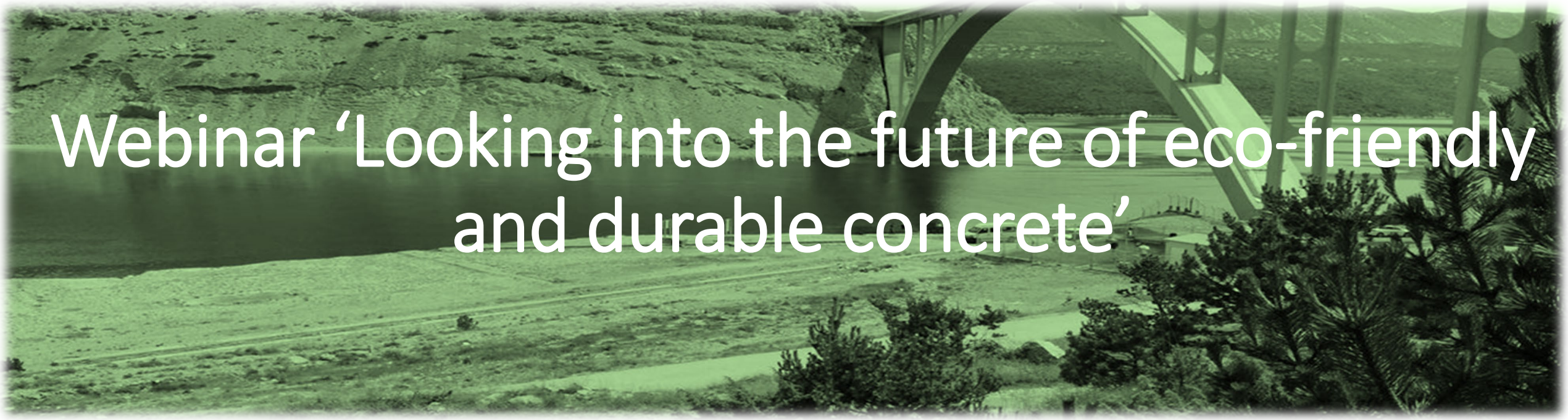
endurcrete

New Environmental friendly and Durable conCrete, integrating industrial by-products and hybrid systems, for civil, industrial and offshore applications



Webinar ‘Looking into the future of eco-friendly and durable concrete’

Final event of the project

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 760639.

Agenda

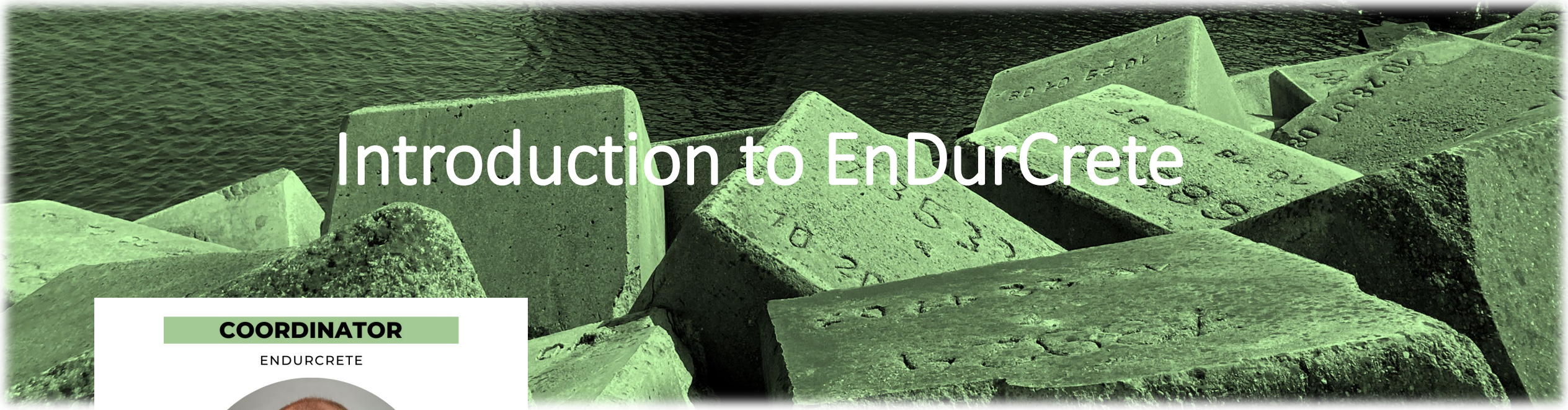
TIME	TOPIC	PARTNERS
11:00 - 11:05	Introduction to the webinar	FENIX TNT
11:05 - 11:15	Introduction to the project, goals, challenges	HC
	Presentation of the Endurcrete project results	
11:15 - 11:55	Cement	HC
	Concrete & Admixtures	HC
	Nanoclay	IBOX
	Carbon based additions	UNIVPM
	Textile	RINA
	Coating	AMS
11:55 - 12:00	BREAK	
12:00 - 12:20	Demo sites	INFRAPLAN
12:20 - 12:40	Reshealience project	RESHEALINCE
	Q&A	
12:40 - 13:00	Health and safety of the technologies	CEA, VITO
	Prevalidation of technologies in the laboratory	ZAG, NTNU
	Modelling of durability over 100 years	RINA, CEA
	Life-cycle assessment	GEO

BUILD UP CO-ORGANIZER

RESHEALIENCE CLUSTER PROJECT

FENIX.TNT MODERATOR

Introduction to EnDurCrete



COORDINATOR

ENDURCRETE

DR. ARNAUD MULLER

Senior Scientist at the Global R&D department of HeidelbergCement AG

Dr. Arnaud Muller, HeidelbergCement AG

Context / Motivation

- Concrete is the world's most consumed man-made material. Concrete based on ordinary Portland (OPC) cement has been the principal structural material for our constructions
- Manufacturing Portland clinker consumes significant mineral resources, energy and fuel. Cement production contributes to 5-8% of global greenhouse gas emissions





- There is need for innovative sustainable and durable concrete solutions where low CO_2, cost-effectiveness and high durability of concrete is a real added value
- A durable concrete material helps the environment by conserving resources and reducing wastes and the environmental impacts of repair and replacement
- Research is needed to develop breakthrough solutions for sustainable and durable concrete

EnDurCrete project

JANUARY 2018

1

6 Mio€

16 Partners

H2020 work programme

End of 2021

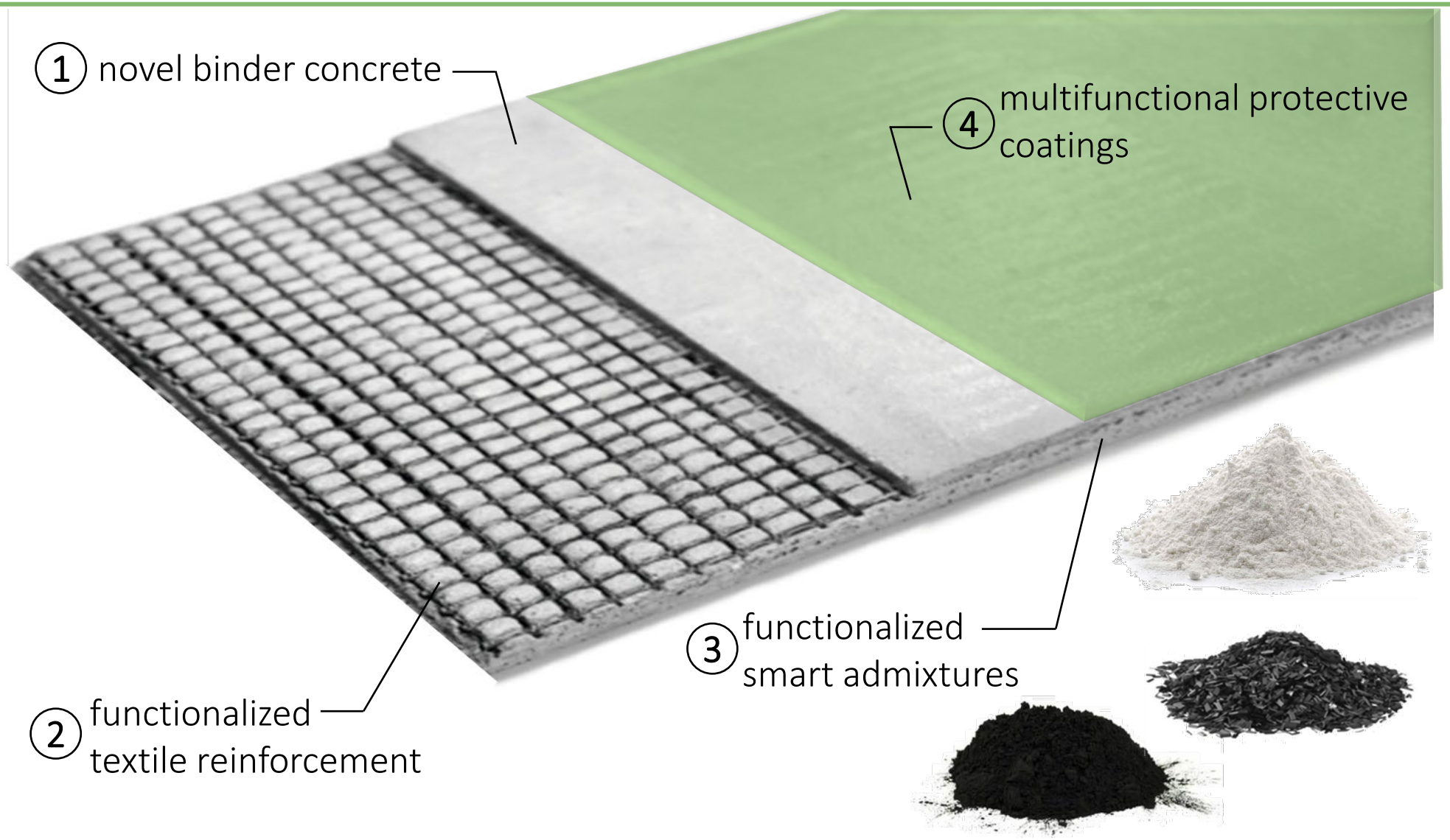
JUNE 2021

30

endurcrete

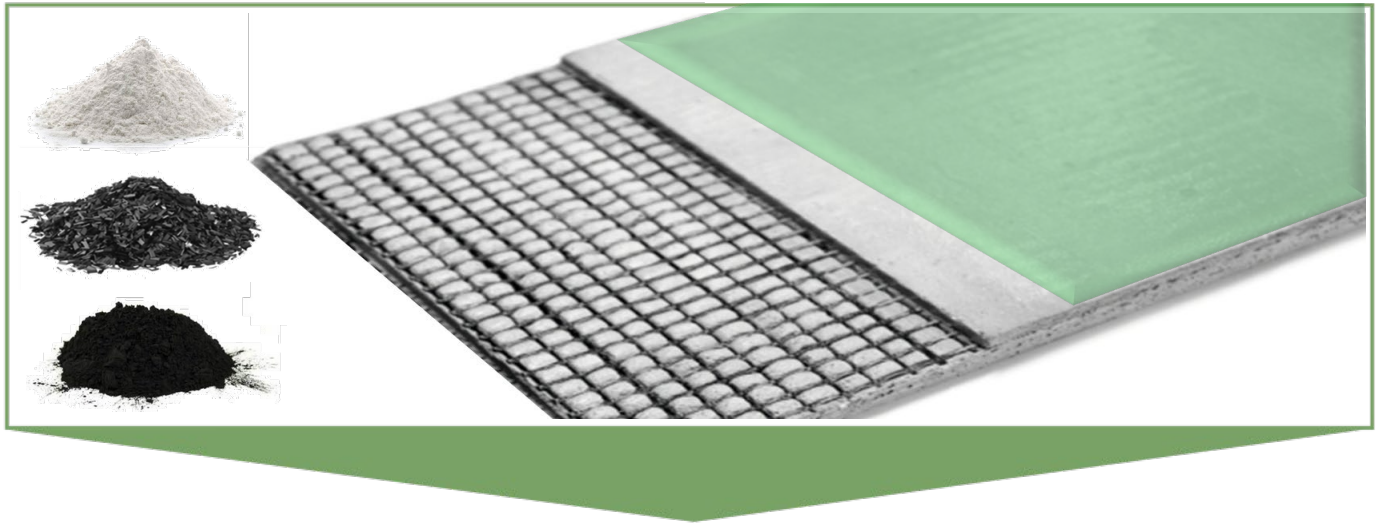
Development of a new cost-effective sustainable reinforced concrete for long lasting and added value applications.

Project concept



Integrated approach

Developed technology



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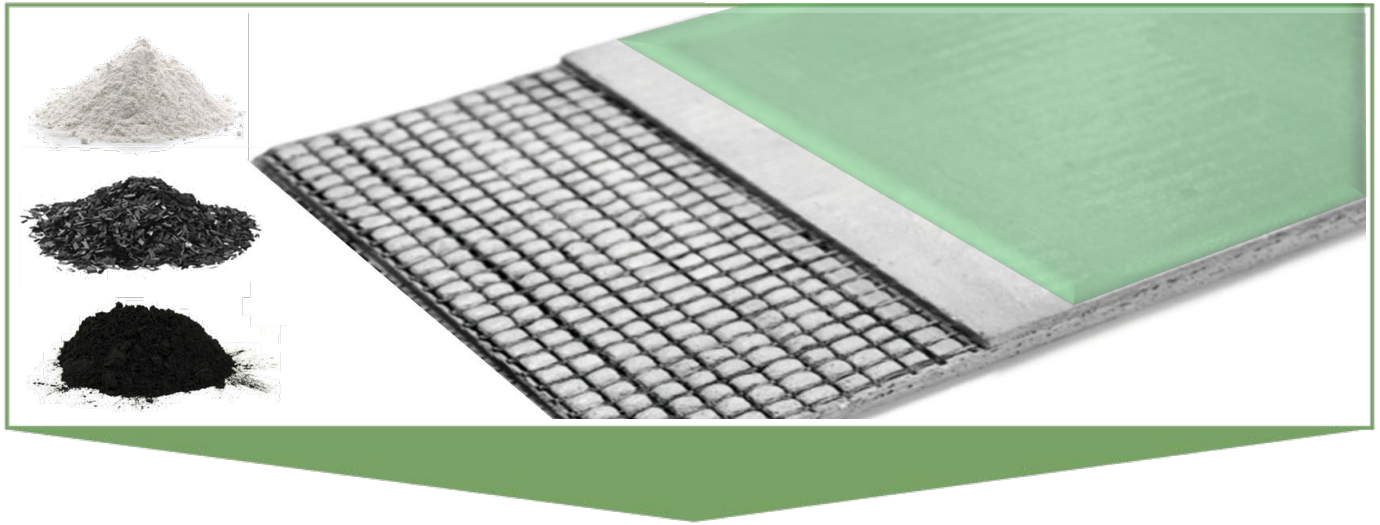
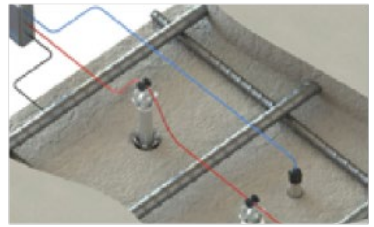


Durability modelling, testing, monitoring and standardization



Integrated approach

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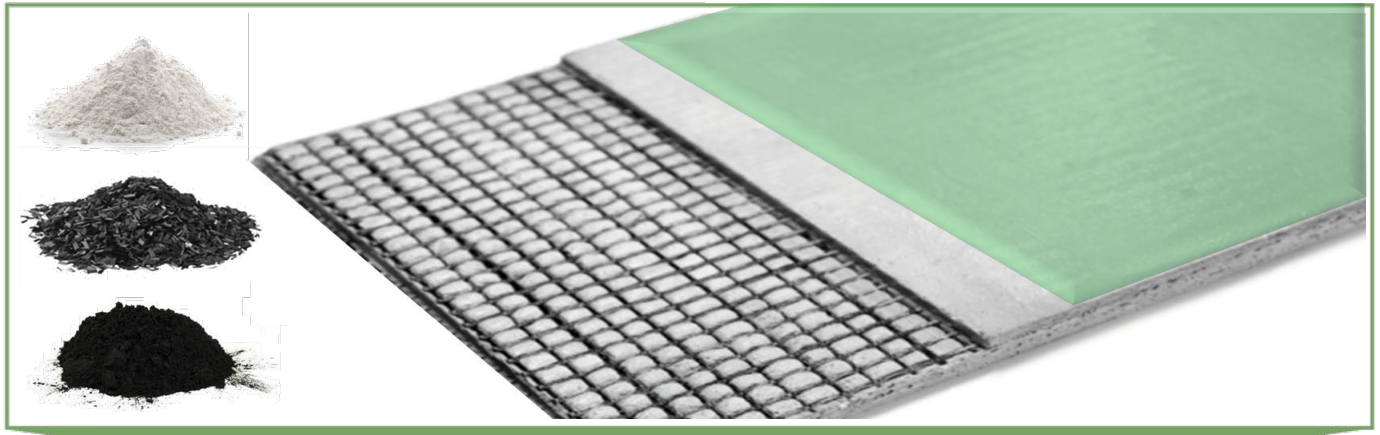
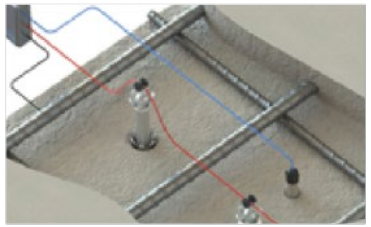
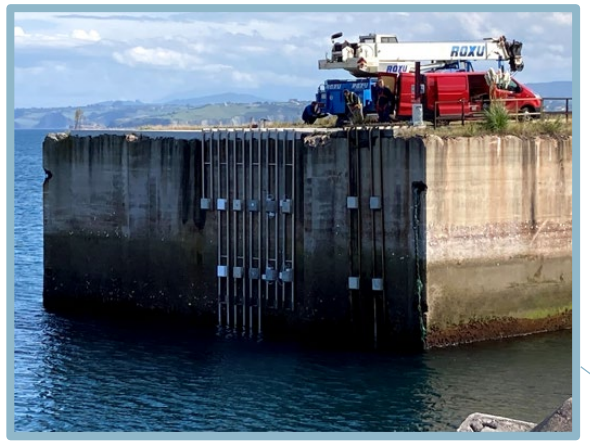


Durability modelling, testing, monitoring and standardization

Demonstration of pre-cast and ready-mix concrete prototypes in harsh environments



Demosites to prove concept



Ship Yard, Norway

Port of Gijón "El Musel", Spain

Mining tunnel facility in Leon, Spain

Krk Bridge, Croatia

Project in a nutshell

Overall Approach

- Test functionality of **new concrete technologies** under severe operating conditions (4 demo-sites)
- Develop **experimental and numerical tools** to understand factors affecting the durability and to capture the multiscale evolution of damage
- Develop **models for service life prediction**

Expected Impact

- Strengthening **competitiveness of the European industry**, including in the field of “green” technologies
- Positive **LCA balance**
- At least **30% improved durability**
- At least **30% lower cost**

Contact and further information

Project website

www.endurcrete.eu

Follow project latest news on social media

Contact project Partners directly

Explanation of the concept:

- Cement
- Concrete and admixtures
- Nanoclay
- Carbon based additions
- Textile
- Coating

Development of novel Portland Composite Cements

SPEAKER

ENDURCRETE

GERD BOLTE

Team Leader of the Cement & Binder Technology Group at HeidelbergCement Global R&D

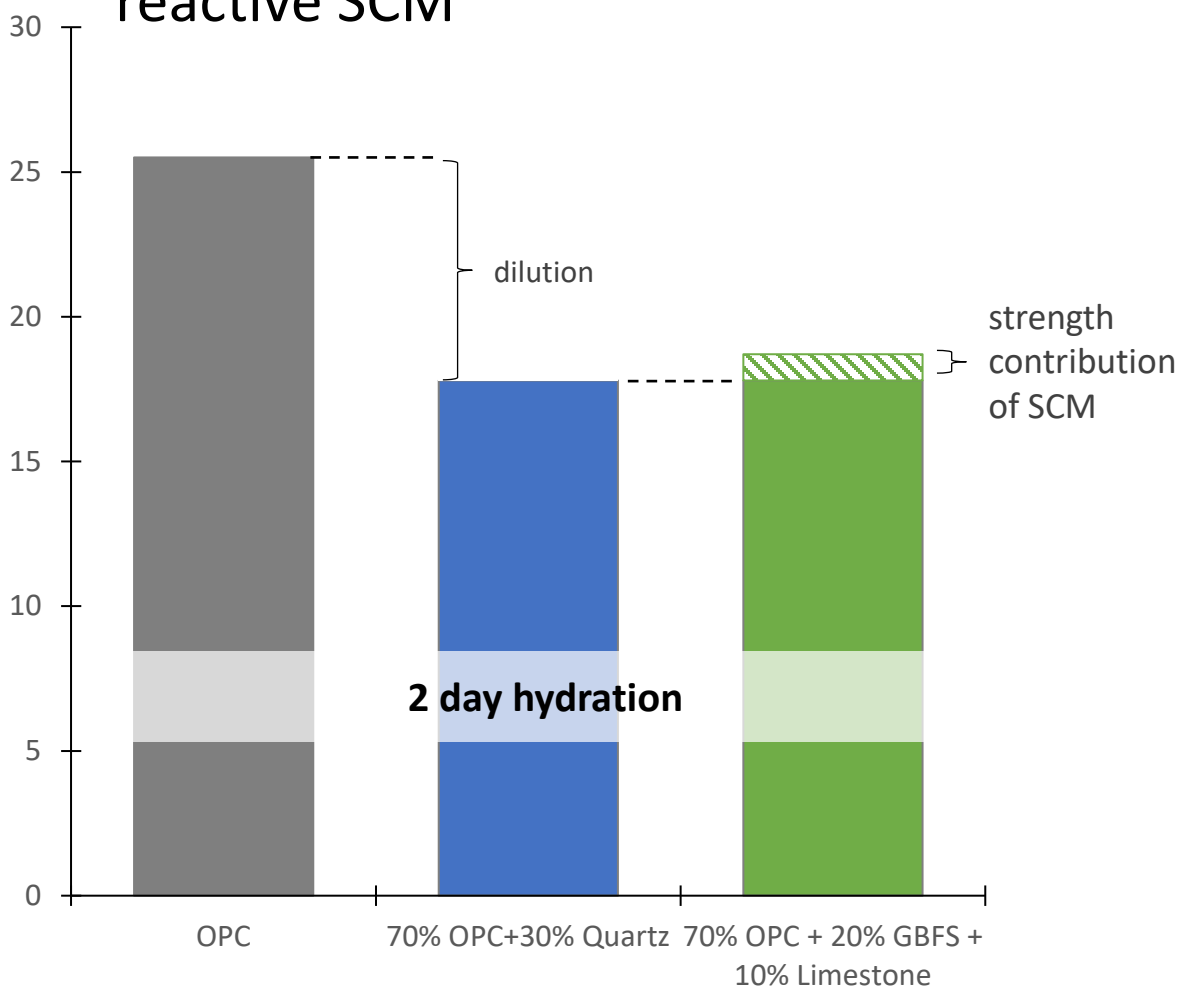
Gerd Bolte, HeidelbergCement AG

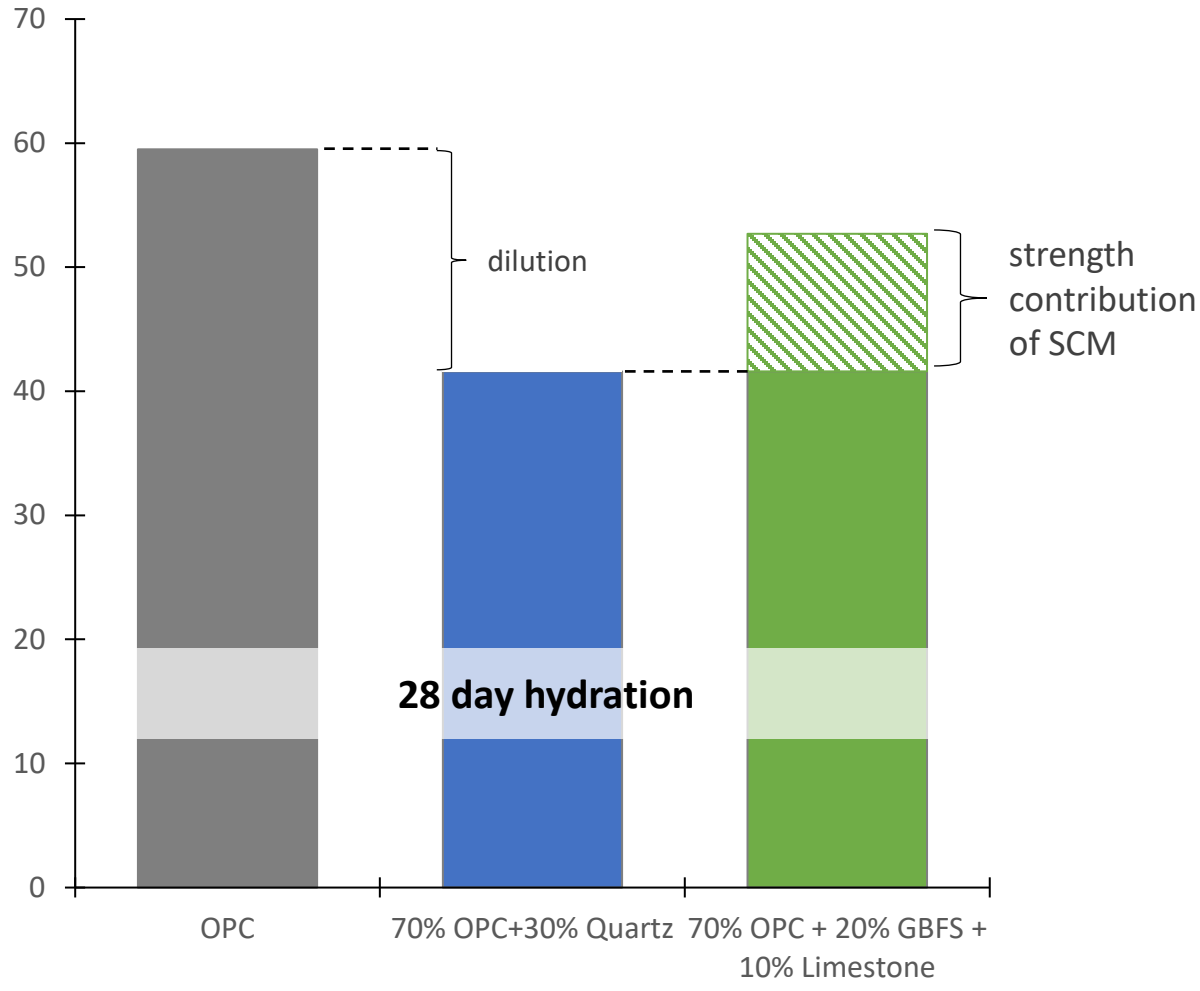
Development of novel Portland Composite Cements

- Cement is one of the most manufactured and processed goods on earth. Unfortunately, cement production is associated with significant CO_2 emissions
- The production of Portland cement clinker, the main component of today's cement, is associated with high CO_2 emissions
- The objective is to develop environmentally friendly concrete by reducing the proportion of Portland clinker in cement and replacing it with additional supplementary cementitious materials
- The new cement standard EN197-5 opens up new possibilities for low-clinker cements CEM II/C and CEM VI, through the use of granulated blastfurnace slag (GBFS), fly ash (V) and limestone (LL) in more flexible combinations

Development of novel Portland Composite Cements

- In composite cements, high reactive clinker mineral phases diluted with less reactive SCM



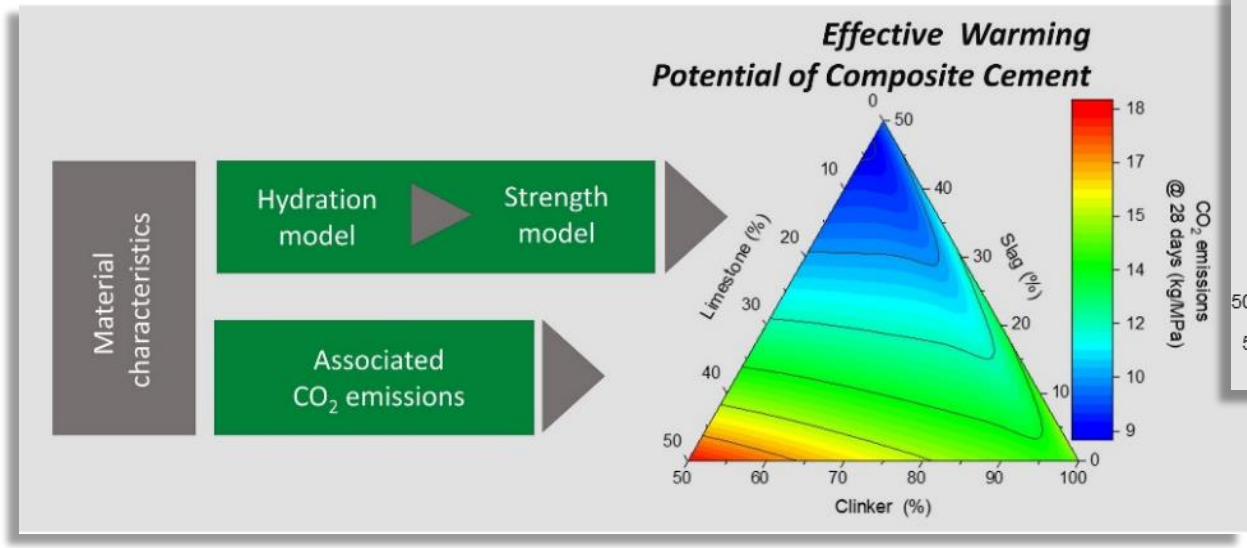


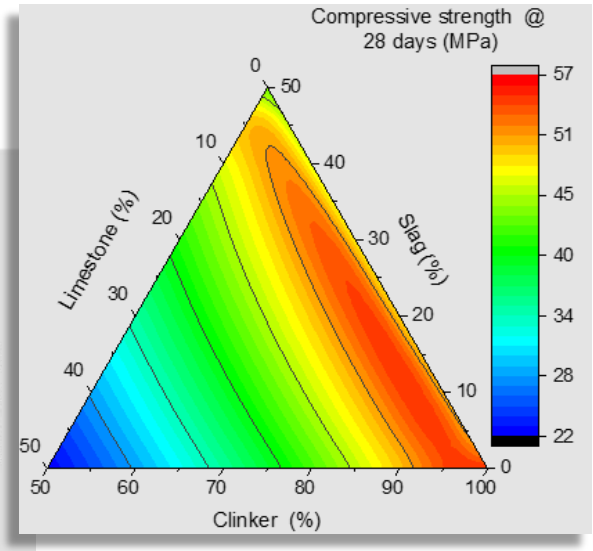
Development of novel Portland Composite Cements

- Separate grinding technology was used to adjust the fineness of each cement constituents to meet the given target strength and workability
- Objective:
  - enhance the synergies between them (Portland cement clinker, granulated blast-furnace slag and fly ash or limestone)
  - maximize the clinker replacement

Development of novel Portland Composite Cements

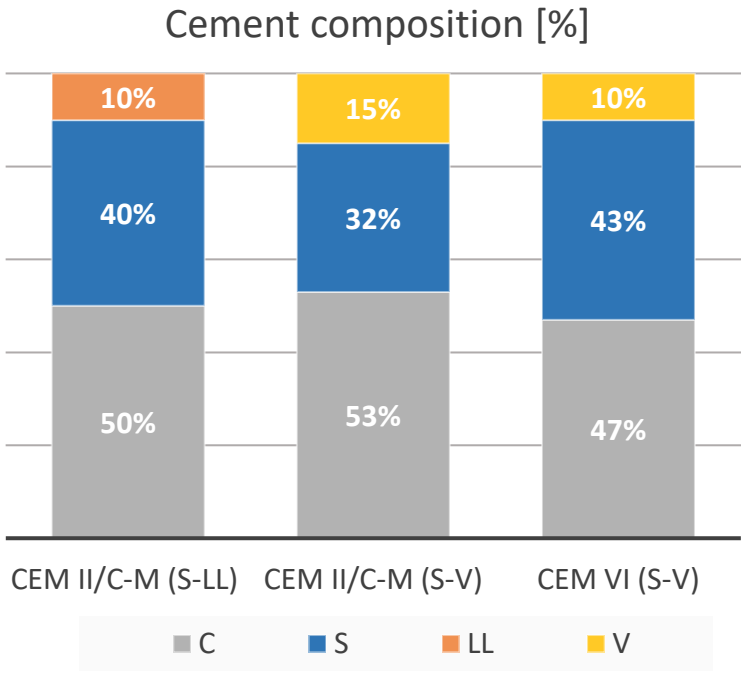
- The design of a composite cement of three main constituents that meets the requirements in terms of quality and ecology is very complex
- By using an empirical model for strength prediction and combining it with the calculated CO_2 emissions related to the composite cement, the number of tests is significantly reduced.
- The result shows that by separating the limestone grinding from the clinker grinding, it is possible to replace 10% of the clinker and/or GBFS with limestone.
  The CO_2 footprint is thus significantly reduced at comparable cement performance

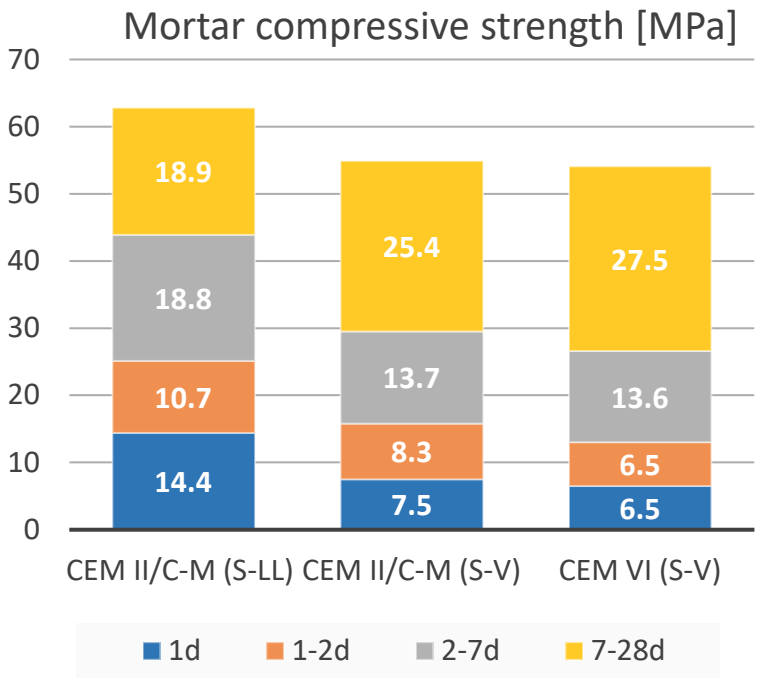




Development of novel Portland Composite Cements

- In 2018 and 2019, these novel cements CEM II/C-M and CEM VI were produced for the first time on a large scale at a HeidelbergCement plant and delivered to our project partners





Concrete and admixtures

SPEAKER

ENDURCRETE

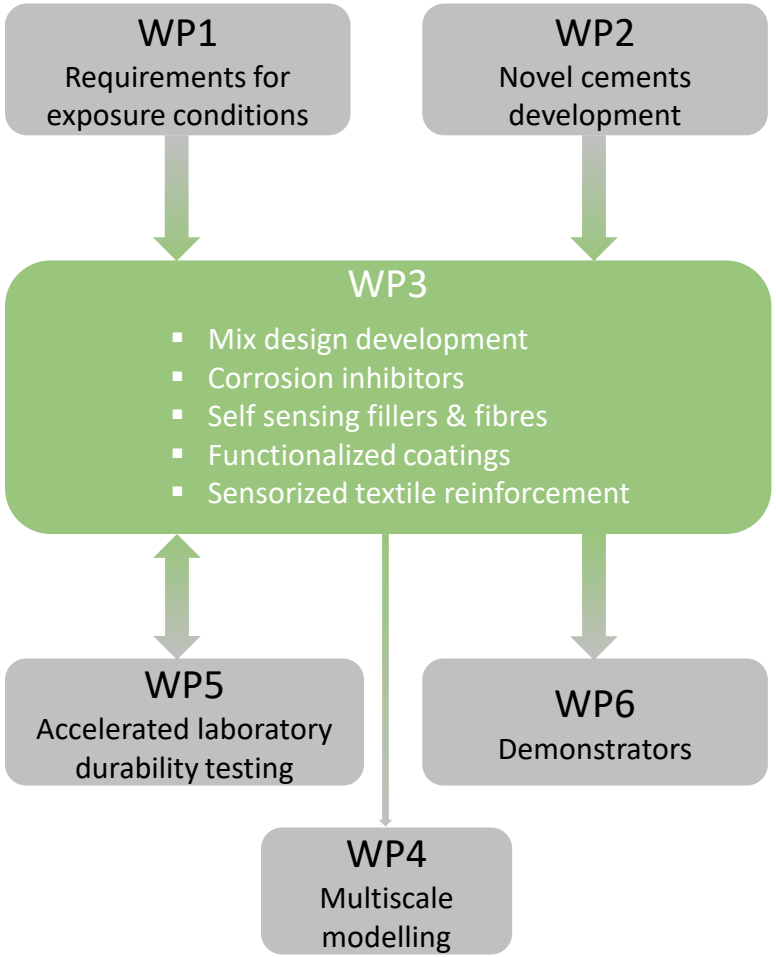
DR. NIKOLA MIKANOVIC

Principal Scientist at the Global R&D department of HeidelbergCement AG

Dr. Nikola Mikanovic, HeidelbergCement AG

WP3 objectives and workflow

- Develop concrete compositions to be tested under severe operating conditions on selected demo sites
  - to comply with the requirements defined in WP1
  - based on novel binders developed in WP2
- Incorporate novel additive technologies to improve concrete durability in cost-effective way
- Perform laboratory durability testing of these concretes in WP5
- Based on their performance, concrete compositions to be further tuned and rolled out for production large scale field specimens in WP6

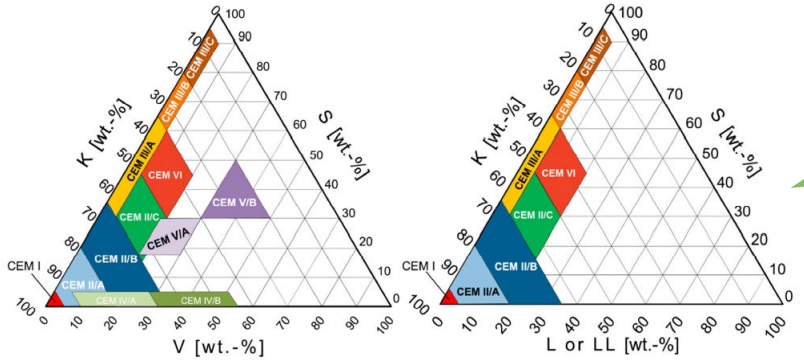


Step 1: EnDurCrete compositions with novel cements

Performance requirement	Marine Port – ES Bridge - HR	Tunnel - ES	Offshore - NO
Strength class	C35/45	C40/50	C50/60
Exposure class(es)	XS1, XS2, XS3	XD1, XA2	XS3, XF4
Max. w/c - ratio	0.45	0.5	0.4
Min. cement content	340 kg/m^3	320 kg/m^3	340 kg/m^3
Workability	S5 or SCC	S5 or SCC	S5 or SCC
Workability retention	min. 30‘	min. 30‘	min. 30‘
Early strength*	15 MPa	15 MPa	15 MPa
Other(s)	Water penetration: avg. < 20mm, max. 30mm† Drying shrinkage: < 250µm/m at 7d	Water penetration: avg. < 20mm, max. 30mm† Drying shrinkage: < 250µm/m at 7d	Chloride diff. coefficient: < 4 x 10-12 m^2/s‡ Air-entrainment: > 4.0%, spacing factor < 0.25mm$^{\times}$ Initial set: max. 9h

WP1 – Design and production requirements for structures exposed to aggressive environment

WP2 - Development and characterisation of new green and low-cost cementitious materials



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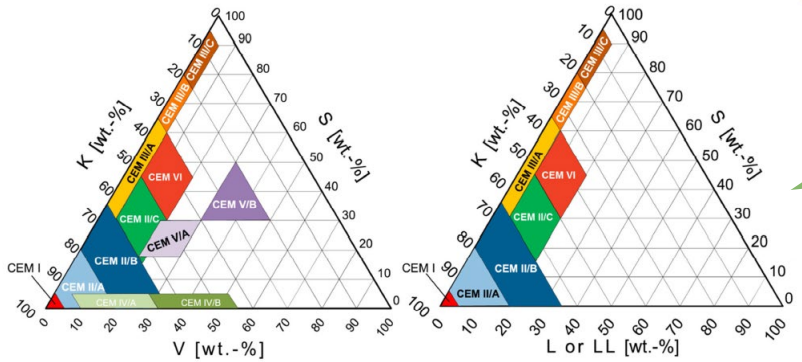
	Marine C35/45 concrete kg/m^3	Tunnel C40/50 concrete kg/m^3	Offshore C50/60 concrete kg/m^3
EDC-D CEM II/C (S-LL)	360	-	440
EDC-PL CEM VI	-	480	-
Sabbia Lavata 0/4	968	883	831
Gravel Pisello 5/10	390	356	410
Gravel Ghiaino 10/15	575	525	575
VC-2014	1.0	0.9	1.0
VF-10150666	1.5	1.4	1.5
SikaAer Solid	-	-	3.5
Water	162	187	159
W/C ratio	0.45	0.39	0.36

WP1 – Design and production requirements for structures exposed to aggressive environment

WP2 - Development and characterisation of new green and low-cost cementitious materials



Step 2: Impact of novel additives on properties of EnDurCrete

	Marine C35/45 concrete kg/m³	Tunnel C40/50 concrete kg/m³	Offshore C50/60 concrete kg/m³
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D3.1 - compliant mix designs with novel binders

+

Novel functionnalized nano-additives (CHAR, RCF, nanoclays)

Impact of additives on fresh and early age hardened properties

Step 2: Impact of novel additives on properties of EnDurCrete

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D3.1 - compliant mix designs with novel binders

+

Novel functionnalized nano-additives (CHAR, RCF, nanoclays)

Impact of additives on fresh and early age hardened properties

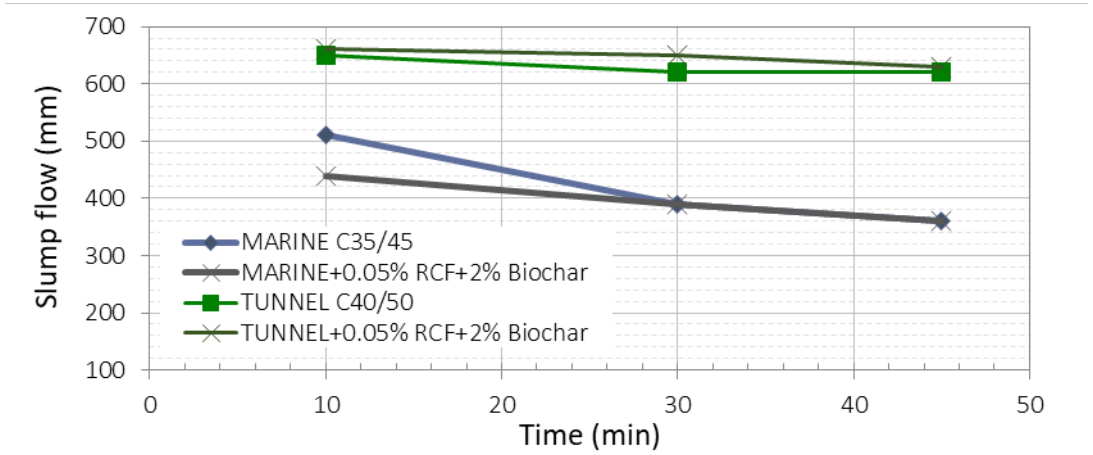
Outcome:

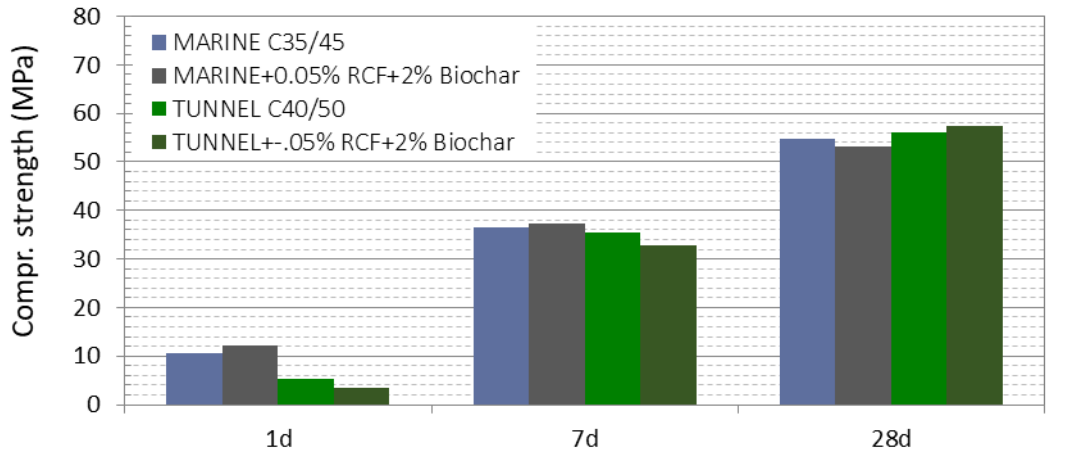
- Functionalized nanoclay has strong detrimental impact on workability, slump life and hydration kinetics
- Reasons for detrimental impact of nanoclay on strength development not clear → not to be implemented in offshore concrete
- Char and RCF have a limited impact on the hydration kinetics and strength development, but detrimentally impact initial workability and slump life
- Appropriate HRWRs identified for both nano clay and carbon-based materials to allow meeting all rheological requirements

Step 3: EnDurCrete compositions with novel cements and additives

EnDurCrete for Port Dijon and mining tunnel demo

	Port Dijon demo Marine C35/45 concrete kg/m³		Mining tunnel demo Tunnel C40/50 concrete kg/m³	
	no additives	with additives	no additives	with additives
EDC-D CEM II/C (S-LL)	360	375	--	-
EDC-PL CEM VI	--	--	480	480
Sabbia Lavata 0/4	968	884	883	846
Gravel Pisello 5/10	390	358	356	347
Gravel Ghiaino 10/15	575	613	525	512
CFG-6mm carbon fibres	--	0.925	--	0.925
Biochar	--	7.5	--	9.6
VC-2014	1.0	--	0.9	--
VF-10150666	1.5	--	1.4	--
PC2	--	0.75	--	1.0
PC3	--	1.7	--	2.3
Water	162	169	187	187
W/C ratio	0.45	0.45	0.39	0.39

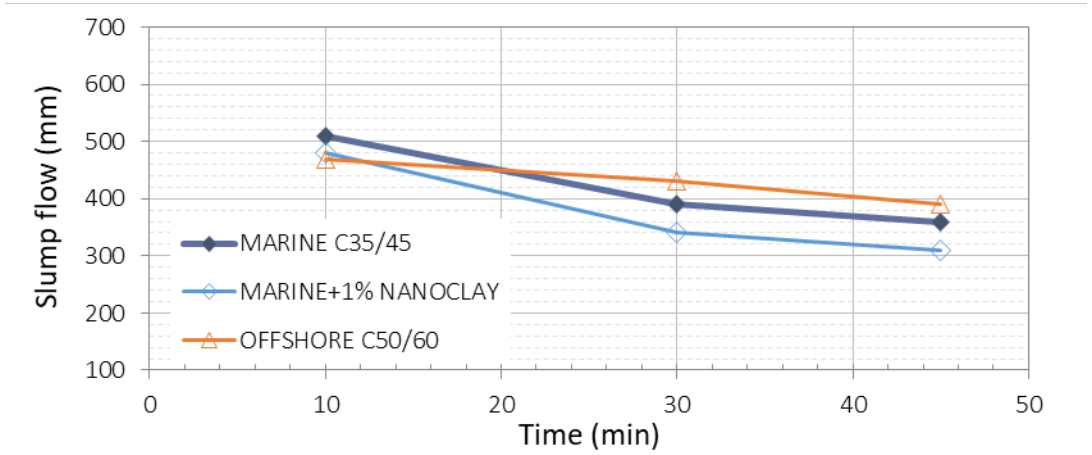


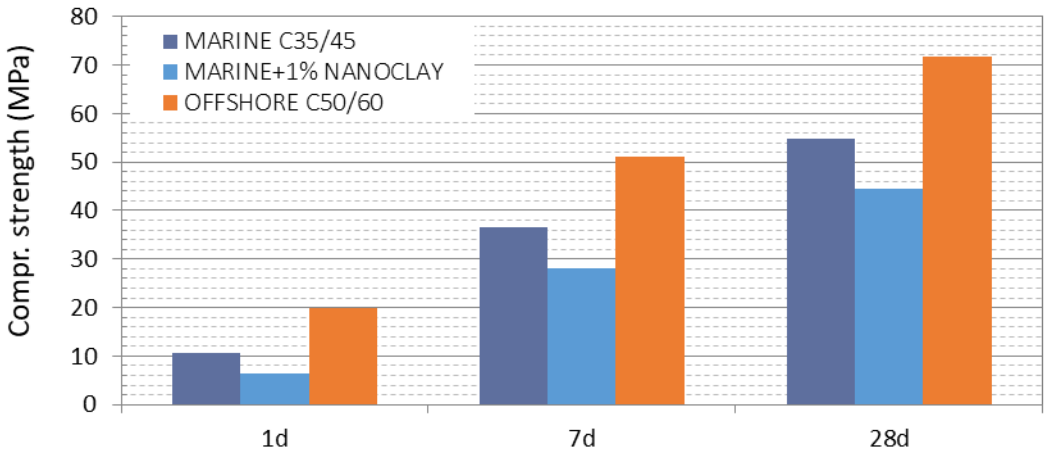


Step 3: EnDurCrete compositions with novel cements and additives

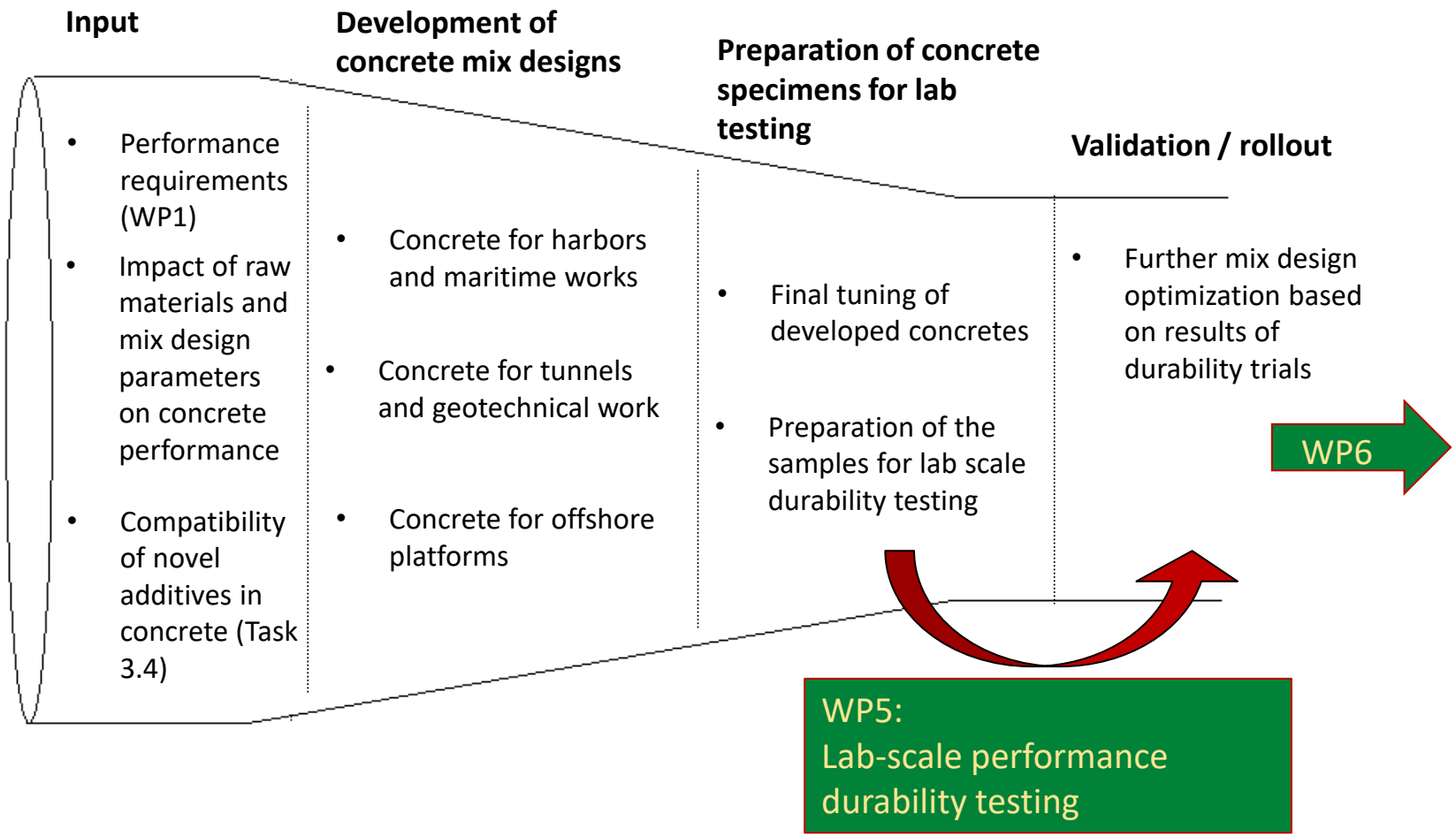
EnDurCrete for Krk bridge and offshore demo

	Demo in Norway Offshore C50/60 concrete kg/m³	Krk bridge demo Marine C35/45 concrete kg/m³	
	no additives	no additives	with additives
EDC-D CEM II/C (S-LL)	440	360	375
Sabbia Lavata 0/4	831	968	906
Gravel Pisello 5/10	410	390	361
Gravel Ghiaino 10/15	575	575	617
PC 5B nanoclay inhibitor	--	--	3.75
VC-2014	1.0	1.0	--
VF-10150666	1.5	1.5	--
PC2	--	--	1.45
PC3	--	--	1.0
SikaAer Solid	3.5	---	-
Water	159	162	169
W/C ratio	0.36	0.45	0.45

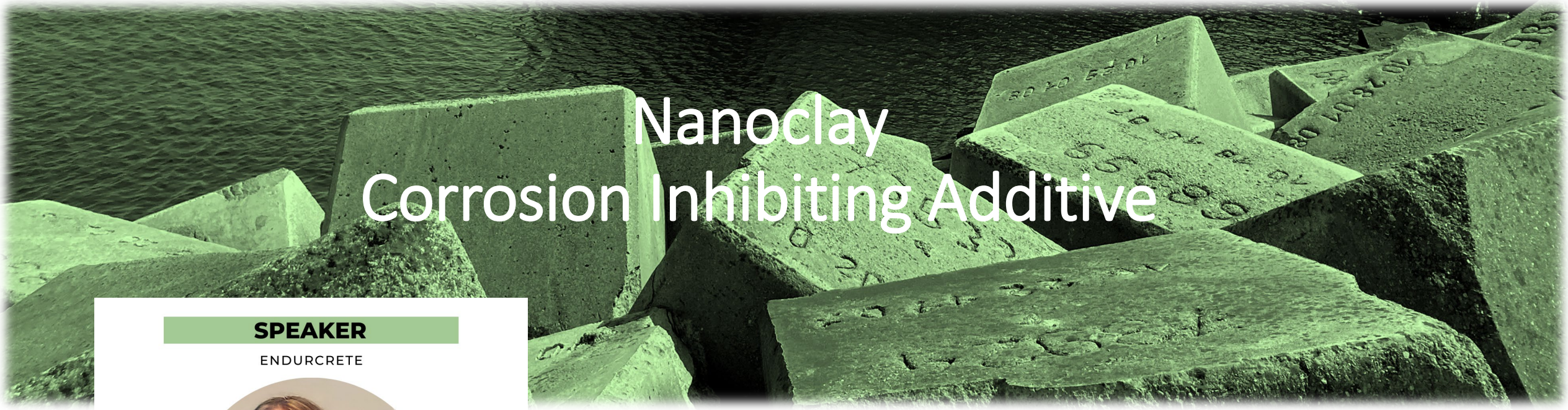




Conclusions



Nanoclay
Corrosion Inhibiting Additive



SPEAKER

ENDURCRETE

MARGARITA LECHA

Senior Engineer and Innovation Manager at I-Box Create S.L.

