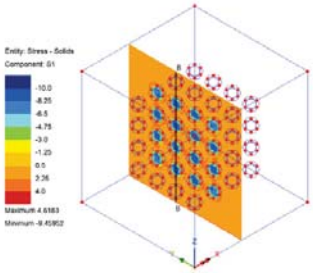
- **Continuum damage mechanics CDM & smeared cracks** *(Mazars and Pijaudier-Cabot 1989)*
- **Plasticity models and smeared cracks** *(Este & Willam 1994)*
- **Plastic-Damage models and smeared cracks** *(Lee & Fenves 1998)*
- **Strong discontinuity methods 'X-FEM E-FEM .. + cohesive crack interface model** *(Belytschko X-FEM 1999ff; Wells & Sluys 2001, Oliver et al. 2003)*
- **Discrete cracks with interface elements or changing topology** *(Ingraffea& Saouma, 1985)*
- **Micro-mechanics based models** *(Nemat-Nasser & Horii 2013 :Pensée & Kondo, 2002)*
- **Meso-mechanical models** *(Lopez & Carol, 2007)*



FE simulation of Collins' tests



X-FEM simulation after Bordas et al

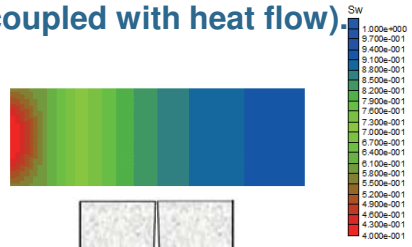


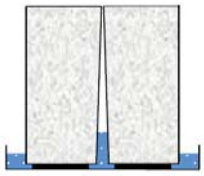
Meso simulation to validate mm model, Davies & Jefferson

Fluid transport through micro-cracked porous media (coupled with heat flow).

Gawin & Schrefler (2006)

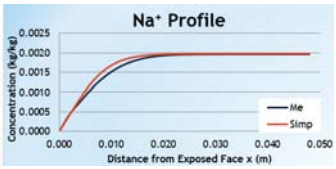
- Mass balance
- Darcy flow
- Fick's diffusion
- Dispersion (Collins)
- 'Isotherm' equation (van Genuchten)
- Kelvin's law
- Fourier's Law





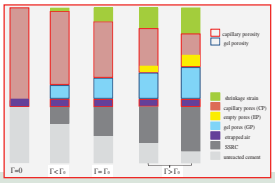
Capillary flow in discrete cracks *(Carmeliet et al. & Gardner et al.)*

- Mass balance
- Lucas Washburn (modified)



Chemical reactive transport *(Bear 2009)*

- Mass balance
- Freundlich type isotherms
- Poisson Nernst Planck equations

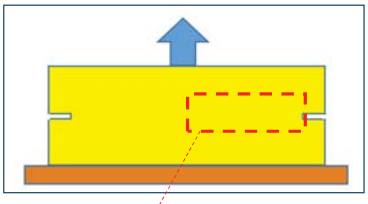


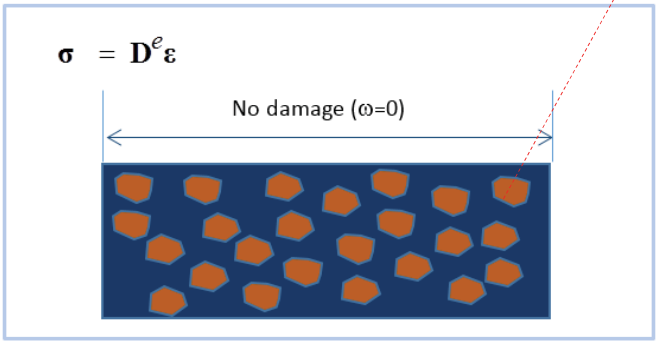
Chemical curing / hydration (e.g. Schlinder & Folliard,2005)

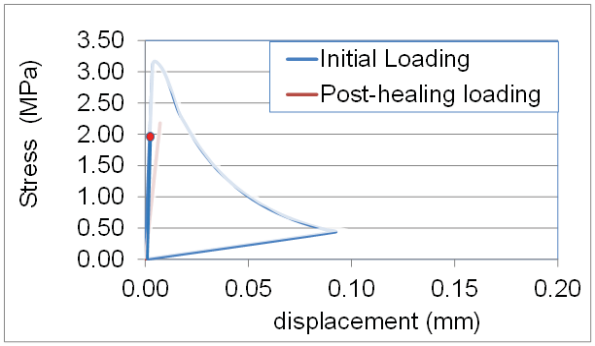
- Arrhenius equation
- Hydration model

Continuum damage and cohesive zone self-healing models

Main principles







Continuum damage and cohesive zone self-healing models

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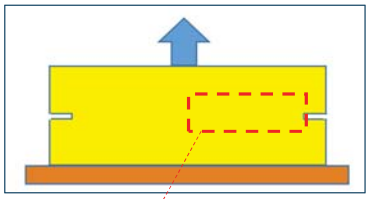
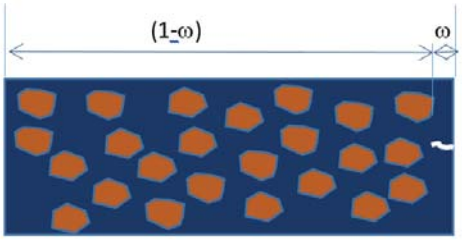
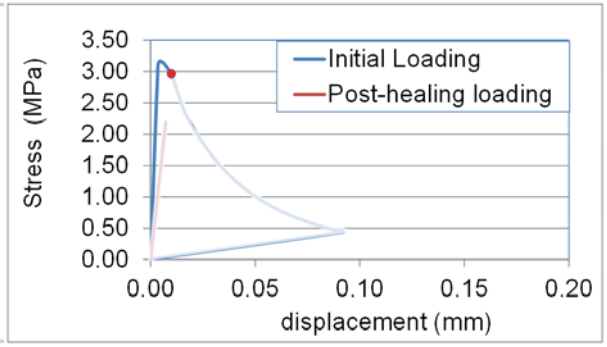


$$\boldsymbol{\sigma} = (1-\omega)\cdot \mathbf{D}^{e}\boldsymbol{\varepsilon} \quad + \quad 0$$