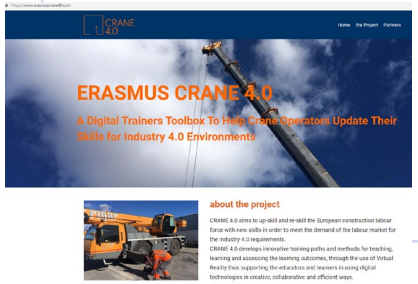
Eng. MSc. Margarita Lecha, I-Box Create S.L.

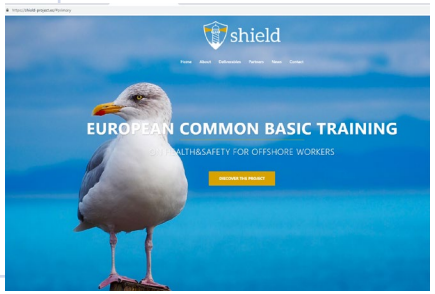
The company

- SME located in Valencia (Spain) working on R&D and Training projects related with Construction and Renewable Energy sectors
- Awarded with the Spanish Ministry “Innovative SME” seal since 2015

Advancedd Materials	Wave Energy	Innovative Training
• CORROLESS • ENDURCRETE	• Feasibility study for the Implementation of Wave Energy Generation Systems in sea and port Infrastructures	• CRANE 4.0 • eRD • AGILE4CIRC • SHIELD

PYME INNOVADORA
Válido hasta el 21 de julio de 2025
GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN





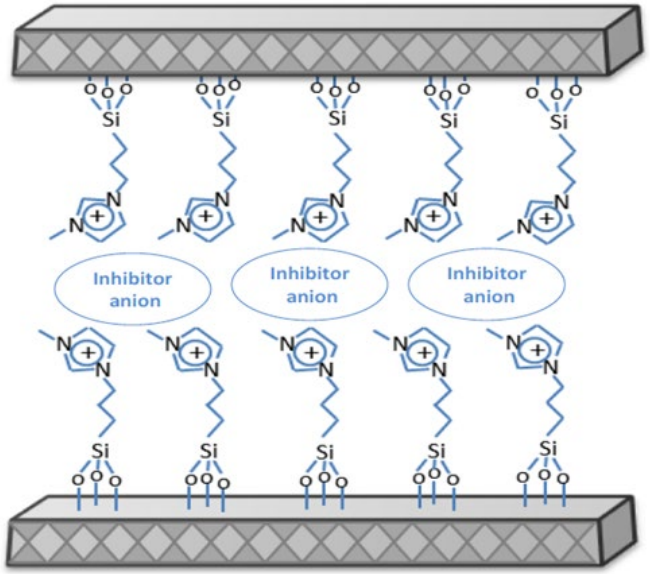
Background

- Since the beginning of its activity, IBOX has been developing an R&D line focused on the development of new products for **application in concrete as corrosion inhibitors** or as self-repairing materials.
- The knowledge is based on the development of a former company, Cyes Infraestructuras S.A., through the TRAINER project (New Autonomous and Intelligent Regeneration Technology). This project, financed by the national organism CDTI and with a total budget of 17,685,325 €, was based on the **development of technology and knowledge that would allow the development of different materials** (coatings, concrete, pavements and composites) with a **self-repairing nature**. In the case of Cyes, they collaborated with the Spanish company Acciona to work on **concrete**.

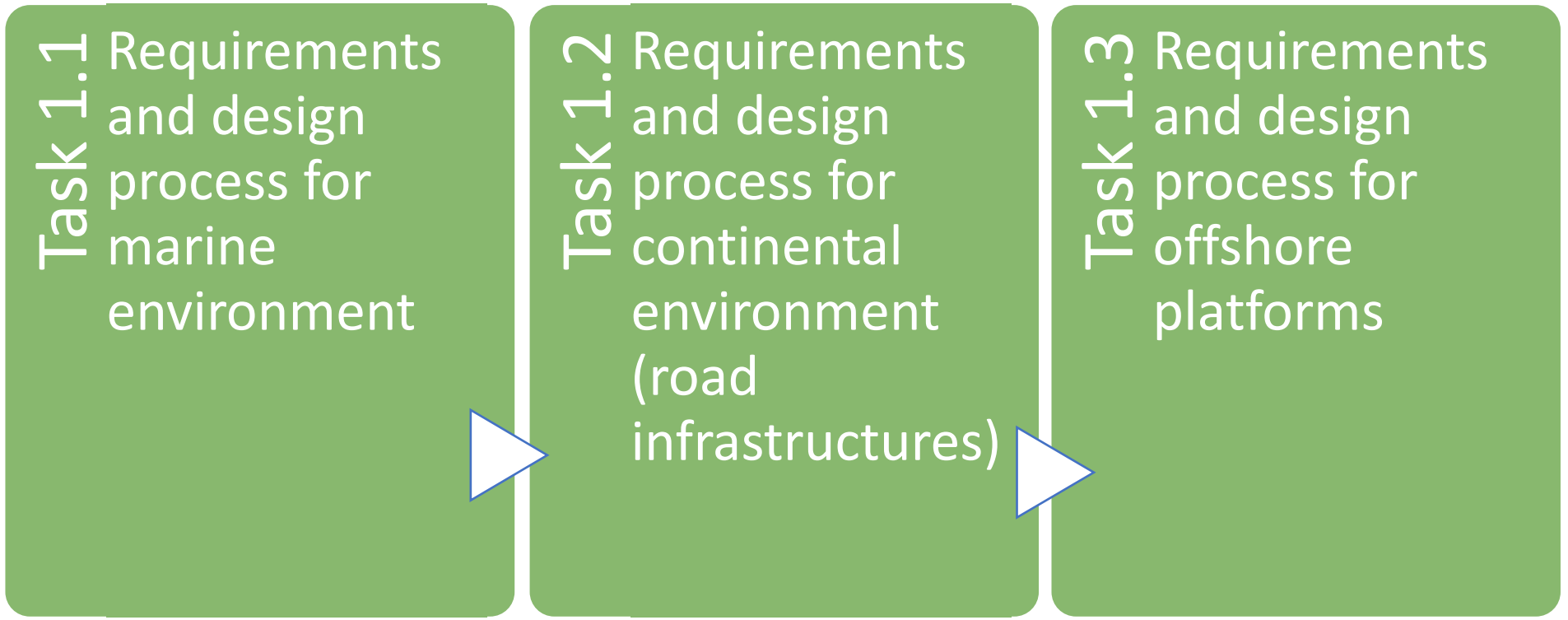
  ->The result was a Corrosion Inhibiting Additive.
- Cyes and I-Box signed an agreement in 2014 where the latter would be in charge of all technological development and exploitation.

Background

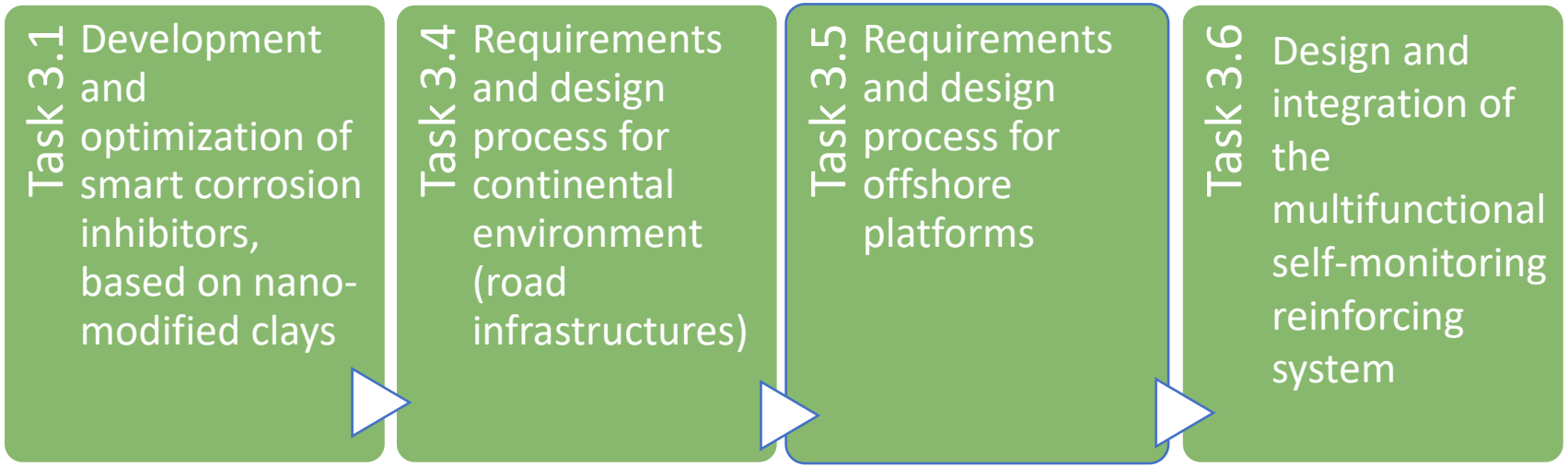
- In May 2019 we achieved the Patent ES2680269 “CONCRETE MIXTURE THAT INCLUDES A LAMINAR CLAY OF CATIONIC EXCHANGE, LAMINAR CLAY OF CATIONIC EXCHANGE AND USE”
- What is CORROLESS?
  - A lamellar clay that comprises an organosilane anchored in its interlaminar space and at least one anionic compound bound to said organosilane by electrostatic forces within the clay interlayer. The clay thus modified is an intermediate compound to be able to insert anions in a matrix with a positive charge with a great exchange capacity that in principle would have admitted cations, such as smectites. The result is that it has the ability to release in a controlled way the corrosion inhibitor anions interspersed between its sheets in response to an increase in the concentration of chloride anions or a decrease in pH in cement-based compositions such as reinforced concrete.



EnDurCrete tasks for IBOX



EnDurCrete tasks for IBOX



Activities were focused on the use of nano-modified clays for the development of inhibitors to be released in cement based materials.

Maximum 1% of cement weight. They will cost 65% less than current commercial solutions and will increase the life time of concrete (or the time corrosion damage takes to appear) up to 3 times according to accelerated tests of potential corrosion, considering as benchmark concrete without inhibitors. The target sale price will be of 2 €/Kg.

Requirements for the additives

Task 3.1 Development and optimization of smart corrosion inhibitors, based on nano-modified clays

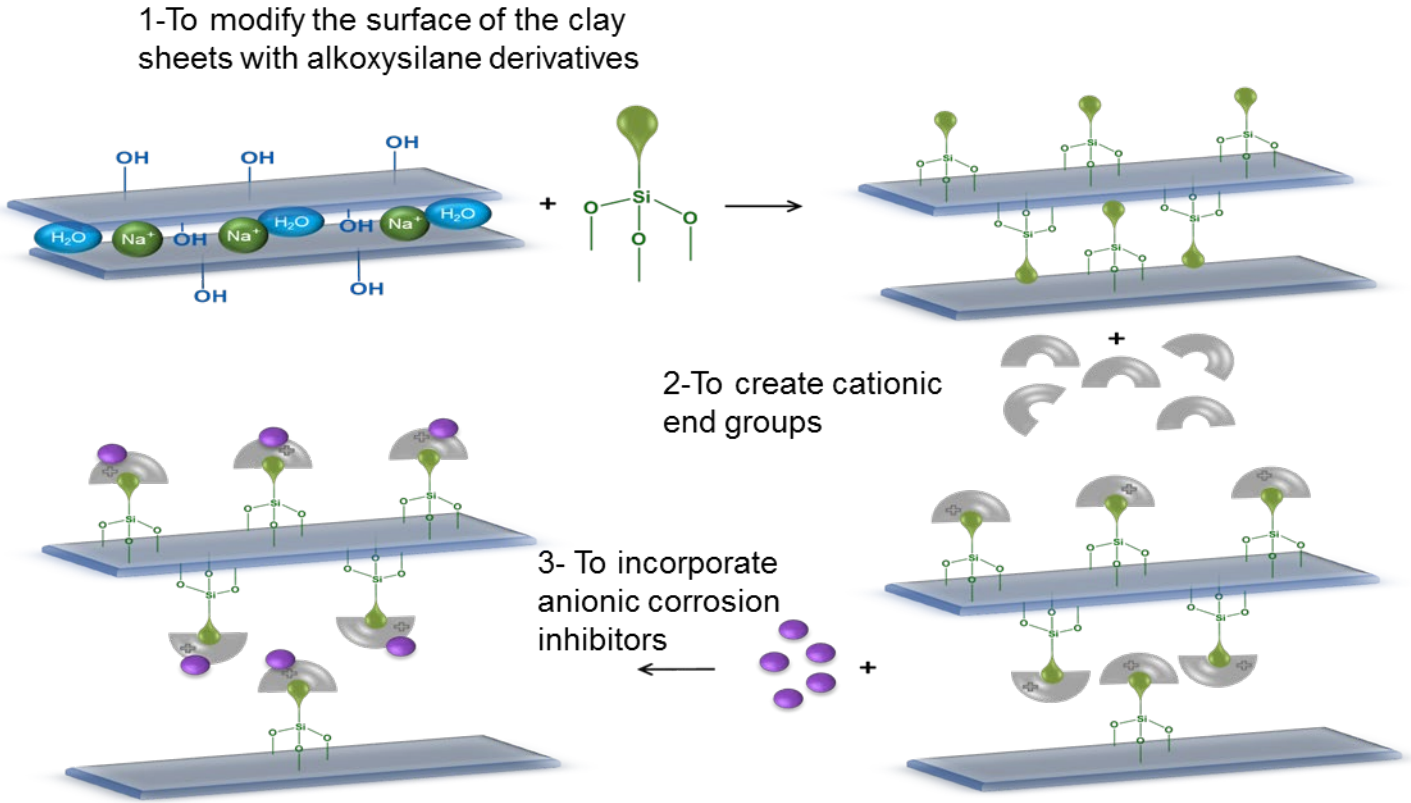
- The rheological behaviour should give an initial slump in the range of 200-210 mm and it should not delay the cement hydration kinetics.

- To be able to scale up the production of the inhibitors in quantities close to the kilogram in one reaction. This was to be able to supply large quantities of product to the project partners in order to carry out the necessary tests and the development of the demonstrators

EnDurCrete tasks for IBOX

- The synthesis of the product implies, in a first step, **modifying the surface of the clay sheets with alkoxysilane derivatives** having cationic end groups. Then, the **anionic corrosion inhibitor is incorporated** and bound through electrostatic interactions to these cationic terminal groups.

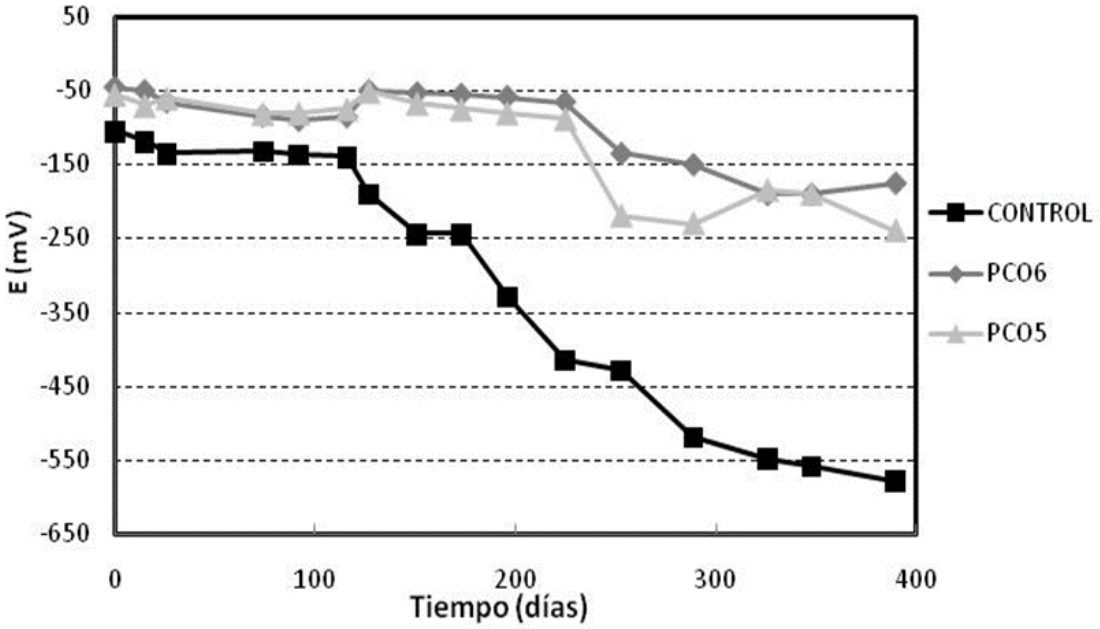
SCHEME OF THE DIFFERENT STEPS FOR THE SYNTHESIS OF SMART CORROSION INHIBITORS



From the Lab….

The technology was already tested in concrete and its anti-corrosion properties were proved. It did not have any negative effect on mechanical resistance and other concrete properties.

Figure shows the corrosion potential determination according to ASTM C 876 (Standard Test Method for Half-Cell Potentials), with prepared specimens immersed in a solution with 5% by weight of sodium chloride to accelerate the corrosion processes.



Concrete specimen without inhibitor additive (CONTROL) and two types of concrete specimens with inhibitory additive based on nanoclays (PC05 and PC06)

Concrete specimen without inhibitor additive (CONTROL) and two types of concrete specimens with inhibitory additive based on nanoclays (PC05 and PC06)

From the Lab….

LAB TESTED IN CONCRETE proved the anti-corrosion properties of this technology, with no negative effect on mechanical resistance and other concrete properties

… to preparation of inhibitors

1. To optimise the proportions of modifier and corrosion inhibitor to fit to the concrete requirement and not modify the hydration kinetics of cement.

2. To control the release of inhibitor anion as a function of changes in environmental conditions, such as reducing the pH or increasing the chloride concentration.

3. To maintain the corrosion intensity at very small values during electrochemical studies in solution even when the concentration of chlorides in the alkaline solution is high.

- Following the indications of SIKA and modifying the quantities of reagents to be used, reducing the amount of modifier alkoxysilane and anion inhibitor of corrosion it was prepared PC5 product, that did not affect (delay) the hydration kinetics of the cement The organic dosage (corrosion inhibitor anion) of the sample PC5 is about 45 % by weight.

- Achieved the scaling-up of the production of the corrosion inhibitor, reaching in a single synthesis almost 1 kg of product.

- Release assays were carried out in aqueous solution, the ability to release the inhibitor anion in a controlled manner in connection with environmental conditions, such as reducing the pH of the concrete or increasing the chloride concentration, were confirmed.

- The ability of these products to maintain the corrosion intensity at very small values during electrochemical studies in solution was also been confirmed in aqueous environment.

… to the Pilot Scale

Task 6.2 Prototyping, demonstration and performance validation in a maritime port in Spain

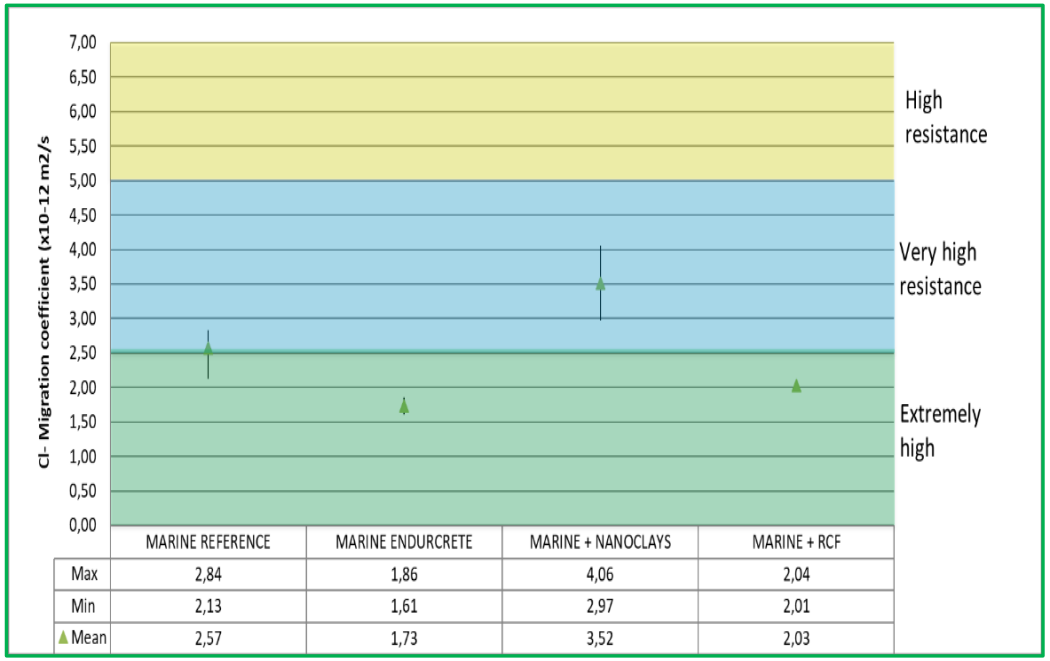
Spray (XS1)

Tidal (XS3)

Submerged XS2)

Pilot scale: Prototyping, demonstration and performance validation in marine port in Spain

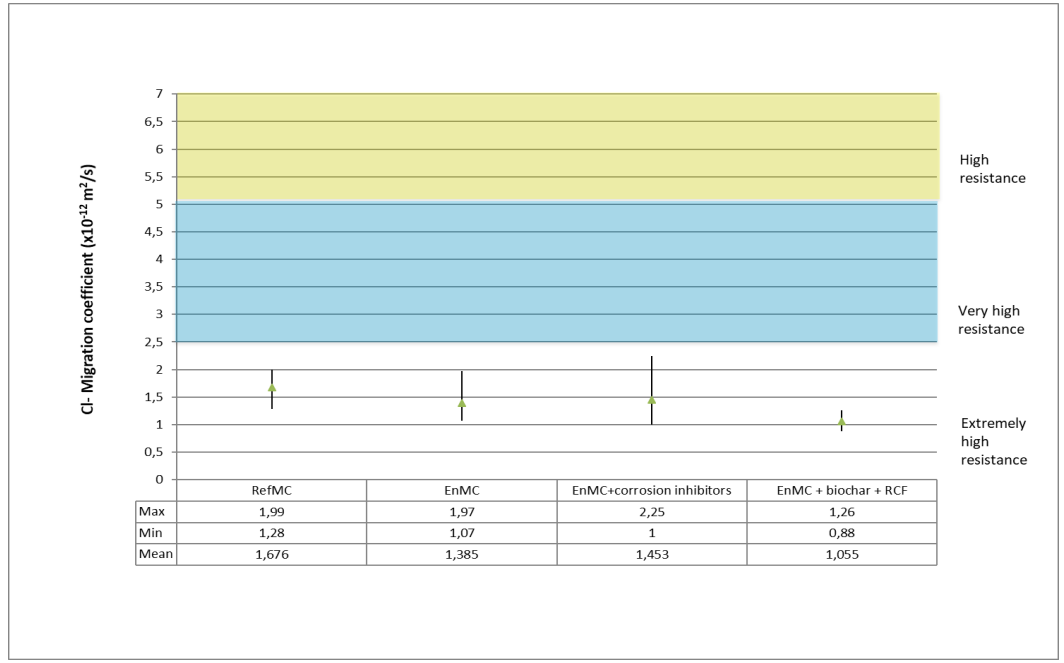
6 Month



	MARINE REFERENCE	MARINE ENDURCRETE	MARINE + NANOCLAYS	MARINE + RCF
Max	2,84	1,86	4,06	2,04
Min	2,13	1,61	2,97	2,01
Mean	2,57	1,73	3,52	2,03

Non-steady state chloride migration coefficient

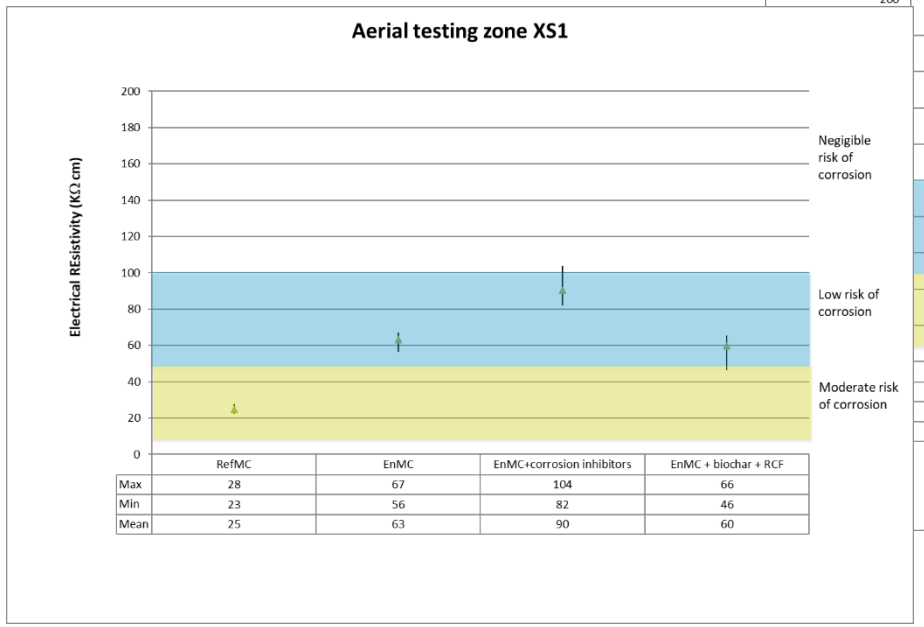
12 Month



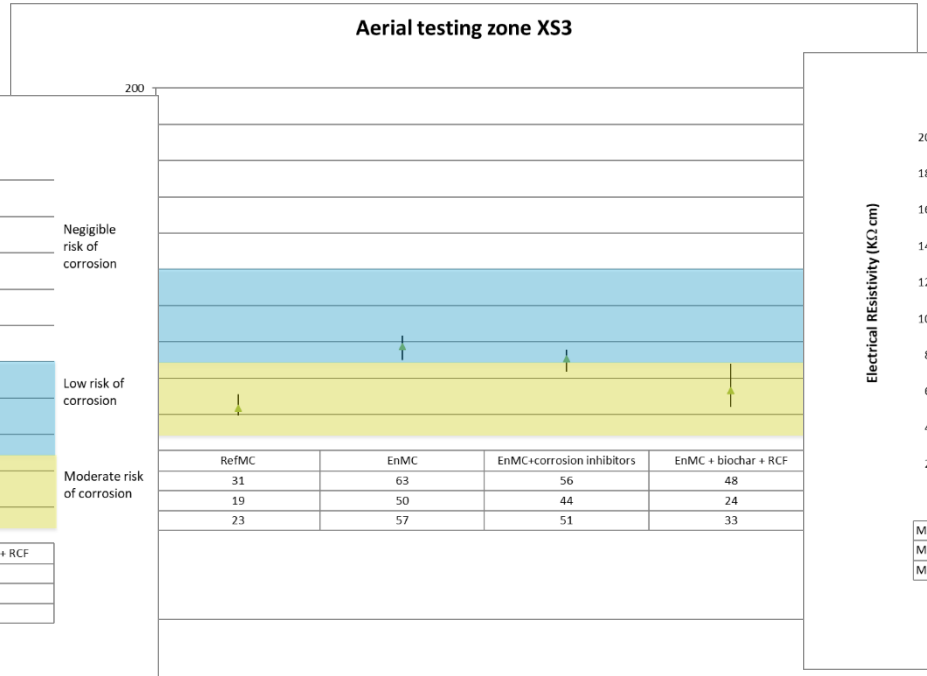
	RefMC	EnMC	EnMC+corrosion inhibitors	EnMC + biochar + RCF
Max	1,99	1,97	2,25	1,26
Min	1,28	1,07	1	0,88
Mean	1,676	1,385	1,453	1,055

Pilot scale: Prototyping, demonstration and performance validation in marine port in Spain

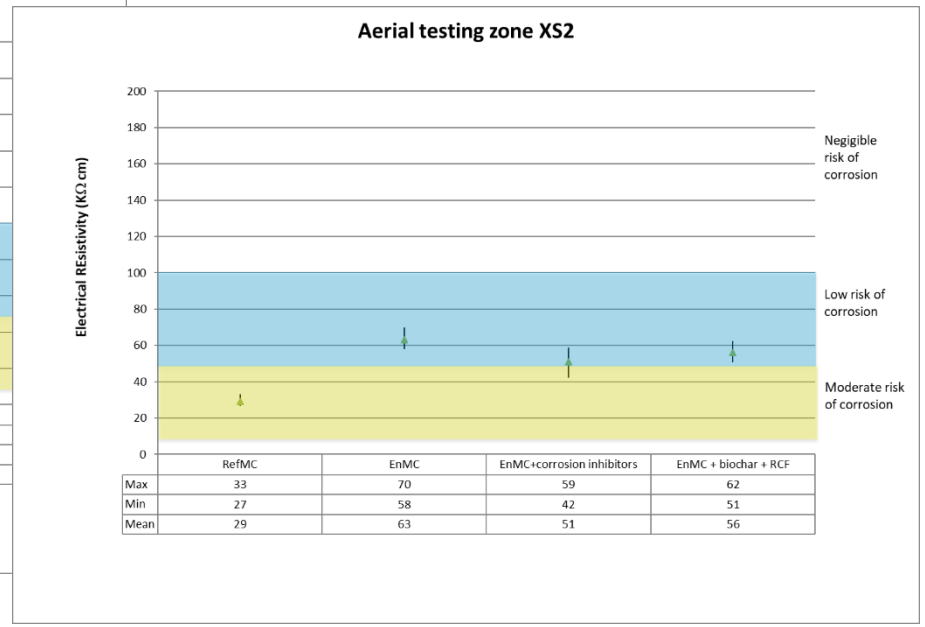
12 Month



Electrical resistivity on aerial testing zone samples



Electrical resistivity on tidal testing zone samples



Electrical resistivity on submerged testing zone samples

Carbon based additions for self-sensing concrete

SPEAKER

ENDURCRETE

FRANCESCA TITTARELLI

Professor of Materials Science and Technology
at Università Politecnica delle Marche

Francesca Tittarelli, UNIVPM

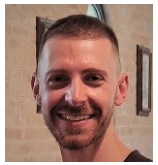
Ancona - 43°37’N 13°31’E

Ancona - 43°37’N 13°31’E

Department of Industrial Engineering and Mathematical Sciences - DIISM

Mechanical and Thermal Measurements Group (MTM)

Prof. Gian Marco Revel
Coordinator of ECTP Materials and Sustainability Committe



Prof. Paolo Chiariotti

Gloria Cosoli

Giuseppe Pandarese

Nicola Giulietti

Ancona - 43°37'N 13°31'E

Department of Industrial Engineering and Mathematical Sciences - DIISM

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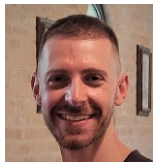


Prof. Paolo Chiariotti

Gloria Cosoli

Giuseppe Pandarese

Nicola Giulietti

Department of Materials, Environmental Sciences and Urban Planning - SIMAU

Materials Group

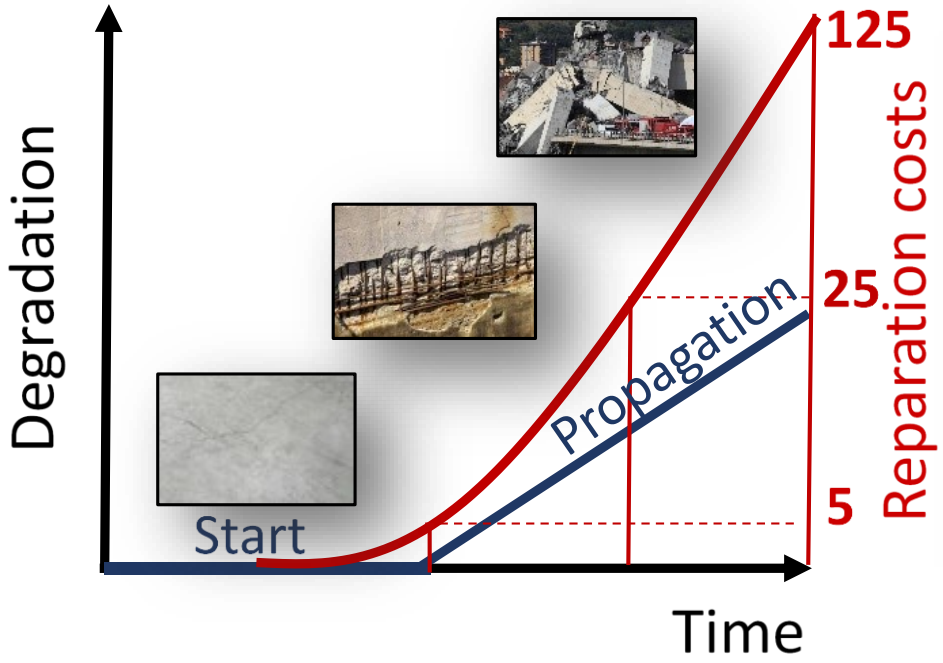
Prof. Francesca Tittarelli

Alessandra Mobili

Prof. Tiziano Bellezze

CHALLENGE

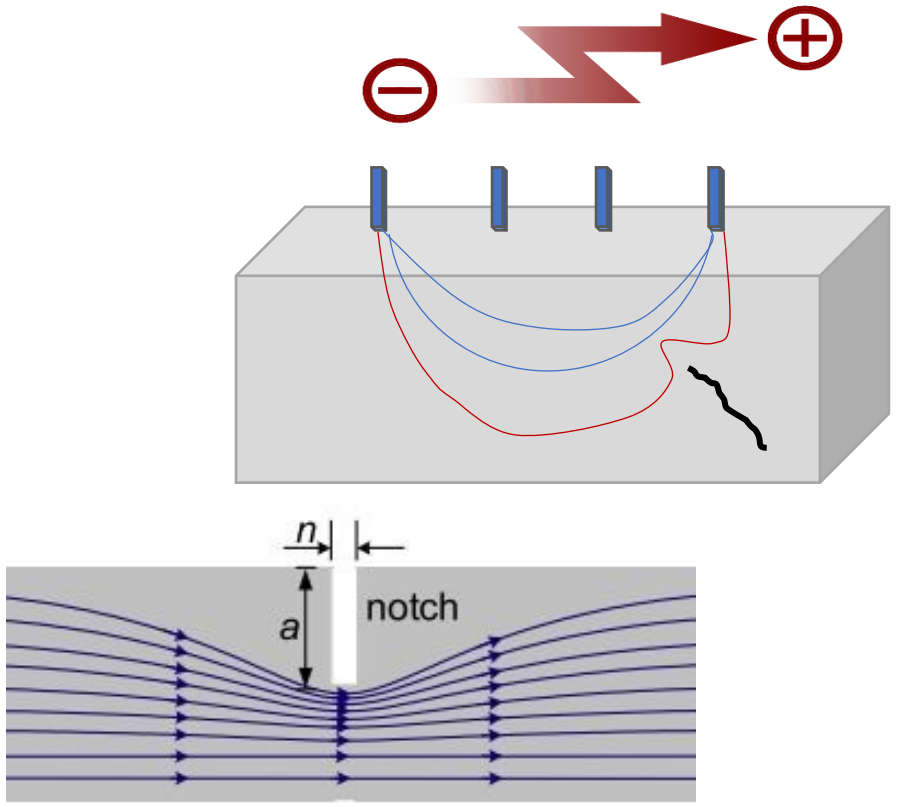
De Sitter Jr., W.R., Costs for Service Life Optimisation, the Law of Fives



Collapse of the Morandi Bridge, August 14th 2018, Genova, Italy

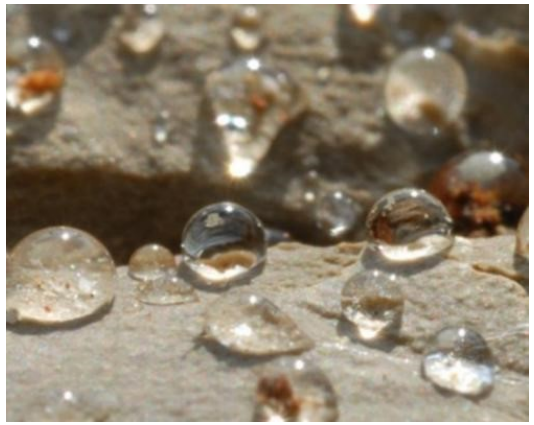
CONTINUOUS MONITORING

SELF-SENSING CONCRETE

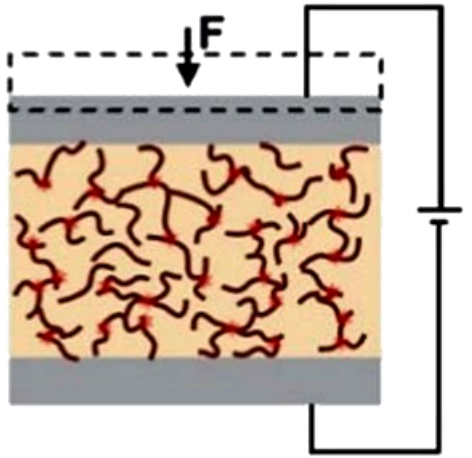


✓ Cracking

Self-sensing is the ability of a material to perceive its own condition, as

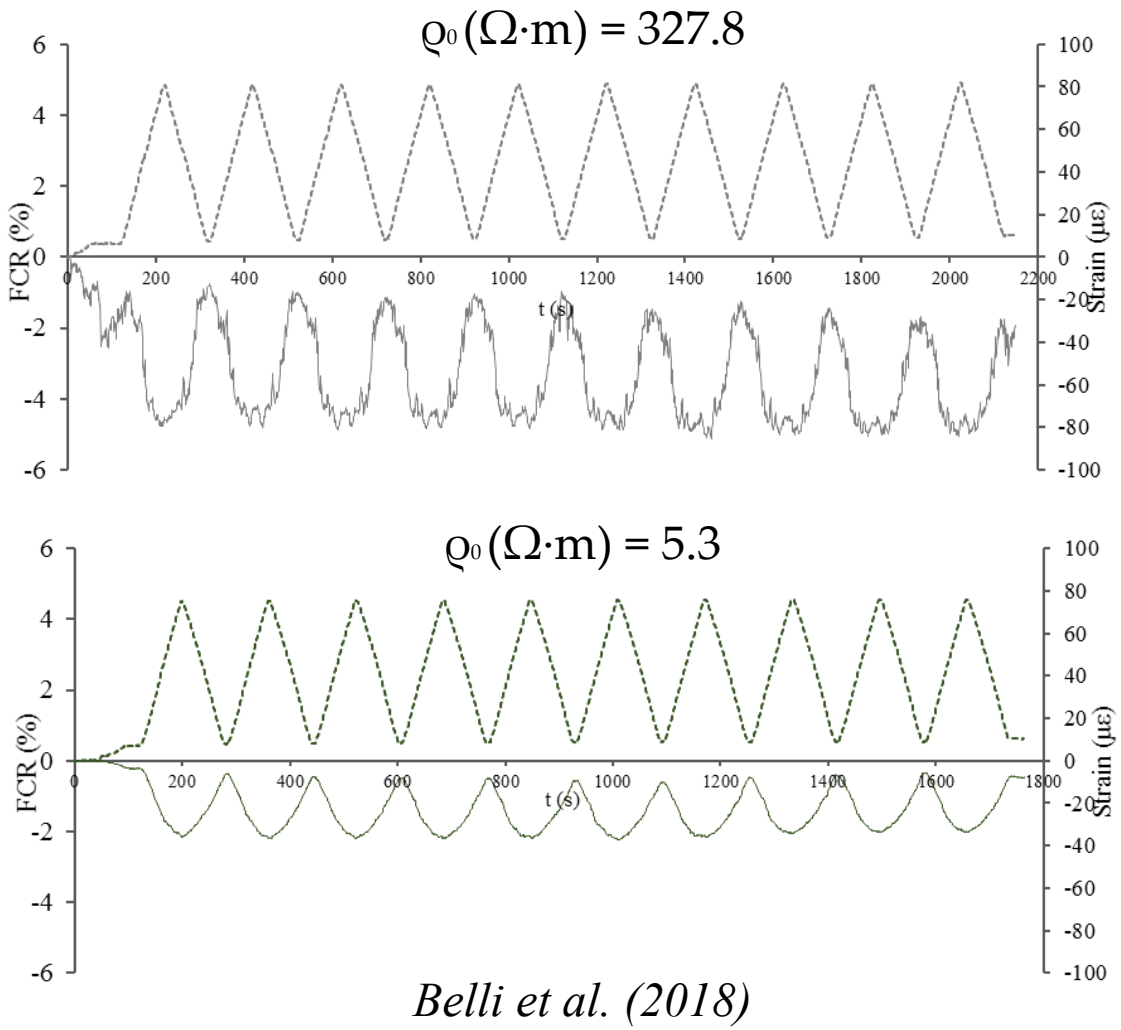


✓ Water/Aggressive substances penetration

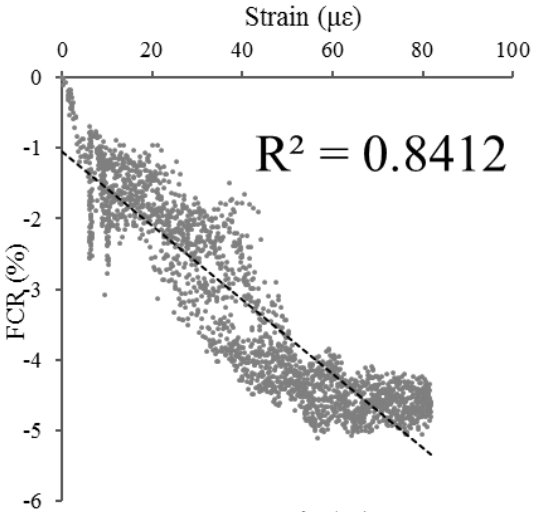


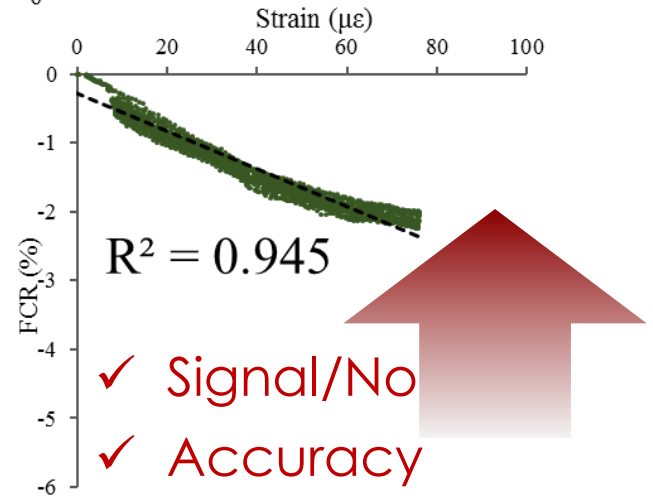
✓ Strain

SELF-SENSING CONCRETE



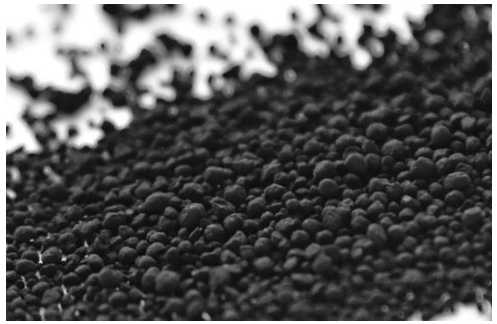
Belli et al. (2018)



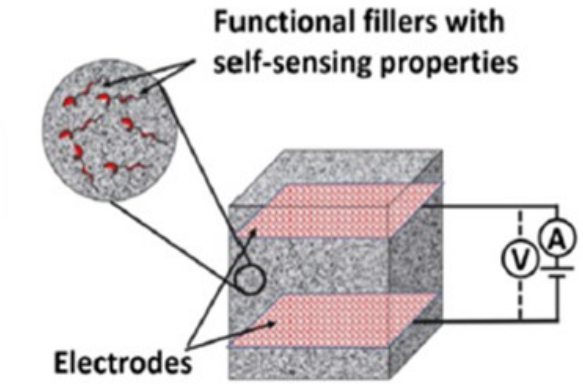


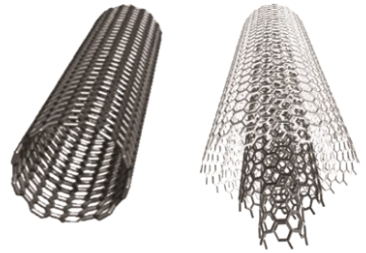
- ✓ Signal/No
- ✓ Accuracy
- ✓ Low-cost instrumentation

Commercial additions for self-sensing concrete

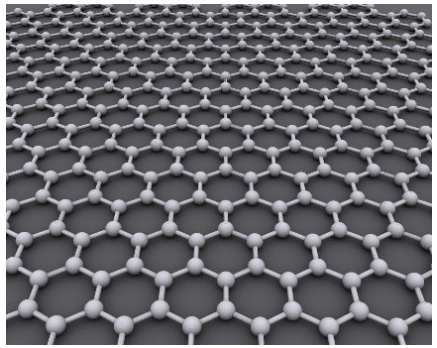


Carbon black



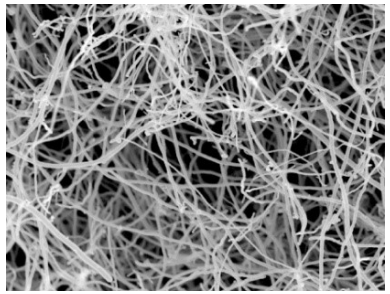


Carbon Nananotubes



Graphene

High Electrical Conductivity

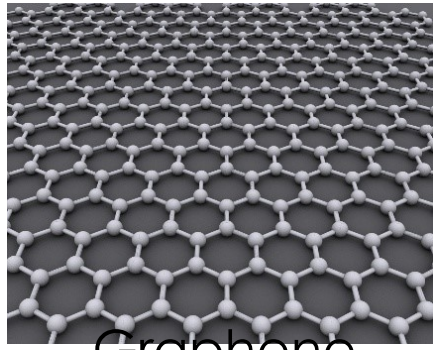


Carbon Nanofibers

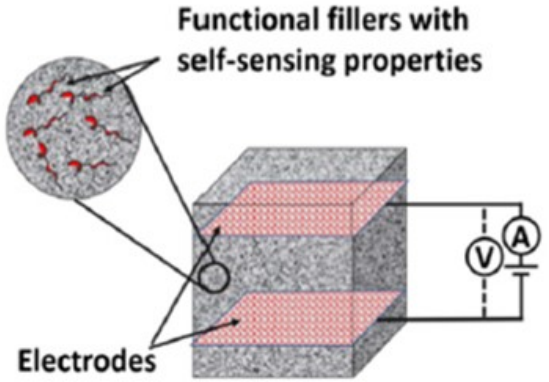
Commercial additions for self-sensing concrete

Carbon black

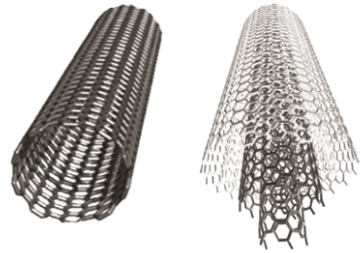
High Cost



Graphene

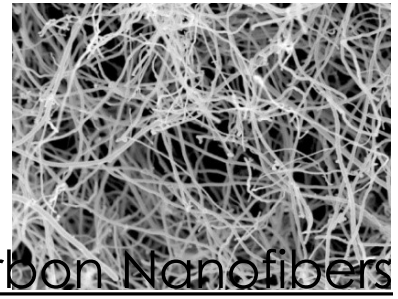


High Electrical Conductivity



Carbon Nananotubes

High Toxicity

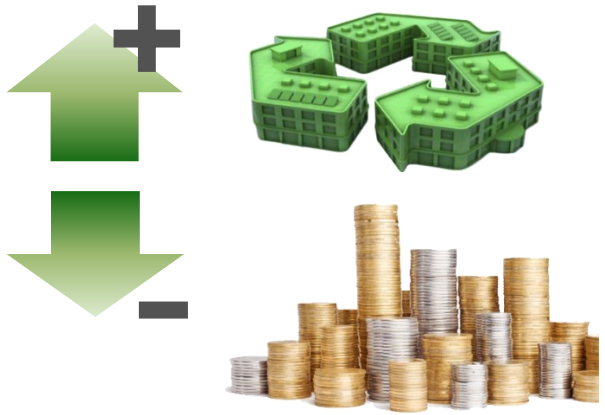


Carbon Nanofibers

Innovative carbon-based additions for self-sensing concrete

CARBON BASED ADDITIONS

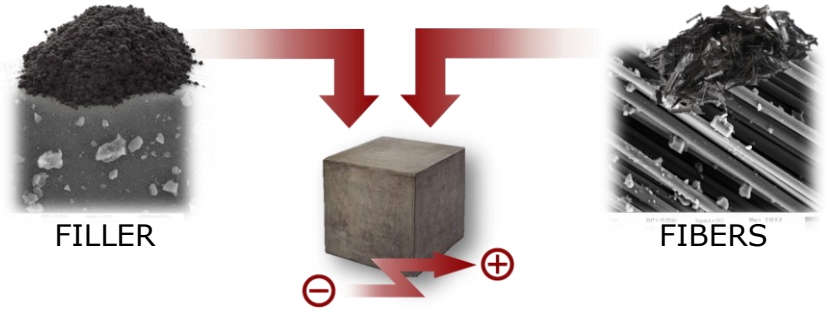
INDUSTRIAL BY-PRODUCTS

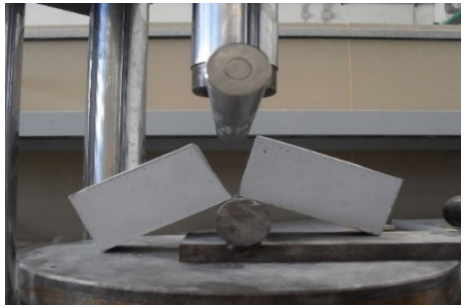


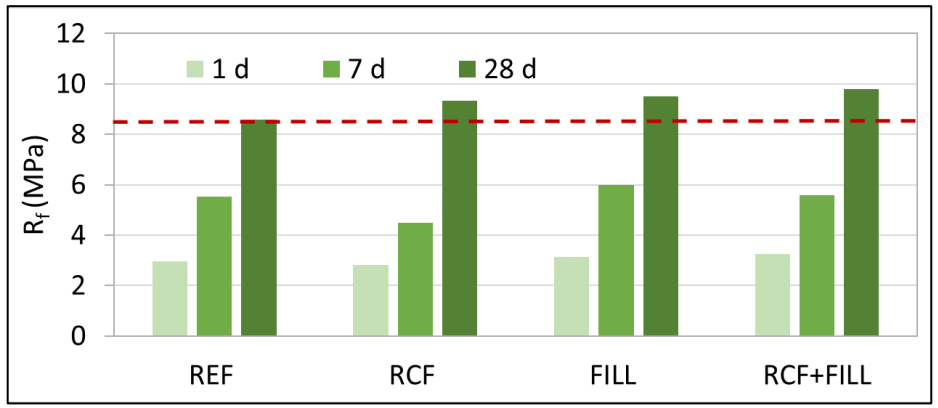
✓ BIOCHAR

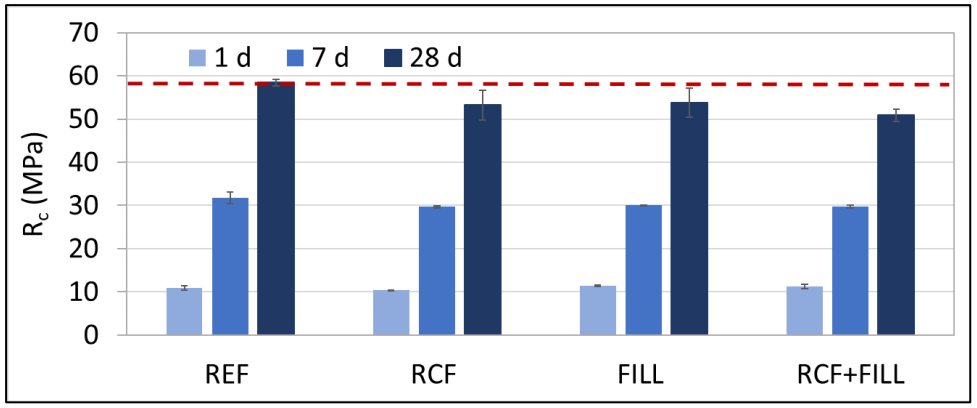
✓ RECYCLED CARBON FIBERS

Mechanical performances

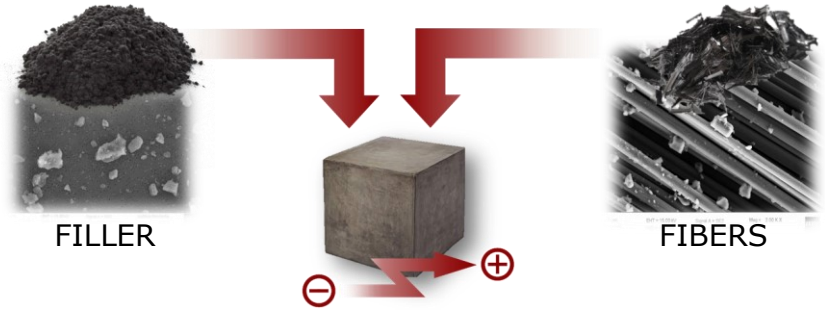


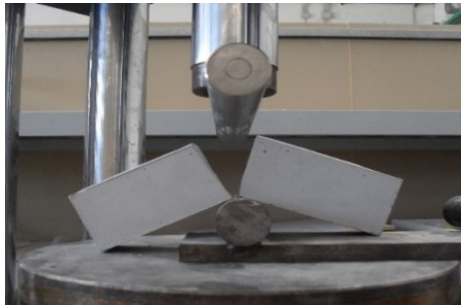


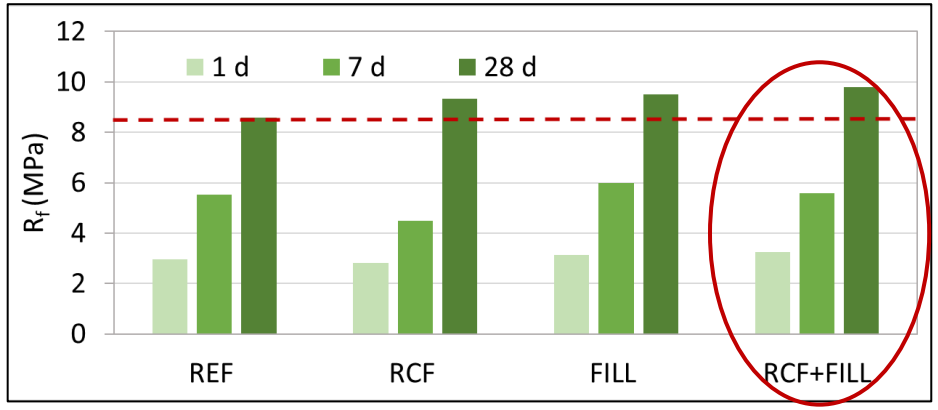


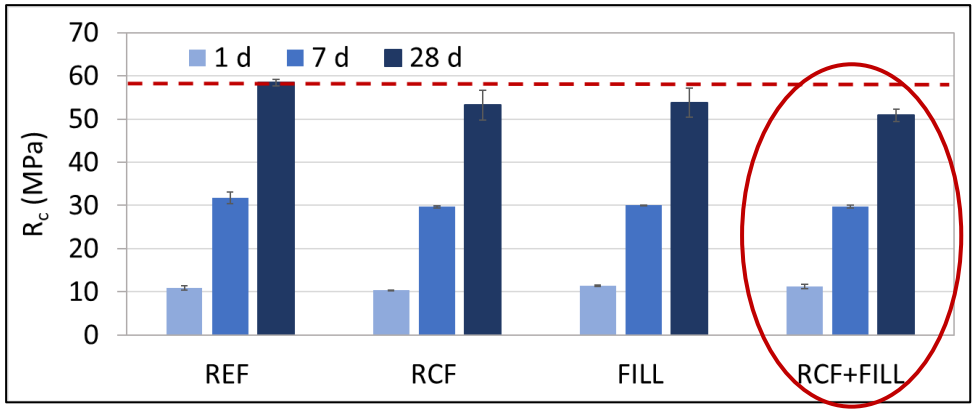


Mechanical performances

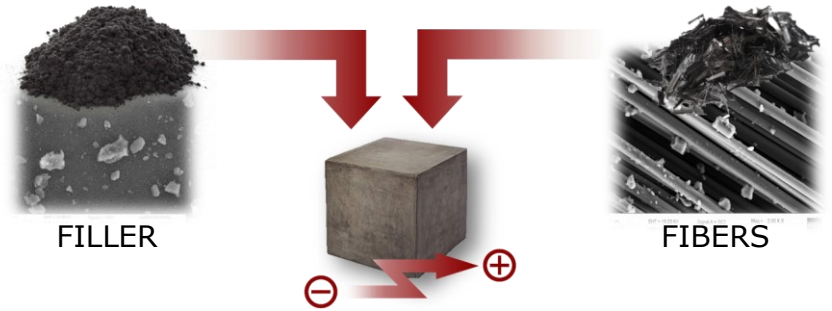


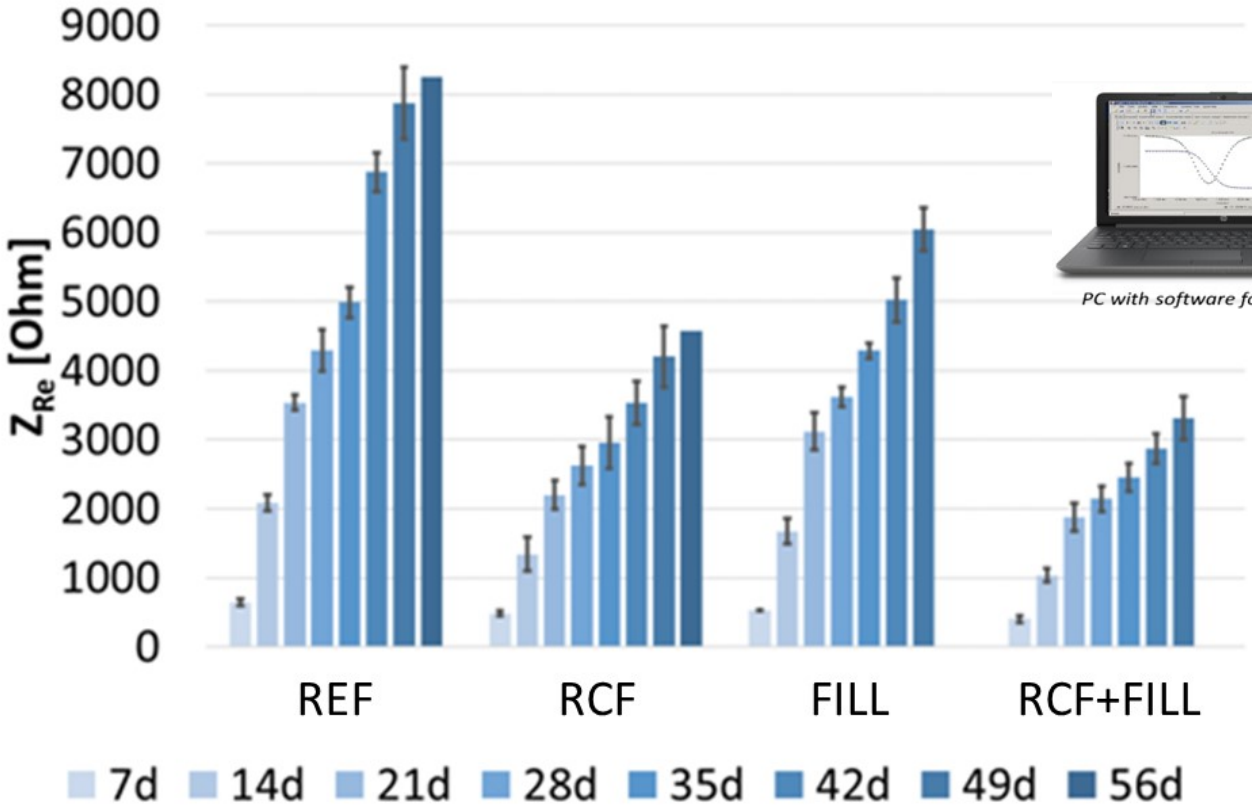






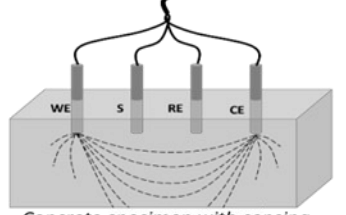
Electrical performances





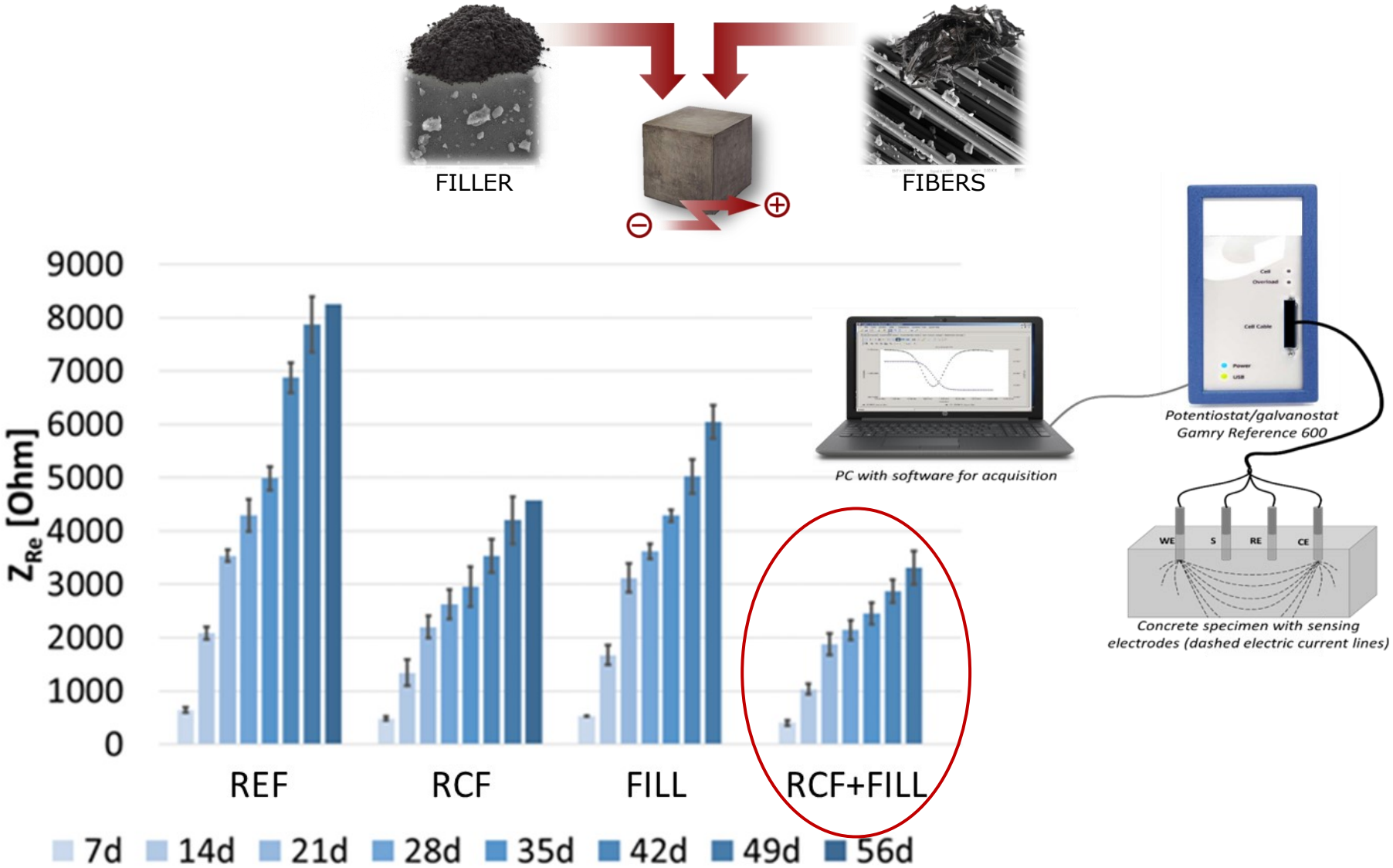
PC with software for acquisition


Potentiostat/galvanostat
Gamry Reference 600

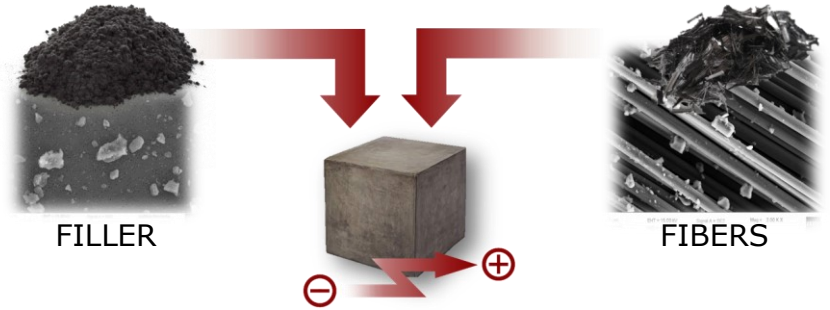


Concrete specimen with sensing electrodes (dashed electric current lines)

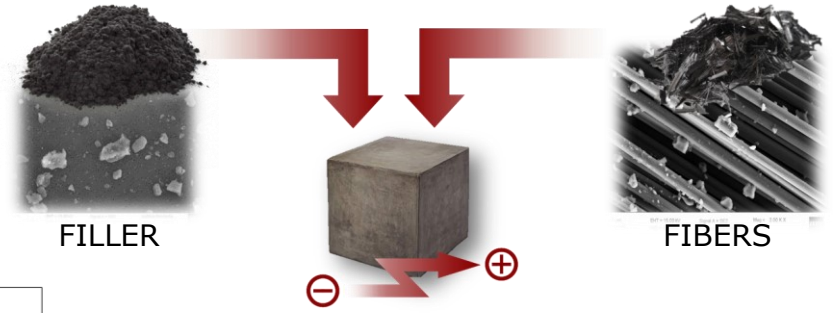
Electrical performances

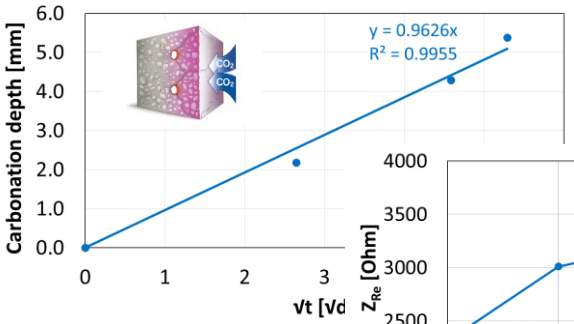


Self-sensing performances

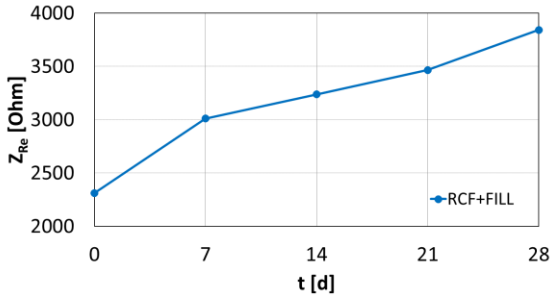


Self-sensing performances

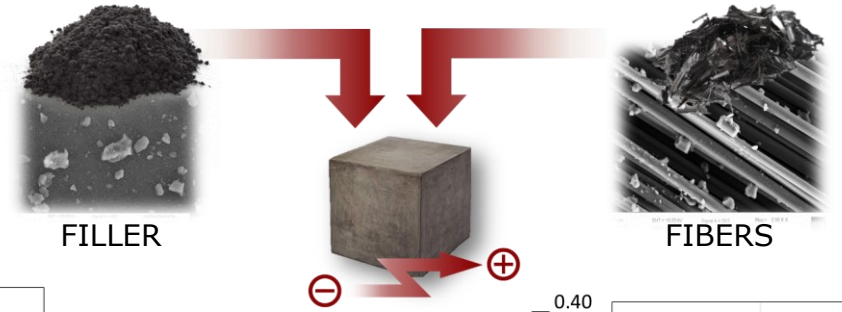


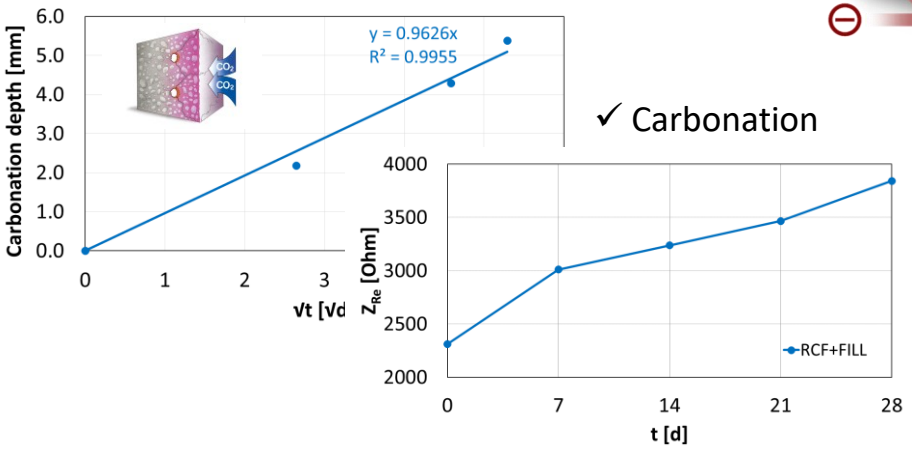


✓ Carbonation

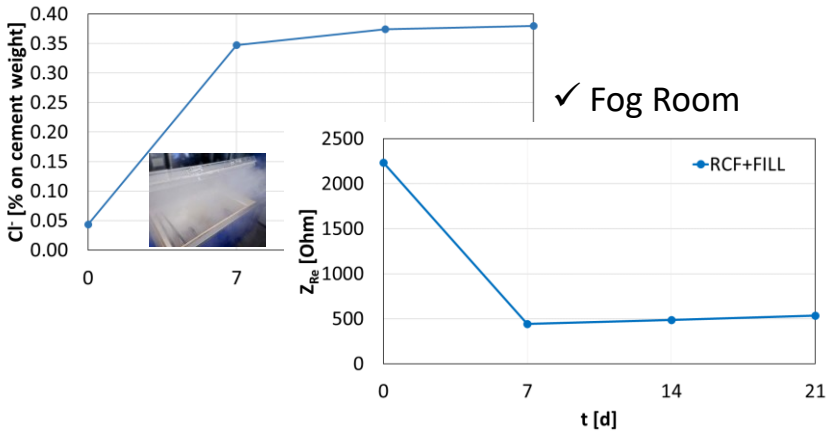


Self-sensing performances



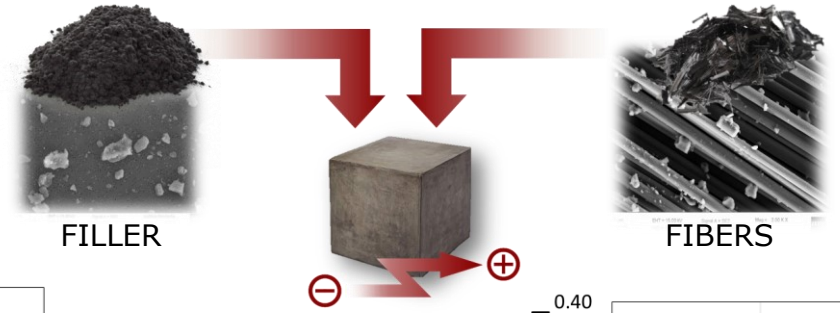


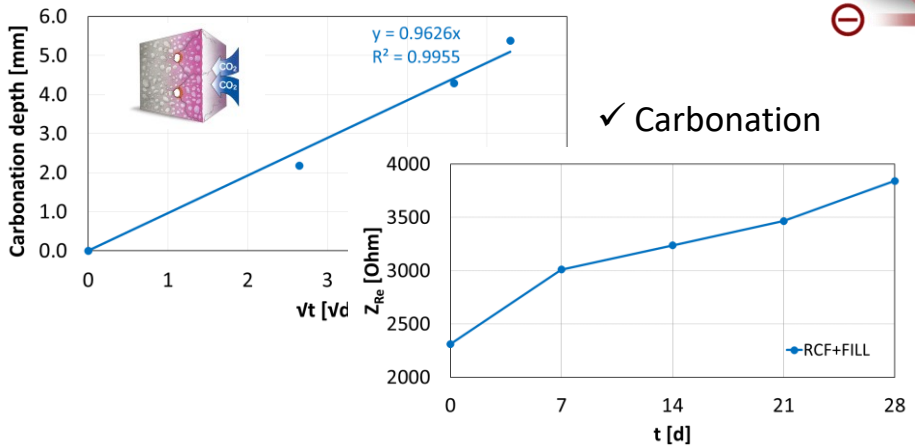
✓ Carbonation



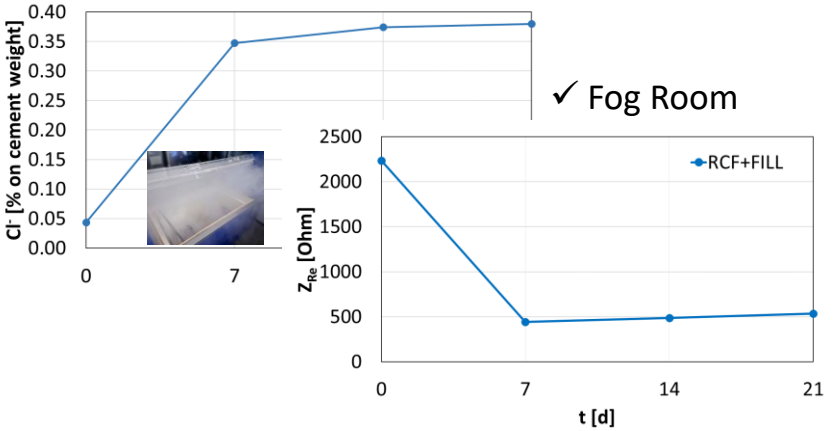
✓ Fog Room

Self-sensing performances

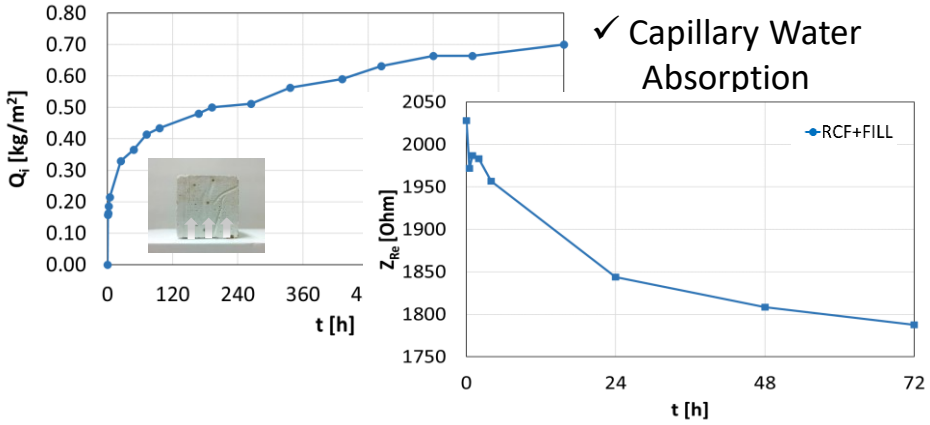




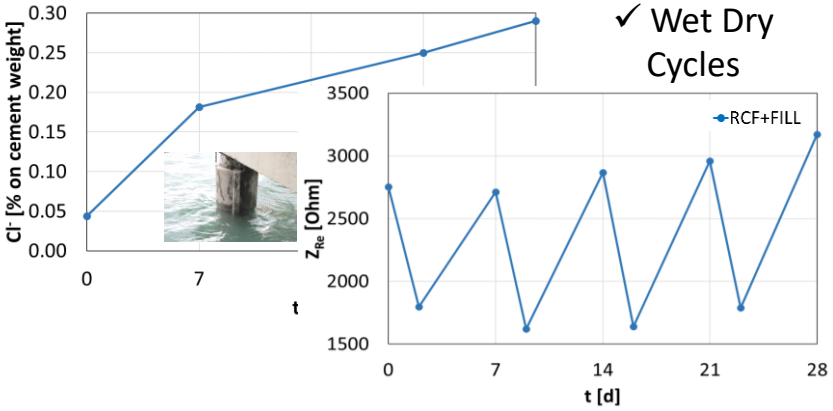
✓ Carbonation



✓ Fog Room

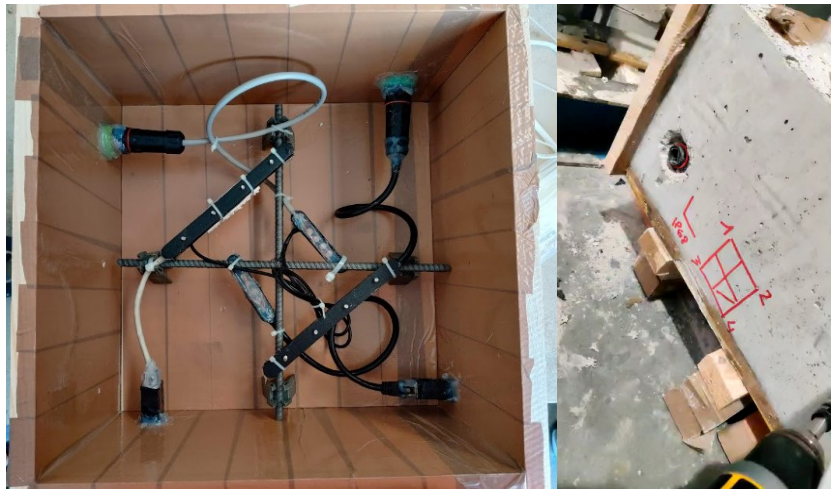


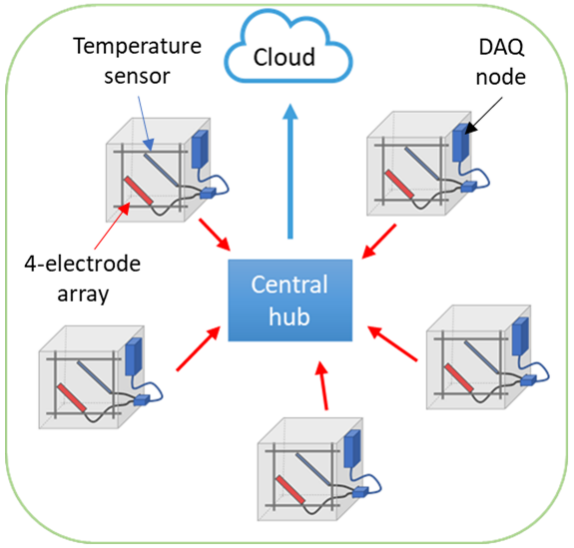
✓ Capillary Water Absorption



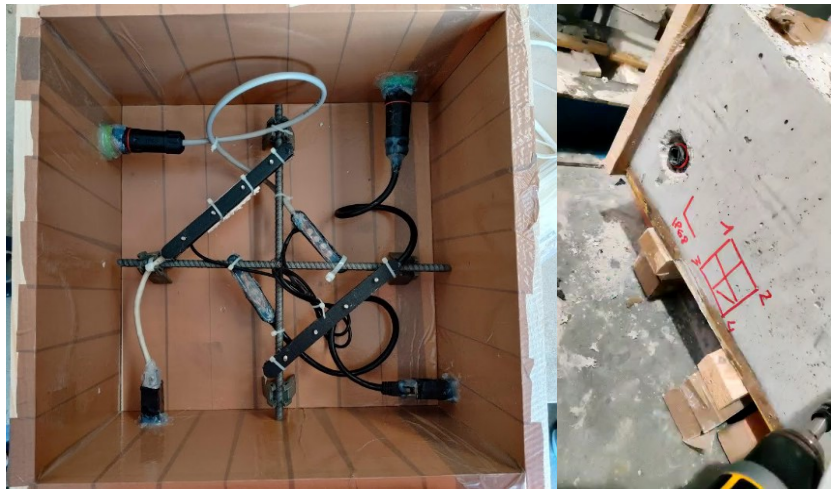
✓ Wet Dry Cycles

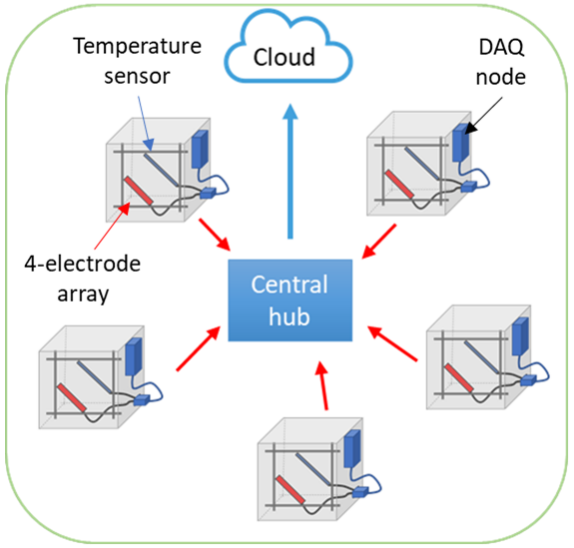
Monitoring system by self-sensing concrete blocks

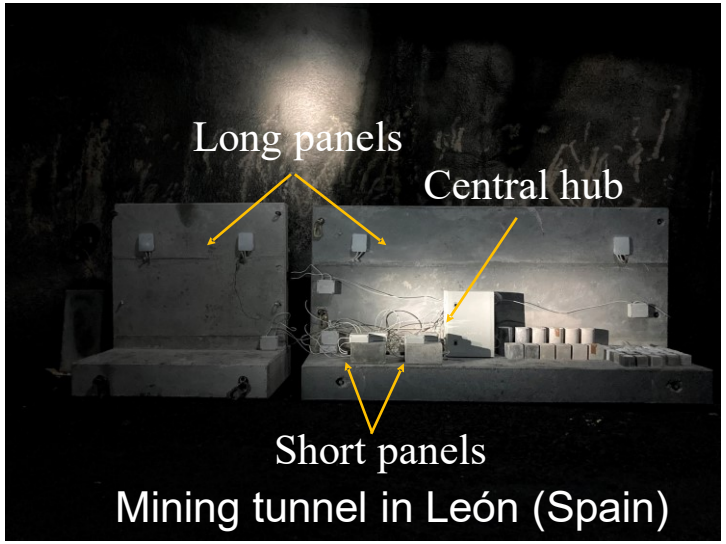




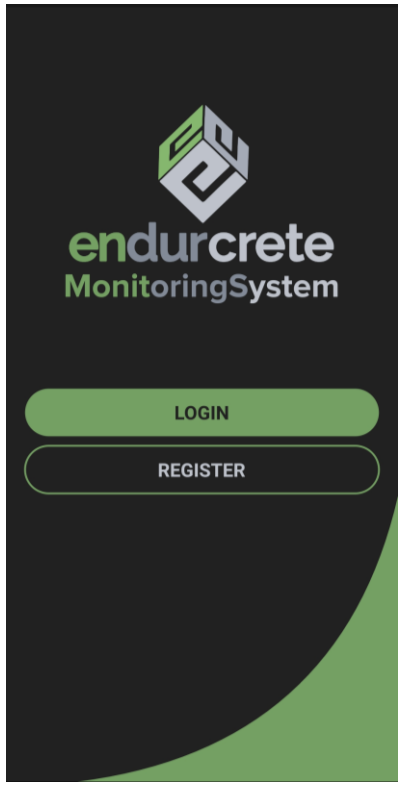
Monitoring system by self-sensing concrete blocks





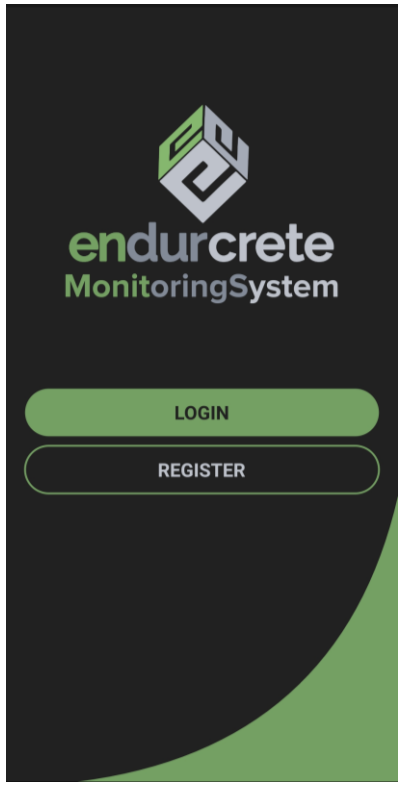


Monitoring system by self-sensing concrete blocks: Mobile Application



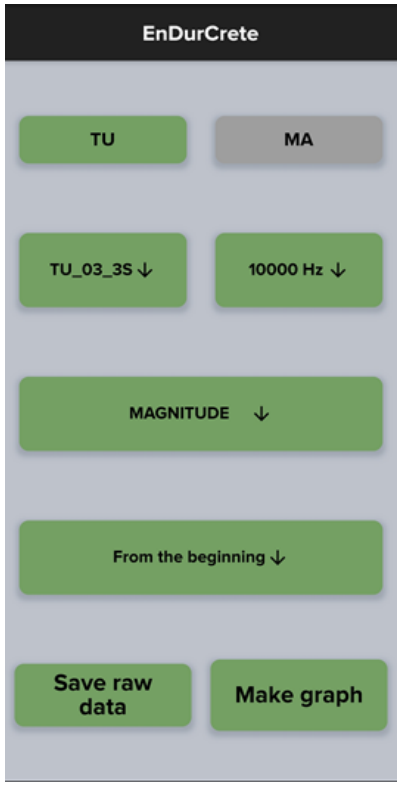
Home Page

Monitoring system by self-sensing concrete blocks: Mobile Application

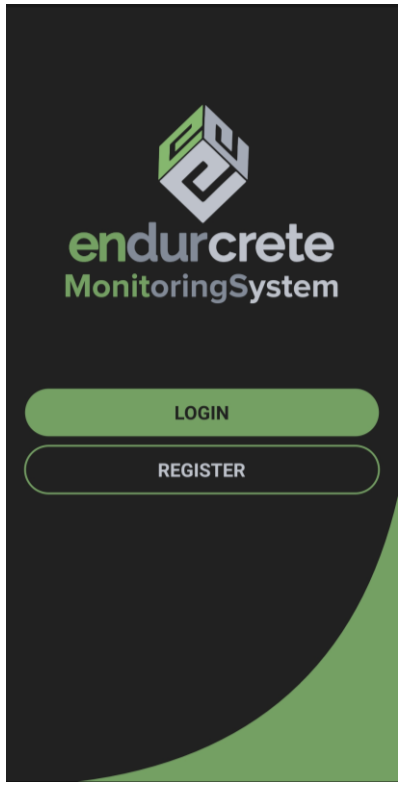


Home Page

Parameter Selection



Monitoring system by self-sensing concrete blocks: Mobile Application



Home Page

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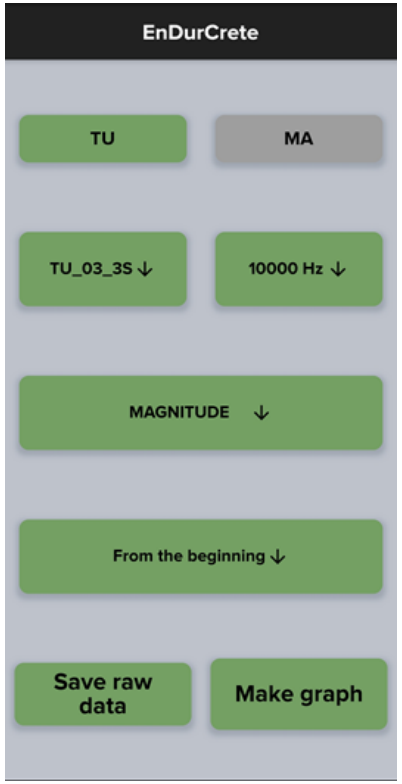
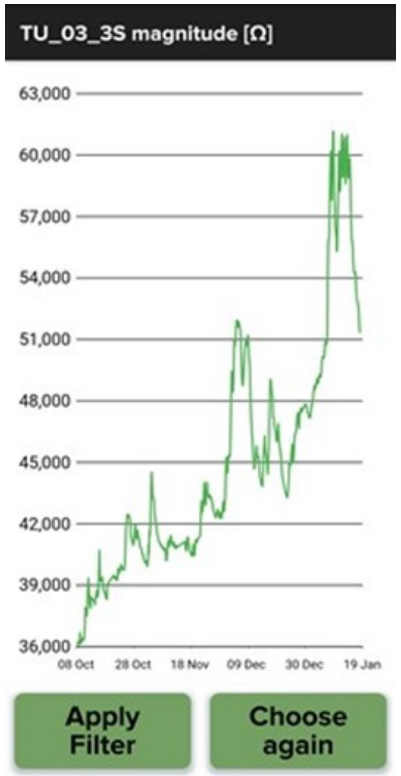
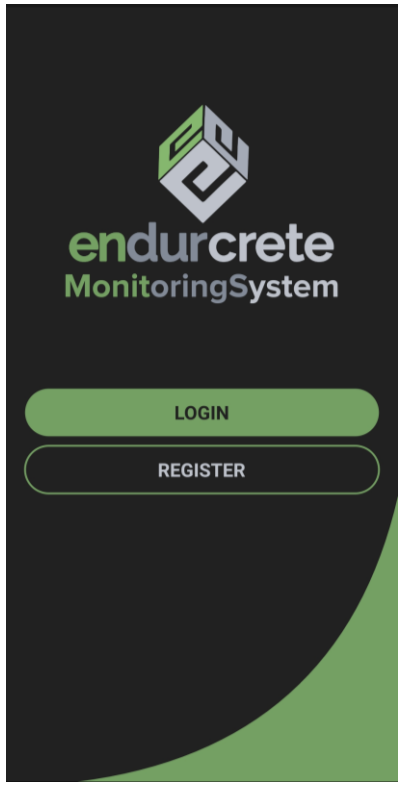




Graph over time

Monitoring system by self-sensing concrete blocks: Mobile Application



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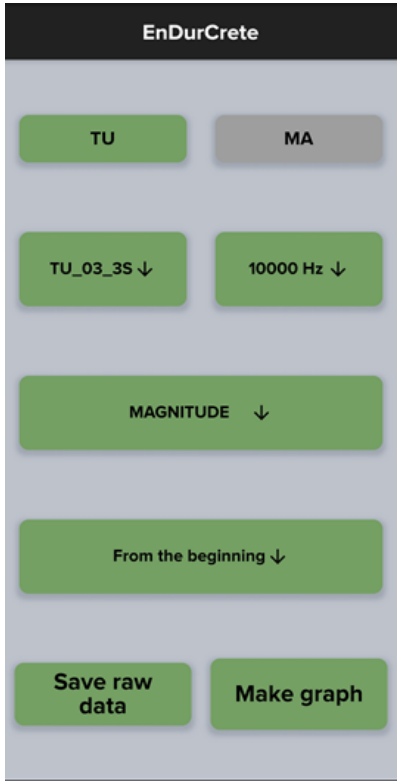
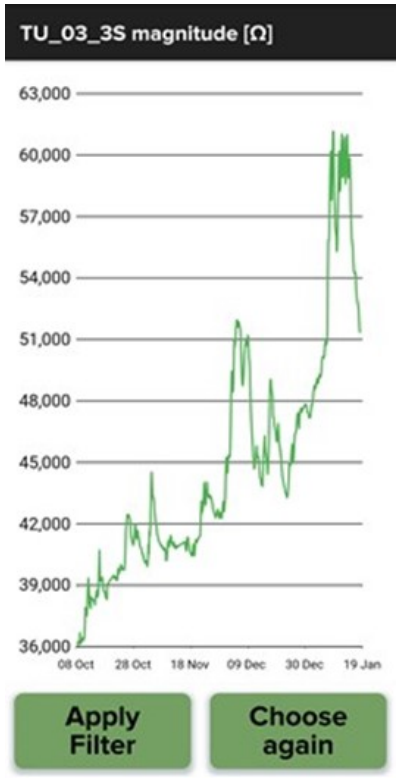
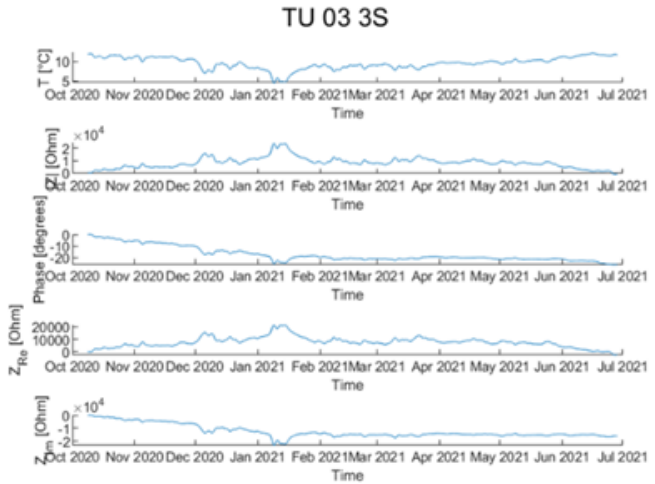
Parameter Selection

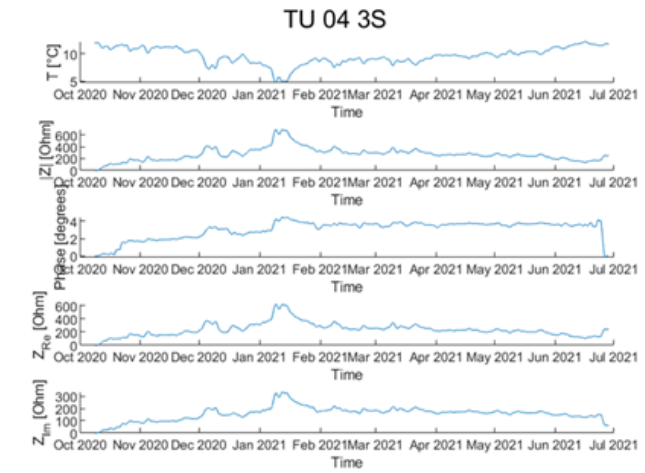




Graph over time

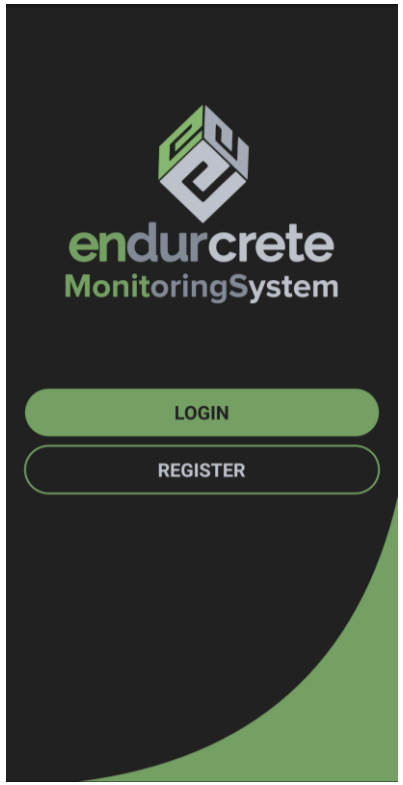


without conductive additions



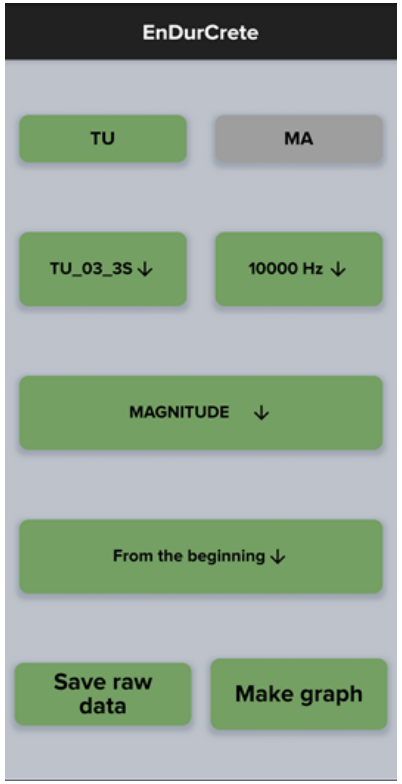
with conductive additions

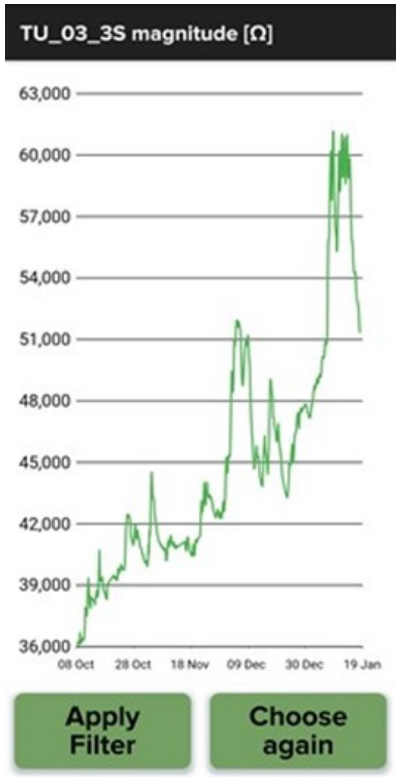
Monitoring system by self-sensing concrete blocks: Mobile Application



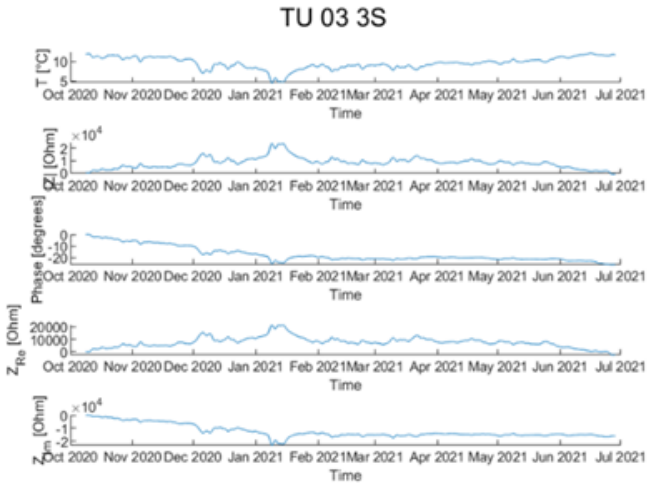
Home Page

Parameter Selection

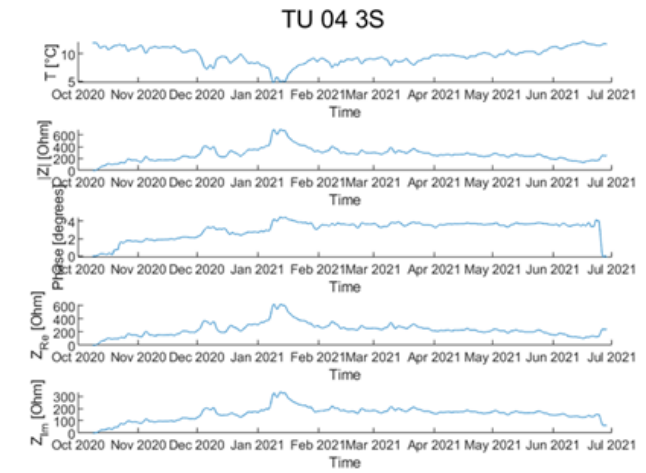




Graph over time



without conductive additions



with conductive additions

Main outcomes:

- ✓ signals measured in the panels with conductive additions have a higher SNR with respect to those measured in the panels without additions
- ✓ the monitoring system did not show any faults during the demo test activities
- ✓ data were not affected by any issues attributable to the aggressive exposure

Textile Reinforced Concrete panels sensorized with distributed Fiber Optic Sensors

SPEAKER

ENDURCRETE

PAOLO ANTONIO CORVAGLIA

Project Manager and Research Coordinator at Rina Consulting

Paolo Corvaglia/Rina Consulting S. p. A.