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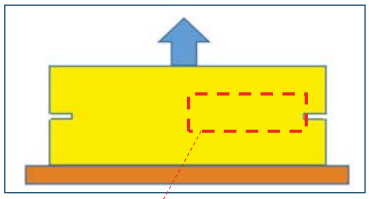

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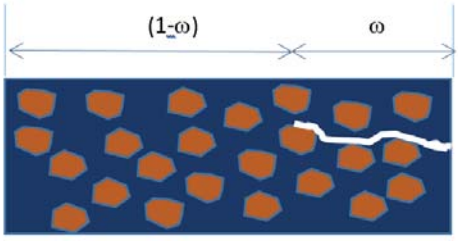

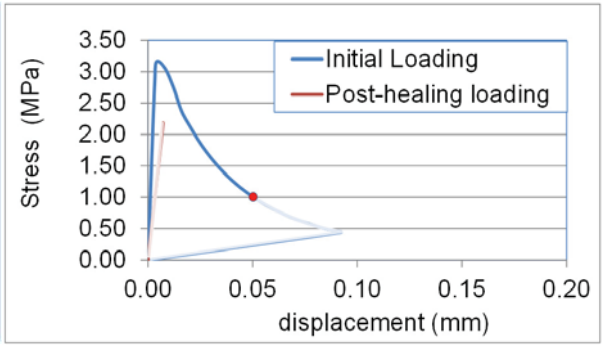

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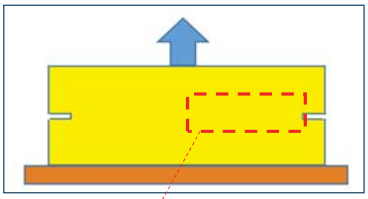

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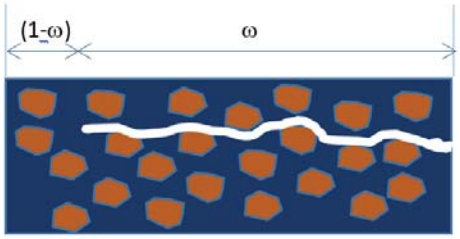

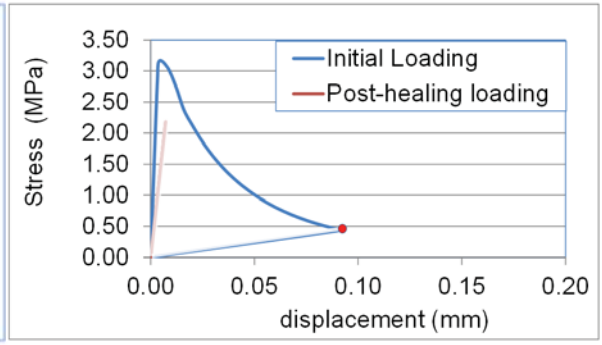

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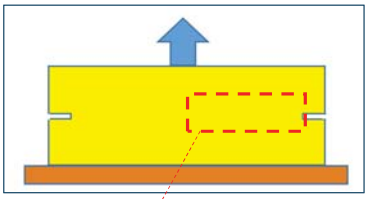

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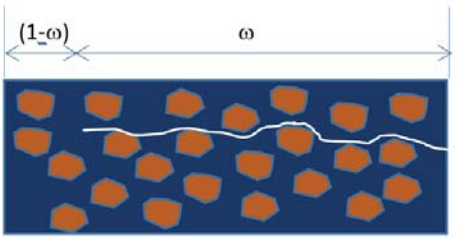

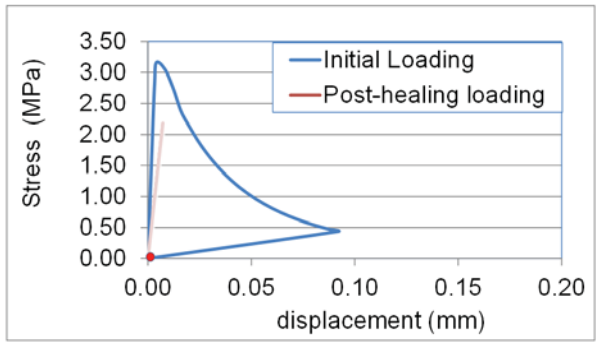

Continuum damage and cohesive zone self-healing models

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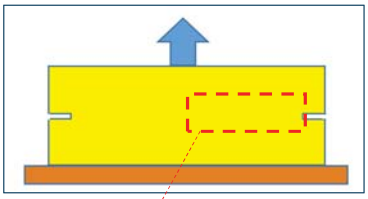
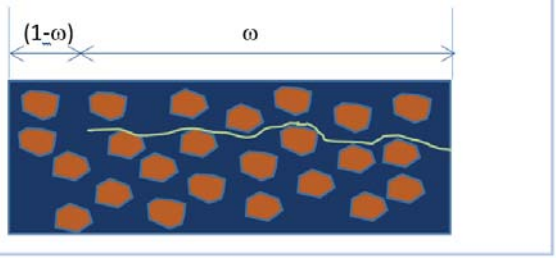
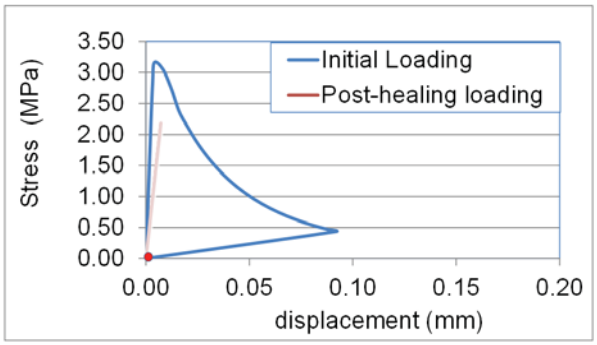


$$\boldsymbol{\sigma} = (1-\omega)\cdot\mathbf{D}^e\boldsymbol{\varepsilon} + h\cdot\omega\cdot\mathbf{D}^e(\boldsymbol{\varepsilon}-\boldsymbol{\varepsilon}_h)$$





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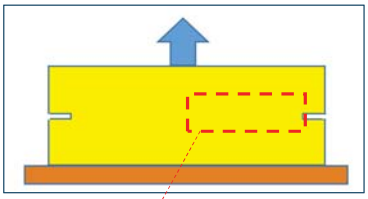

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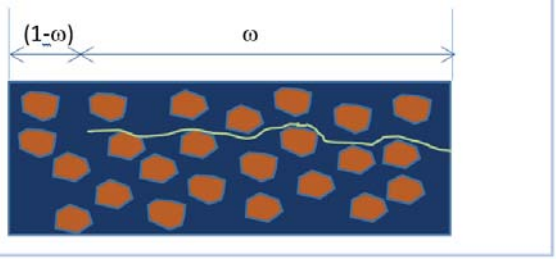

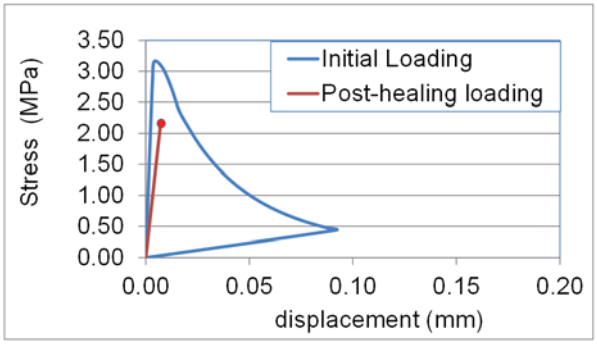

Continuum damage and cohesive zone self-healing models

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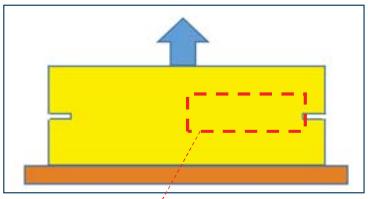

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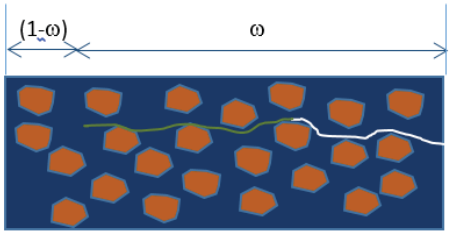
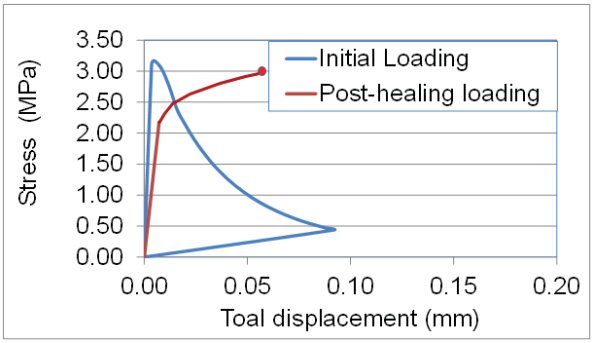
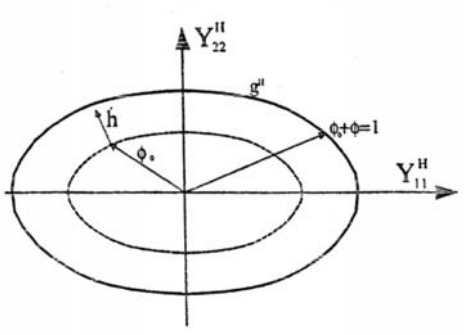




EXAMPLES OF EXISTING CDH MODELS

Barbero et al. (2005)

- Continuum damage-healing mechanics
- Healing included in Helmholtz thermo-dynamic (TD) potential
- Postulated the existence of a healing surface like a yield surface
- Anisotropic DH using principal tensor components
- Validations: Fibre-reinforced layered composite polymer pure shear test



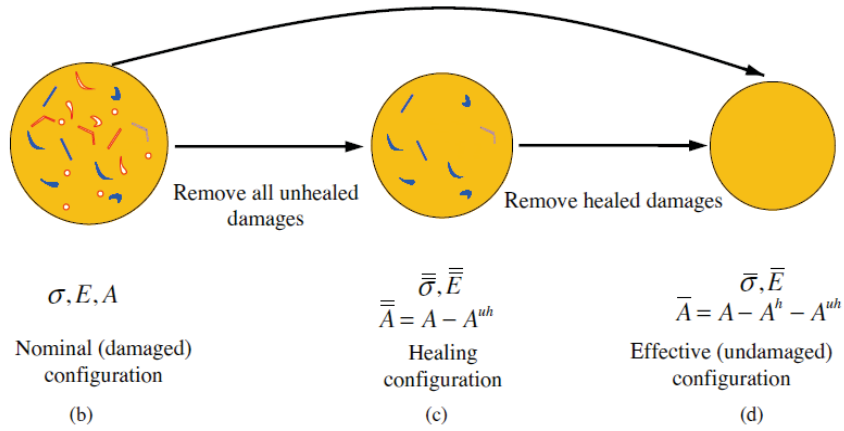
From Barbero et al. 2005

EXAMPLES OF EXISTING CDH MODELS

A series of models by Abu Al-Rub and co-workers:

(e.g. Abu Al-Rub & Darabi 2012a,b: Alsheghri & Abu Al-Rub, 2015)

- Applied to asphaltic concrete and PMMA
- Visco-elasticity / visco-plasticity included in some models
- Uses the concept of an effective un-cracked state or configuration



$$\bar{\bar{\boldsymbol{\sigma}}} = \frac{\boldsymbol{\sigma}}{1-\omega\cdot(1-h)}$$

$$\bar{\boldsymbol{\sigma}} = \bar{\bar{\boldsymbol{\sigma}}}\cdot\frac{1-\omega\cdot(1-h)}{1-\omega}$$

From Durabi et al. 2012

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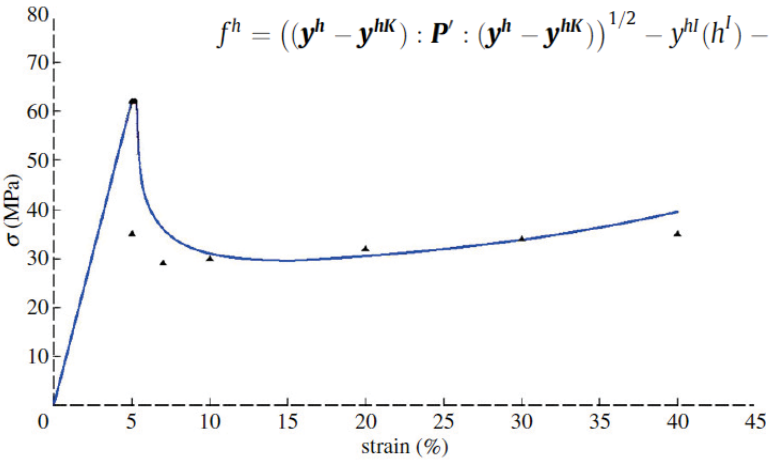
EXAMPLES OF EXISTING CDH MODELS