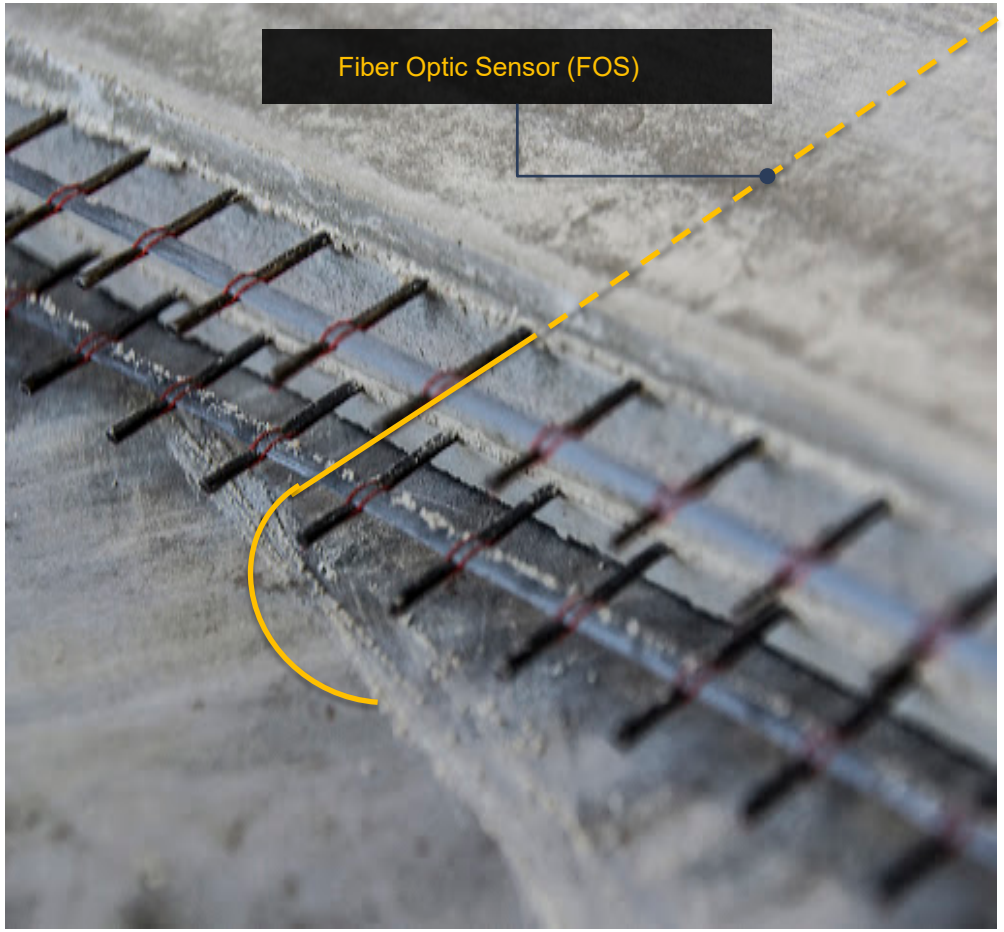
Background and concept

Textile-Reinforced Concrete (TRC)

TRC is an innovative cement-based composite material, taking advantage of the non-corrosive nature of fiber materials (such as AR-glass, carbon, or aramid) for realizing slender and durable concrete structural elements.

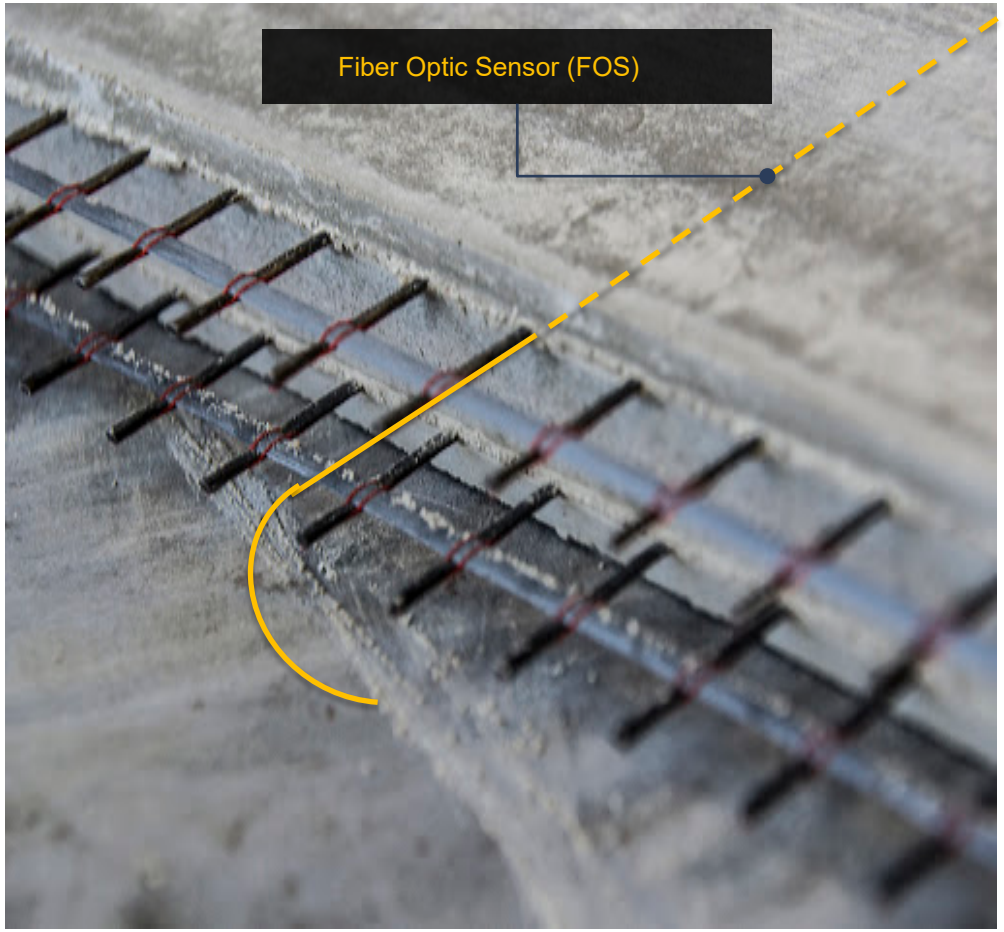
Background and concept

Sensorized Textile-Reinforced Concrete (TRC)



Background and concept

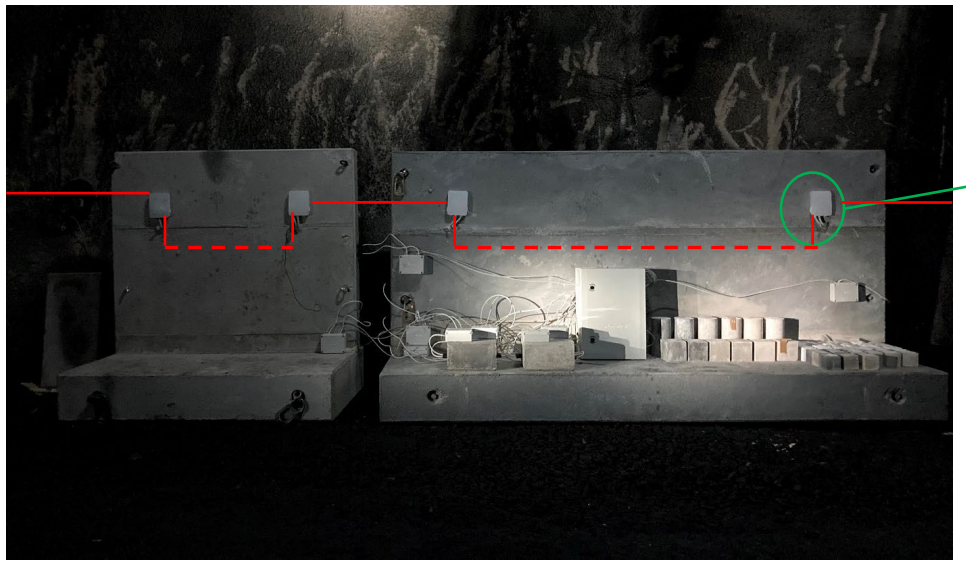
Sensorized Textile-Reinforced Concrete (TRC)

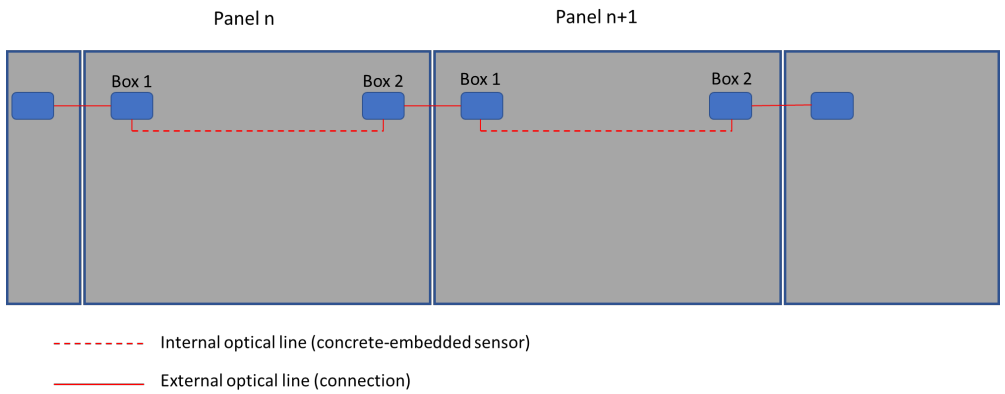


Built-in structural monitoring capability

Background and concept

Sensorized Textile-Reinforced Concrete (TRC): modular solution

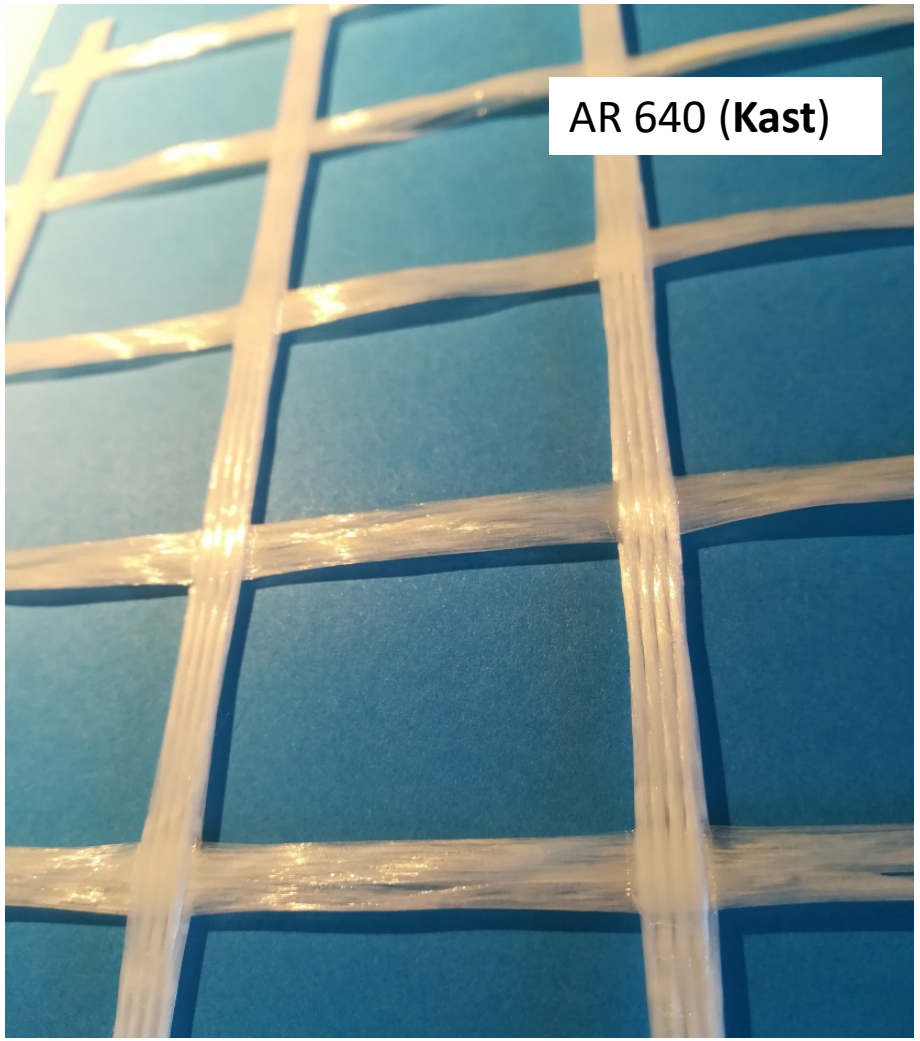




Textile and sensors

Textile

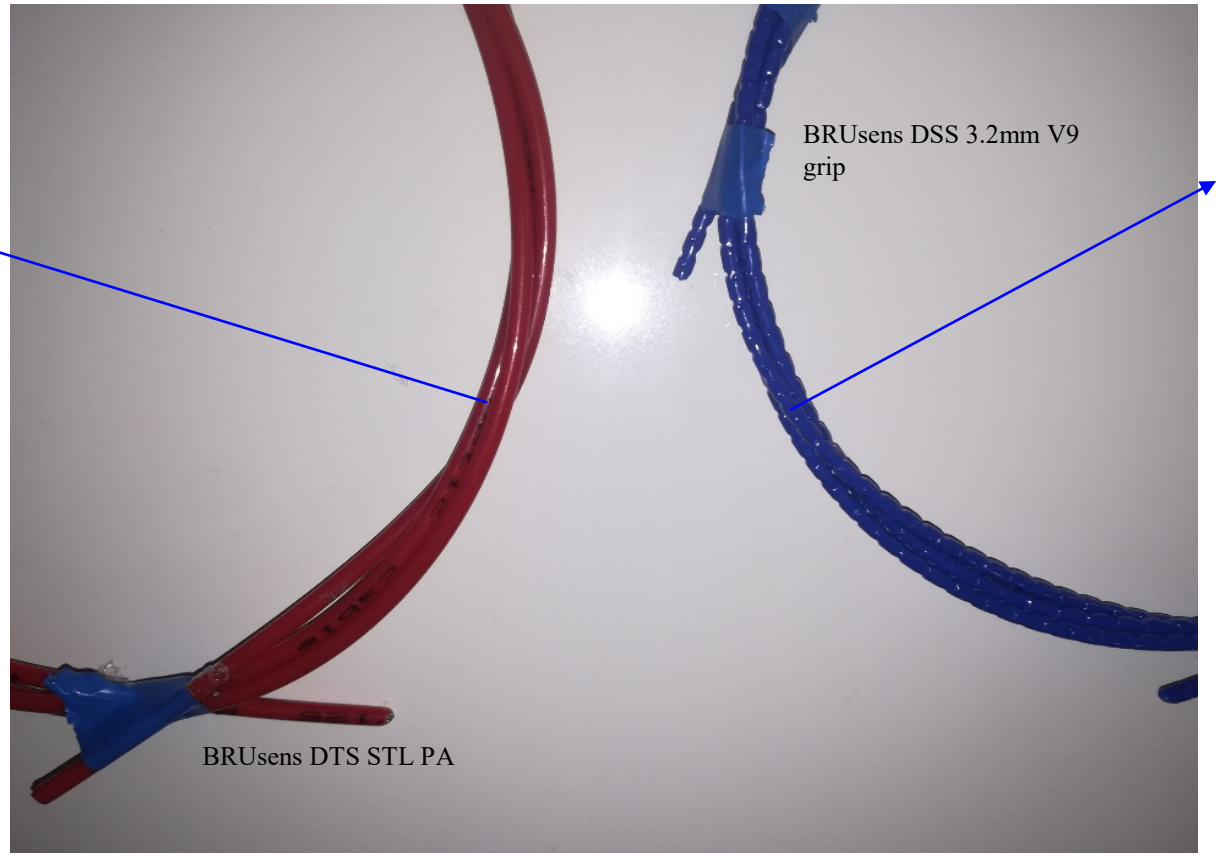
- Fibers material: AR-glass
- Textile structure:
  - Leno woven fabric
  - Mesh opening 3cm x 3cm
  - SBR coating



Textile and sensors

Sensor system

strain insensitive cable for thermal compensation

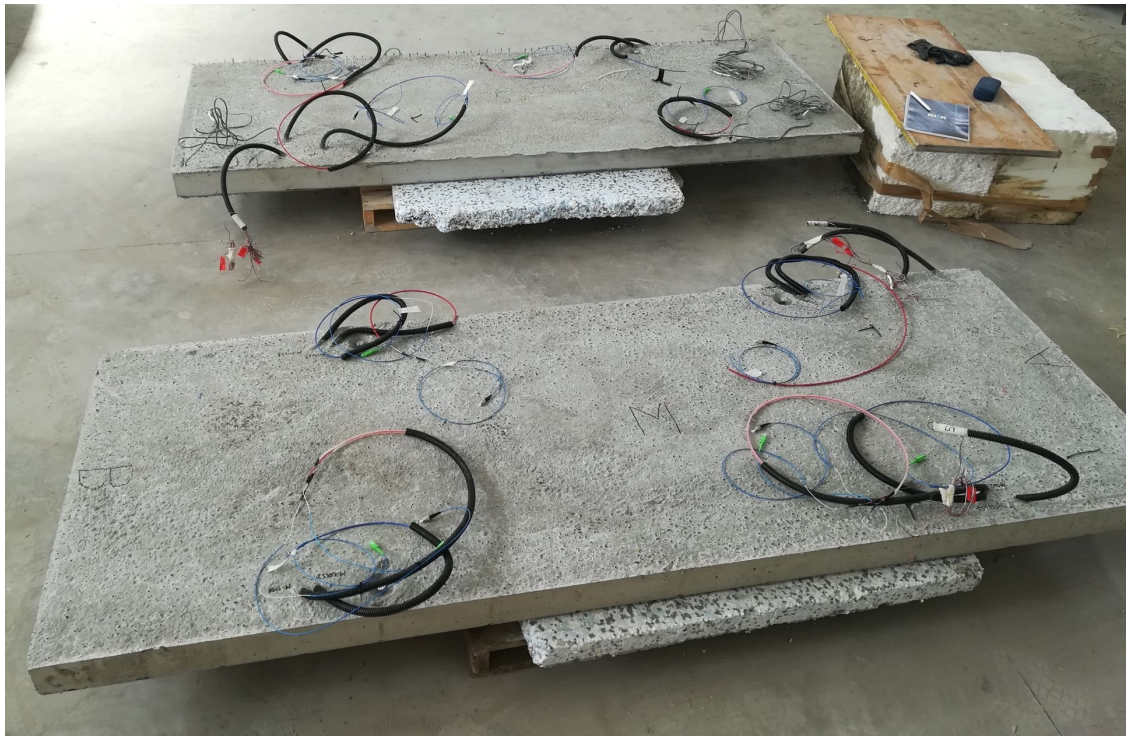


strain sensitive cable

Design, production and testing

Sample A: reference (ordinary r.c.)

Sample B: Sensorized TRC

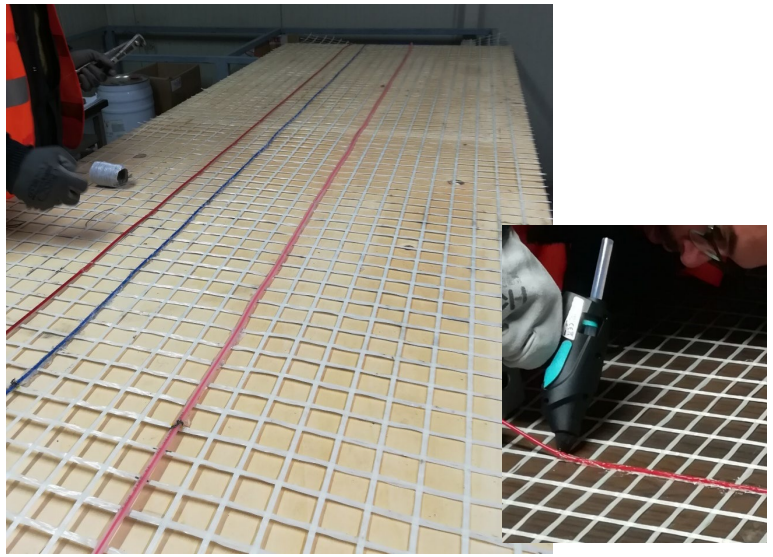


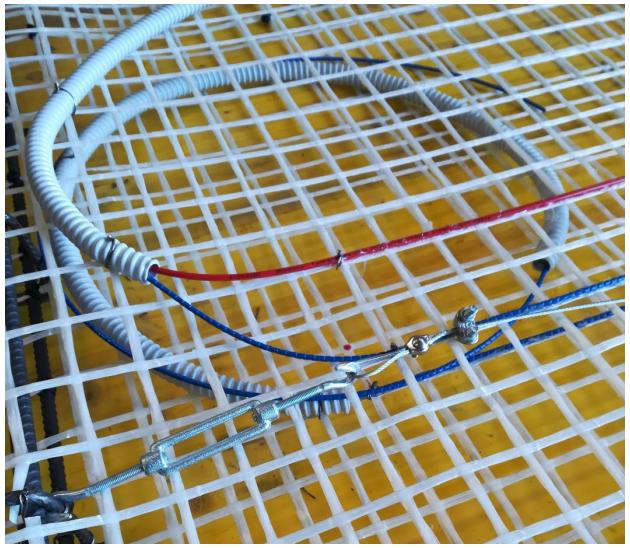
Same stiffness

Overall dimensions 250x90x10 cm

Design, production and testing

Textile preparation and sensor fastening and protection





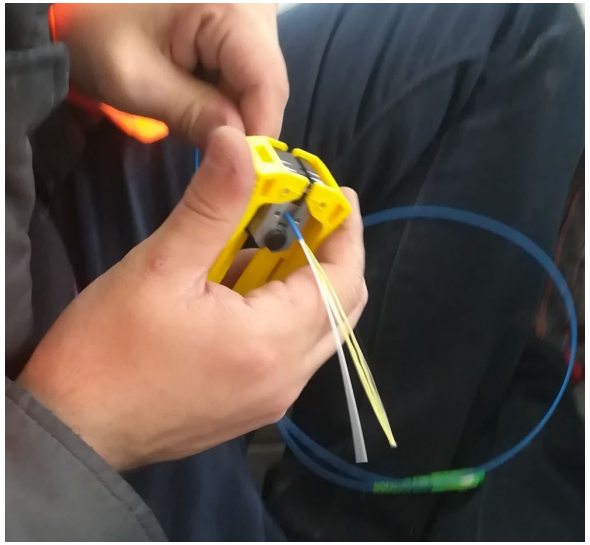
Mould preparation

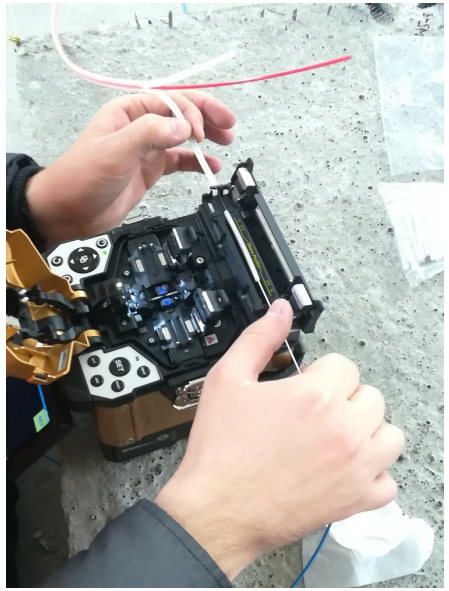
Demoulding

Concrete casting

Design, production and testing

Application of standard optical connectors

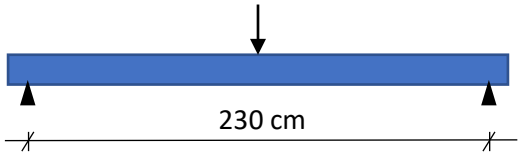




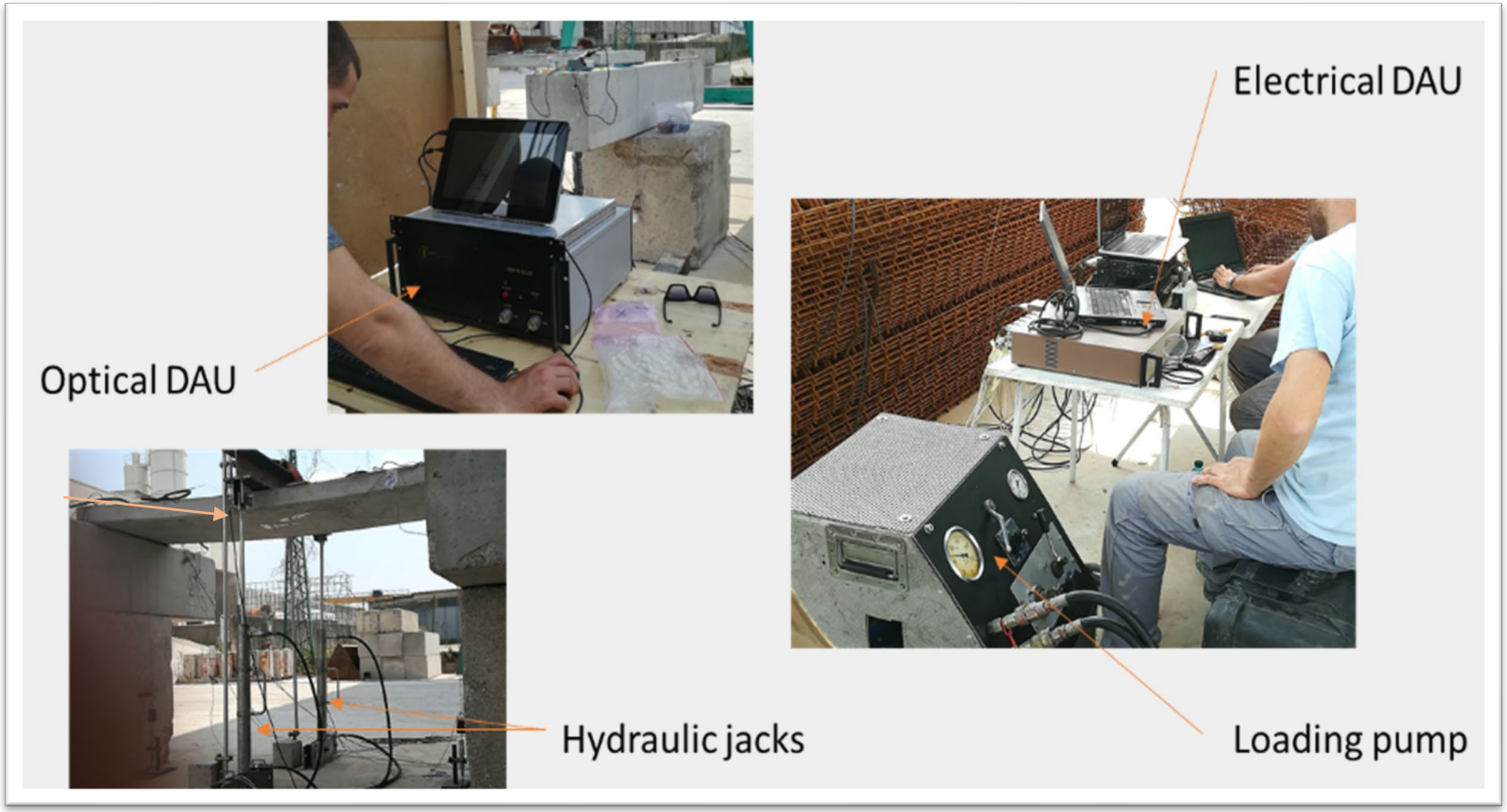
Design, production and testing

Flexure tests set-up

Loading scheme



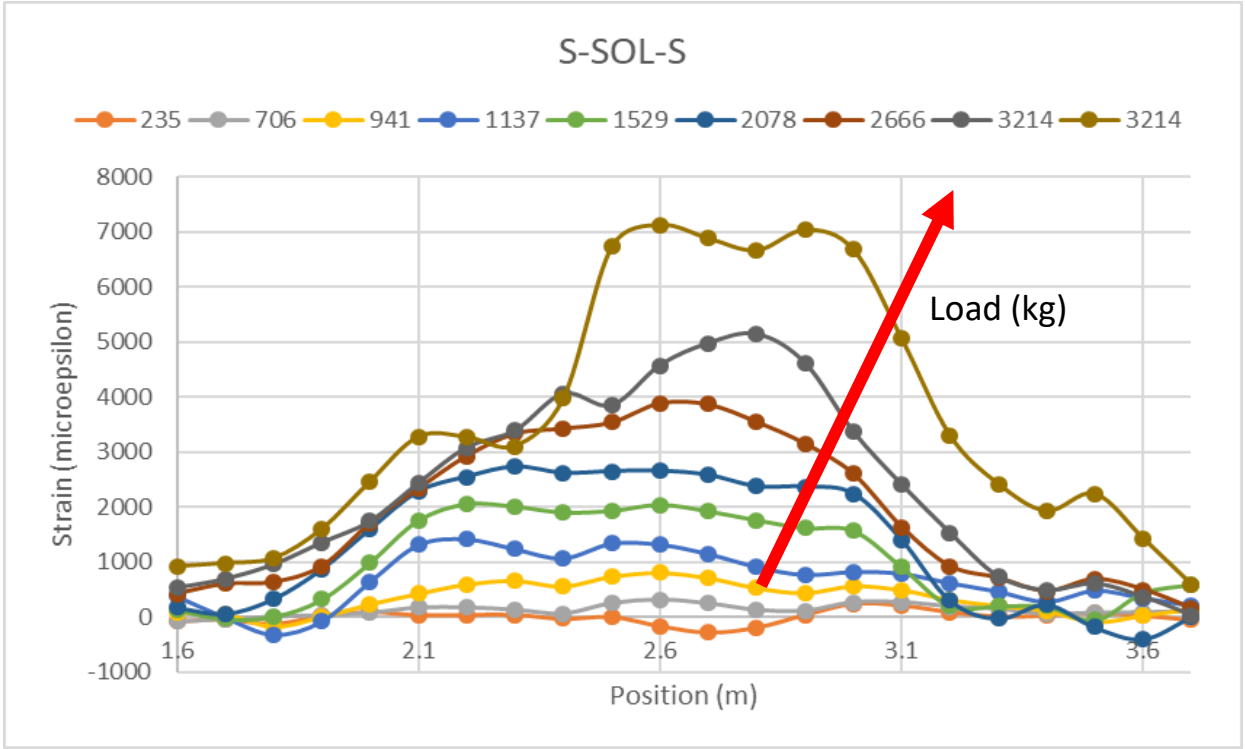
Experimental set-up



Design, production and testing

Strain measurements capability

Sample B

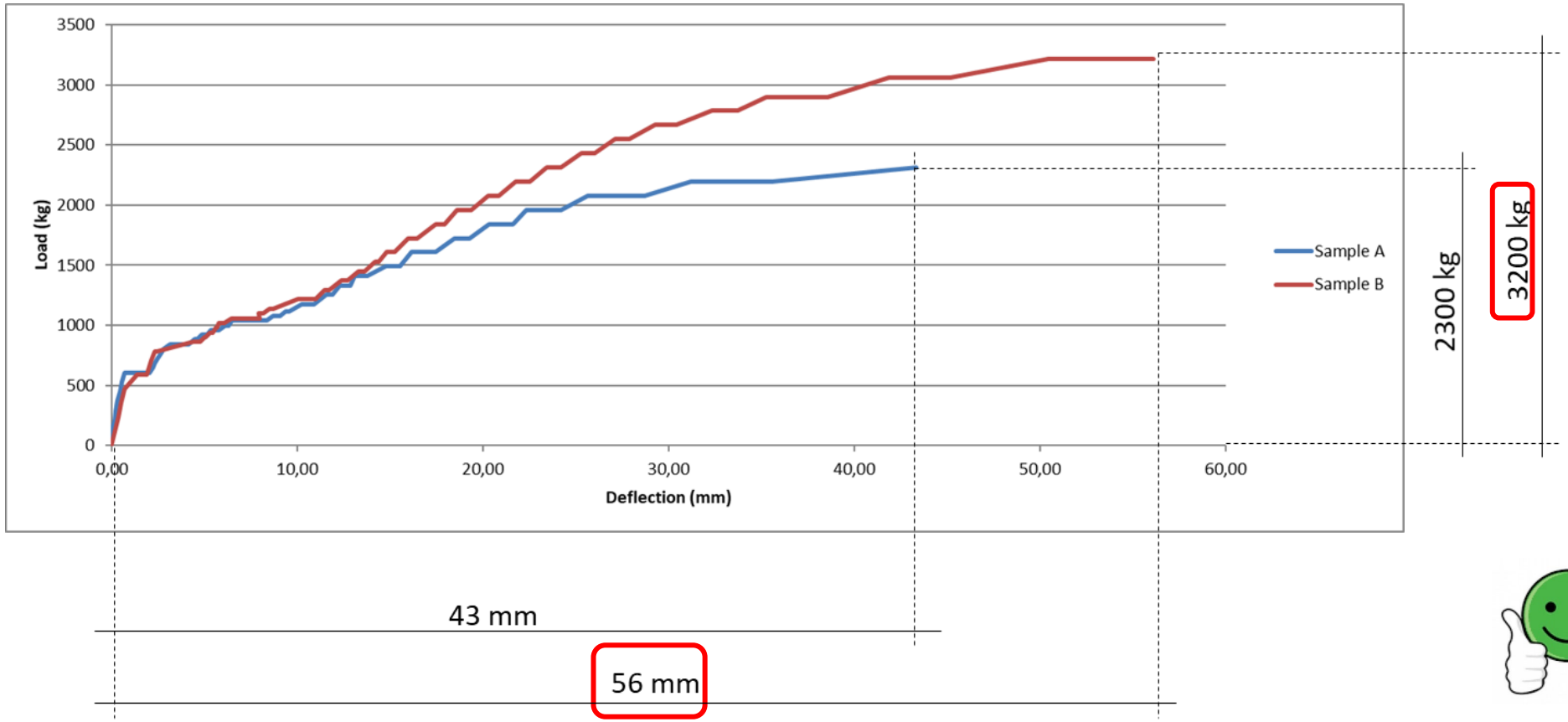


Main outcomes:

- Strain pattern as expected
- Comparable values vs. reference strain gages:

Design, production and testing

Comparison between the two reinforcing systems



+ 39% load carrying capacity

+30% ductility

Prototyping and field validation

Optical connection between modules successfully tested

Prototyping and field validation

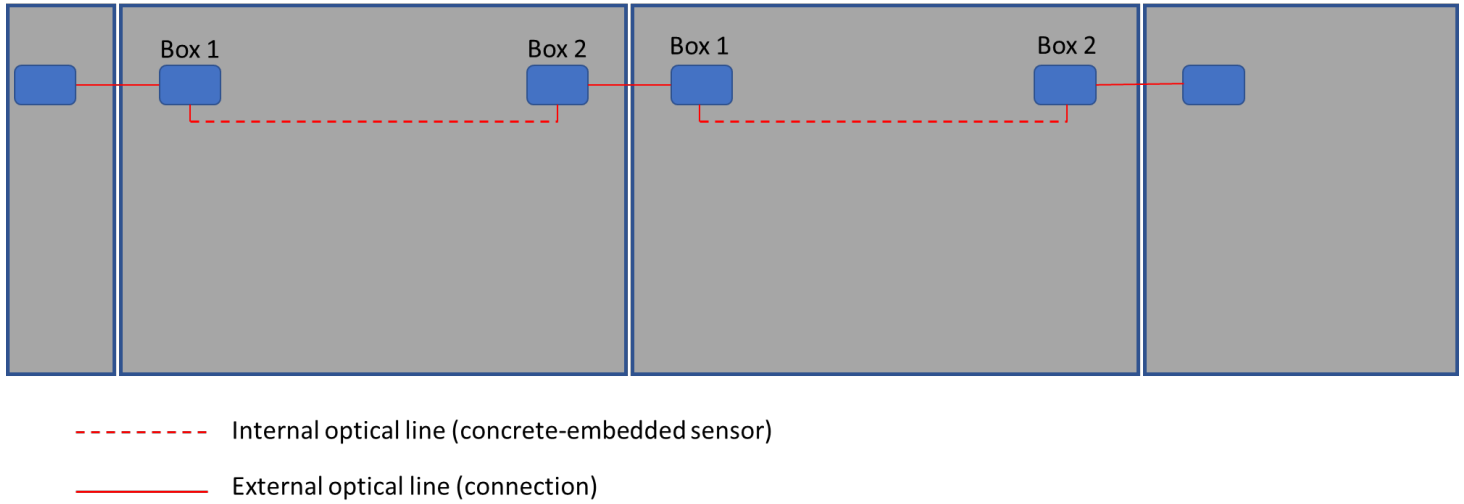
Optical connection between modules successfully tested

Prototyping and field validation

Panel n

Panel n+1

Optical connection between modules successfully tested



Conclusions

- Development and testing of TRC panels sensorized with distributed FOS
- Modular concept of self-sensing components
- The sensors survived the production process and provided consistent data up to advanced cracking stage;
- Enhanced ductility and load-carrying capacity
- Technology demonstrated by large scale prototypes in tunnel environment

Multifunctional coatings for concrete's protection

SPEAKER

ENDURCRETE

MARIA PAPPA

Manager of EU projects at the R&D department of AMSolutions Ltd.