Models by Voyiadjis and co-workers: (e.g. *Voyiadjis et al, 2011,2012a,b,c,2013, 2014*)

- Generalised thermodynamically-based damage-healing formulation
- Healing surface takes a similar form to the damage surface
- Considers response of a shape memory polymer-based self-healing system

$$\Psi(\boldsymbol{e}, \boldsymbol{e}^{p}, \boldsymbol{\alpha}, \boldsymbol{p}, \boldsymbol{d}, \boldsymbol{d}^{K}, \boldsymbol{d}^{I}, \boldsymbol{h}, \boldsymbol{h}^{K}, \boldsymbol{h}^{I}) = W(\boldsymbol{e}, \boldsymbol{e}^{p}, \boldsymbol{d}, \boldsymbol{h}) + H(\boldsymbol{\alpha}, \boldsymbol{p}, \boldsymbol{d}^{K}, \boldsymbol{d}^{I}, \boldsymbol{h}^{K}, \boldsymbol{h}^{I}) + G_{dh}(\boldsymbol{d}, \boldsymbol{h}),$$

$$f^{h} = \left((\boldsymbol{y}^{h} - \boldsymbol{y}^{hK}) : \boldsymbol{P}' : (\boldsymbol{y}^{h} - \boldsymbol{y}^{hK})\right)^{1/2} - y^{hI}(h^{I}) - 1 \leqslant 0,$$



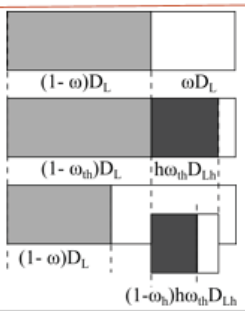
Tensile test on SH SMP at strain rate of 5E-4 /s

From *Voyiadjis et al, 2012*

MICRO-MECHANICAL MODELS: *(Zhu H, et al 2015, Davies & Jefferson, 2017*)*

- Schematic representation

- Equivalent representation



$$\mathbf{D}_{Lh} = B \cdot \mathbf{D}_L$$

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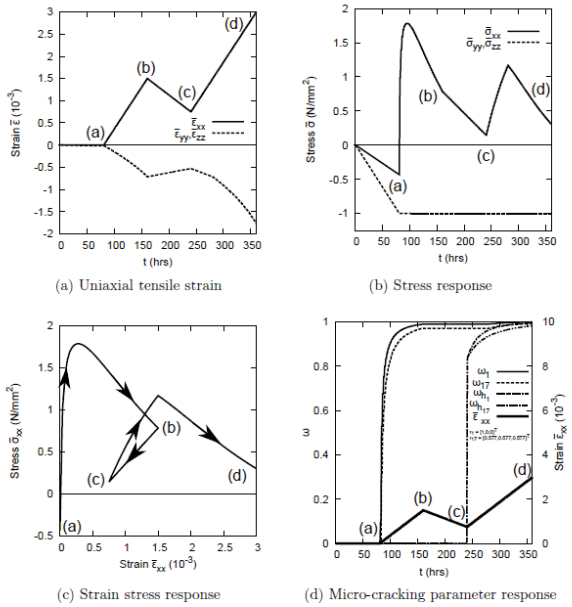
MICRO-MECHANICAL MODEL: Results *by Davies & Jefferson, 2017*

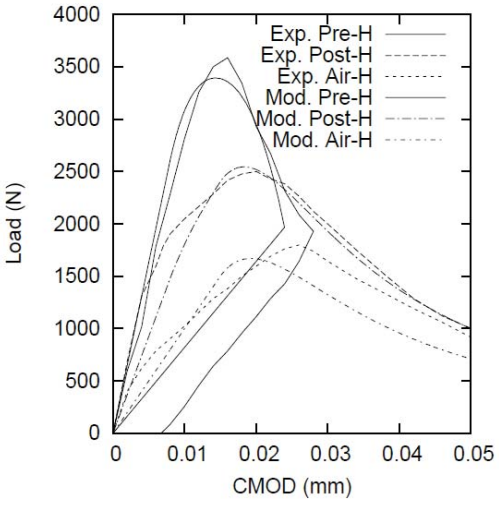


(a) Uniaxial tensile strain (b) Stress response

(c) Strain stress response (d) Micro-cracking parameter response

Figure 8: Model response with confined stress in the y-y and z-z direction

Illustrative path

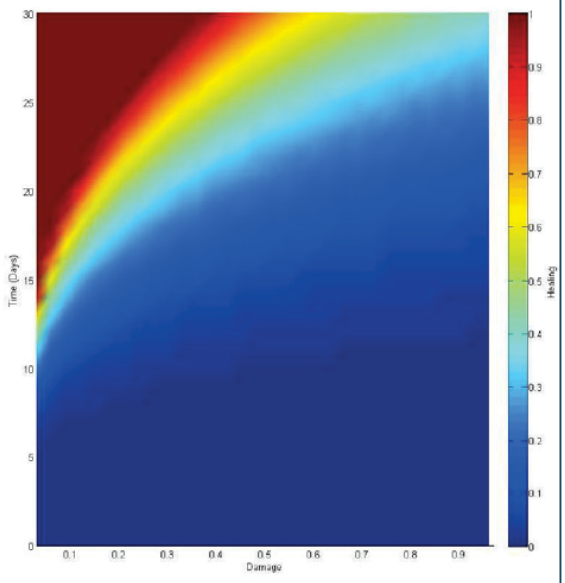


Data from Granger et al. 2007

Chemical-diffusive self-healing model for concrete.