Maria Pappa, AMSolutions

The scope

- **<u>The multifunctional coatings aims to serve the following needs</u>**:

➢ Protection from long-term exposure to the environment:

resistant in weathering, wear and tear, waterproof and increased durability

➢ Reduced maintenance needs: elimination of frequent repaint needs or

replacement of damaged coatings

➢ Cost savings: reduced raw materials, labor and energy cost for repairing/repainting

➢ Low cost solution

➢ Easy application by non specialists: e.g. spraying

- **<u>Achieved by means of:</u>**

➢ Self-healing properties (scratch and gap sealing)

➢ Self-cleaning properties/photocatalytic

➢ Anti-molding properties

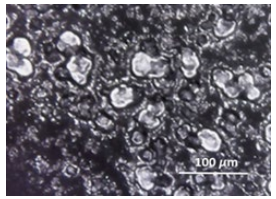
➢ Water resistant

The synthesis

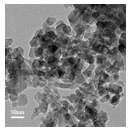
- **Core materials and synthesis**

➢ ***Commercial PU paint*** used as base for the formulation

➢ ***Self-healing agents: microcapsules*** (50µm) containing PU paint.
Synthesized via microencapsulation method



➢ ***TiO_2 nanopowder*** – P25 grade & mix of anatase/rutile, for:
- self-cleaning,
- photocatalytic and
- anti-molding properties



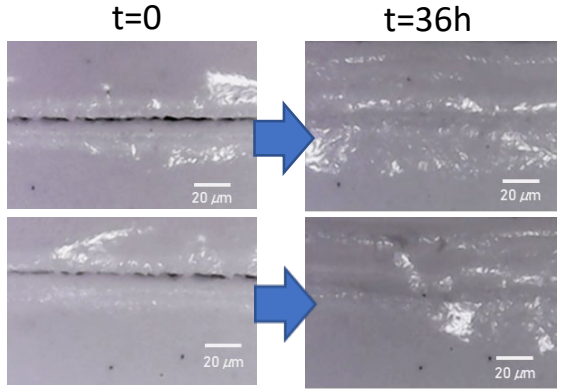
➢ ***Silver ions*** for:
- Anti-molding properties

➢ ***Antibiotic*** for:
- Anti-molding properties

➢ ***ITO nanopowder*** or dispersion of nanoparticles in ethanol, for:
- IR reflectance

The results in the lab

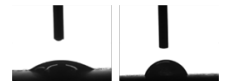
➢ *Self-healing activity*

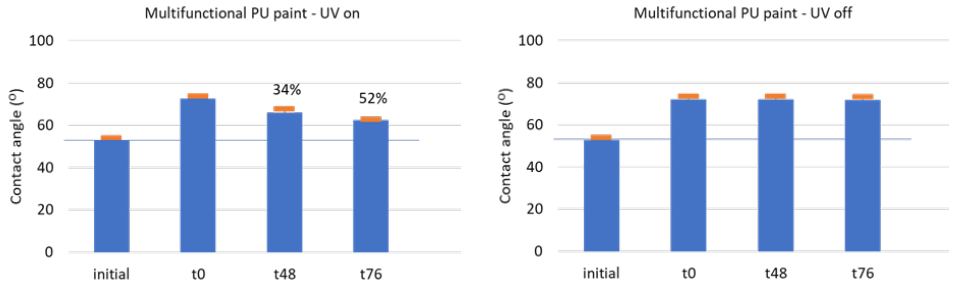


PU-based microcapsules by 7.5wt.% loading

➢ *Self-cleaning activity*

Water angle test - ISO 27448-1 standard

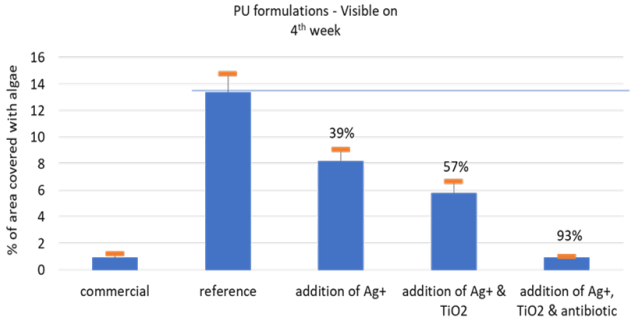


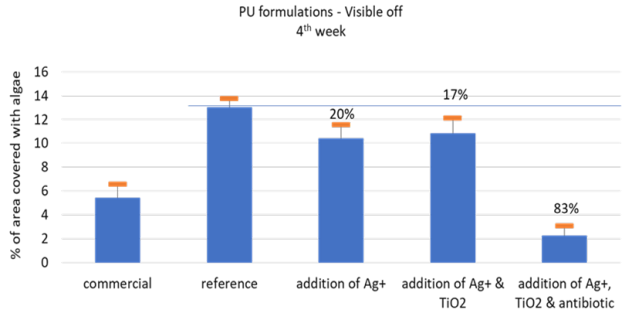


0.4 wt.% of TiO2 (P25 grade)

➢ *Anti-molding activity*

Resistance to fungal growth (BS 3900:1989 Part G6)





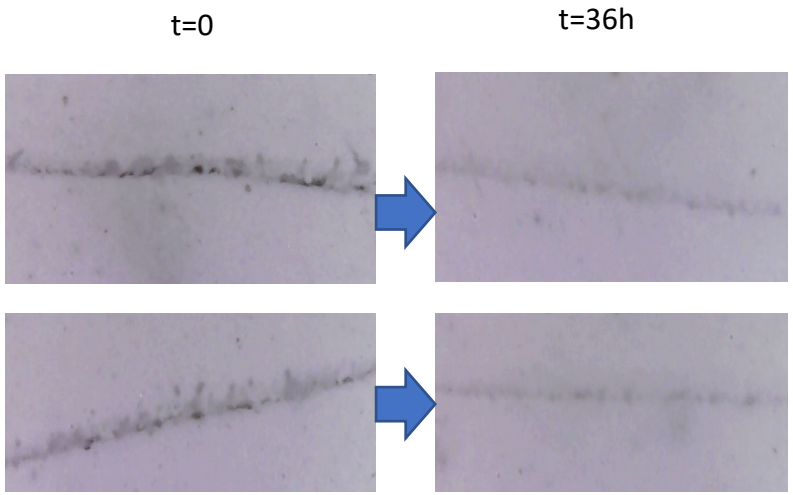
0.002wt.% of silver ions, 0.40 wt.% of TiO2 and 0.0015 wt.% of antibiotic

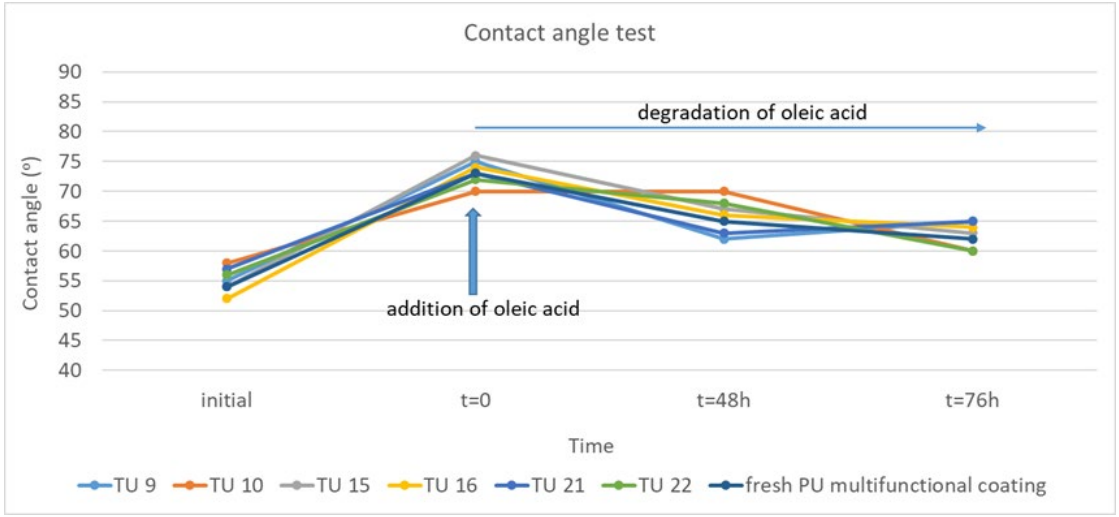
The results in the lab

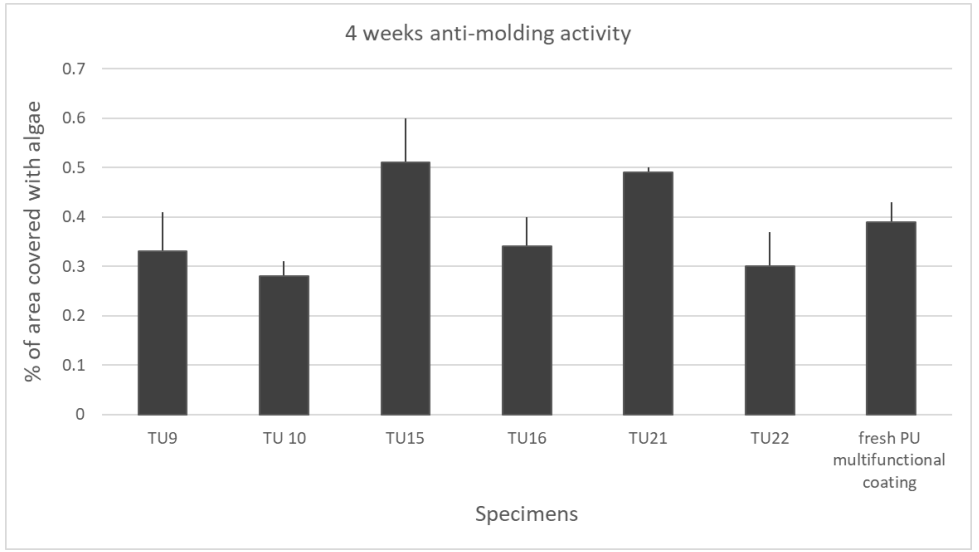
- **Bond strength by pull off test - standard EN 1504-2.2004**: 2N/mm^2
- **Capillary water absorption - SIST EN 1062-3:2008**: $W_{24hours} < 0,1$ kg/m^{2}h$^{0.5}$
- **Water vapor permeability - SIST EN ISO 7783:2018**: Diffusion-equivalent air layer thickness s_d =1.8m

Tests conducted by Slovenian National Building And Civil Engineering Institute

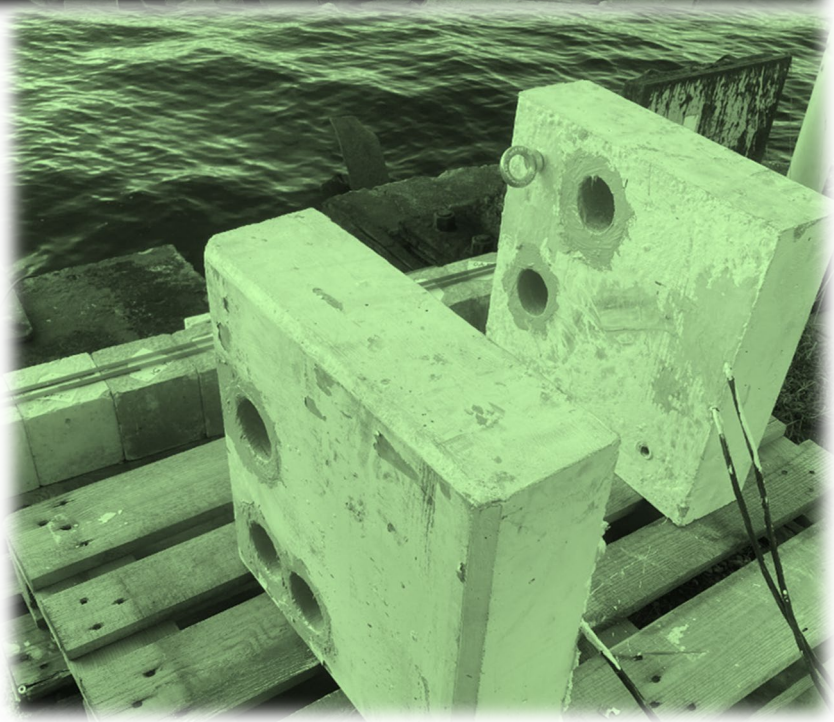
Performance evaluation in the tunnel







Break 5 minutes



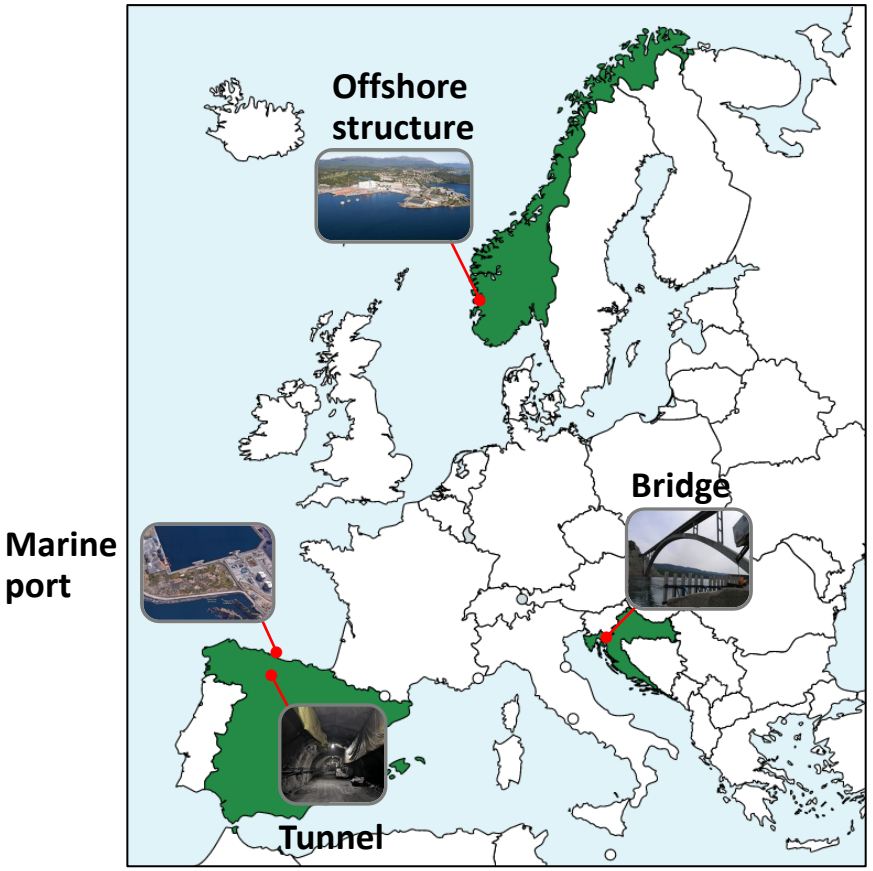
Demonstration sites

Dr. Irina Stipanovic, Infra Plan

Demonstration sites accross Europe

Demonstrate and validate novel concrete solutions (materials & technologies) developed in EnDurCrete project

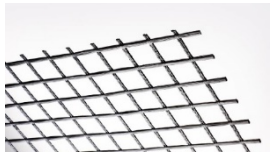
Sites include:



Demo projects included:

- EnDurCrete technologies: cements, corrosion inhibitors, carbon-based green micro-fillers, textile reinforcement, multi-functional protective coatings



- Demo specimens' characteristics: number of specimens, dimensions, exposure class, rebar system, requirements



- Monitoring and testing: Structural Health Monitoring (SHM), Corrosion/environmental sensors, Non-Destructive Testing (NDT), destructive testing




Demo site: Offshore platform in Norway

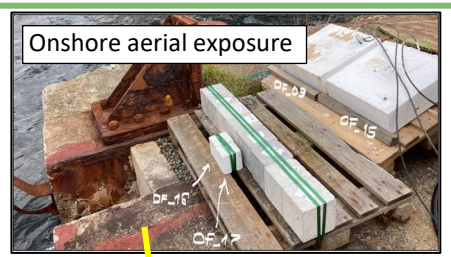
Main partners: KVAERNER/Aker Solutions

Contributors: ZAG, ACCIONA, RINA, AMS, Nuova Tesi System S.r.l.

Test Site

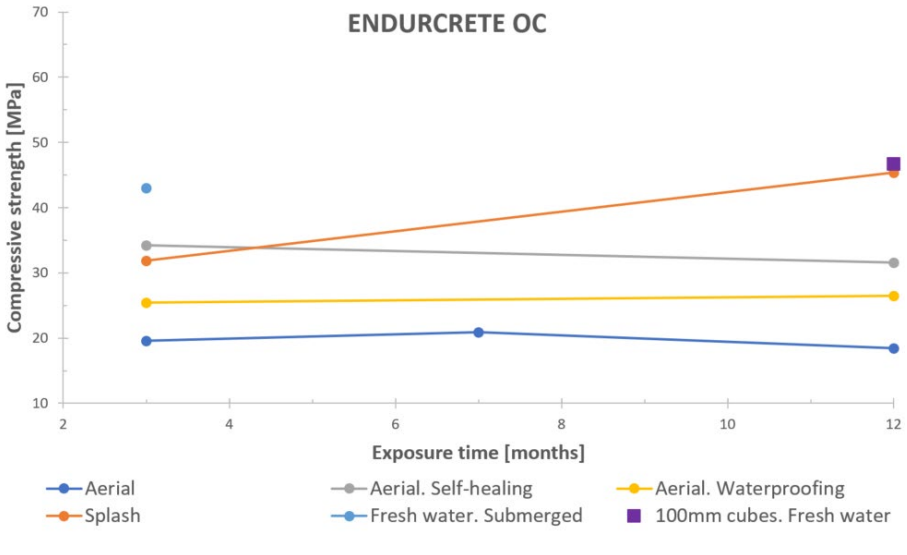
- **2 Offshore Concrete (OC) types**:
  EnOC - CEM II/C-M (S-LL) vs
  RefOC - CEM I 52,5 R + 5%SF.
  w/b 0,36, binder content – 440…470 kg/m^3
- **3 exposures + reference storage** in +20^{o}C water
- **15 concrete panels** 500 x 500 x 150 mm^3:
  - 3 - with textile reinforcement and optical fibers
  - 10 - with corrosion ER sensors
  - 2 - lab storage
  - 4 – with waterproofing coating (AMSolutions), where 2 off with self-healing additive
- **23 cubes** (**100mm** side) and **25 cubes** (**150 mm** side)
- Continuous temperature and humidity monitoring

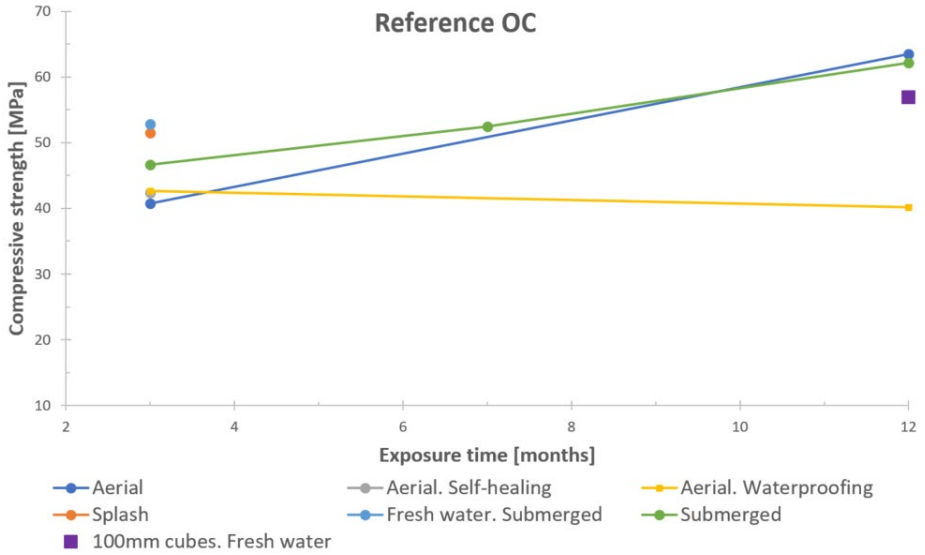
Set up. Scope of work



- **Compressive strength** – drilled cores, cubes
- **Porosity analysis (PF-test)** – cubes stored in +20°C water + exposed to site conditions (after 12 months)
- **Chloride penetration test** – drilled cores
- **Salt-frost scaling slab test** – cubes, exposed to site conditions (after 12 months)
- Sampling for **contact angle measurements**

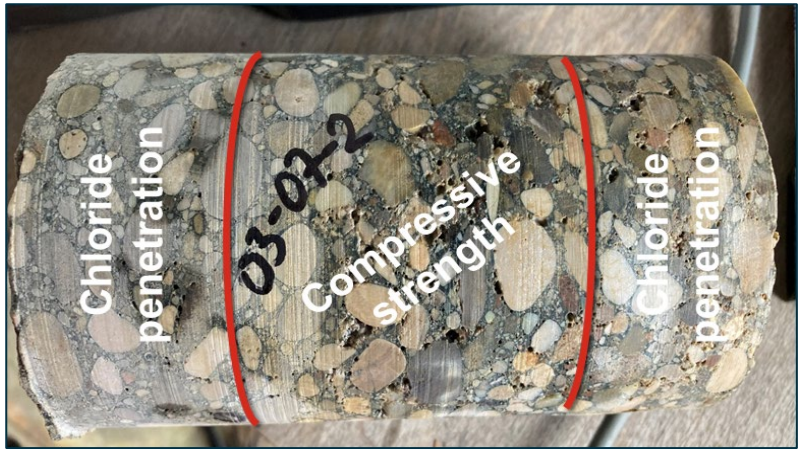
Compressive strength



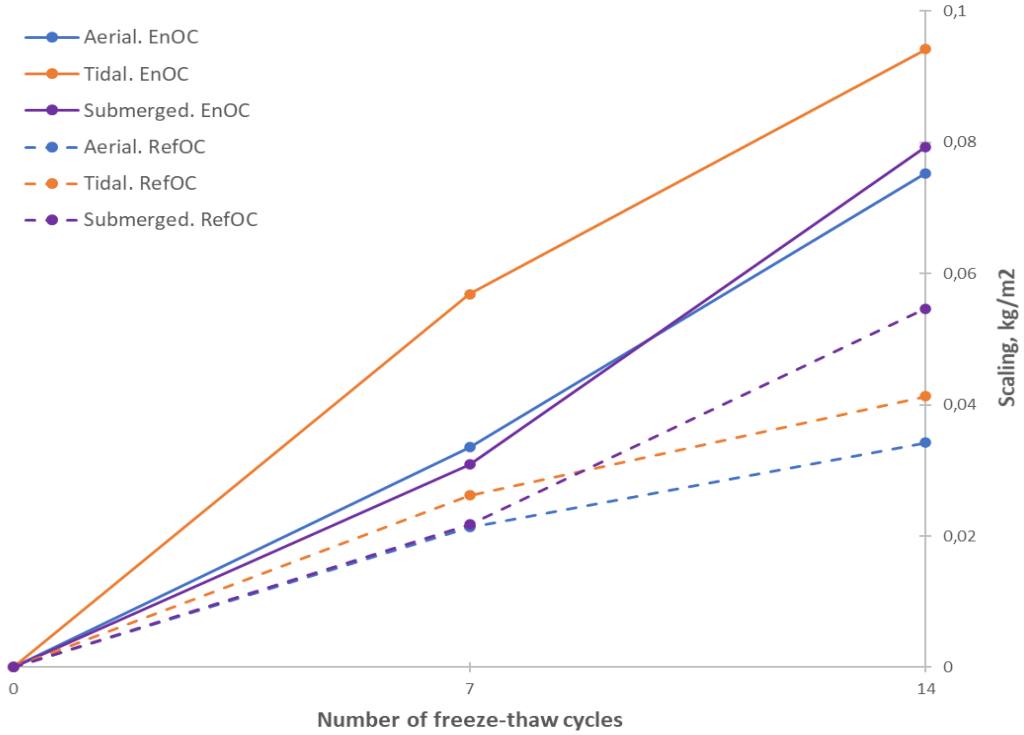


- Panels were water-cured for 42 days, dried about 2 weeks before the exposure
- The compressive strength of RefOC is higher for all the exposures
- Waterproofing membrane stagnates strength development, yet the panels with the membrane gained more strength than without
- Considerable increment of strength in aerial exposure for RefOC vs negligible effect for EnOC supposedly due to difference in permeability

Note: Graphs show only the test results with variation <10%.



Freeze-thaw testing. Preliminary



- Salt-frost slab test is performed acc. to CEN/TS 12390-9
- 3 slabs from 2 cubes taken from each exposure for both concrete qualities
- EnOC seems to be more prone to scaling, yet the amount of scaling is still very small
- Mixes were tested with the same pre-conditioning despite high share of GGBFS in EnOC mix

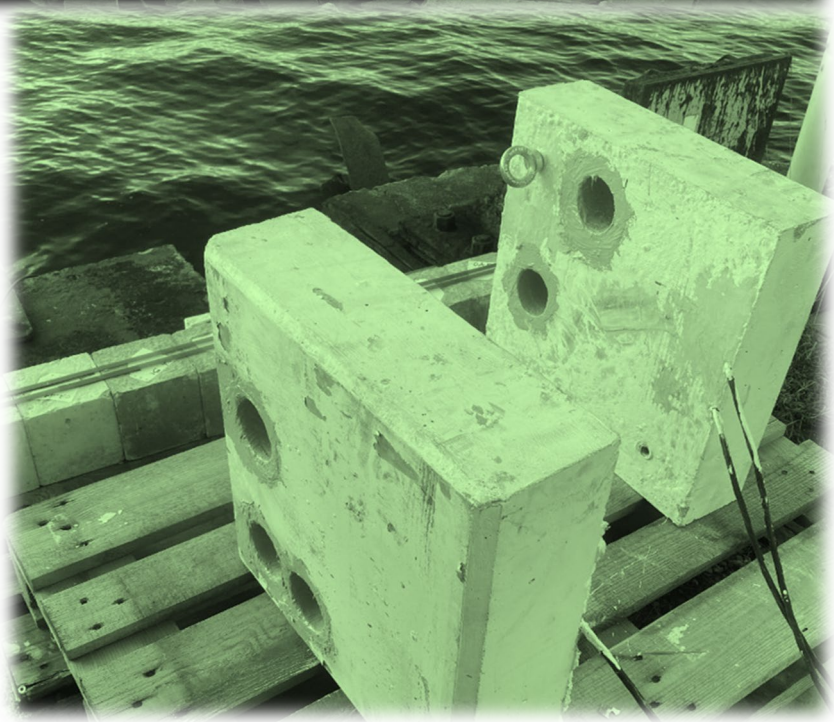
Other results

- **Porosity analysis (PF-test)** shows that EnOC is less permeable than RefOC. The pore protection factor for both concrete is >0.25 (total air content varying 5.0…6.2%), a good pre-requisite to be frost resistant.
- **Chloride penetration test (water soluble Cl^-)** No apparent difference in chloride penetration depth between EnOC and RefOC over 12 months. Highest chloride penetration depth (8mm) in splash zone and submerged zone. Treated panels show minor presence of chlorides up to 5mm depth.
- **Measurements on the ER sensors** (by ZAG) in the first 12 months of exposure did not detect corrosion activities
- **Contact angle measurements of waterproofing membrane** (by Acciona) showed good wettability of the surface implying its hydrophilic properties, as expected.

Demo site: Marine port in Spain

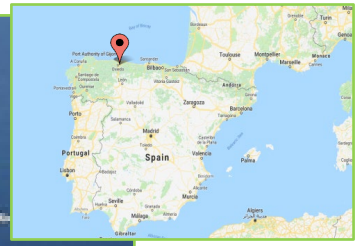
Main partners: ACCIONA

Contributors: NTS, AMS, IBOX, VITO, HC, SIKA



Test site in Spain: marine environment

Prototypes were installed in a concrete dock of the Port Gijón “El Musel” (Spain), supported by Port Authority and coordinated by ACCIONA.



Test site in Spain: marine environment

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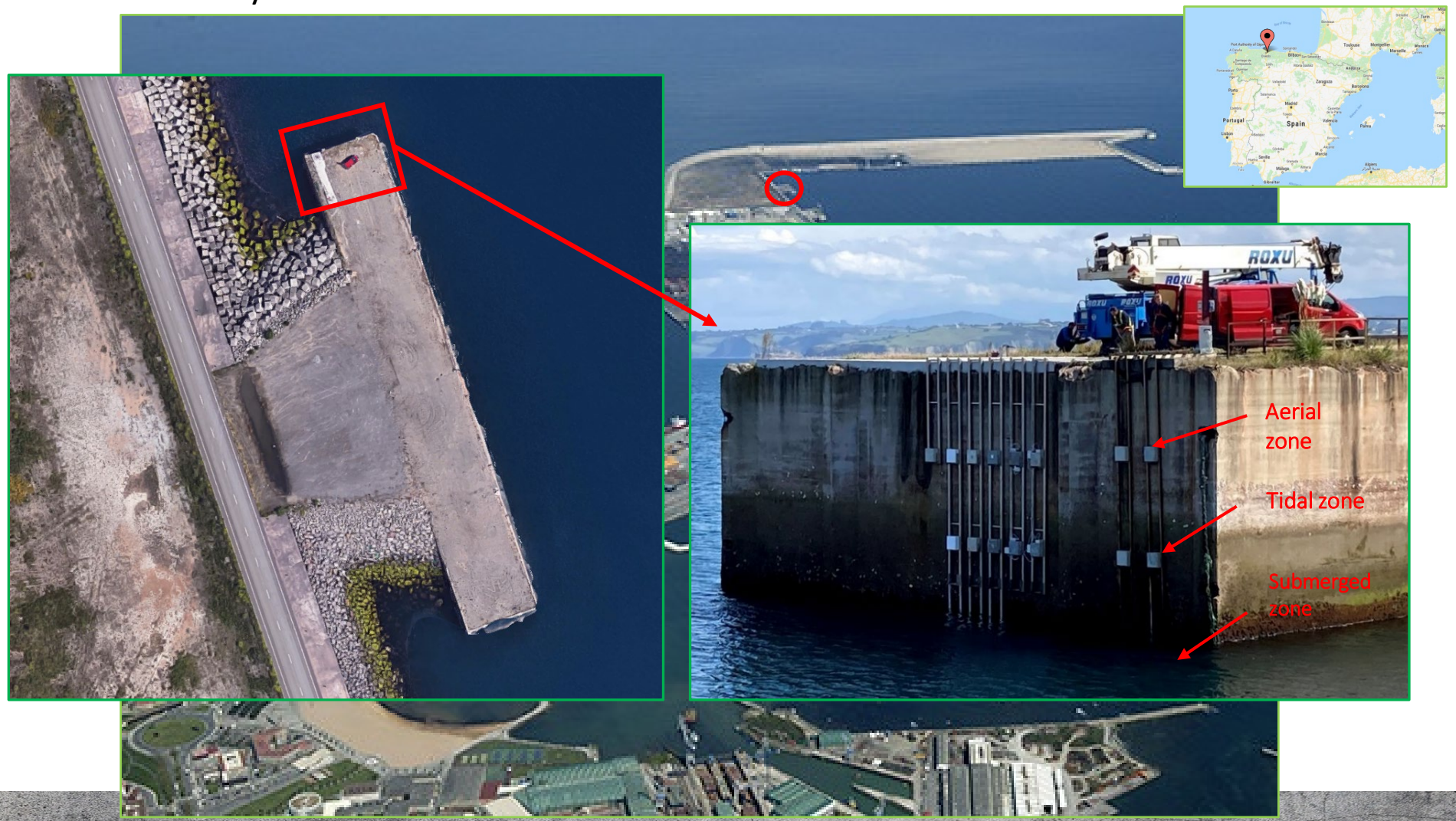
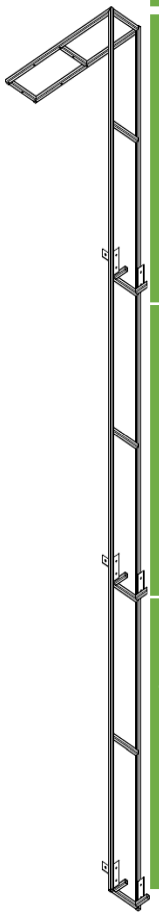


Test site in Spain: marine environment

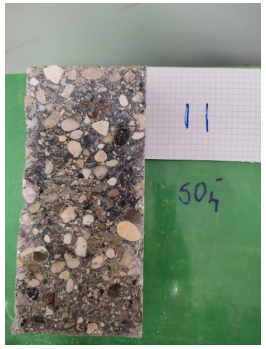
Marine C35/45 concrete

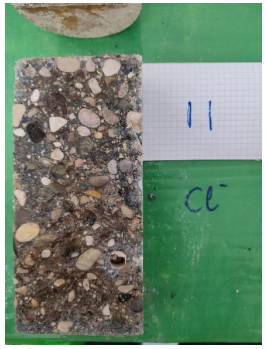
19 PANELS	MARINE REF CEM III/A 42.5 N	MARINE CEM II/C-M (S-LL)	MARINE + Polyurethane coating	MARINE + Corrosion inhibitors	MARINE + Biochar + Recycled Carbon Fibres (RCF)
AERIAL testing zone XS1	Carbonation Chlorides Sulphates Compressive streght Electrical resistivity	Carbonation Chlorides Sulphates Compressive streght Electrical resistivity	Carbonation Chlorides Sulphates Compressive streght Electrical resistivity	Carbonation Chlorides Sulphates Compressive streght Electrical resistivity	Carbonation Chlorides Sulphates Compressive streght Electrical resistivity
TIDAL testing zone XS3	Carbonation Chlorides Sulphates Compressive streght Electrical resistivity	Carbonation Chlorides Sulphates Compressive streght Electrical resistivity	Carbonation Chlorides Sulphates Compressive streght Electrical resistivity	Carbonation Chlorides Sulphates Compressive streght Electrical resistivity	Carbonation Chlorides Sulphates Compressive streght Electrical resistivity
SUBMERGED testing zone XS2	Carbonation Chlorides Sulphates Compressive streght Electrical resistivity	Carbonation Chlorides Sulphates Compressive streght Electrical resistivity	Carbonation Chlorides Sulphates Compressive streght Electrical resistivity	Carbonation Chlorides Sulphates Compressive streght Electrical resistivity	

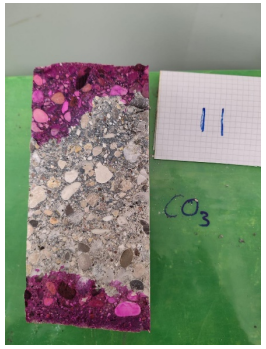


Test site in Spain: marine environment

SPLASH	TIDAL	SUBMERGED



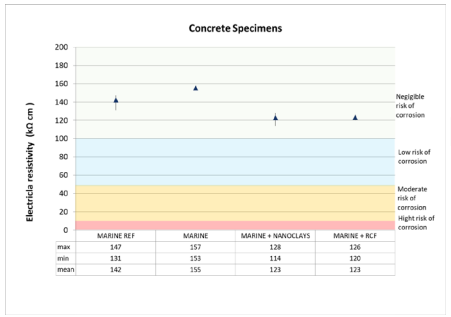


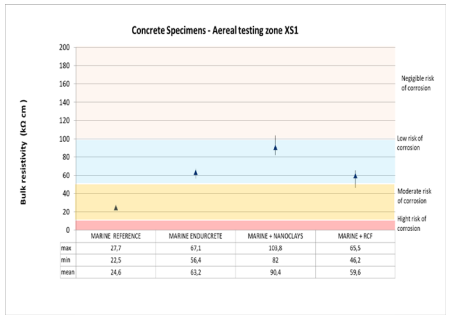


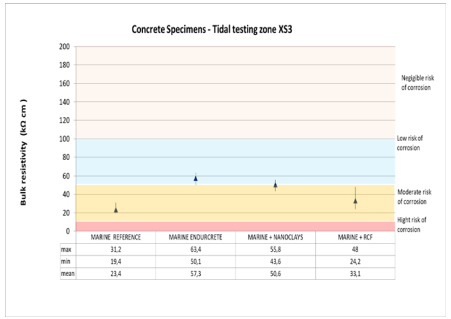
EXPOSED SAMPLES 12 MONTHS

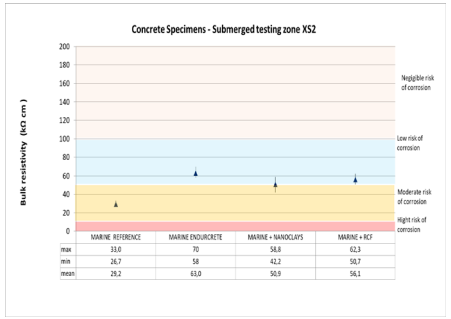
PENETRATION TESTS (mm)		Marine REF CEM III/A 42.5 N	Marine EnD CEM II/C-M (S-LL)	Marine EnD + Corrosion inhibitors	MARINE EnD + biochar + RCF
Aerial zone	SULFATES	-	-	-	-
	CHLORIDES	5	-	-	3
	CARBONATION	5	-	-	1
Tidal zone	SULFATES	-	-	-	-
	CHLORIDES	10	5	11	5
	CARBONATION	-	-	-	-
Submerged zone	SULFATES	7	-	-	-
	CHLORIDES	22	11	11	12
	CARBONATION	-	-	-	-

COMPRESSIVE STRENGTH (MPa)	Marine REF. CEM III/A 42.5 N	Marine EnD. CEM II/C-M (S-LL)	Marine EnD+ Corrosion inhibitors	MARINE EnD + biochar + RCF
Aerial zone	61	64	67	62
Tidal zone	64	66	68	67
Submerged zone	70	62	68	65







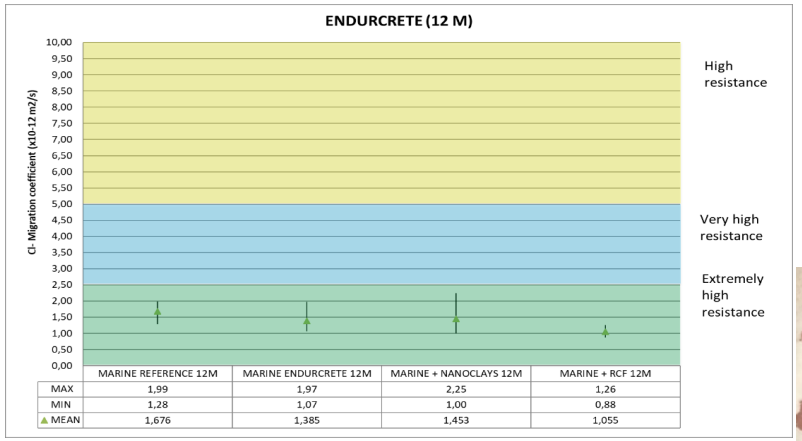


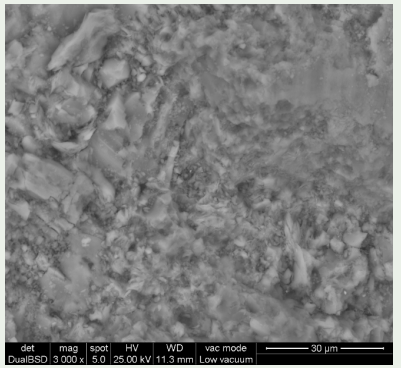
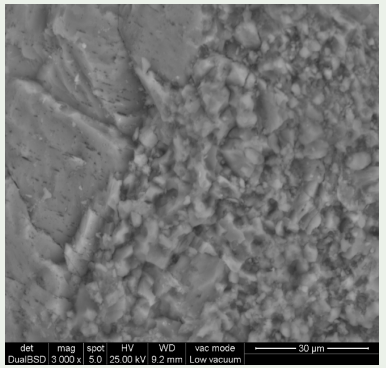
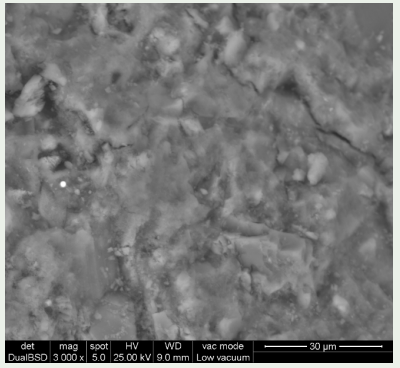
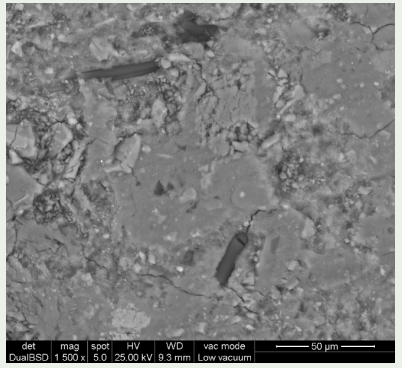
Test site in Spain: marine environment

HUMIDITY CHAMBER (12 MONTHS)

POROSITY ASSESSMENT UNE - EN 1936	Marine REF. CEM III/A 42.5 N	Marine EnD. CEM II/C-M (S-LL)	Marine EnD+ Corrosion inhibitors	MARINE EnD + biochar + RCF
mean pore size	0.04 µm	0.02 µm	0.02 µm	0.02 µm
apparent density	2.38 g/mL	2.35 g/mL	2.14 g/mL	2.19 g/mL
porosity	6.27 %	7.28 %	8.55 %	8.39 %

PENETRATION OF WATER UNDER PRESSURE UNE-EN 12390-8	Marine REF. CEM III/A 42.5 N	Marine EnD. CEM II/C-M (S-LL)	Marine EnD+ Corrosion inhibitors	MARINE EnD + biochar + RCF
Maximum water penetration (mm)	15	5	6	8
Mean value	7	2	4	5



REFERENCE	MARINE ENDURCRETE
	
ENDURCRETE + CORROSION INHIBITORS	ENDURCRETE + BIOCHAR + RCF
	

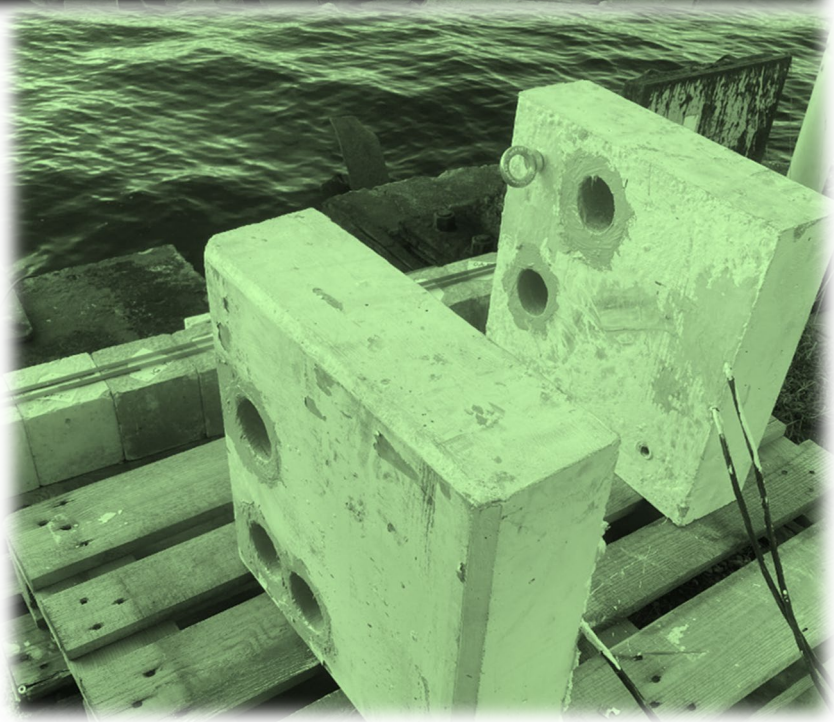
Test site in Spain: marine environment

- **SULFATES PENETRATION:**
  - **Splash and tidal: no penetration**
  - **Submerged: best results with CEM II/C-M (S-LL)**
- **CHLORIDES PENETRATION:**
  - **Best results with CEM II/C-M (S-LL) in all zones**
- **CO_2 PENETRATION:**
  - **No penetration with CEM II/C-M (S-LL)**
- **BULK RESISTIVITY:**
  - **CEM III/A 42.5 N - moderate risk of corrosion**
  - **CEM II/C-M (S-LL) – low risk of corrosion**
- **SEM**
  - **No significant differences**

Demo site: Tunnel in Spain

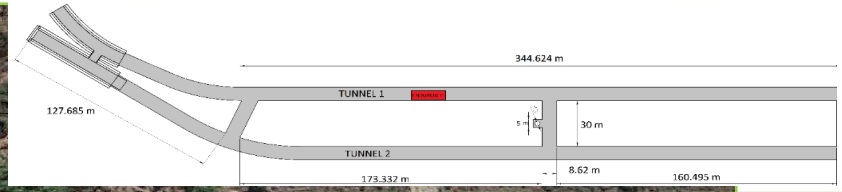
Main partners: ACCIONA

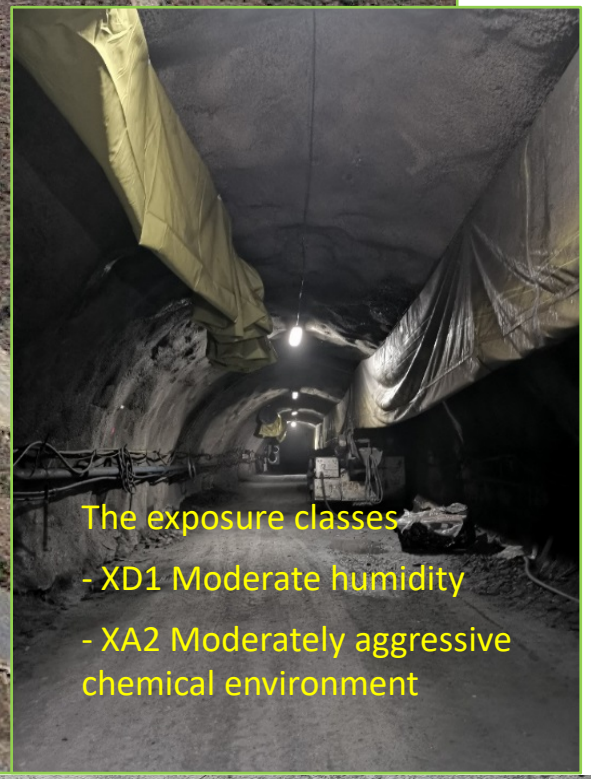
Contributors: NTS, AMS, IBOX, VITO, HC, SIKA



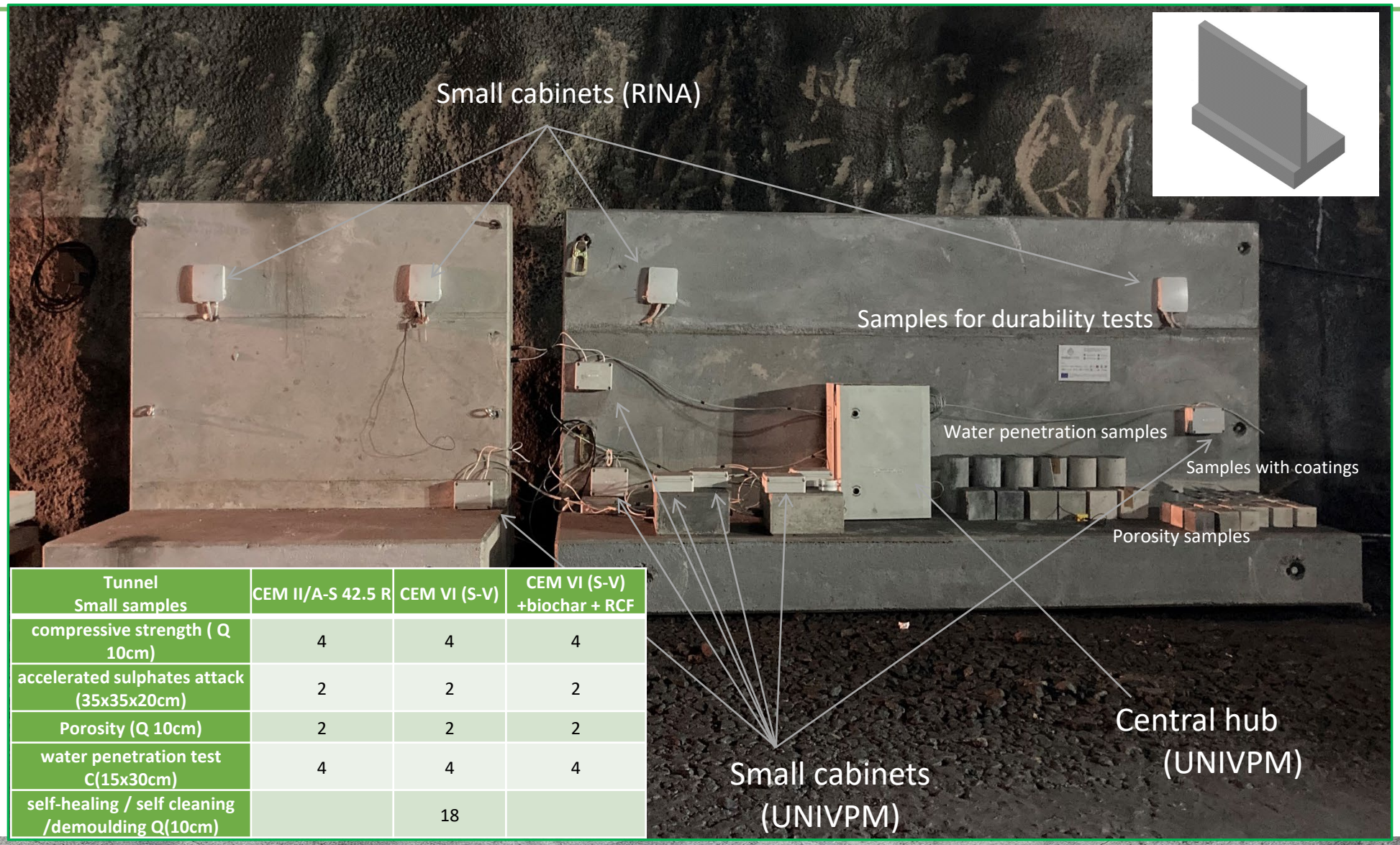
Test site: tunnel environment

FSB is a public entity engaged in the mining, construction, renewable energies. Tunnel is a coal mine out of service used as a research centre, investigation of excavation techniques, spraying shotcrete tests…





Test site: tunnel environment

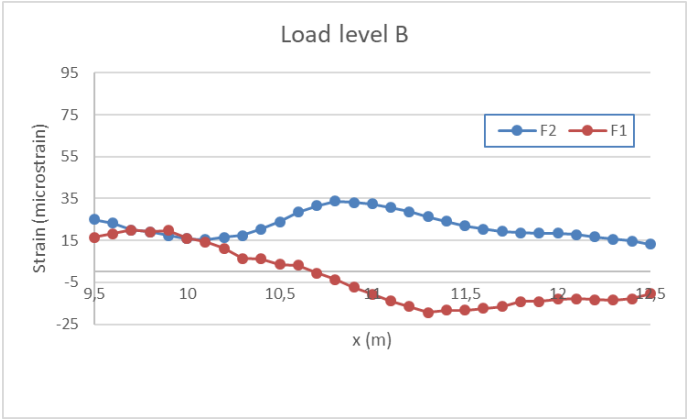


Tunnel Small samples	CEM II/A-S 42.5 R	CEM VI (S-V)	CEM VI (S-V) +biochar + RCF
compressive strength (Q 10cm)	4	4	4
accelerated sulphates attack (35x35x20cm)	2	2	2
Porosity (Q 10cm)	2	2	2
water penetration test C(15x30cm)	4	4	4
self-healing / self cleaning /demoulding Q(10cm)		18	

Test site: tunnel environment

Monitoring system: Rebars together with textile reinforcement and sensors

Load was increased gradually at steps of 73 kg/m^2 each



Load level A: full row of 4 water tanks, maximum load 730 kg/m^2
Load level B: full row of 4 water tanks + 2 water tanks in the middle; maximum load 1100 kg/m^2

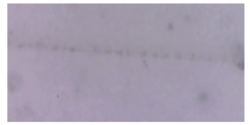
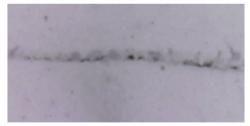
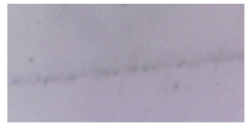
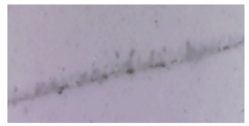
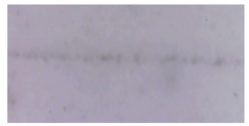
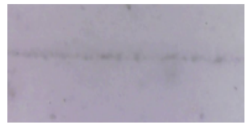
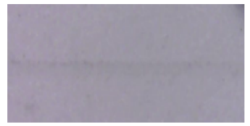
COMPUTER VISION

Despite the reduced thickness, the algorithm was able to identify the crack and measure them

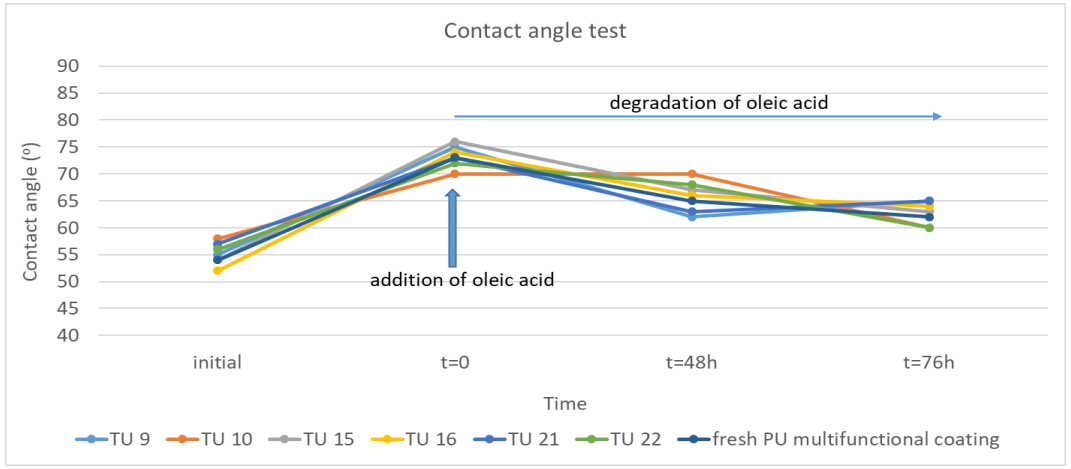
Use of the device equipped with a depth sensor to deal with the surface roughness, making the use of markers unfeasible

Test site: tunnel environment

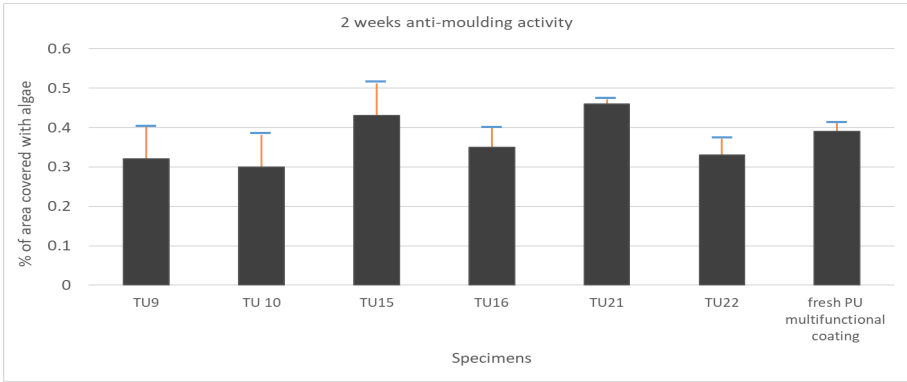
- Self-healing properties assessment (AMSolutions): seal gaps on its surface caused by crack formation

Specimen code	t=0	t=36h
TU 09		
TU 10		
TU 15		
TU 16		
TU 21		
TU 22		

- Self-cleaning properties assessment (AMSolutions): ISO 27448

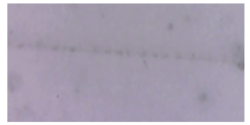
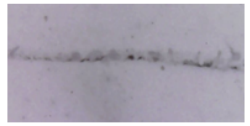
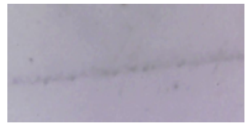
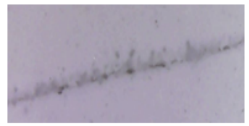
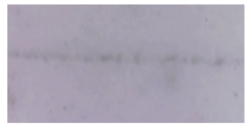
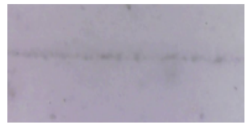
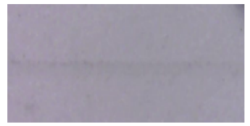


- Anti-moulding properties assessment

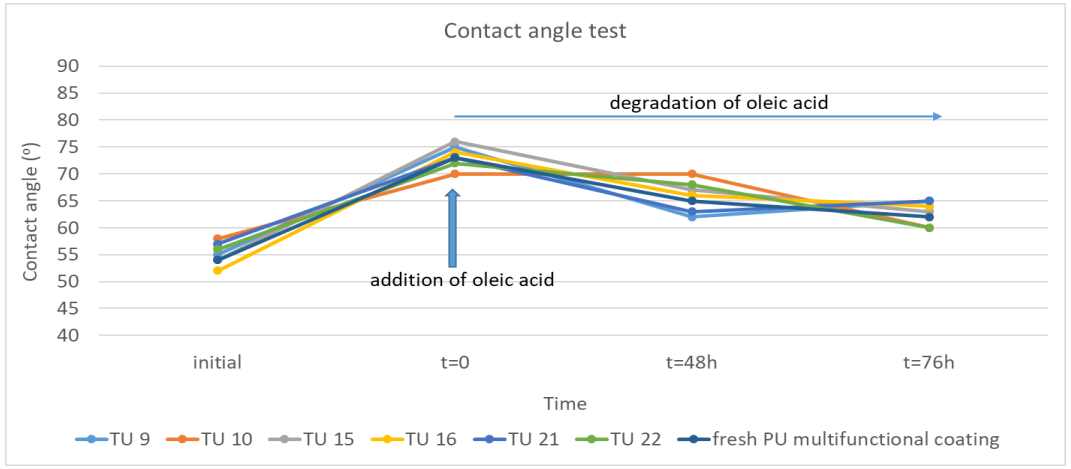


Test site: tunnel environment

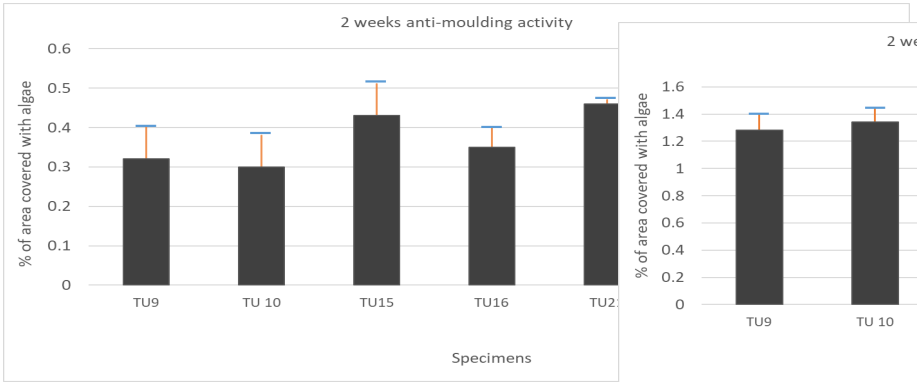
- Self-healing properties assessment (AMSolutions): seal gaps on its surface caused by crack formation

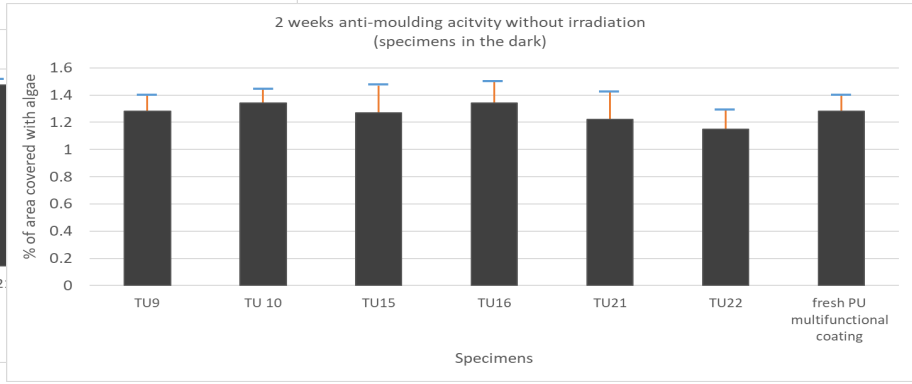
Specimen code	t=0	t=36h
TU 09		
TU 10		
TU 15		
TU 16		
TU 21		
TU 22		

- Self-cleaning properties assessment (AMSolutions): ISO 27448



- Anti-moulding properties assessment





Test site: tunnel environment

Durability tests

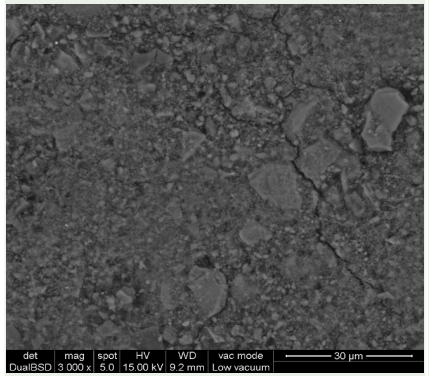
Compressive Strength (Mpa)	Tunnel REF. CEM II/A-S 42.5 R	Tunnel EnD CEM VI (S-V)	Tunnel End. + biochar + RCF
12 MONTHS	67 MPa	75 MPa	75 MPa

POROSITY ASSESSMENT UNE - EN 1936	Tunnel REF. CEM II/A-S 42.5 R	Tunnel EnD CEM VI (S-V)	Tunnel End. + biochar + RCF
mean pore size	0.04 µm	0.02 µm	0.02 µm
apparent density	2.22 g/mL	2.25 g/mL	2.28 g/mL
porosity	7.24 %	7.94 %	8.46 %

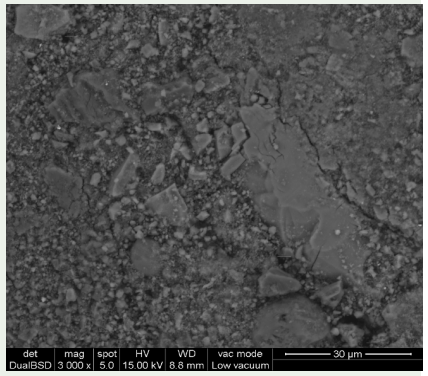
PENETRATION OF WATER UNDER PRESSURE UNE-EN 12390-8	Tunnel REF.	Tunnel EnD.	Tunnel EnD + biochar + RCF
Maximum water penetration (mm)	14	NO PENETRATION	NO PENETRATION
Mean value (mm)	10	NO PENETRATION	NO PENETRATION

- **NO SULFATES PENETRATION**
  - **No penetration in any mix design**
- **SEM**
  - **No significant differences at microstructural level**

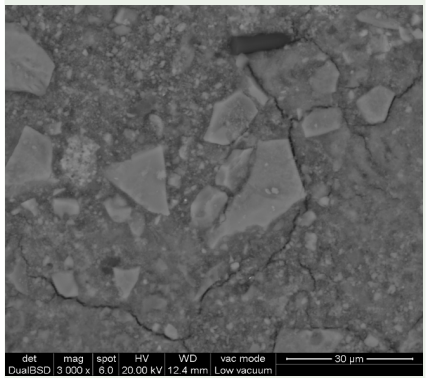
TUNNEL REFERENCE



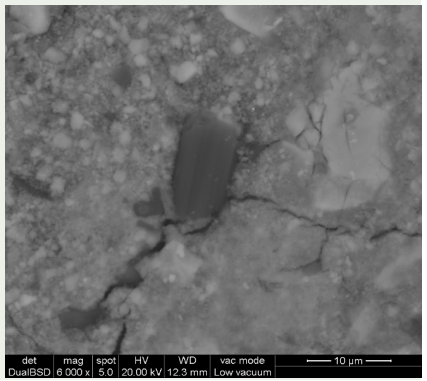
TUNNEL ENDURCRETE



TUNNEL + BIOCHAR + RCF



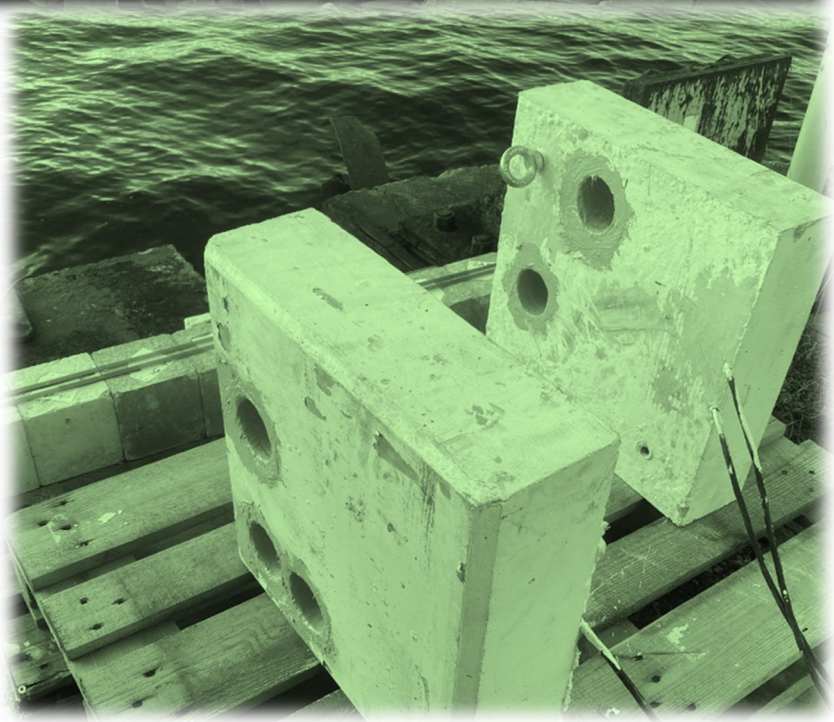
BIOCHAR



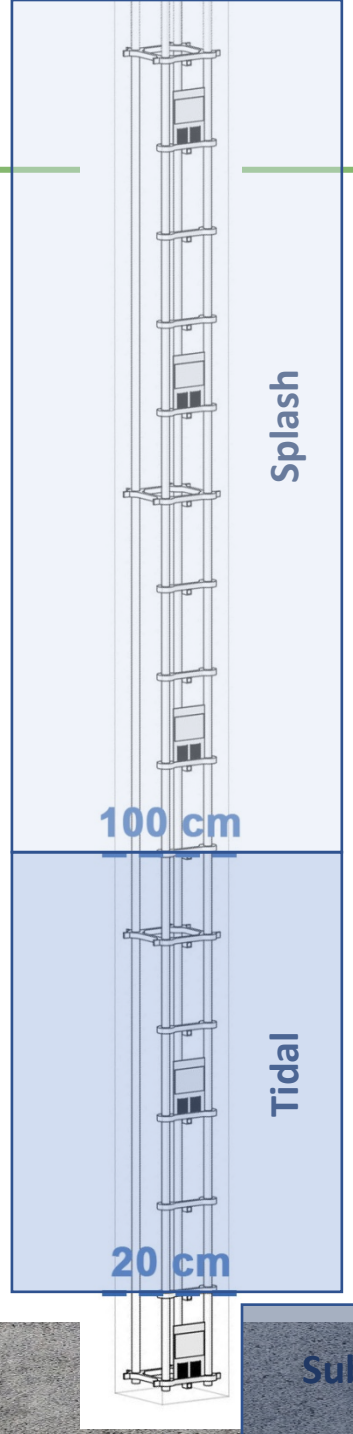
Demo site: Krk bridge in Croatia

Main partners: Infra Plan, ZAG

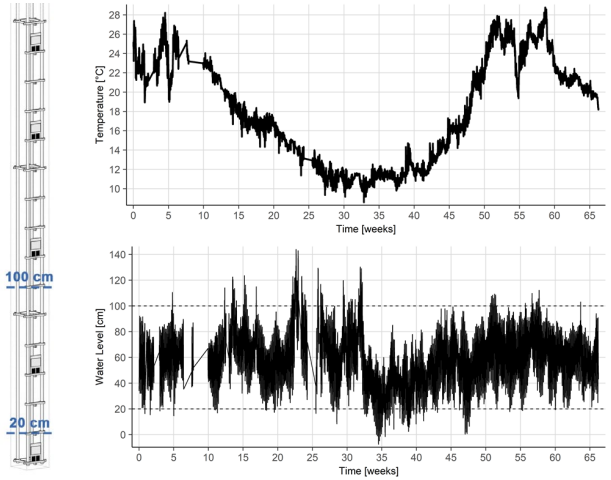
Contributors: HC, AMS, CEA, NTNU



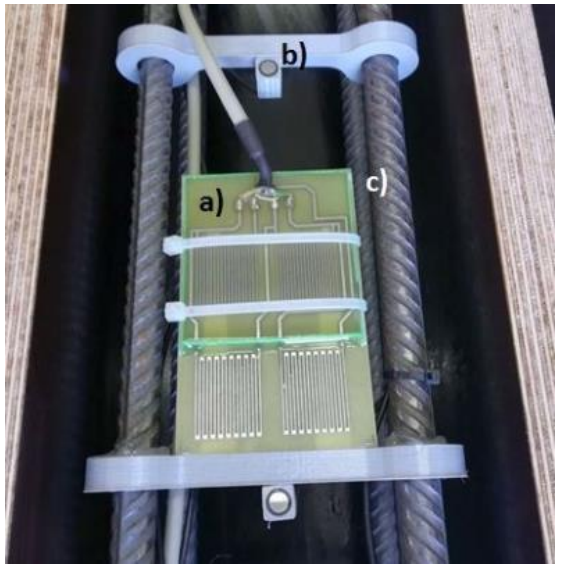
Test site: marine environment



- **5 materials**: 3 NEW concrete systems (2 cements, 1 coating) & 2 refer. mat.
- **2 types of corrosion sensors**: CME & ER
- **3 zones of exposure**: submerged, tidal, splash
- 12 columns and 56 cubes in different exposure zones
- **Continuous corrosion monitoring** with wi-fi data acquisition system and **environmental monitoring**
- **Periodic testing of concrete durability properties** (chloride profile, porosity, mineral phase change, mass, ultrasound velocity, Eigen frequency)



Corrosion tests



1 column contains:

a) 16 CME sensors

Measuring **partial (corrosion) currents**, distributed **between exposure zones** over period of **time**.

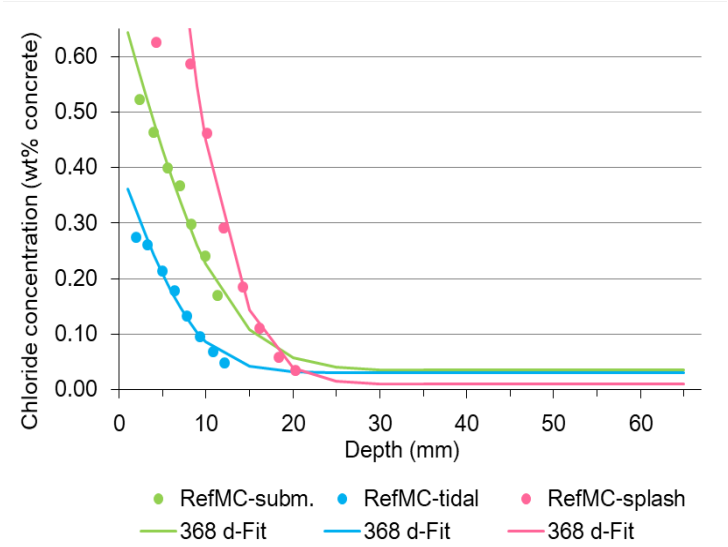
b) 5 ER sensors

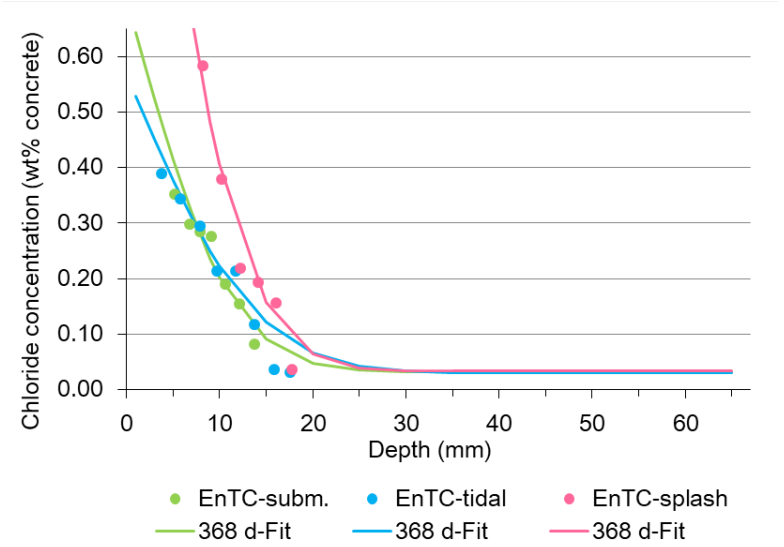
Physical corrosion monitoring technique, measuring **thickness reduction** of ER sensor due to corrosion over period of **time**.

c) 4 steel reinforcing rebars

Final visual examination

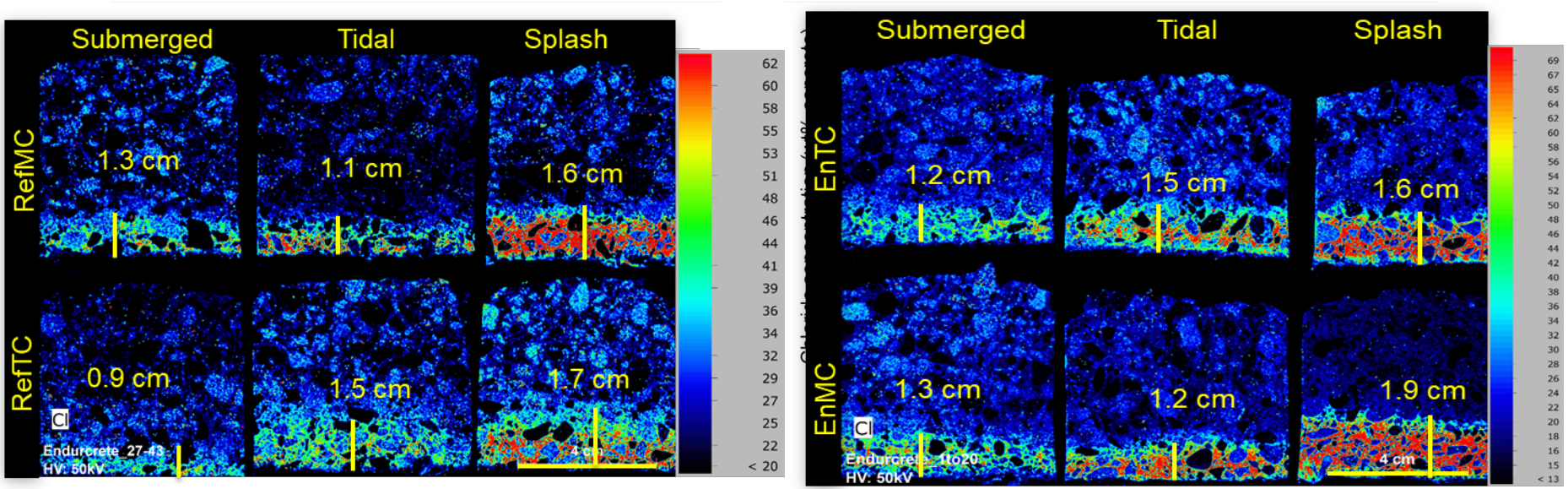
Chloride penetration results





	EnMC			RefMC		
	Subm.	Tidal	Splash	Subm.	Tidal	Splash
Initial chloride content (wt%)	0.049	0.011	0.046	0.035	0.030	0.010
Chloride content at the exposed surface (wt%)	0.780	0.927	1.328	0.700	0.405	1.975
Non-steady state diffusion coefficient (10^{-12} m^2 s^{-1})	1.35	0.84	1.62	1.39	0.76	1.06
Coefficient of determination R^2	0.927	0.990	0.967	0.964	0.987	0.990

Chloride penetration results



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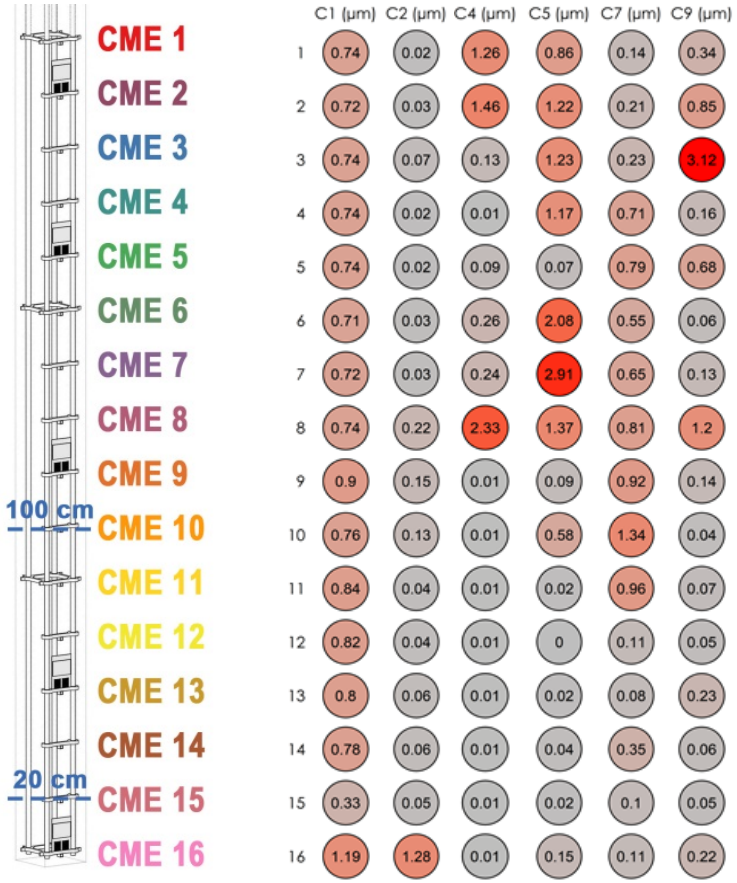
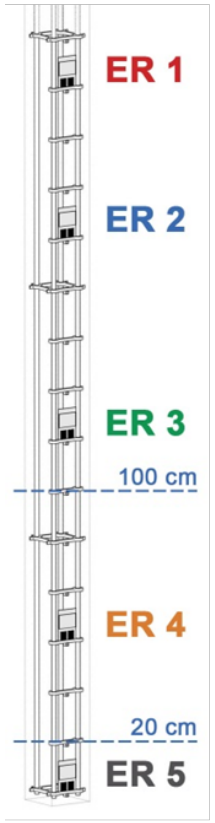
Corrosion monitoring results

Coupled multi-electrode measurements



	C1 (µm)	C2 (µm)	C4 (µm)	C5 (µm)	C7 (µm)	C9 (µm)
1	0.74	0.02	1.26	0.86	0.14	0.34
2	0.72	0.03	1.46	1.22	0.21	0.85
3	0.74	0.07	0.13	1.23	0.23	3.12
4	0.74	0.02	0.01	1.17	0.71	0.16
5	0.74	0.02	0.09	0.07	0.79	0.68
6	0.71	0.03	0.26	2.08	0.55	0.06
7	0.72	0.03	0.24	2.91	0.65	0.13
8	0.74	0.22	2.33	1.37	0.81	1.2
9	0.9	0.15	0.01	0.09	0.92	0.14
10	0.76	0.13	0.01	0.58	1.34	0.04
11	0.84	0.04	0.01	0.02	0.96	0.07
12	0.82	0.04	0.01	0	0.11	0.05
13	0.8	0.06	0.01	0.02	0.08	0.23
14	0.78	0.06	0.01	0.04	0.35	0.06
15	0.33	0.05	0.01	0.02	0.1	0.05
16	1.19	1.28	0.01	0.15	0.11	0.22

Electrical resistivity measurements



	C1 (µm)	C2 (µm)	C3 (µm)	C4 (µm)	C5 (µm)	C6 (µm)	C7 (µm)	C8 (µm)	C9 (µm)	C10 (µm)	C11 (µm)	C12 (µm)
1	0	0	1	0	0.2	0	0.6	0.2	0	0	0.1	0
2	0	0	0	9.7	0	0	0.2	0.2	0	0	0.2	0.3
3	0	0	0	0.2	0	0	0.3	0.5	0	0.2	0.3	0
4	0.1	0.4	0.1	0.5	0.7	0	0.7	0.7	0.5	0.4	0.6	0.7
5	0.1	0.2	0.1	0.4	0	220	0	0.6	0.1	0	0.4	0

Conclusion

- no significant corrosion activitiy to make final conclusions about different materials and exposure zones
- only different current fluctuations among different columns and no evident stable anodic and cathodic currents so far
- Minor differences in durability properties
- New cements are comparable to reference cements (CEM II / A-S 42,5R and CEM III / A 42,5N (EDC-PL))

Presentation of the cluster project

COORDINATOR

RESHEALIENCE

LIBERATO FERRARA

Professor of Structural Analysis and Design at Politecnico di Milano

Liberato Ferrara, Representative of the Reshealience project

Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement Nº 760824

RESHEALIENCE
Ultra High Durability Concrete

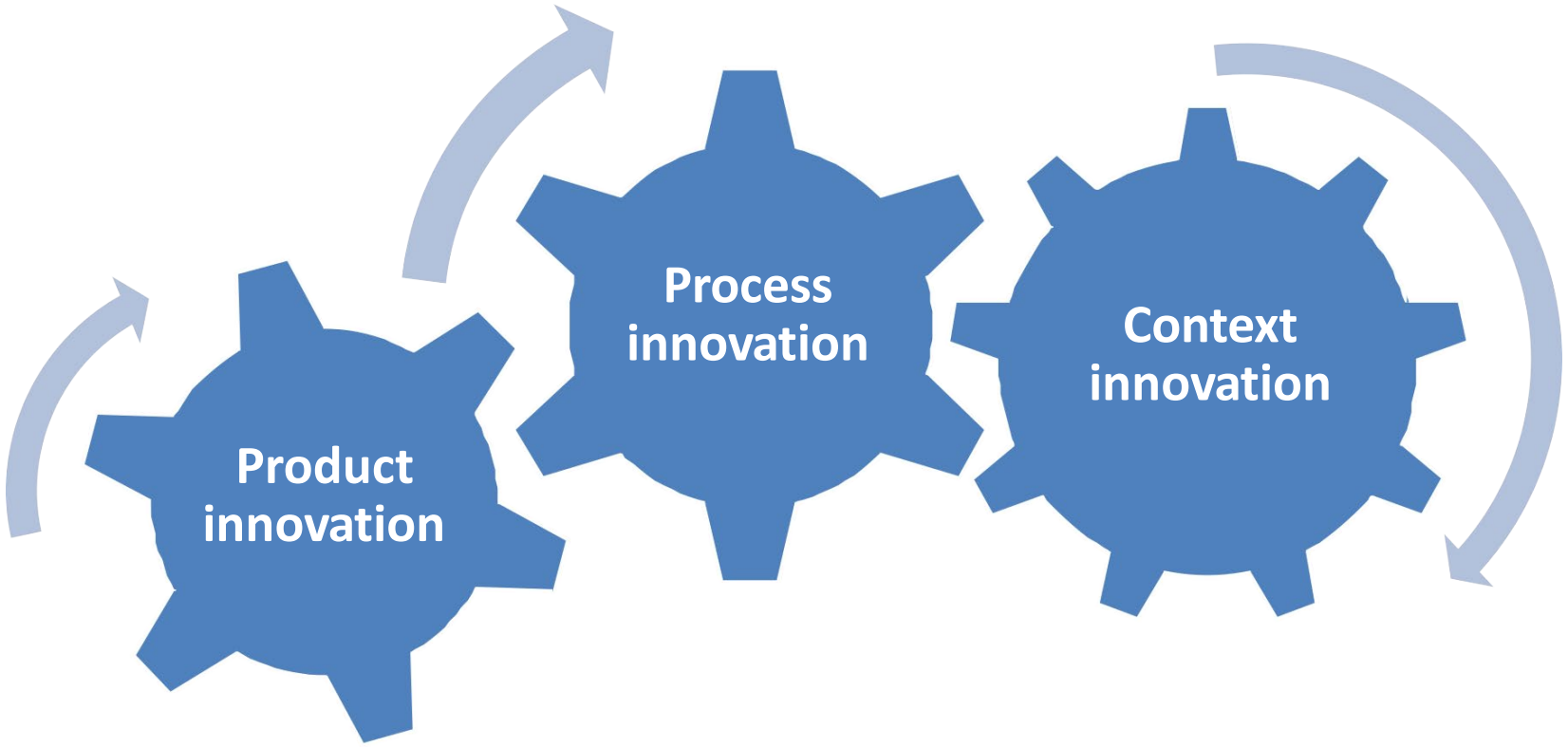
POLITECNICO MILANO 1863

Rethinking coastal defence and Green-energy Service infrastructures through enHancEd-durAbiLity high-performance cement-based materials

The concrete construction industry and the XXI century societal and economic challenges: the vision and approach of the ReSHEALience project

Liberato Ferrara
Department of Civil and Environmental Engineering, Politecnico di Milano

The «sustainability» strategy



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Horizon H2020 European Union Funding for Research & Innovation

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Current «societal» challenges for civil engineering

Transportation Infrastructures :

1% GDP investment in infrastructures results into +1.5% GDP in 4 years

http://ec.europa.eu/growth/sectors/construction/index_en.htm

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Current «societal» challenges for civil engineering

Transportation Infrastructures :

Every year road interruptions and traffic congestion delays cost an average of USD 3600 to each household!

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Current «societal» challenges for civil engineering

Coastal protection: Europe has a 66000 km coastaline (3 times as much the one of US)

Coastal defense infrastructure market: 660 bn€/y + 4% year growth foreseen

a very likely increase of the European average 100-year extreme sea level of 34–76 cm under a moderate mitigation scenario, and of 58–172 cm under a high emissions scenario

Nearly 700000 EU citizens exposed to coastal flooding

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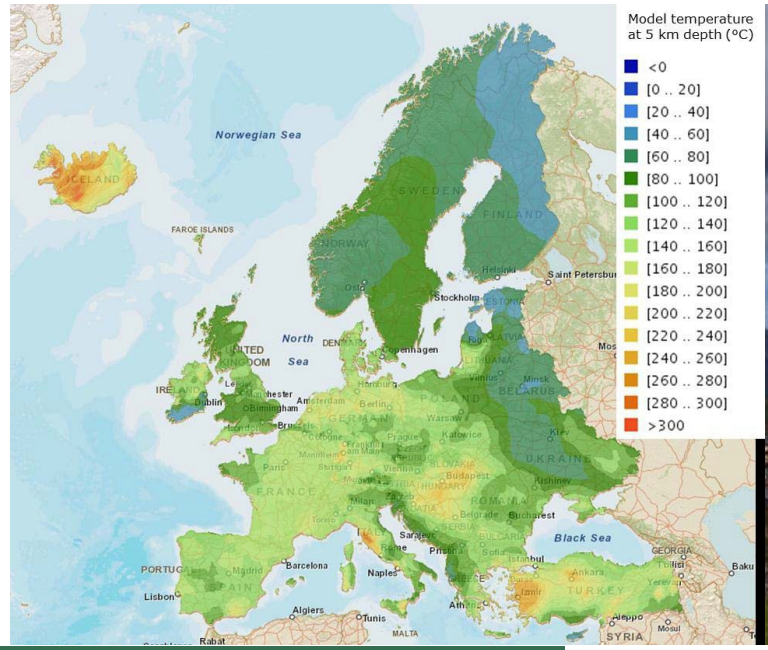
Current «societal» challenges for civil engineering

Green growth: promoting the growth of clean energy production

EGS: engineered geothermal system - stimulating deep hot resources that are otherwise not exploitable - provided technological challenges are overcome, the installed capacity of EGS technology could reach between 1200 GW to 12000 GW worldwide (currently it is 60 GW)
https://ec.europa.eu/jrc/en/news/new-report-analyses-geothermal-energy-sector



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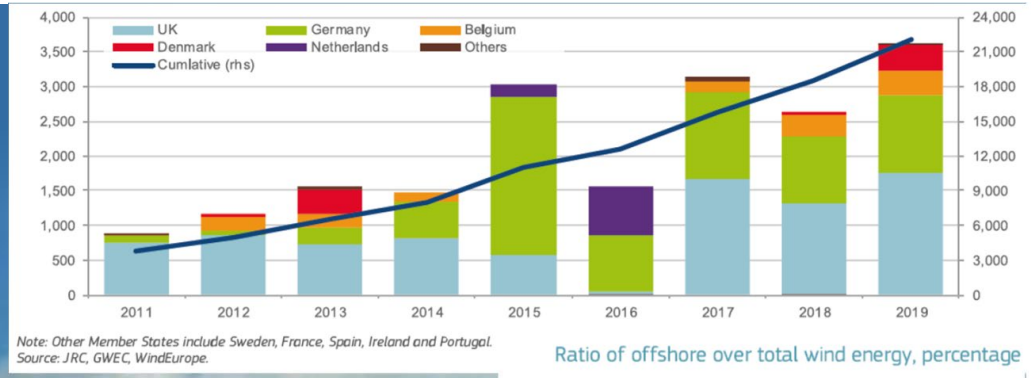
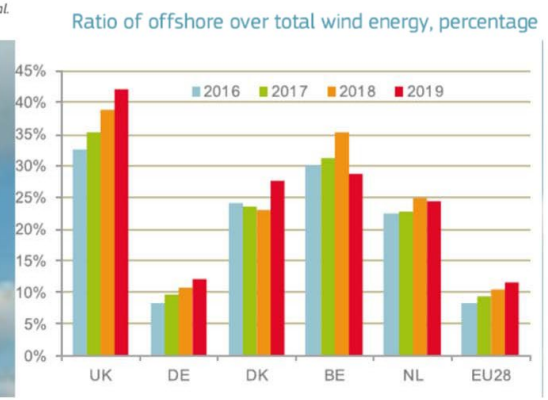
Current «societal» challenges for civil engineering

Green growth: promoting the growth of clean energy production

Offshore wind

https://ec.europa.eu/maritimeaffairs/policy/blue_growth_en





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Current «societal» challenges for civil engineering

Blue growth: doubling revenues in 2020-2030 (from 5 to 10 bln€)

70% of the planet is water but only 5% of economy develops in it. The 'blue' economy represents roughly 5.4 million jobs and generates a gross added value of almost €500 billion a year.

https://ec.europa.eu/maritimeaffairs/policy/blue_growth_en

Table 2.3 Preliminary assessment of the impact of the COVID-19 economic crisis on the Blue Economy

Sector	Size	Initial impact	Recovery path
Established sectors			
Marine living resources	Medium	Strong	Lagged
Marine non-living resources	Small	Medium	Prompt
Marine renewable energy	Nascent	Strong	Prompt
Port activities	Medium	Strong	Prompt
Shipbuilding and repair	Small	Medium	Lagged
Maritime transport	Medium	Strong	Prompt
Coastal tourism	Very large	Strong	Very lagged
Emerging sectors			
Blue bioeconomy	Small	Strong	Prompt
Ocean energy	Nascent	Small	Prompt
Desalination	Nascent	Small	Prompt
Maritime defence	Small	Small	Prompt
Cables	Nascent	Small	Prompt
Research and Education	Nascent	Small	Prompt
Marine observation	Nascent	Small	Prompt

Source: Commission Services.

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The blue growth
and the challenges for civil engineering

YEARLY COST OF CORROSION: 2.5 USD TRILLION (3.4% WORLD GDP)

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The blue growth
and the challenges for civil engineering

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The green growth
and the challenges for civil engineering

durable and resilient infrastructures
to support and boost green growth

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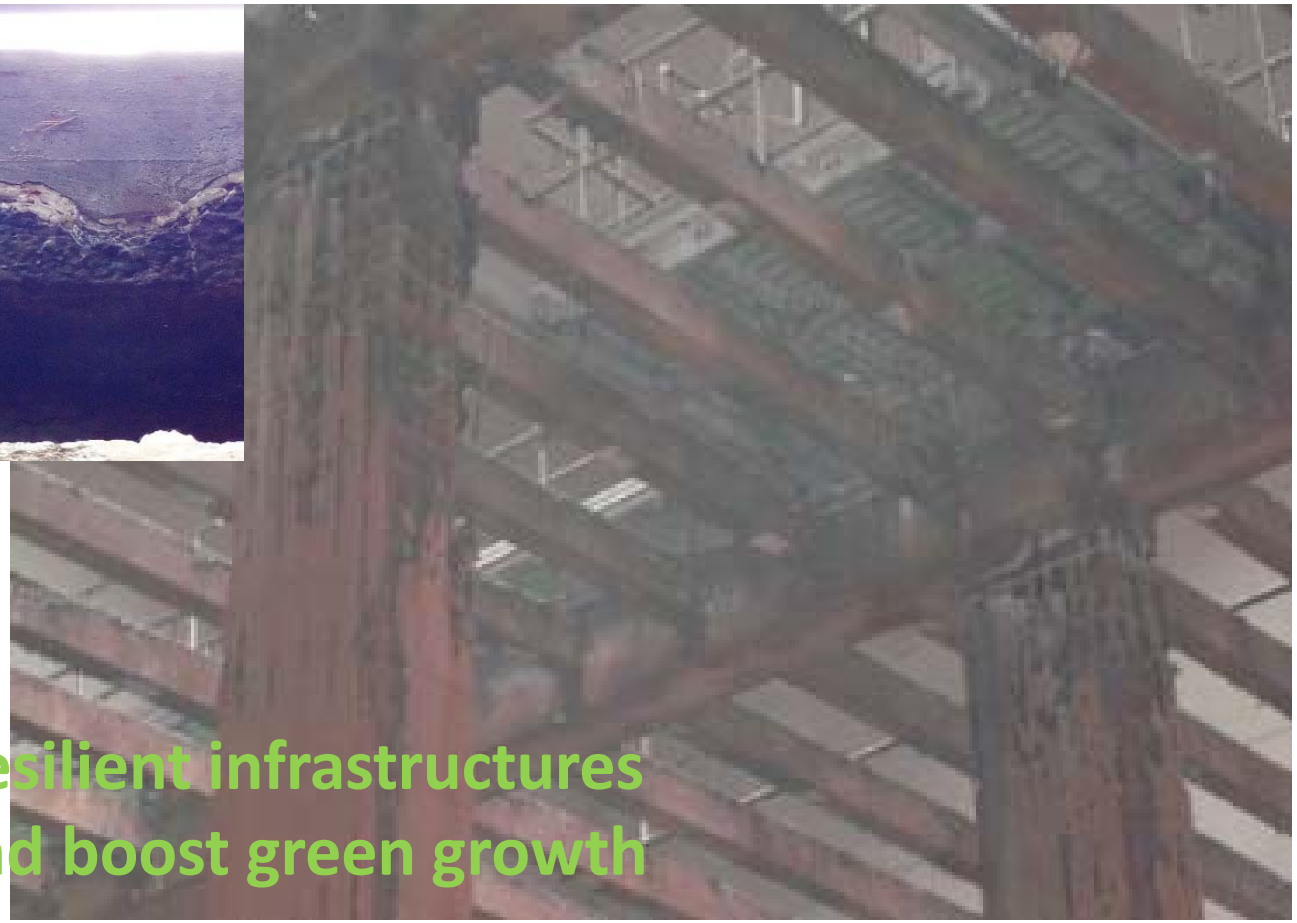
The green growth
and the challenges for civil engineering



durable and resilient infrastructures
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Current «societal» challenges for civil engineering

Structures in XS/XA exposures

Design prescriptions (EN 1992-1-1; *fib* Model Code 2010, ACI)

XS exposure

Exposed to airborne salt

Permanently submerged

Tidal, splash and spray zones

XA exposure

Slightly aggressive chemical attack

Moderately aggressive chemical attack

Highly aggressive chemical attack

	Maximum w/c	minimum cement content		minimum compressive strength	minimum concrete cover	maximum crack width
		kg/m³		MPa	mm	mm
XS	0.40 - 0.65	300 - 400		25 - 40/50	25 – 75	0.1 - 0.4
				150 (UHPC)	10 – 30	?
XA	0.45 - 0.65	275	- 400	25/30 to 40/50	-	0.1 - 0.3
		325				
		325				

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The ReSHEALience project challenge

The challenge

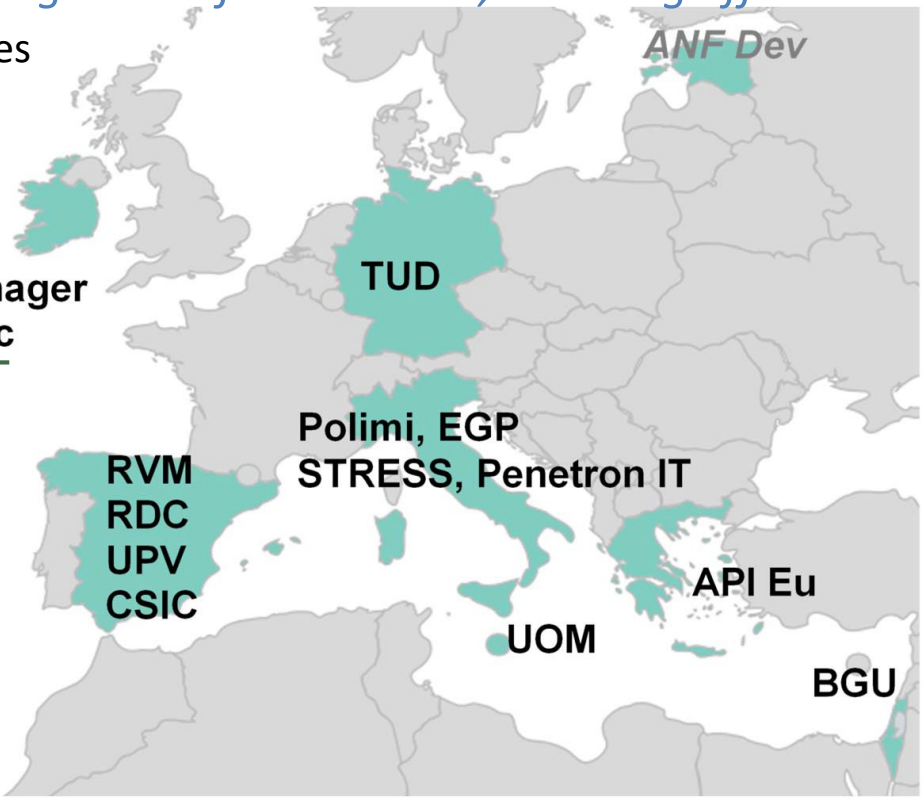
Improved material durability in buildings and infrastructures, including offshore

13 (+1) partners + 3 LTPs from 7 (+1) countries

5.5 M€

RESHEALIENCE

Ultra High Durability Concrete



JANUARY 1 2018 → MARCH 31 2022

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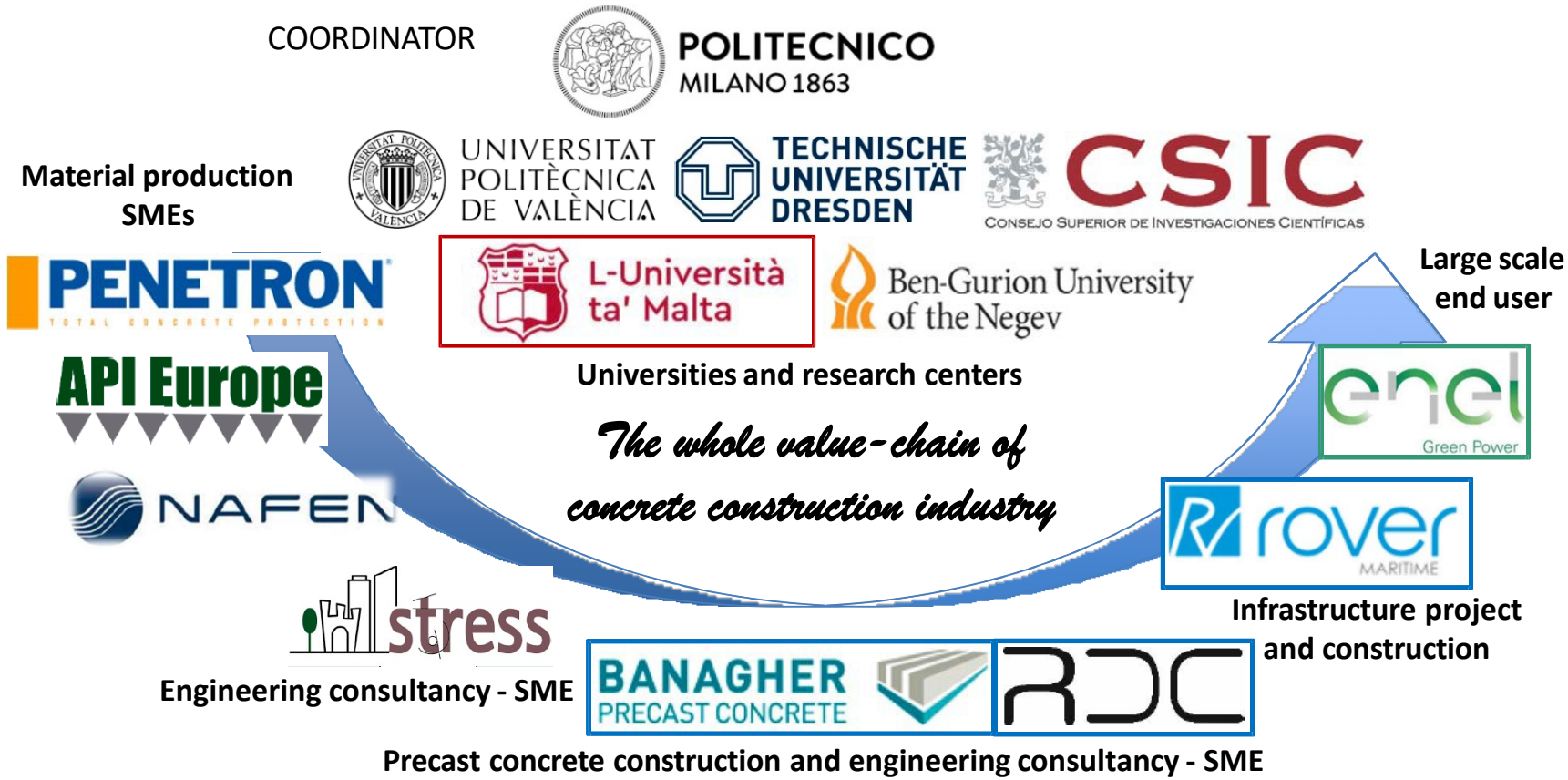
The «ReSHEALience» project consortium



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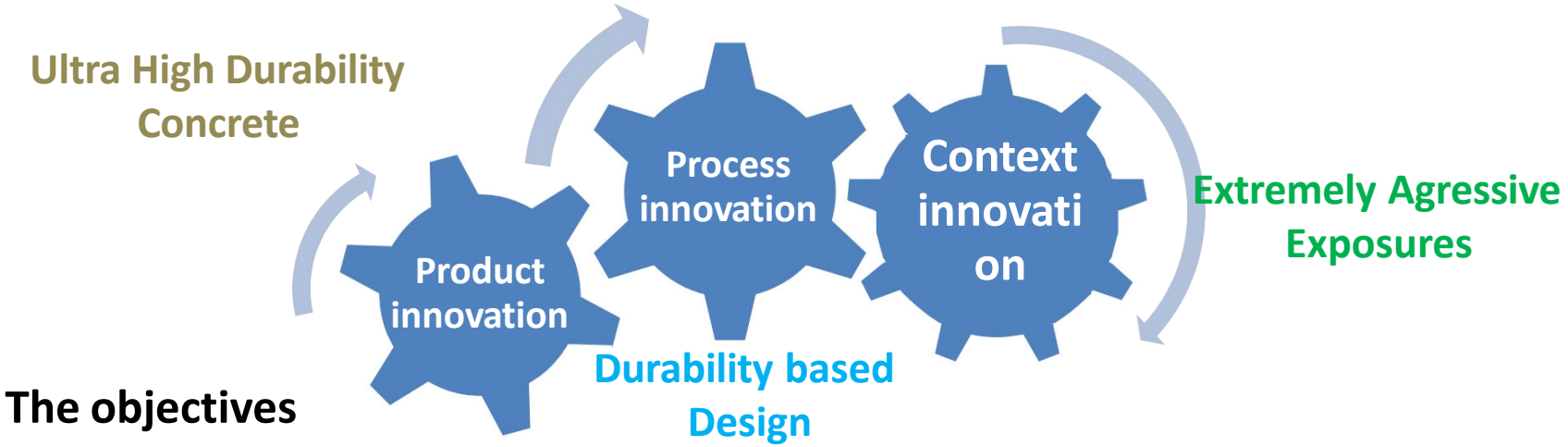
The «ReSHEALience» project concept

The strategy

Develop a **Ultra High Durability Concretes** (**UHDCs**) and a methodology for **Durability modelling** of materials and **Durability Assessment-based Design** of buildings and structures to improve durability and predict their **long-term performance** under **Extremely Aggressive Exposures**



The objectives

MATERIAL	STRUCTURAL	RESILIENCE	COSTS	ACCURACY	BUSINESS PLANS	IMPACT
100%	30%	30%	50%	75%	7	300
of improvement in un-cracked state	of improvement in cracked state	of increase of service life	of reduction of maintenance costs	of accuracy of the modelling	One per industrial partner	subscribers per year to the newsletter

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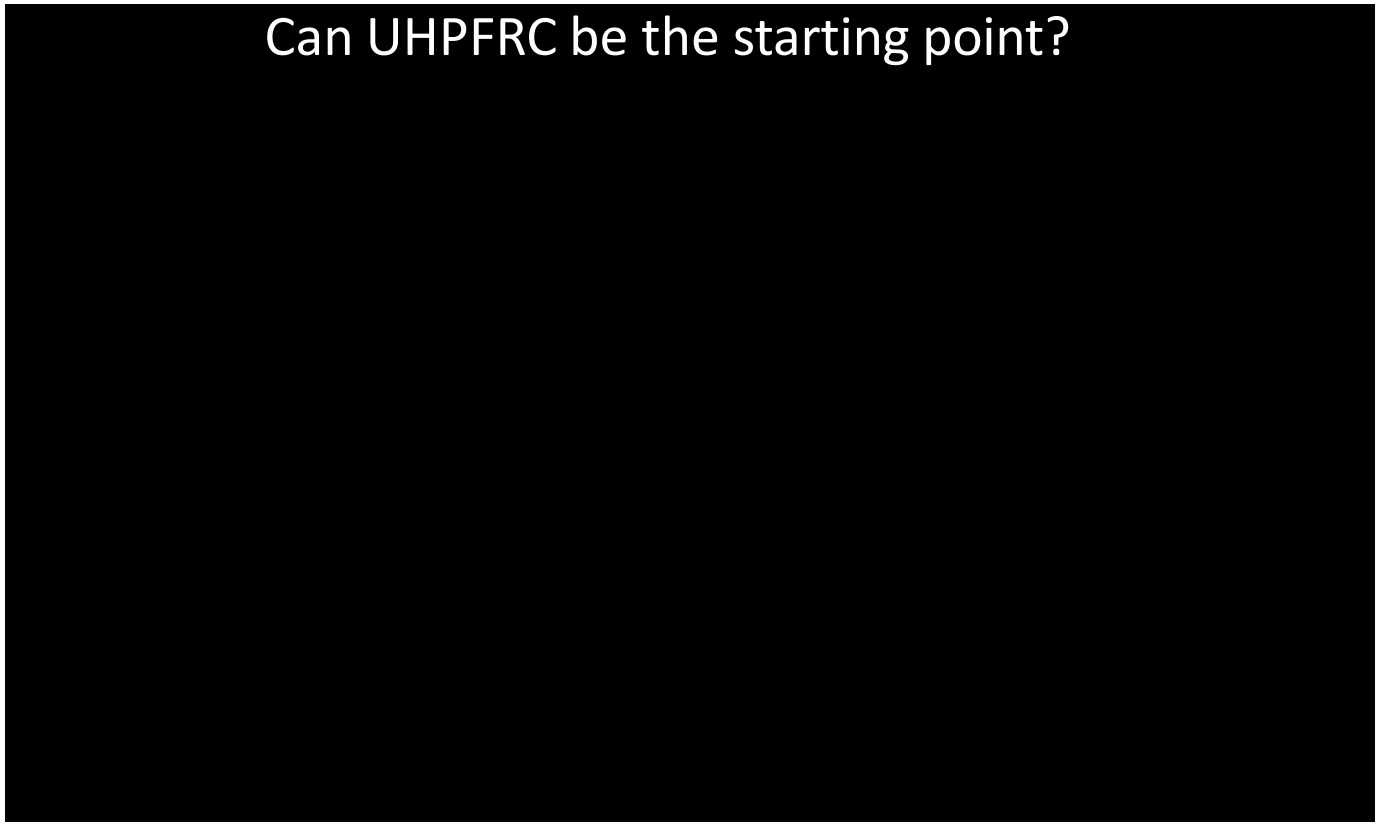
Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement Nº 760824

The ReSHEALience project concept Material innovation: UHDC



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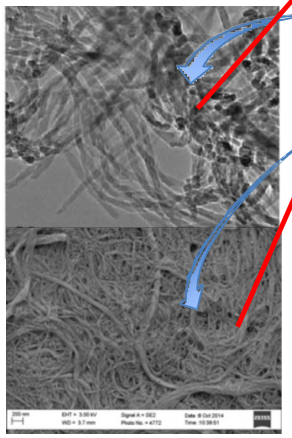
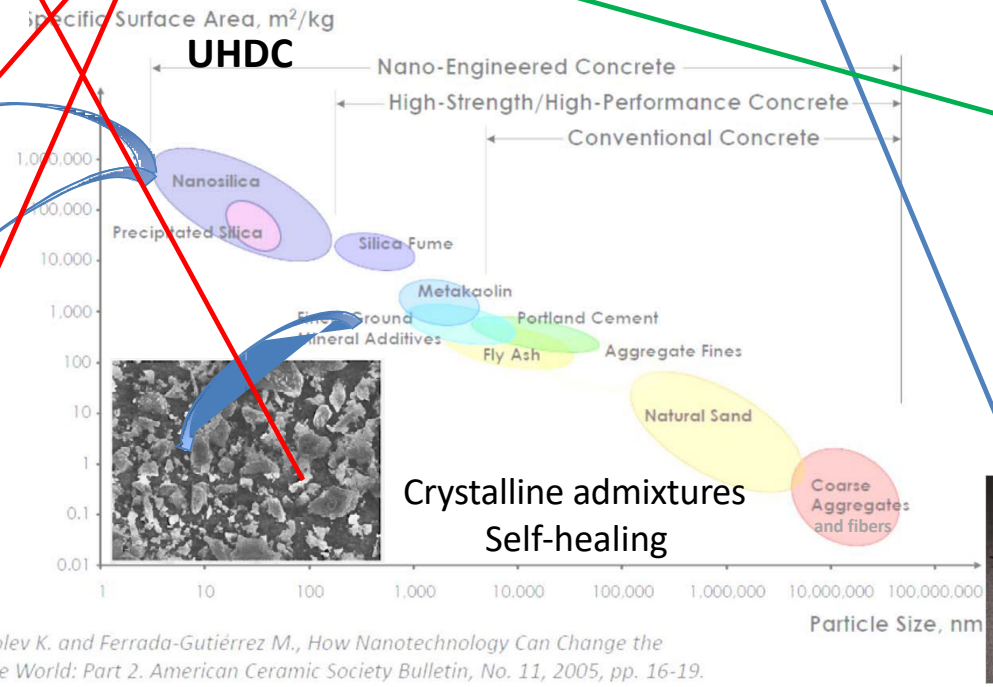
The ReSHEALience project concept
Material innovation: UHDC

Ultra High Durability Concrete (UHDC): ***"strain-hardening fibre/textile reinforced cementitious material with micro- and nano-scale functionalizing constituents, especially added to obtain a high durability in the cracked state under extremely aggressive exposure conditions".***

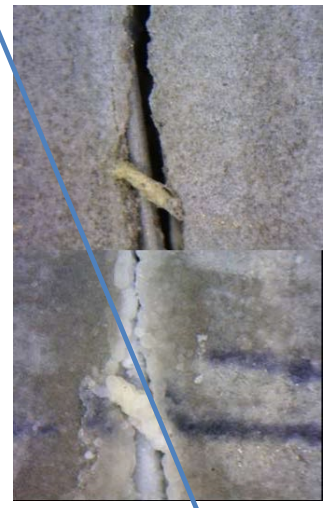
Alumina nanofibres
Nano-reinforcement

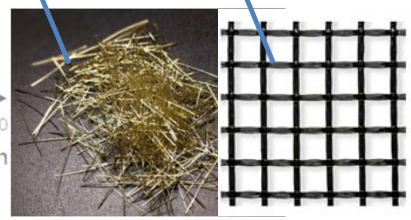


Cellulose nanofibrils
and nanocrystals
Self-curing



Crystalline admixtures
Self-healing





[1] Sobolev K. and Ferrada-Gutiérrez M., How Nanotechnology Can Change the Concrete World: Part 2. American Ceramic Society Bulletin, No. 11, 2005, pp. 16-19.