Aliko-Benítez et al. (2015)

- Simulates chemical transport of carbonate ions and the reaction with calcium ions available from the cement.
- Mass balance of CO_3 ions
- Fick's law are used to govern the transport of CO_3 ions through the moisture phase of the cementitious medium
- Precipitation rate proportional to available ions
- No direct comparison with experiments but some interesting numerical results comparing damage and ultimate healing for different geometries



Aliko-Benítez et al. (2015)

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Modelling of Autogenous Healing in UHPC.

Hilloulin et al. 2014.

- A hydro-chemo-mechanical coupled model.
- Hydration reactions from an Arrhenius equation.
- Coupled with isotropic damage model
- Fick's-law based diffusion model.
- The latter uses a damage dependent diffusion coefficient.
- Healing (i.e. hydration) products transported by liquid water.
- Healing is simulated as a reduction in damage – linked to hydrates volume in the damage region
- Simulates specimens from Granger et al. (2007)

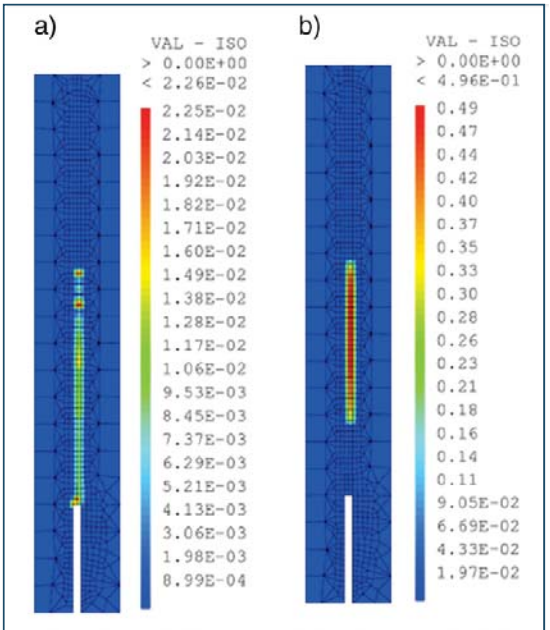
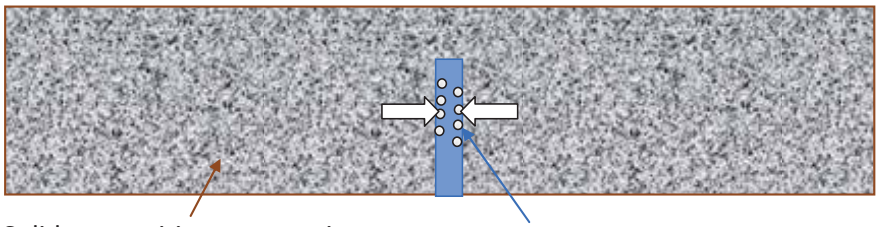


Fig. 5. Residual damage after 20 days of healing a) with normal diffusion and hydration parameters (residual damage close to 0 all along the crack), b) with increased hydration (crack completely healed at its bottom part).

From Hilloulin et al (2015)

Model for early age healing: *Chitez & Jefferson, Cem & Conc Res, 2016*



Main assumptions:

a) The 'self-healing' material derives directly from unhydrated cement

b) Unhydrated cement grains dissociate in pore water, release various ions that are transported and accumulate in regions of low concentration

c) Ions transported by advection, diffusion, dispersion through pore fluid

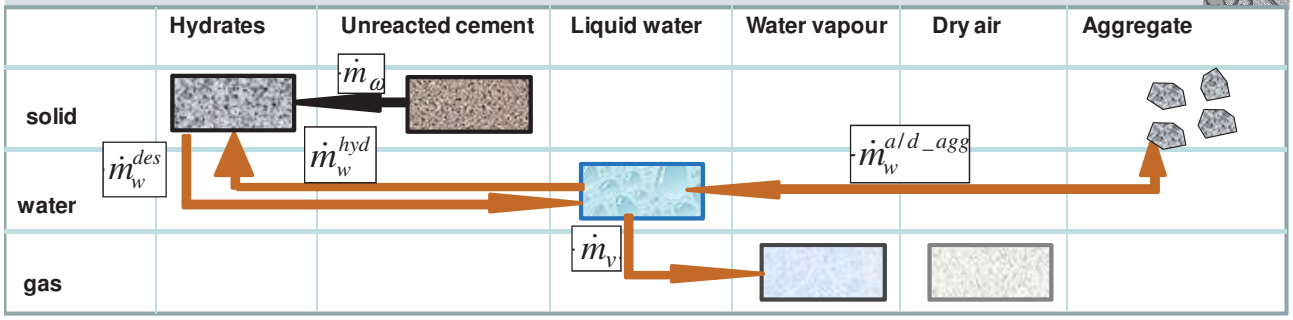
d) Cracks are initially filled with water and then are filled with precipitates

e) Precipitates develop according to a Freundlich type isotherm

$$m_\omega = \underbrace{\left(\alpha_P S_w^{cap}\, \omega^{\beta_P}\right)}_{Freundlich} \rho_w \eta_{cap}$$

f) Porosity in the "crack" gradually reduces

$$\eta_j(\Gamma, V_P) = 1 - \frac{V_P}{V_{crack}}$$



Moisture mass balance for liquid (w) & vapour (v) relative to solid skeleton (s)

$$\dot{\bar{\rho}}_w + \dot{\bar{\rho}}_v + div\left(\bar{\rho}_v \bar{v}^{vg}\right) + div\left(\bar{\rho}_w \bar{v}^{ws}\right) = -\dot{m}_w^{hyd} - \dot{m}_w^{a/d\_agg} + \dot{m}_w^{des}$$

Conservation of heat energy

$$\overline{\rho C}_p \dot{T} + div\left(-\lambda_T^{eff}\, grad(T)\right) = -\dot{m}_v \Delta H_v + Q_h$$

Mass balance for solute

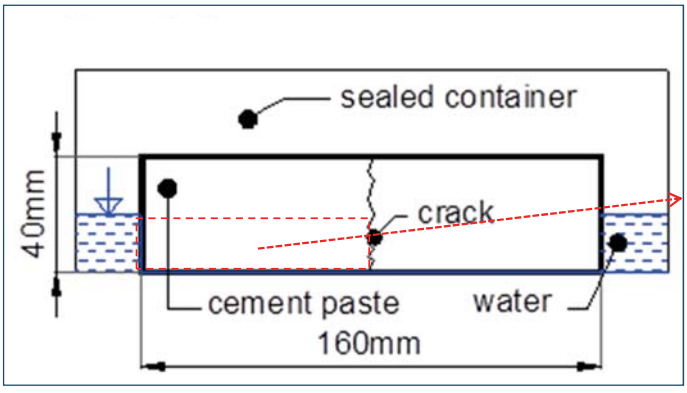
$$\dot{\bar{\rho}}_\omega + div\left(\bar{\rho}_\omega \bar{v}^{ws}\right) + div\left(\bar{\rho}_\omega \bar{v}^{\omega w}\right) = -\dot{m}_\omega$$