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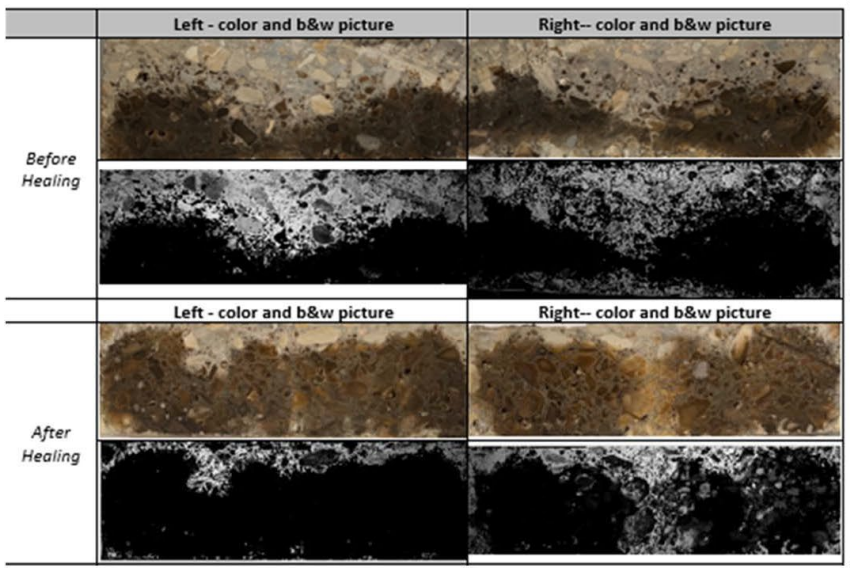
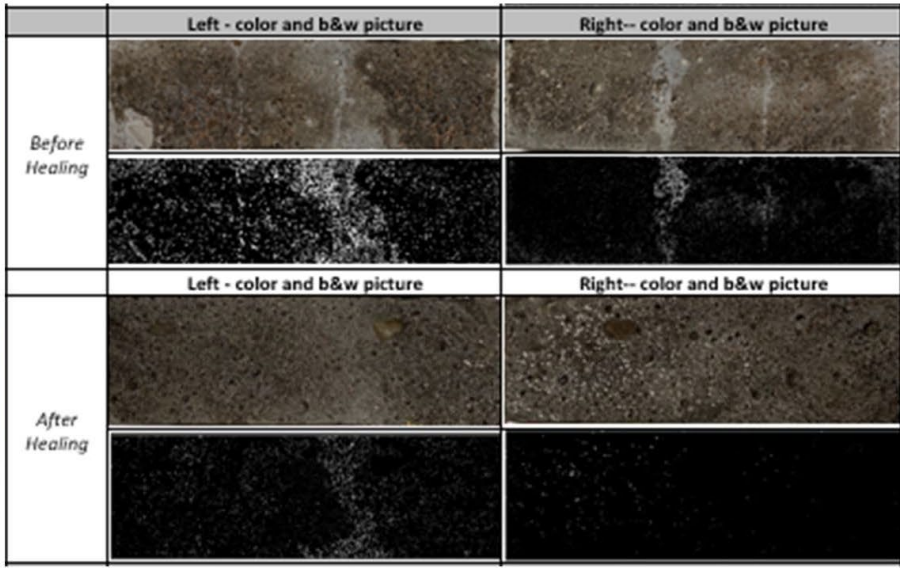
The ReSHEALience project concept
Material innovation: from UHPC to UHDC

Self-healing stimulators: crystalline admixture (Penetron Admix ®)

Resistance to chloride penetration – tests made at UPV



Conventional concrete



UHPC + self-healing stimulator

Serna and Roig-Flores

Unpublished results

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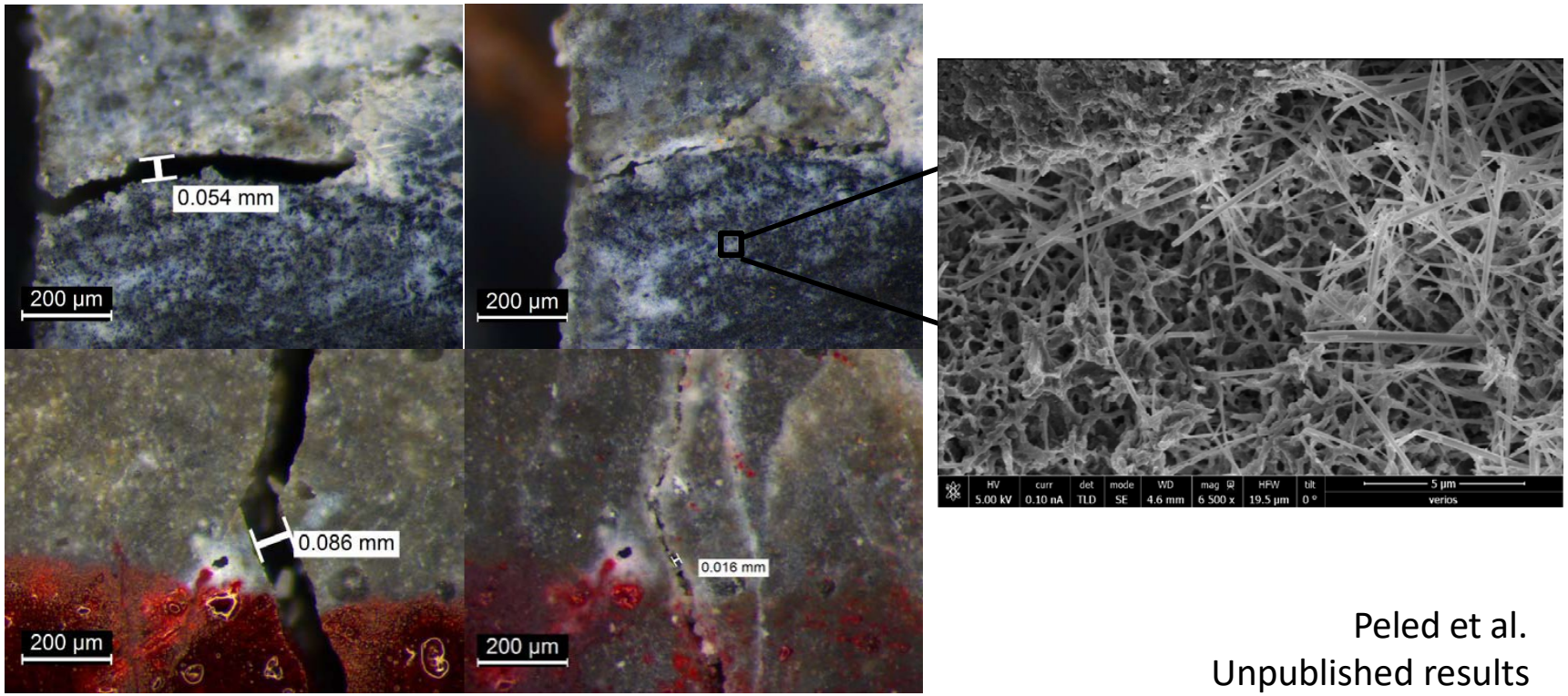
Recovery of (im)permeability: tests on TR-UHDC – tests made at BGU



Peled et al.
Unpublished results

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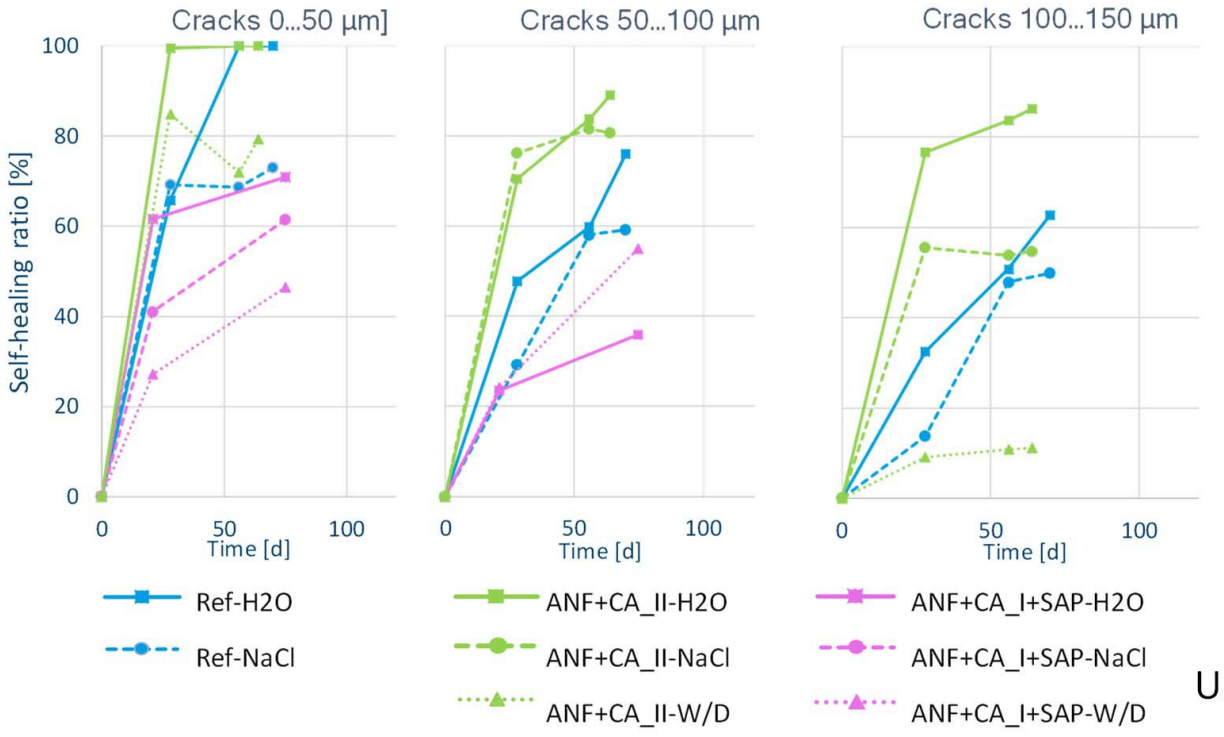
The ReSHEALience project concept
Material innovation: from UHPC to UHDC

Crystalline admixture (Penetron Admix®) and alumina nanofibres (Nafen®) effectiveness of crack closure: tests on TR-UHDC made at TUD



Unpublished results from partner TUD

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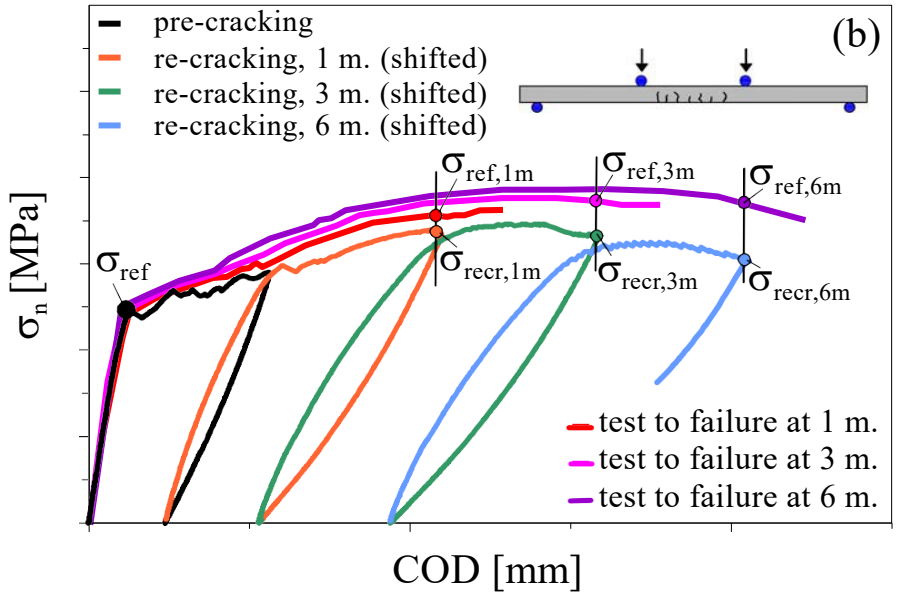
Material innovation: from UHPC to UHDC

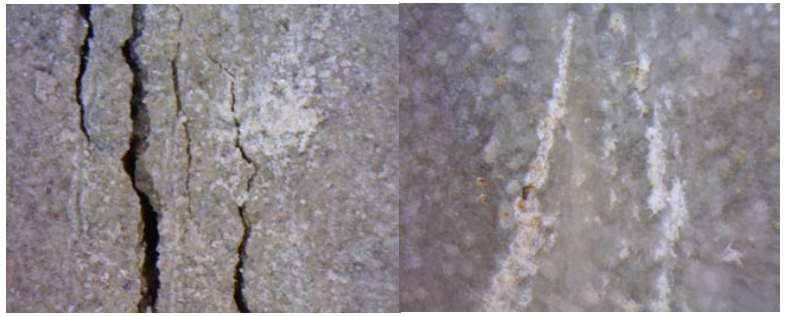
Self-healing stimulators: crystalline admixture (Penetron Admix ®)

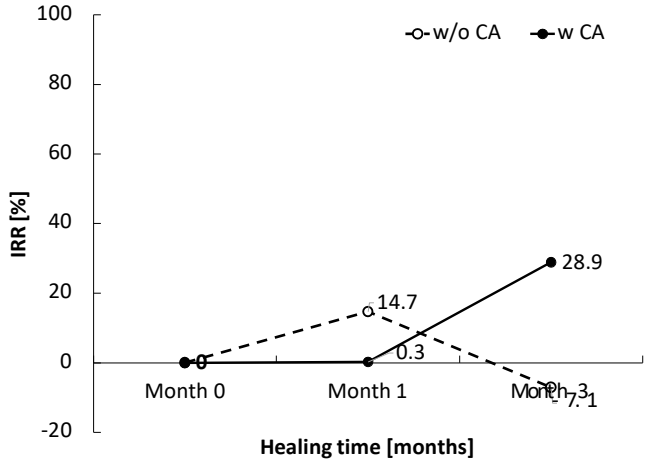
Stability of mechanical performance – tests made at PoliMi



$$IRR[\%] = \left(\frac{(J_{recr,i} - (J_{ref,i}}{(J_{ref}}\right) 100$$

Cuenca et al., unpublished results





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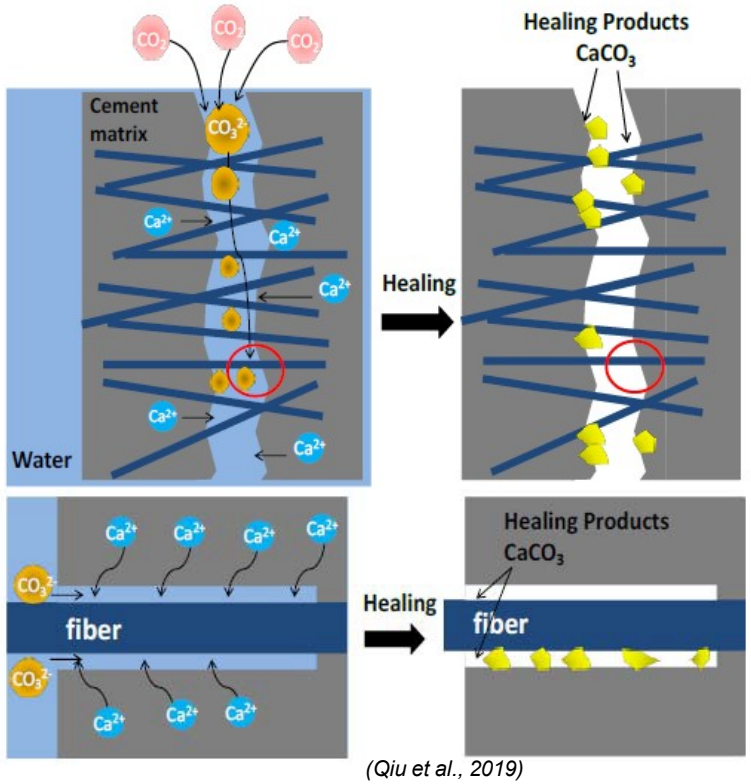
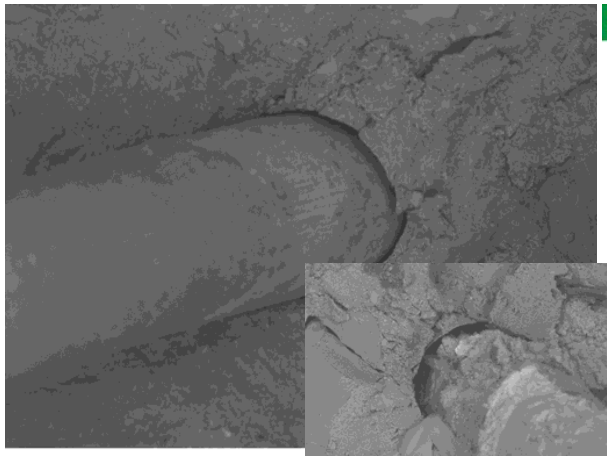
The ReSHEALience project concept
Material innovation: from UHPC to UHDC

Self-healing stimulators: crystalline admixtures

Stability of mechanical performance – tests on self-levelling UHDC



(Qiu et al., 2019)



EnCoRe
ENvironmentally-friendly solutions for COncrete with REcycled and natural components

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Universidade Federal do Rio de Janeiro

www.uhdc.eu

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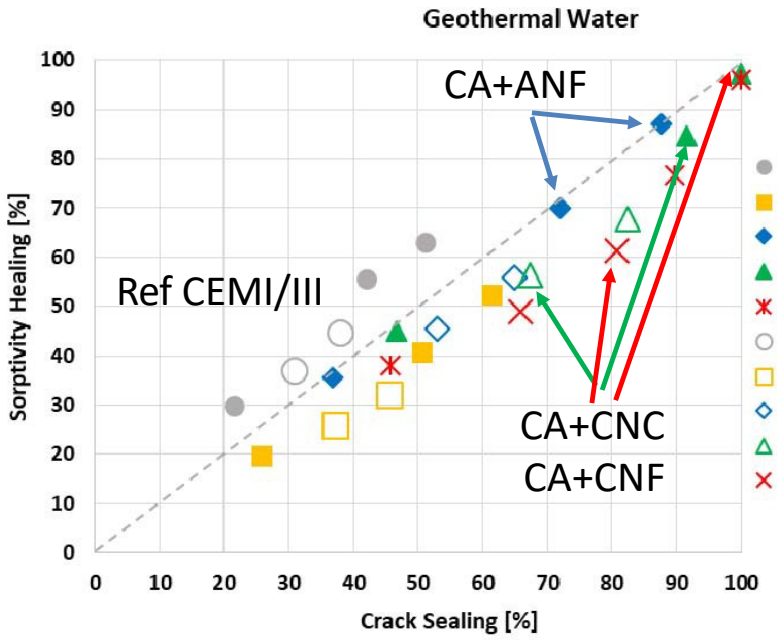
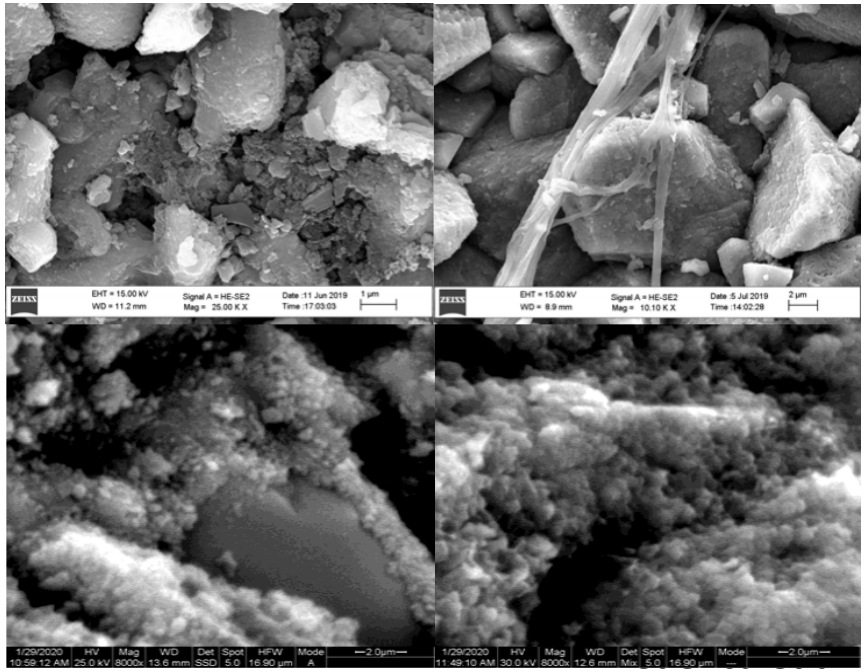
The ReSHEALience project concept
Material innovation: from UHPC to UHDC

Synergy between crystalline admixtures (Penetron Admix ®) and alumina nanofibres (Nafen®) or cellulose nanofibrils/crystals(API Europe® effectiveness of (im()permeability recovery: tests made at PoliMi





Construction and Building Materials, in review

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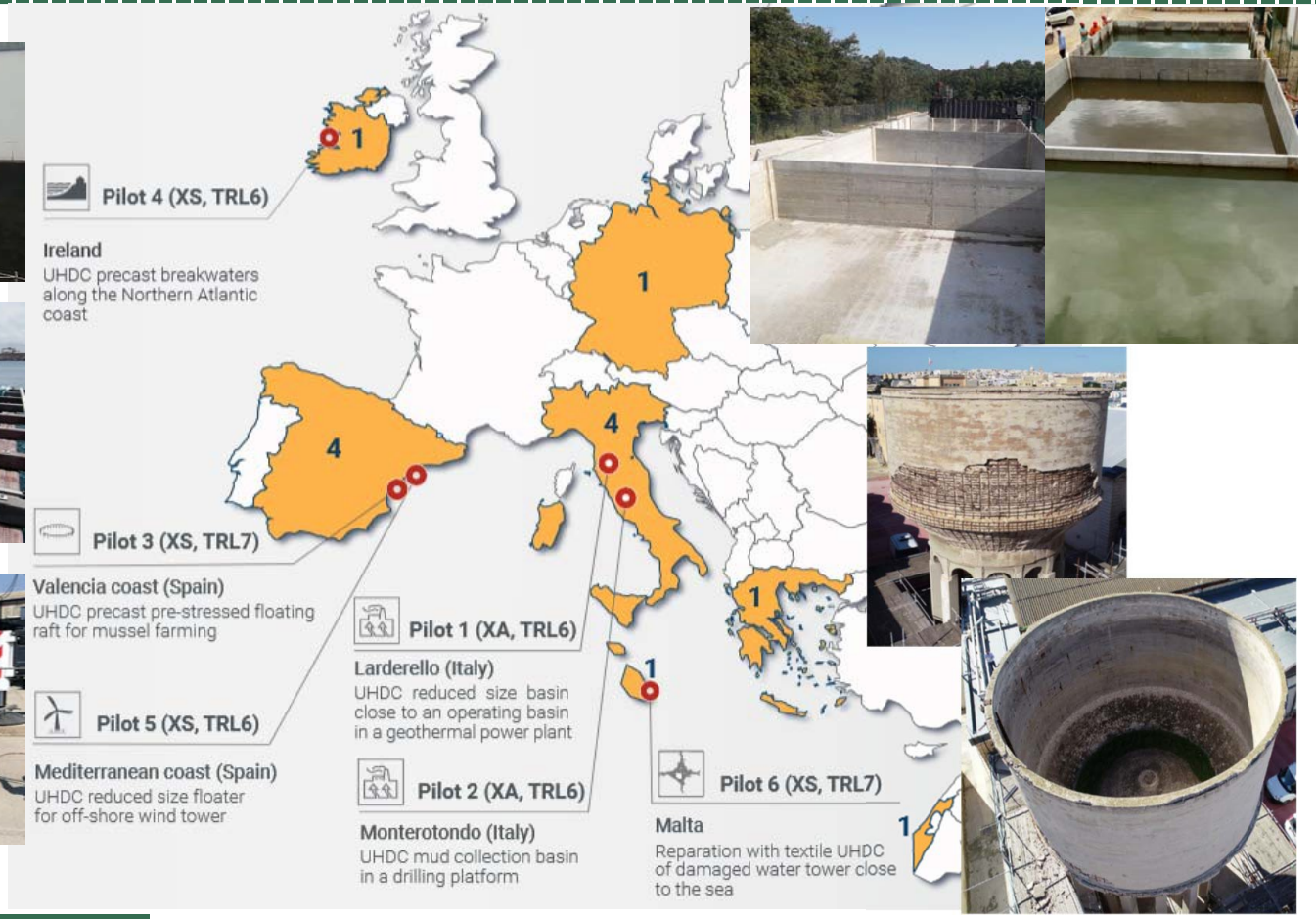
The ReSHEALience project concept - Context innovation:
Blue Growth, Green Energy, R/C Heritage Conservation



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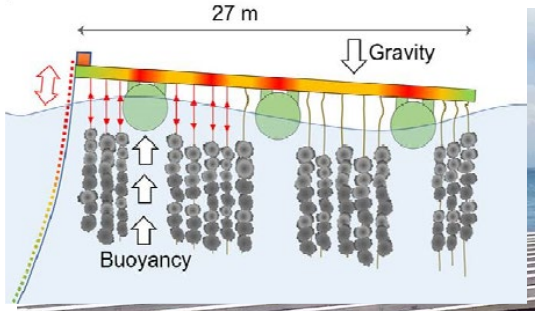

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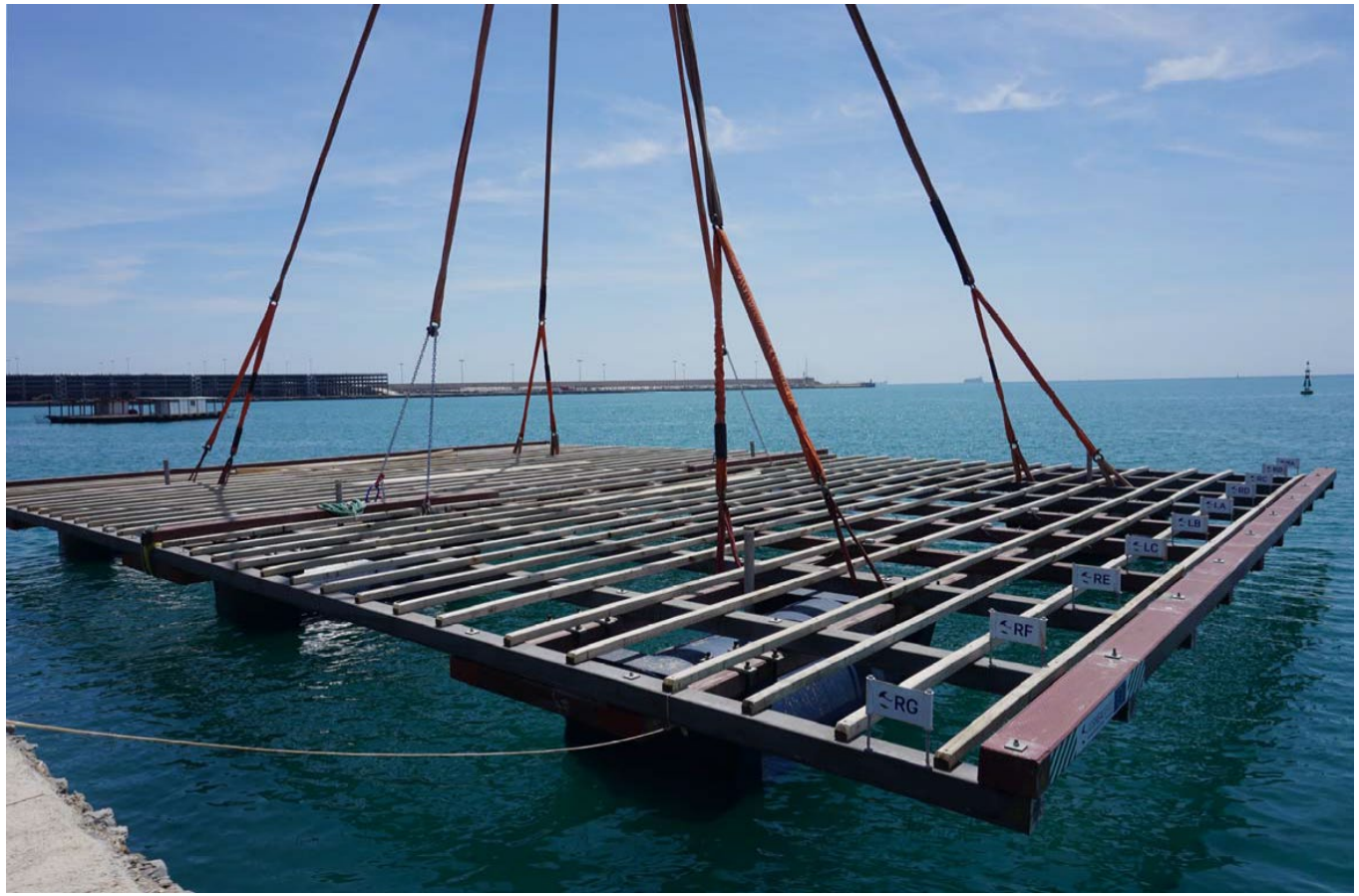

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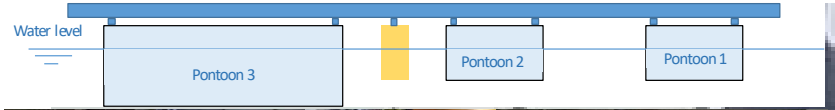

BANAGHER PRECAST CONCRETE

TECHNISCHE UNIVERSITÄT DRESDEN

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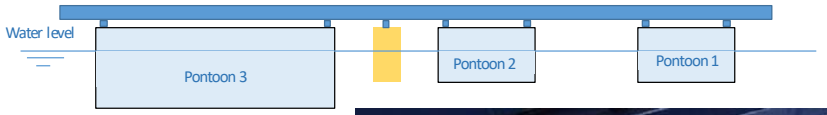

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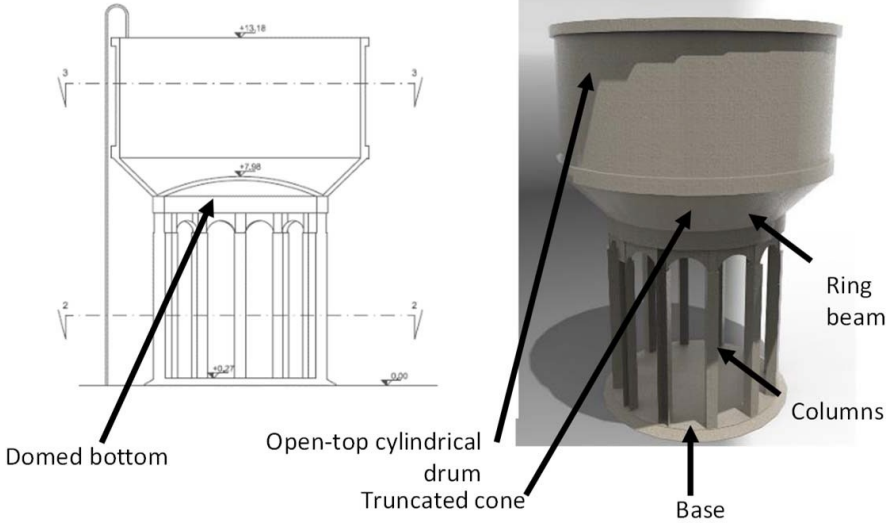
L-Università ta' Malta

Ben-Gurion University of the Negev



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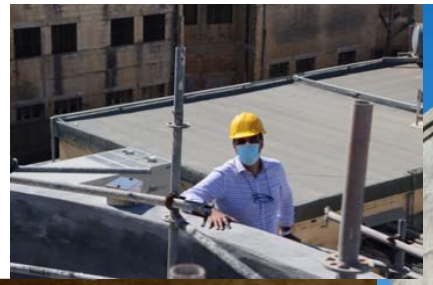

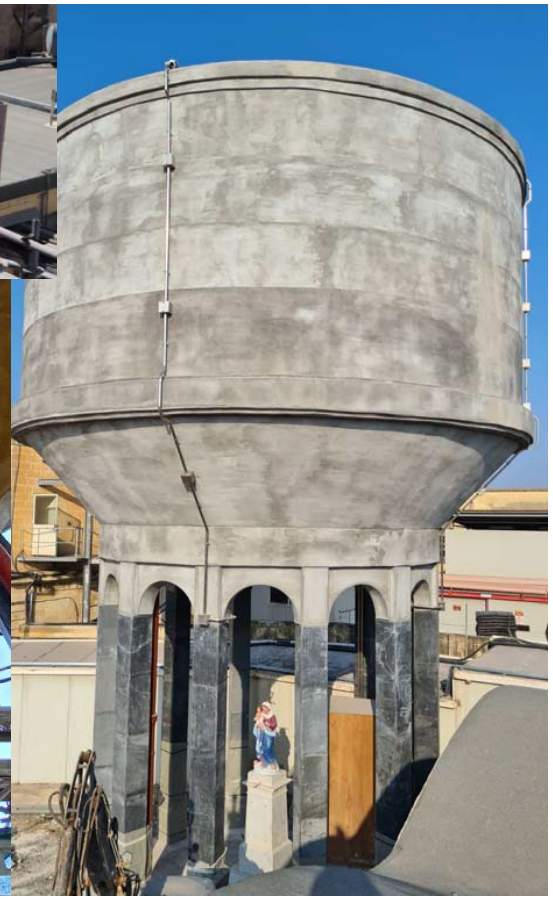

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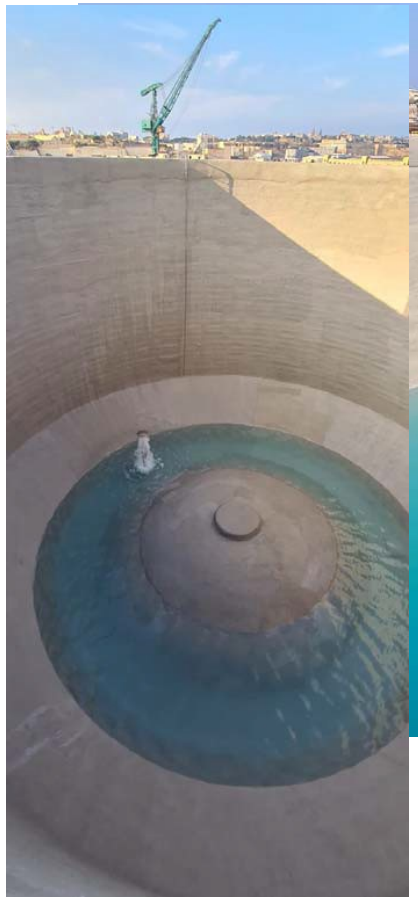

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ReSHEALience project: towards a novel holistic design concept

Constituents	XA-	XA-CA CEMIII	XA-CA +ANF	XA-CA +CNC	XA-CA +CNF
CEM I 52,5 R	*600*	*-*	*600*	*600*	*600*
CEM III	*-*	*600*			
Slag	*500*				
Water	*200*	*200*	*200*	*200*	*200*
Steel fibers Azichem Readymesh 200	*120*	*120*	*120*	*120*	*120*
Sand 0-2mm	*982*	*982*	*982*	*982*	*982*
Superplasticizer Glenium ACE 300	*33*	*33*	*33*	*33*	*33*
Crystalline admixtures	*3*	*3*	*3*	*3*	*3*
*Alumina nanofibers**	*-*	*-*	*0.25*	*-*	*-*
*Cellulose nanocrystals**	*-*	*-*	*-*	*0.15*	*-*
*Cellulose nanofibrils**	*-*	*-*	*-*	*-*	*0.15*

* *% by cement mass*

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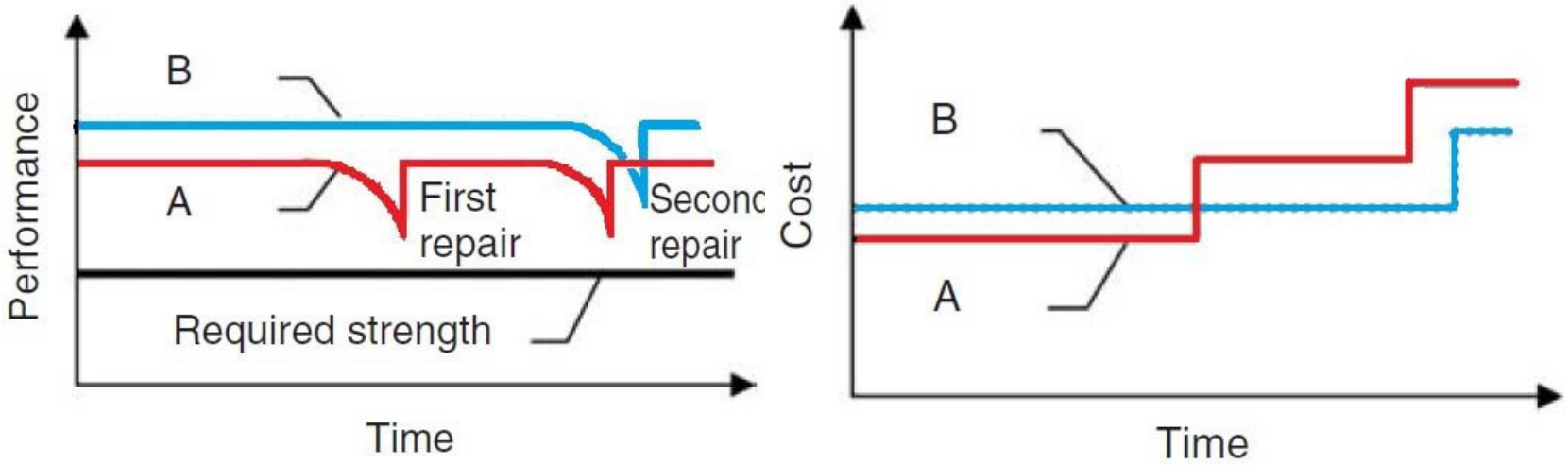

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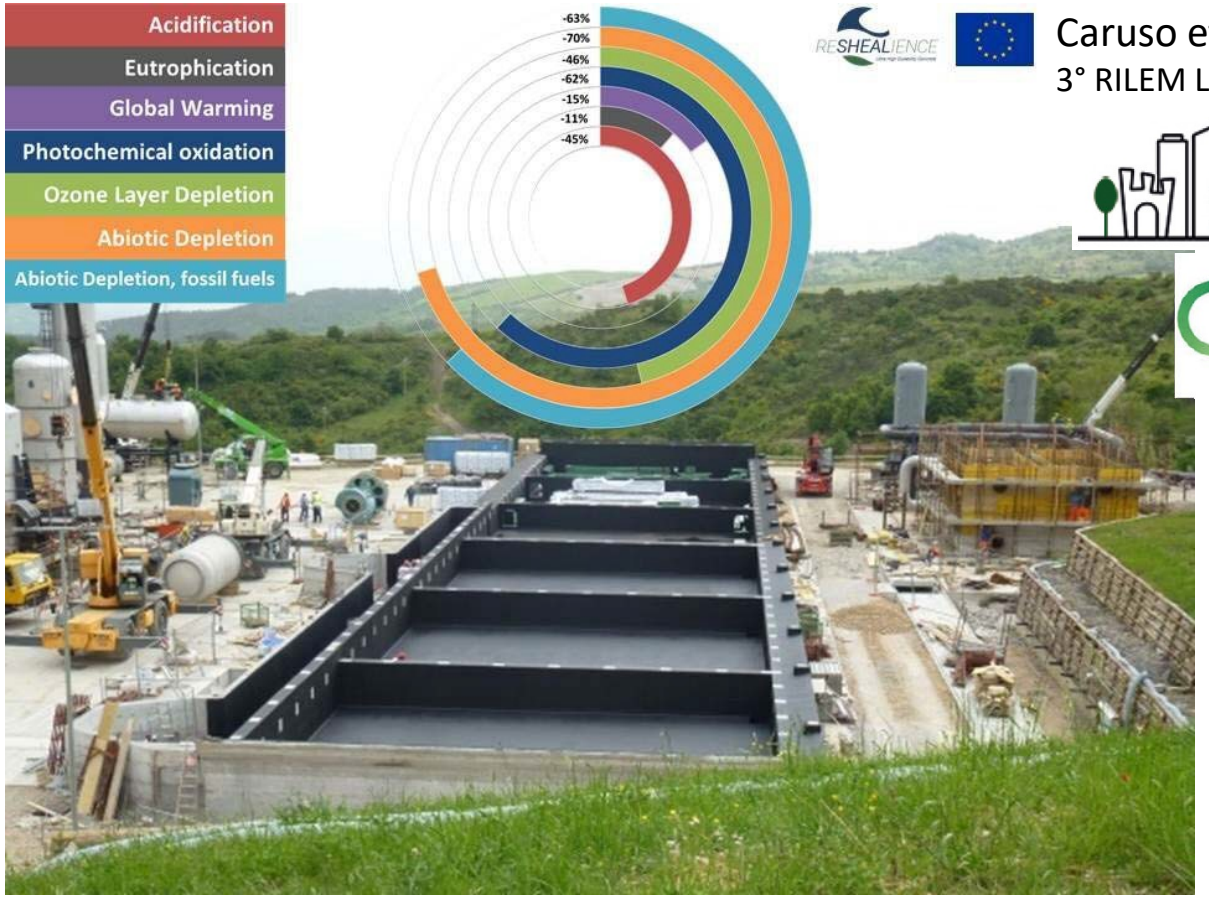
ReSHEALience project: concluding remarks in a durability and LCA based «structural design» nutshell



Caruso et al., 2020
3° RILEM LCA symposium

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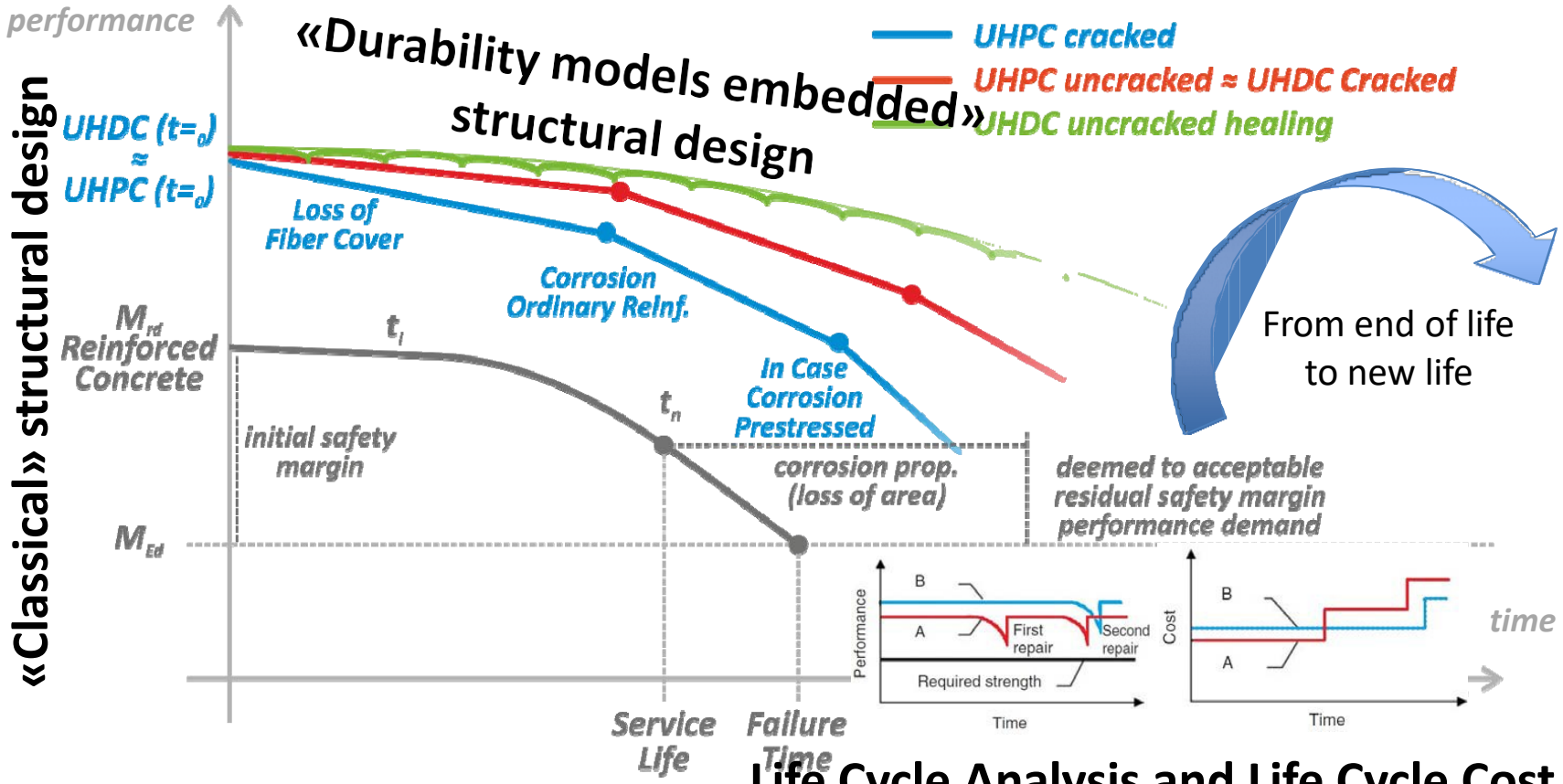
The ReSHEALience project concept
Process innovation: Durability based Design



Life Cycle Analysis and Life Cycle Cost

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The ReSHEALience project concept Process innovation: re/up cycling

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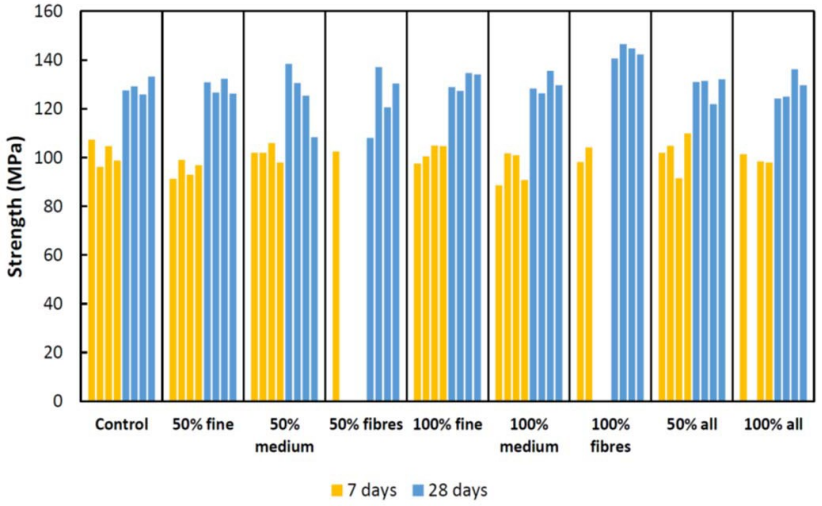
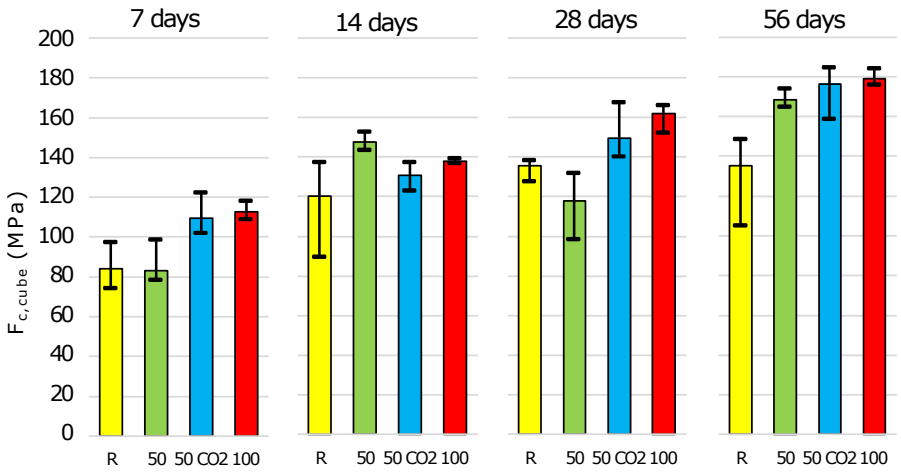
Unpublished results





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The ReSHEALience project concept Process innovation: re/up cycling

Niranjan K. Prabhu PhD thesis, unpublished image

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Current «societal» challenges for civil engineering

Reflection Paper addresses the role of materials in the post-covid society

Published on 24.09.2020 by EMMC - European Commission - A4M_Alliance for Materials - EUMAT

Which scenario?