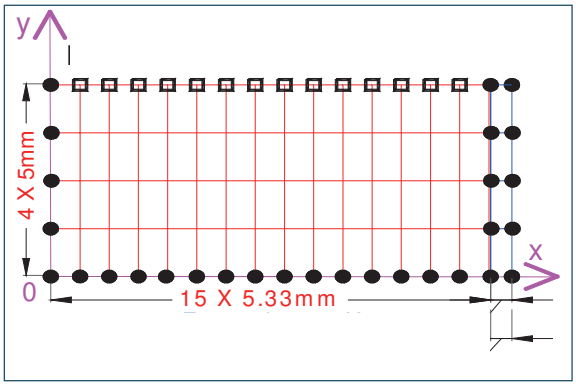
Discretised equations

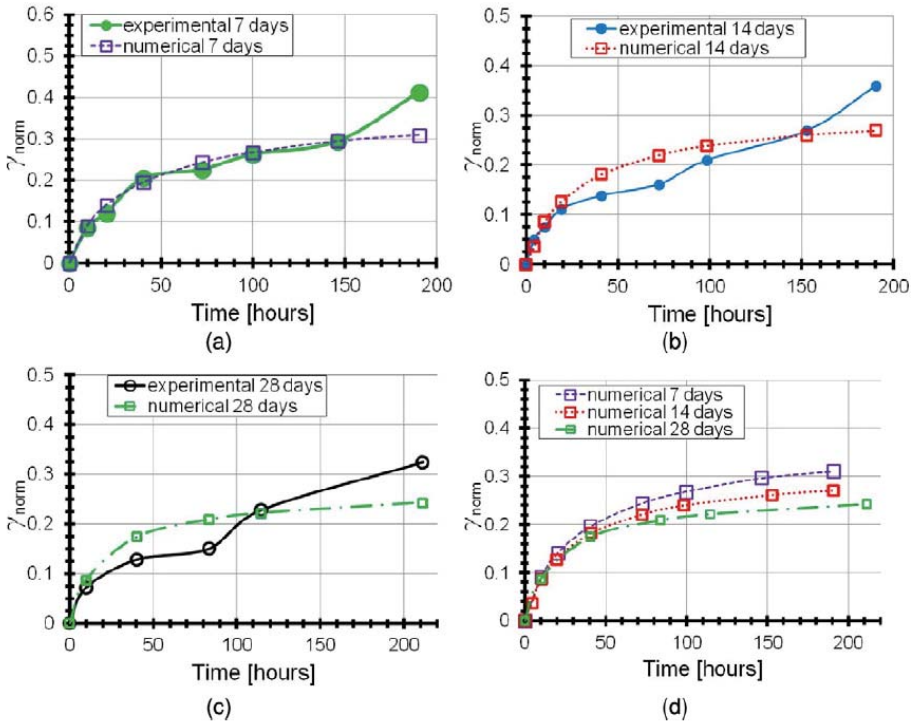
$$\int_{\Omega_e} N \begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} N^T \begin{Bmatrix} \dot{S}_w \\ \dot{T} \\ \dot{\omega} \end{Bmatrix} d\Omega_e + \int_{\Omega_e} \nabla N \begin{bmatrix} K_{11} & K_{12} & K_{13} \\ K_{21} & K_{22} & K_{23} \\ K_{31} & K_{32} & K_{33} \end{bmatrix} \nabla N^T \begin{Bmatrix} S_w \\ T \\ \omega \end{Bmatrix} d\Omega_e = \begin{Bmatrix} F_{1e} \\ F_{2e} \\ F_{3e} \end{Bmatrix}$$

Example: *Experiment by Huang,Ye, Damidot. Cem. Concr. Res. (2013)*

- Crack formed in prismatic specimens 7, 14 and 28 days from casting.
- Placed in sealed containers partially filled with water for 200 hours.
- Morphology of the self-healing deposits investigated
- Precipitates include C-S-H; CH; $CaCo_3$ and other hydrates.

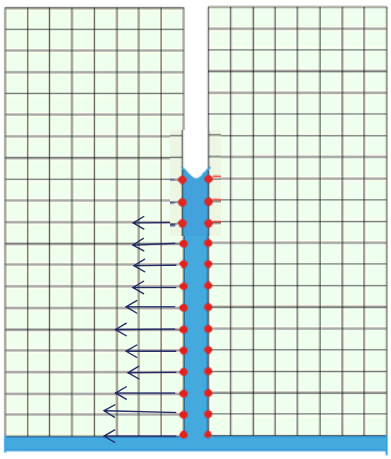


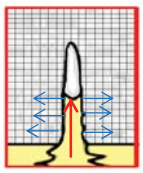




Flow of healing agents in discrete cracks, coupled to flow in porous continuum and t0 cohesive damage-healing model

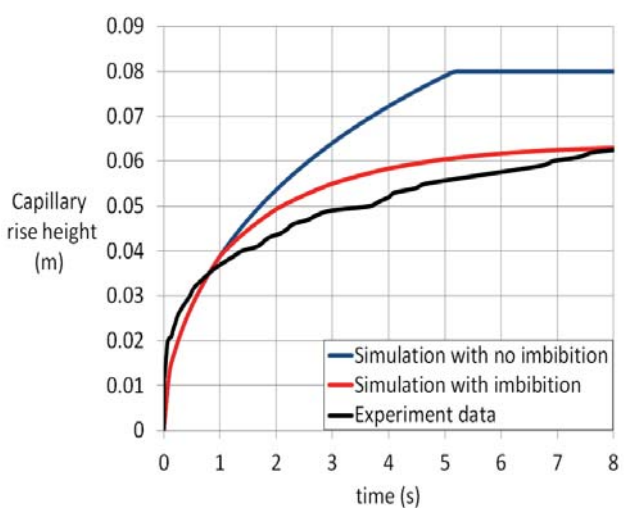
Gardner et al, 2012, 2014, 2017, Ma et al, 2017**



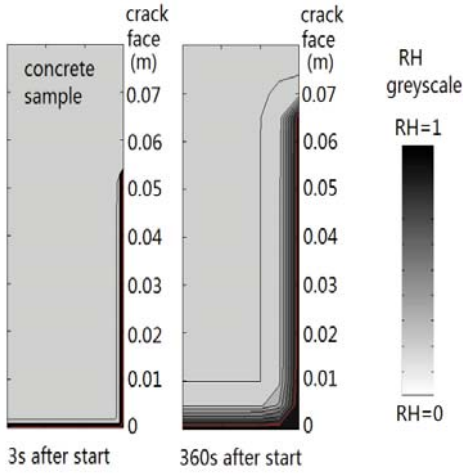


$$Q_{i-1} = \int_0^z \frac{\left(\int_x^z q(x')_{i-1}\, dx'\right)}{A(x)\left(\frac{k(x)}{\mu} + \frac{\beta_w b(x)}{2}\right)} dx$$

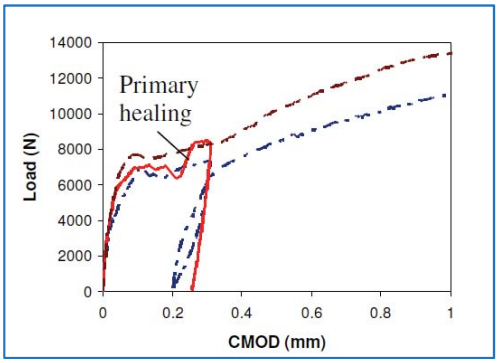
$$z_i = z_{i-1} + \frac{p_{c0}(1-\beta_s) - \rho g z_n \sin(\phi) - Q_i}{\frac{2\beta_m}{b} + \eta} \cdot \Delta t$$

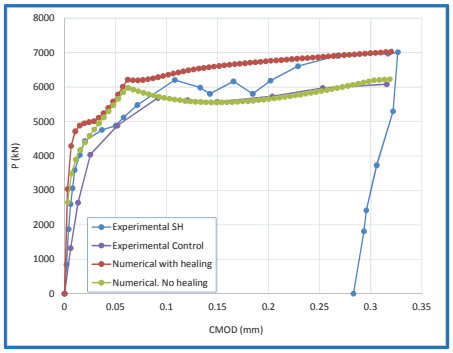


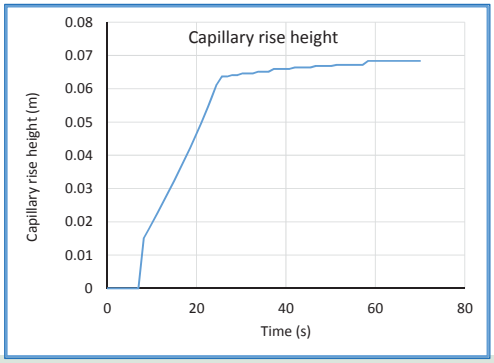
Capillary rise in the discrete crack of width 0.1mm



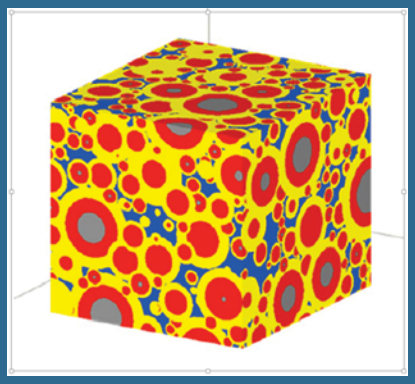
Modelling results of the RH in surrounding matrix







HYMOSTRUC

REF / MODEL	BRIEF DESCRIPTION
HYMOSTRUC *(van Breugel, 1991)* 	• HYMODTRUC simulates hydration and diffusion processes with spherical elements dispersed in an aqueous medium • ter Heide (2005) modelled the autogenous self-healing with bridging particles • Koenders (1997) The transition to self-healing by incorporating a bar & ribbon model • Ye and van Breugel (2007) upgraded HYMOSTRUC to allow for a 3D analysis and studies self-healing of microcracks • Huang and Ye (2011,12,13) simulated breaking of embedded water capsules and their effect on healing • van Breugel (2016) explored filling of micro-cracks and the densification of the microstructure adjacent to the crack.

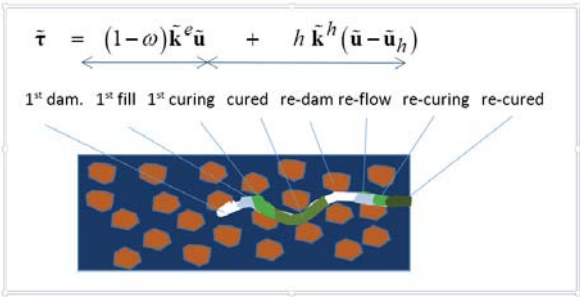
OTHER MODELS

Reference	Brief description
Zemskov, Jonkers and Vermolen *Journal of Intelligent Material Systems and Structures 2014*	Simulates bacterial self-healing using level sets to track healing processes in a diffusion type FE analysis. Moving boundaries track calcium carbonate and the dissolution of the capsule contents.
Mergheim & Steinmann. *Computational Mechanics 2013.*	An isotropic damage-healing model coupled to a realsitic healing curing model. Allows for damage - healing, re-damage and a single occurrence of re-healing.
Zhou, Zhu, Yan, Ju, Zhang. *Construction and Building Materials 2016*	Considers microcapsules as circular voids and employs a two-dimensional particle flow code (PFC2D) to study the fracturing behaviour of concrete specimens containing one microcapsule and one microcrack.
Hilloulin, Hilloulin, Grondin, Loukili, De Belie. *Cement and Concrete Research: 2016.*	Combines a particle-hydration model (CEMHYD3D) with an FE code (Cast3M) to simulate micro-crack healing. The healing of micro-cracks of 10 width microns are explored with this coupled model.
Hazelwood, Jefferson, Lark, Gardner. *Engineering Structures , 2015.*	Layered beam visco-elastic damage-healing model for concrete and temperature dependent visco-elastic model - based on a modified SLS rheological unit- for SMP tendons. Time dependent simulations look at mechanical loading / creep and shrinkage

Issues/ development needs with mechanics model

Many models are built on restrictive assumptions e.g.

- healing always takes place under zero-strain conditions;
- healing occurs instantaneously;
- healing and damage are never concurrent;
- healed material cannot re-damage;
- healed material can only re-damage once;



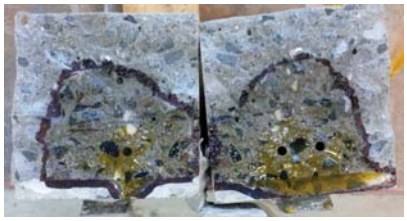
Much more work is needed on

- Coupling healing with transport
- Strength/stiffness of 'healed' materials
- Micro-capsule debonding, fracture
- Time-dependent behaviour of 'healed material'

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
WG3 Modelling
Presenter: Tony Jefferson
COST CA15202 SARCOS
SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

Transport and chemical models

- Parameters that control advection, diffusion and dispersion are highly variable: more data is needed and better means of characterisation
- Statistical variations of transport properties need to be built into models
- Research needed to better establish the dependence of transport properties on the state of cracking
- Two (or multiple) level approaches may be helpful
- Need research to better the reactions (and reactive transport processes) in autogenous healing; including the precipitation
- Time dependent variations of flow properties need to be better established
- Coupling between discrete and diffuse transport processes



$$r_1 = k_a^{CSH.CaCl_2}[CSH.CaCl_2] - k_d^{CSH.CaCl_2}([Ca^{2+}][Cl^-]^2)^{n_1}$$
$$r_2 = k_a^{CSH.NaCl}[CSH.NaCl] - k_d^{CSH.NaCl}([Na^+]^2[Cl^-]^2)^{n_2}$$
$$r_3 = k_a^{CSH.2KCl}[CSH.2KCl] - k_d^{CSH.2KCl}([K^+]^2[Cl^-]^2)^{n_3}$$
$$r_4 = k_a^{CSH.2NaOH}[CSH.2NaOH] - k_d^{CSH.2NaOH}([Na^+]^2[OH^-]^2)^{n_4}$$
$$r_5 = k_a^{CSH.2KOH}[CSH.2KOH] - k_d^{CSH.2KOH}([K^+]^2[OH^-]^2)^{n_5}$$
$$r_6 = k_d^{CAHCaCl_2}[CAHCaCl_2] - k_a^{CAHCaCl_2}([Ca^{2+}][Cl^-]^2)^{n_6}$$

CONCLUDING REMARK

We are but a short way into a long journey,
the end of which may never arrive
but we will enjoy not getting there

NEW INCORPORATIONS

WEST POMERANIAN
UNIVERSITY OF TECHNOLOGY
SZCZECIN
POLAND

INSTITUTION DESCRIPTION

West Pomeranian University of Technology Szczecin (WPUTS)
Faculty of Civil Engineering and Architecture
Department of Concrete Structures and Concrete Technology
Al. Piastow 50, 70-311, Szczecin, Poland; www.zelbet.zut.edu.pl

Research and didactic activity of Department of Concrete Structures and Concrete Technology (KKŻiTB) cover issues related to the design and maintenance of reinforced concrete structures and concrete technology. The particular subjects of our studies are shaping and evaluation of durability and diagnostics of concrete structures and building materials. In a study of building materials we focus especially on concrete, its material modification towards sustainable building composite (including the use of nanomaterials and mineral wastes as components). Our research projects are conducted as a part of international collaboration with such centers as Technical University of Berlin, Germany; Yonsei University, Seul, Korea; Auburn University, Lviv Polytechnic National University, Lviv, Ukraine and others.

WEST POMERANIAN UNIVERSITY OF TECHNOLOGY SZCZECIN
COST CA15202 SARCOS SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

RESEARCH GROUP DESCRIPTION

Research lines (Elzbieta Horszczaruk, Piotr Brzozowski)

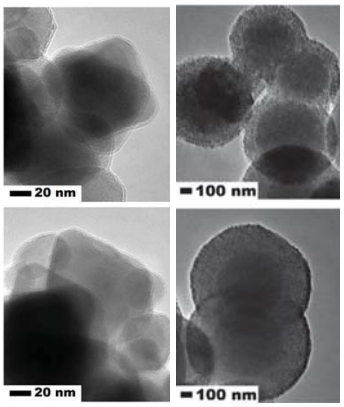
- material designing and optimization of cement concrete composites, including underwater concrete (UWC) and self consolidation concrete (SCC) and modification concrete composites by nanoparticles,
- materials and technologies of repair and protection of building structures , including hydraulic concrete structures,
- sustainable building composites as an element of sustainable development in construction, including utilization of wastes materials like: fly ashes, glass cullet, waste magnetite powder, etc. as the components of building materials.

Group infrastructure

- Isothermal calorimeter TAM-AIR (3-channel calorimeter block).
- Testing machine ZWICK for mechanical properties 100 and 5000 kN, and dynamic load 2x600 kN.
- Test stand for determination of gamma-ray shielding properties of building materials.
- Climatic chamber KK-1000 CHLT for incubation and storage of material samples.

EXPERIENCE ON SELF-HEALING OF CONCRETE STRUCTURES

- Modification of cement composites with nanostructures in order to obtain improved mechanical resistance and reinforcement of the cement matrix under high temperature.
- Application of core-shell nano-structures for targeted modification of the properties of cement composites.
- Utilization of waste materials in repair of underwater concrete structures.



Selected bibliography related to the COST subject:

1. *Horszczaruk E., Brzozowski P.: Effects of fluidal fly ash on abrasion resistance of underwater repair concrete. Wear 376-377, 2017, 15-21.*
2. *Horszczaruk E., Sikora P., Cendrowski K., Mijowska E.: The effect of elevated temperature on the properties of cement mortars. Construction and Building Materials 137, 2017, 420–431.*
3. *Sikora P., Cendrowski K., Markowska-Szczupak A., Horszczaruk E., Mijowska E.: The effects of silica/titania nanocomposite on the mechanical and bactericidal properties of cement mortars. Construction and Building Materials 150, 2017, 738-746.*