"The role of Materials in the post-COVID society"

A reflection on how Materials will enable solutions for a healthy, safe, and resilient society to achieve a sustainable, stable, and stronger economy, able to respond to citizen's demands.

… to create a less dependent, more resilient European economy by guaranteeing raw material supplies, by ensuring higher materials durability, higher energy efficiency, higher degrees of materials re-cycling and re-use and by material-saving through optimized products by design with enhanced repair

Liberato Ferrara, DICA, Politecnico di Milano

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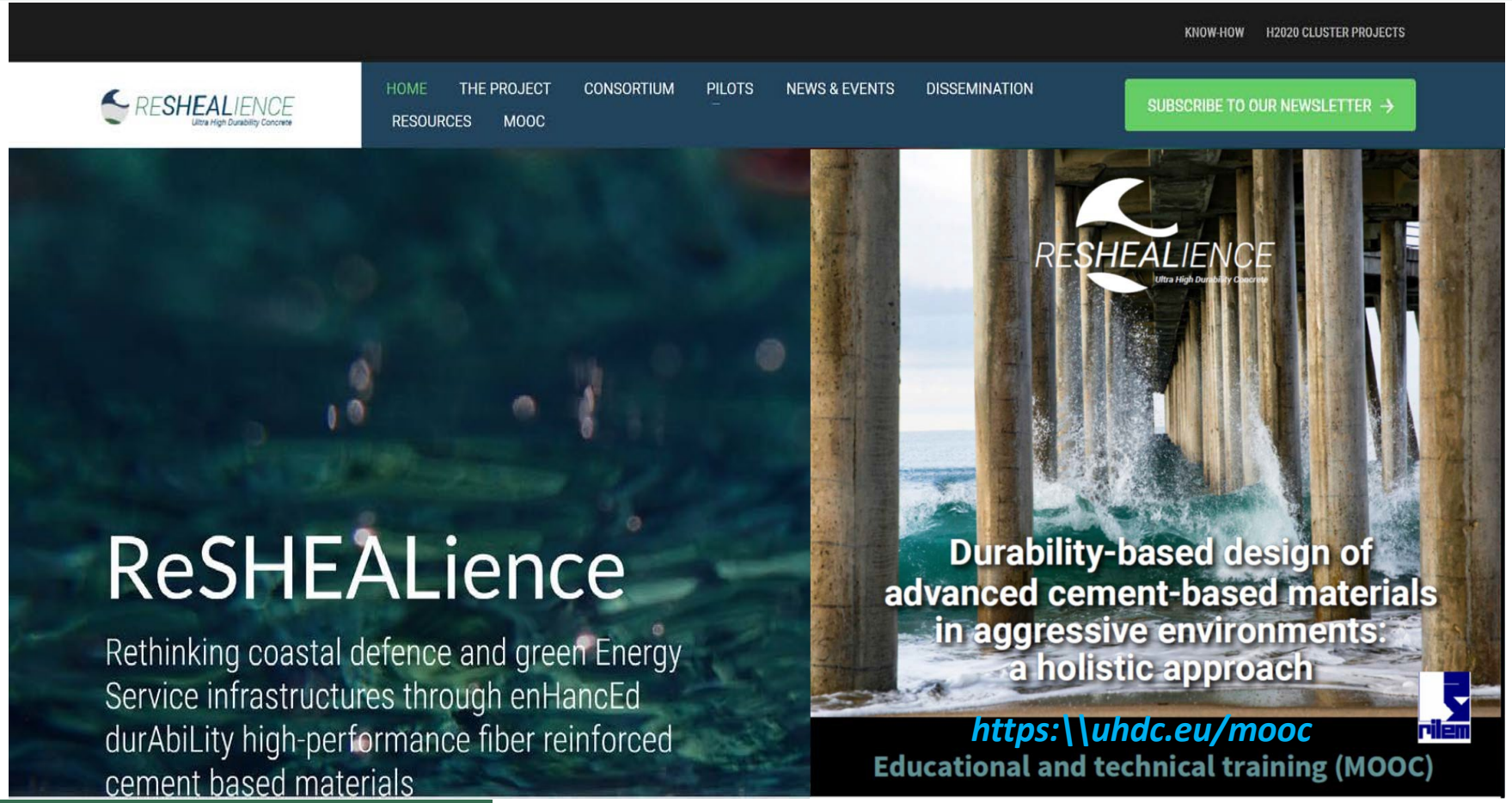

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… educating a new generation of professionals …

Estefania Cuenca, Assistant professor, PoliMi
Francesco Lo Monte, Assistant professor, PoliMi
Antonio Cibelli, PhD student, PoliMi
Salam Maytham, PhD student, PoliMi
Maria Chiara Caruso, LCA expert, STRESS
Cristina Maestre, Communication expert, RDC
Evangelia Enteze, Post-doc researcher, API Europe
Michail Iakovlev, Post-doc researcher, API Europe
Valentina Violante, Project engineer, Penetron IT
Marta Roig Flores, Post-doctoral student, UPV
Eduard Mezquida, PhD student, UPV
Roman Bataller, researcher, UPV
Philipp Kuntz, PhD student, TUD
Michaela Reichardt, PhD student, TUD
Maria Criado, Post-doctoral student, CSIC
Mercedes Gimenez, PhD student, CSIC
Radhu Sripada, Post-doctoral student, BGU
Amer Alatawna, PhD student, BGU
Lior Nahum, PhD student, BGU
Tal Yadlin, PhD student, BGU
Milena Nasner Albany, Post-doctoral researcher, UoM

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Contact Info

For further information on the projects please contact:

prof. Liberato Ferrara
Department of Civil and Environmental Engineering,
Politecnico di Milano
Tel.: +39 02 2399 4387
liberato.ferrara@polimi.it

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on behalf of the ReSHEALience consortium

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and of the ReSHEALients@DICAPolimi

If you always do what you always did, you'll always get what you always got!

Liberato Ferrara, DICA, Politecnico di Milano

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Thank you for your attention!

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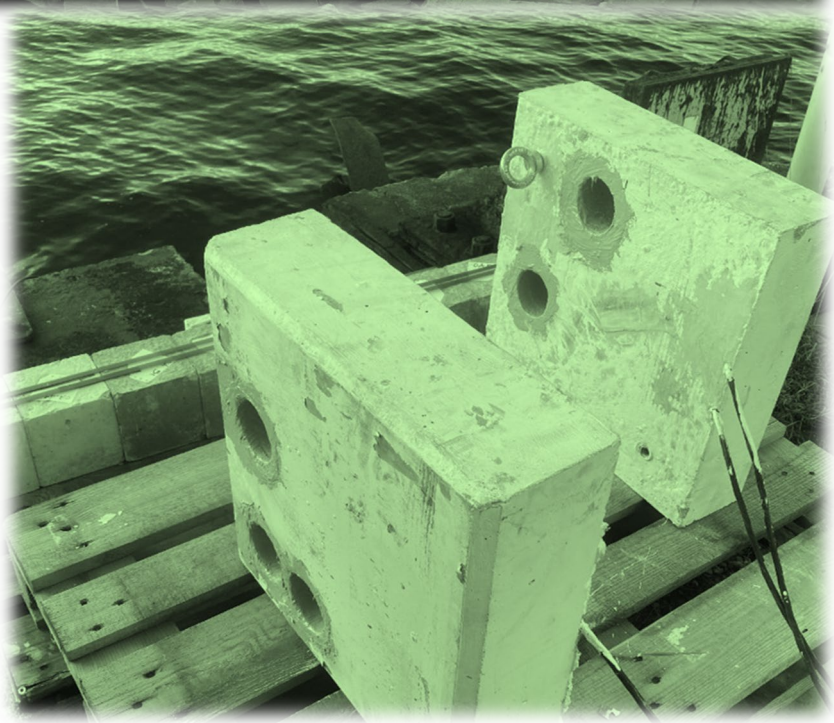
Q&A session



Health and safety of the technologies

SPEAKER

ENDURCRETE

DR. CECILE PHILIPPOT

Project Leader at the NanoSafety Platform of CEA Grenoble

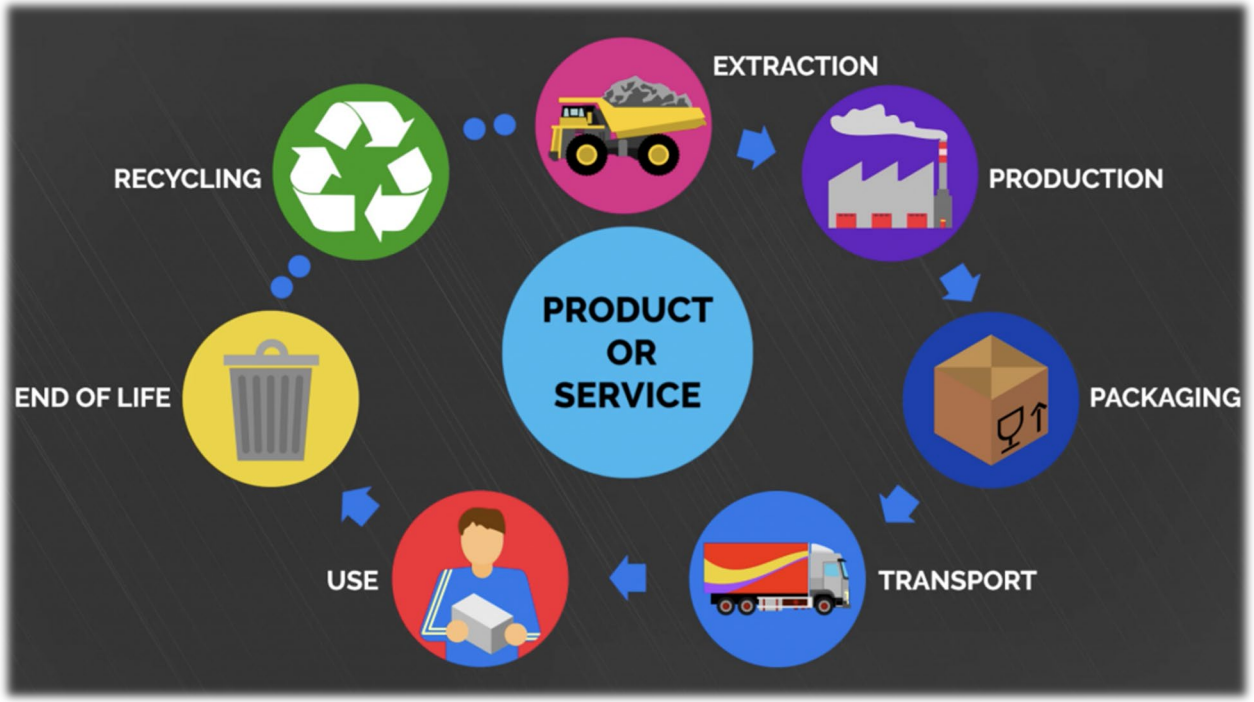
Dr. Cecile Philippot, CEA

Health, safety, environment, and recycling

Is the EnDurCrete concrete safe to use, environmentally friendly and recyclable?

Health, safety, environment, and recycling

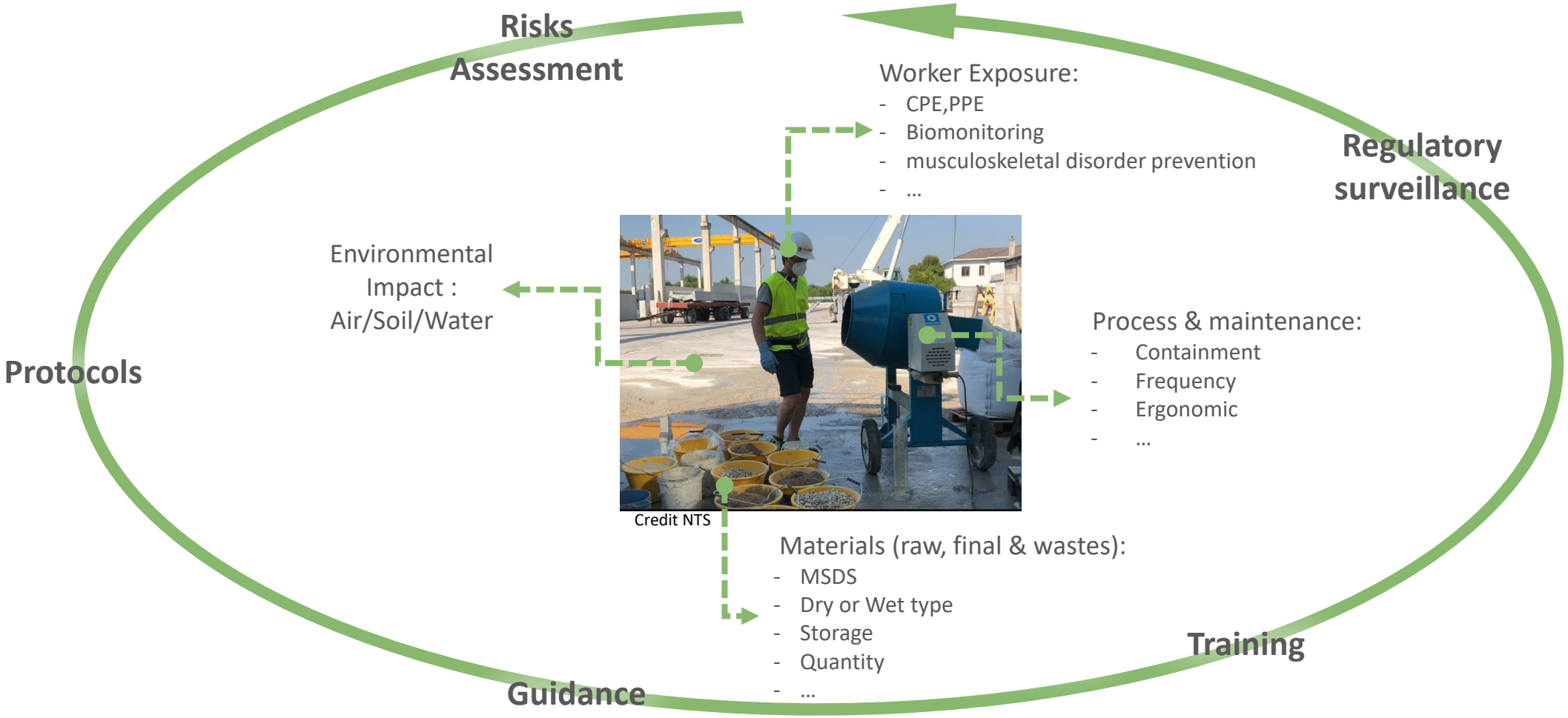
Global approach covering the whole life cycle



https://www.lifecycleinitiative.org/

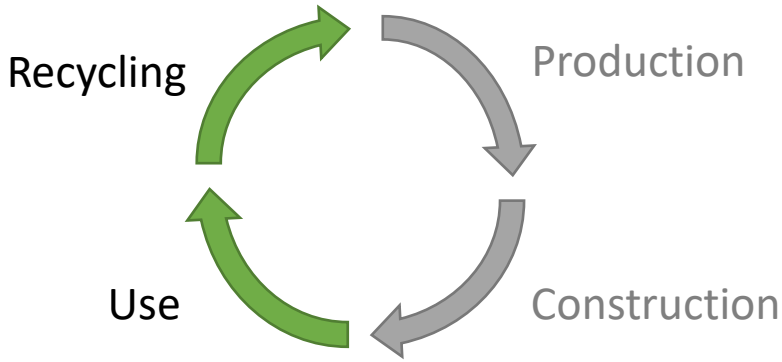
Health and safety

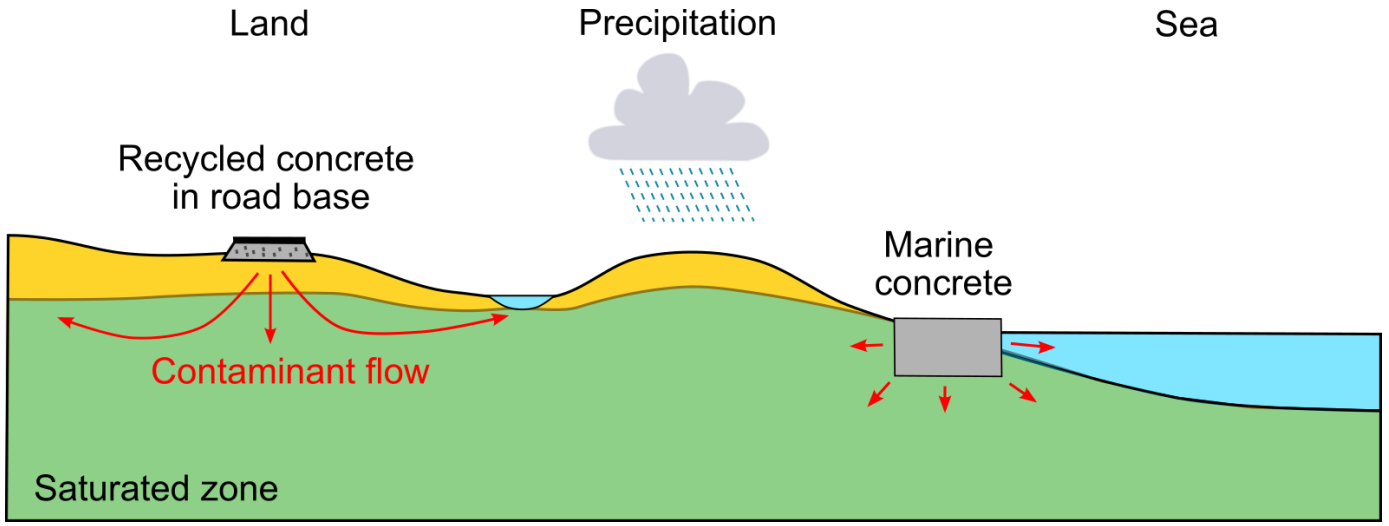
- Safe approach of the production step

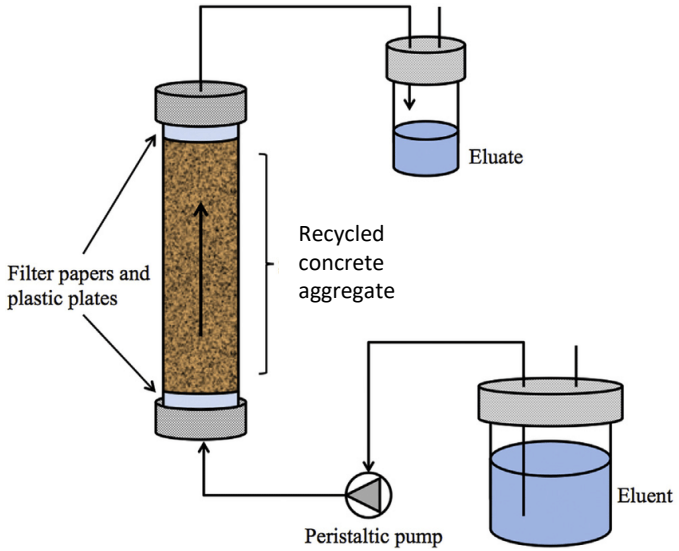


Environmental compatibility

- The use and recycling of EnDurcrete products must not lead to release of contaminants to our environment
- Total content and leaching of potential contaminants is regulated by environmental law
- EnDurCrete products were tested and found to **comply to the regulations in first and second life** use scenarios



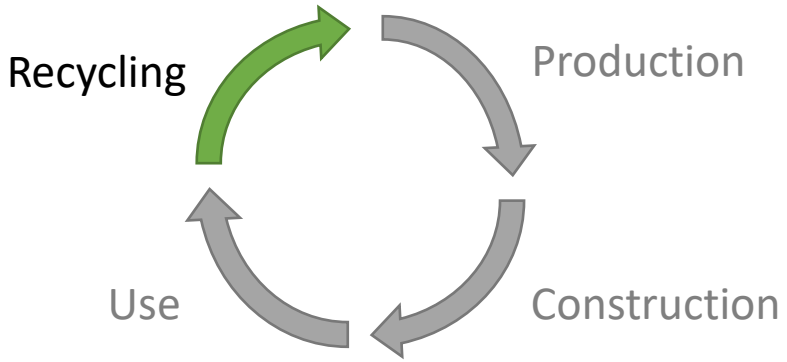




Leaching test set-up (EN 16637-3)

Recyclability

- In many EU countries, demolition concrete is fully recycled
- The recycling of EnDurCrete concretes was investigated to verify their compatibility with current recycling pathways



End-of-life concrete

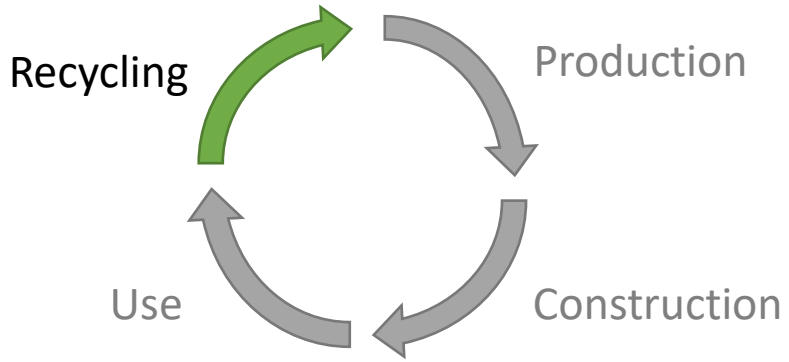
Recycling

RCA use in road base

RCA in new concrete

Recyclability

- In many EU countries, demolition concrete is fully recycled
- The recycling of EnDurCrete concretes was investigated to verify their compatibility with current recycling pathways
- It was concluded that:
  - EnDurCrete concrete can be recycled by conventional recycling facilities



End-of-life concrete

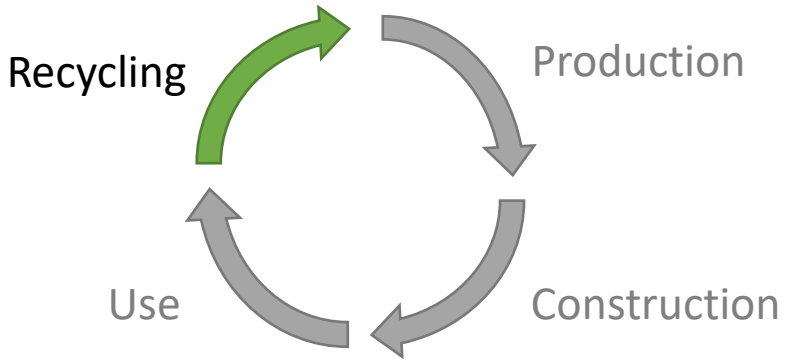
Recycling ✓

RCA use in road base

RCA in new concrete

Recyclability

- In many EU countries, demolition concrete is fully recycled
- The recycling of EnDurCrete concretes was investigated to verify their compatibility with current recycling pathways
- It was concluded that:
  - EnDurCrete concrete can be recycled by conventional recycling facilities
  - The technical characteristics of the EnDurCrete RCA were found to be equivalent to reference RCA (water absorption, resistance against fragmentation, wear)



End-of-life concrete

Recycling ✓

RCA use in road base ✓

RCA in new concrete ✓

Prevalidation of technologies in the laboratory (durability)

SPEAKER

ENDURCRETE

PROF. DR. KLAARTJE DE WEERDT

Professor at Norwegian University of Science and Technology (NTNU)

SPEAKER

ENDURCRETE

PROF. DR. ALISA MACHNER

Tenure Track Professor for Mineral Construction Materials at the Technical University of Munich

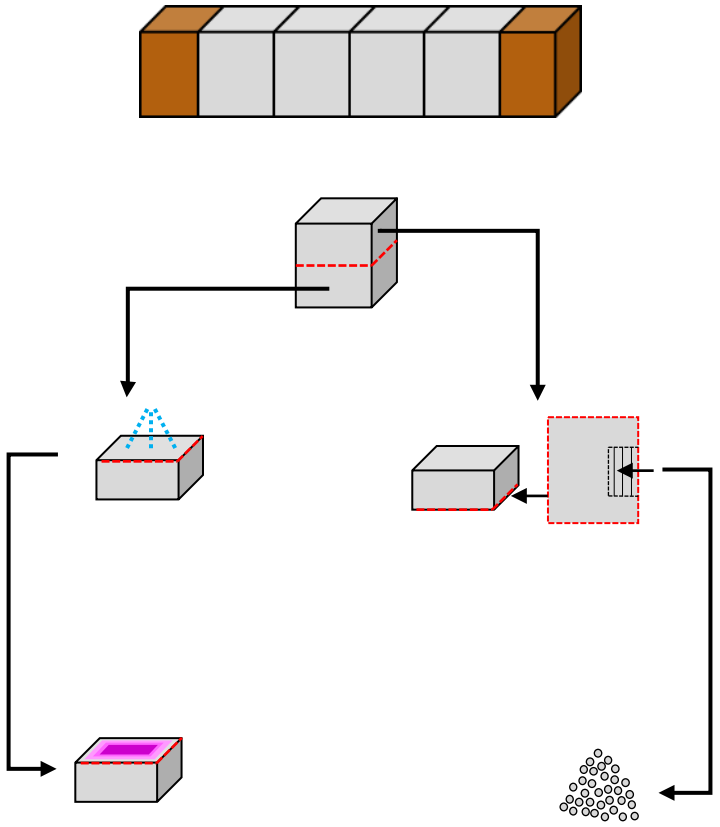
Question on carbonation

We designed an experimental setup to test the carbonation model for concrete prepared with the novel cements.

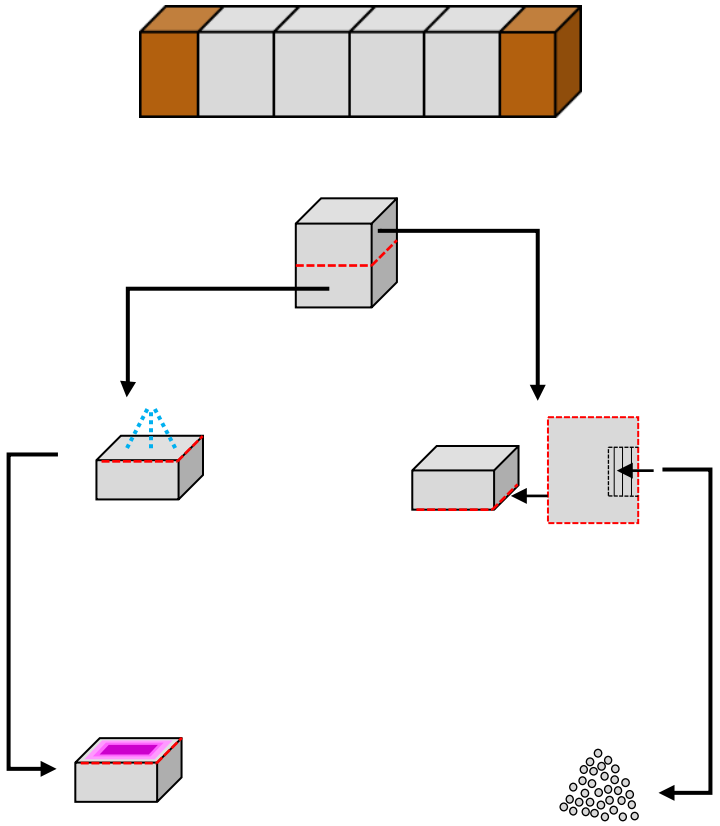
Which parameter should we for sure take into account?

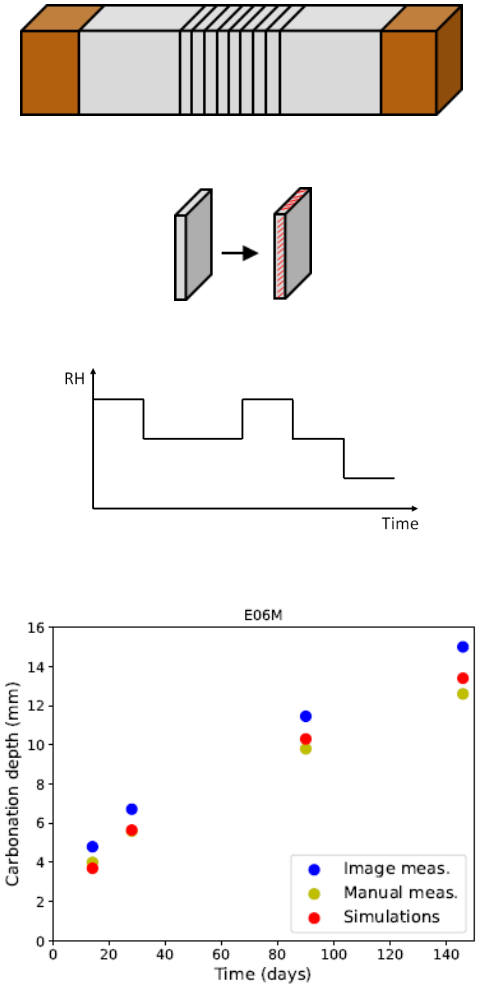
a) relative humidity
b) drying rate
c) cement composition
d) CO_2 concentration
e) w/c ratio

Carbonation



Carbonation





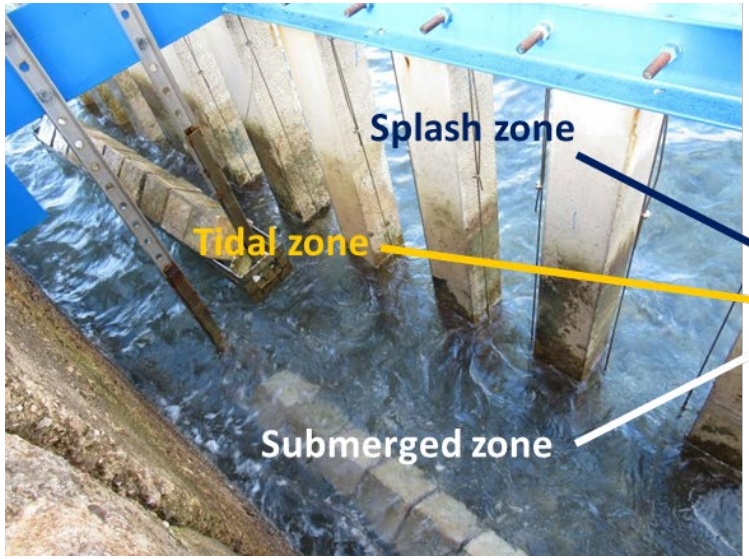
[Gu et al., ongoing work]

Question on chloride ingress

Concrete samples were tested using µXRF after 1 year of marine exposure.

Which exposure zone is most susceptible to chloride ingress?

a) Submerged
b) Tidal
c) Splash



NTNU
Norwegian University of Science and Technology

ZAG

cea

Chloride ingress

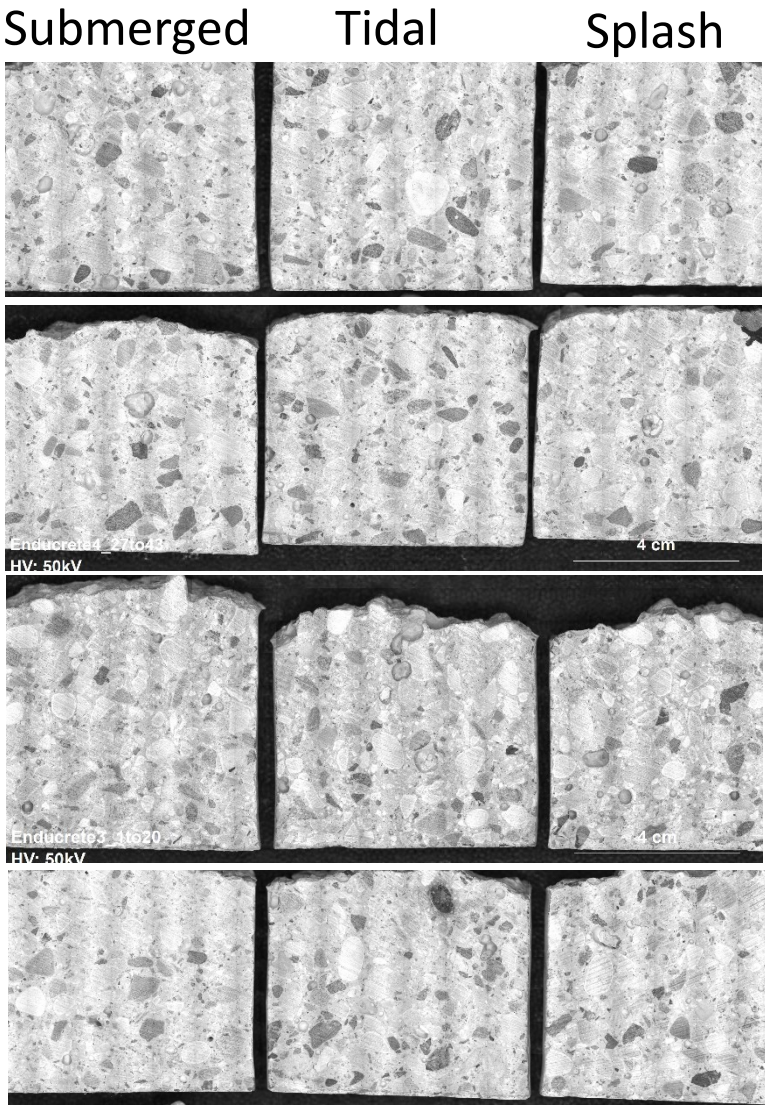
Norwegian University of Science and Technology

References

- Marine Concrete CEM III/A
- Tunnel Concrete CEM II/A-S

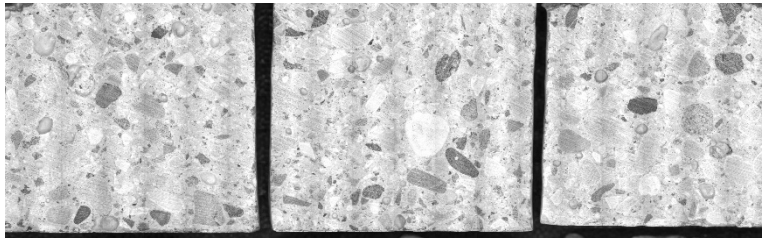
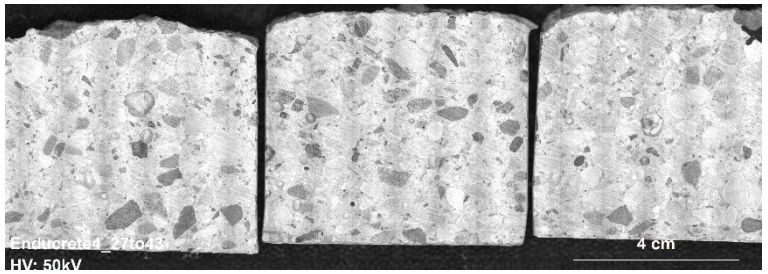
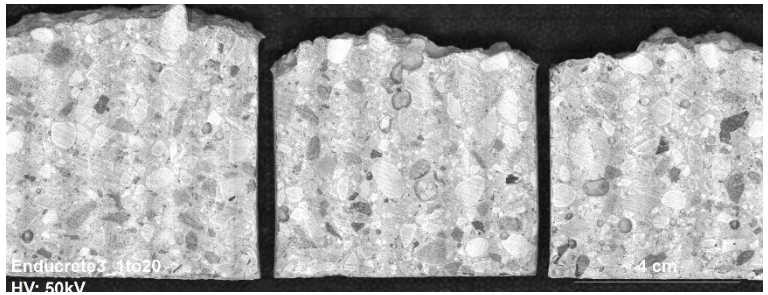
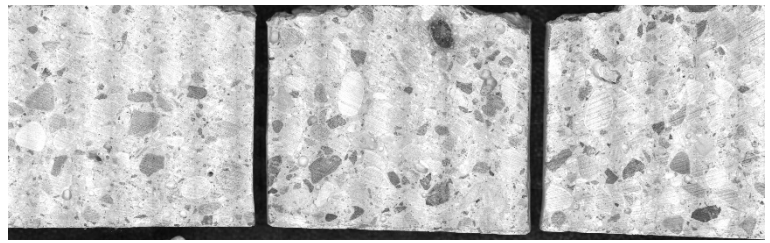
EnDurCrete

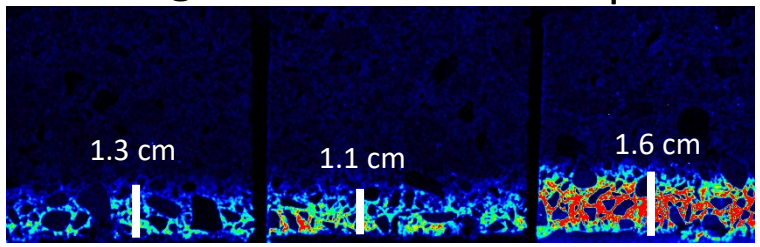
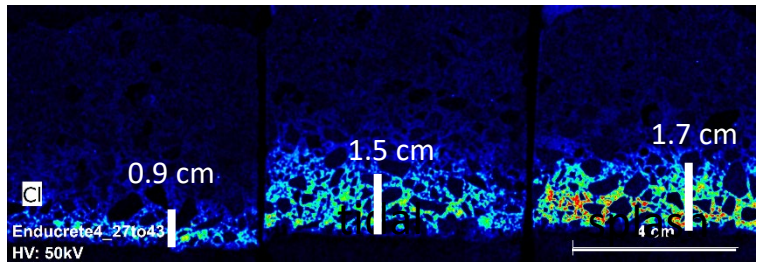
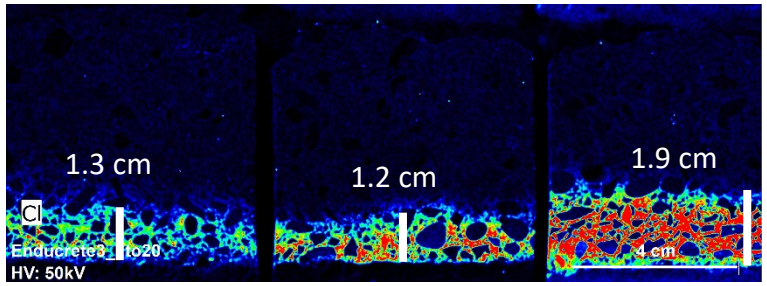
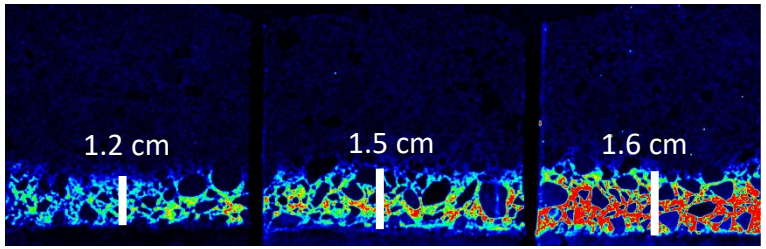
- Marine Concrete CEM II/C (S-LL)
- Tunnel Concrete CEM VI (S-V)



Chloride ingress

Norwegian University of Science and Technology

		Submerged	Tidal	Splash
References	Marine Concrete CEM III/A			
	Tunnel Concrete CEM II/A-S			
EnDurCrete	Marine Concrete CEM II/C (S-LL)			
	Tunnel Concrete CEM VI (S-V)			

Submerged	Tidal	Splash
		
		
		
		

Modelling of durability over 100 years

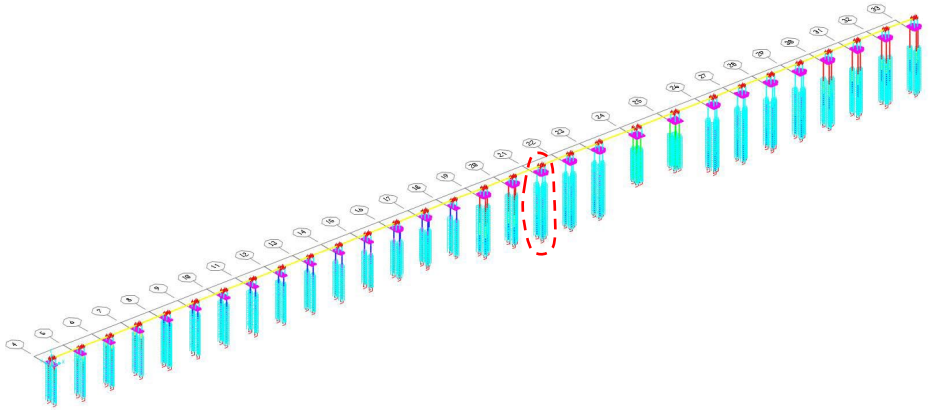
Ruben Valsecchi, RINA Consulting S. p. a

Question on Service life evaluation

Which materials/combination of them lead to the highest increase in Service Life?

Service life evaluation – Chloride (1)

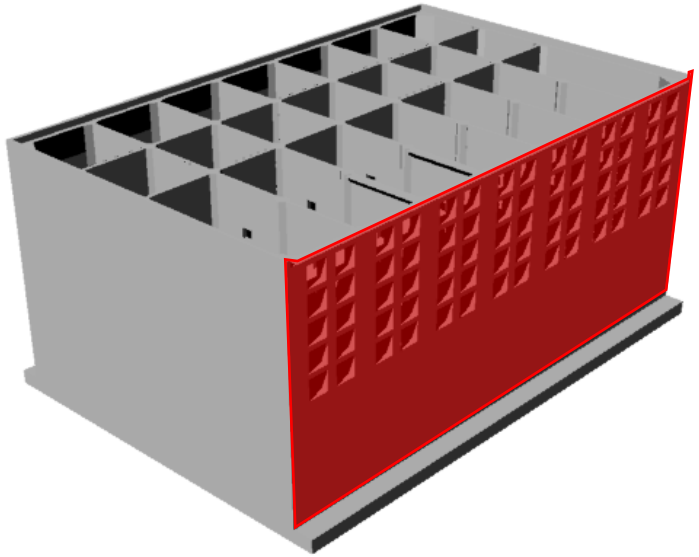
REINFORCED CONCRETE PIER in Marine environment



The PILES are the critical element of this kind structure

The SERVICE LIFE of the CRITICAL PILE ELEMENT is going to represent the STRUCTURE SERVICE LIFE

REINFORCED CONCRETE DISSIPATION BOX in Marine environment

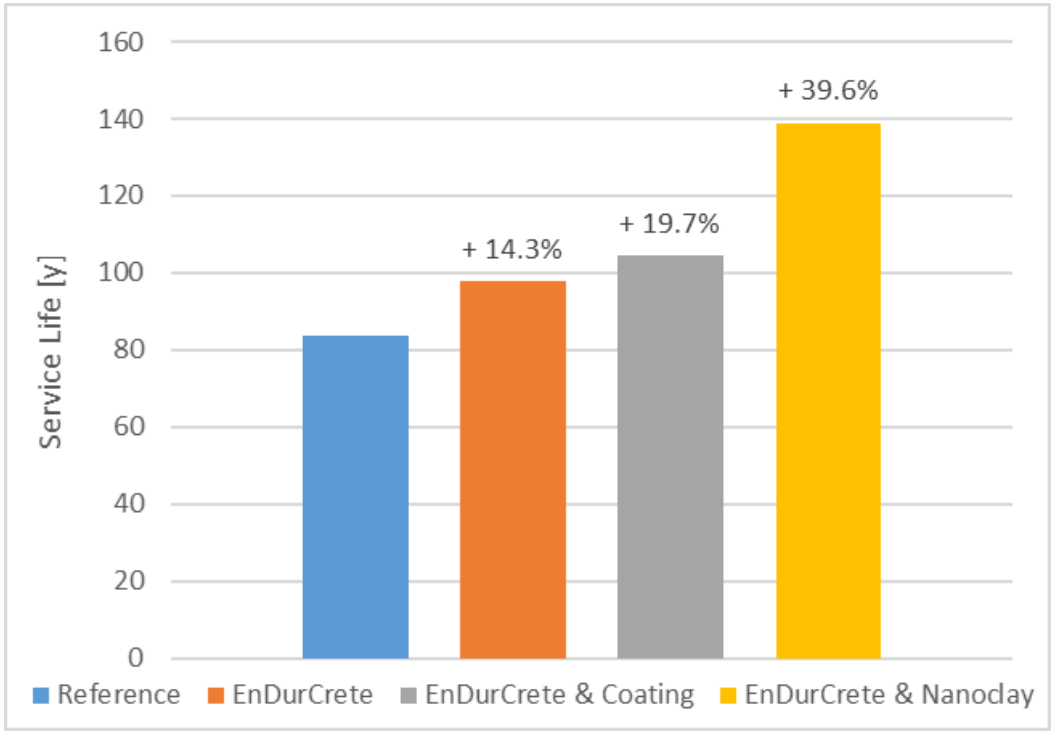


The INNER & EXTERNAL R/C WALLs are the critical element of this kind structure

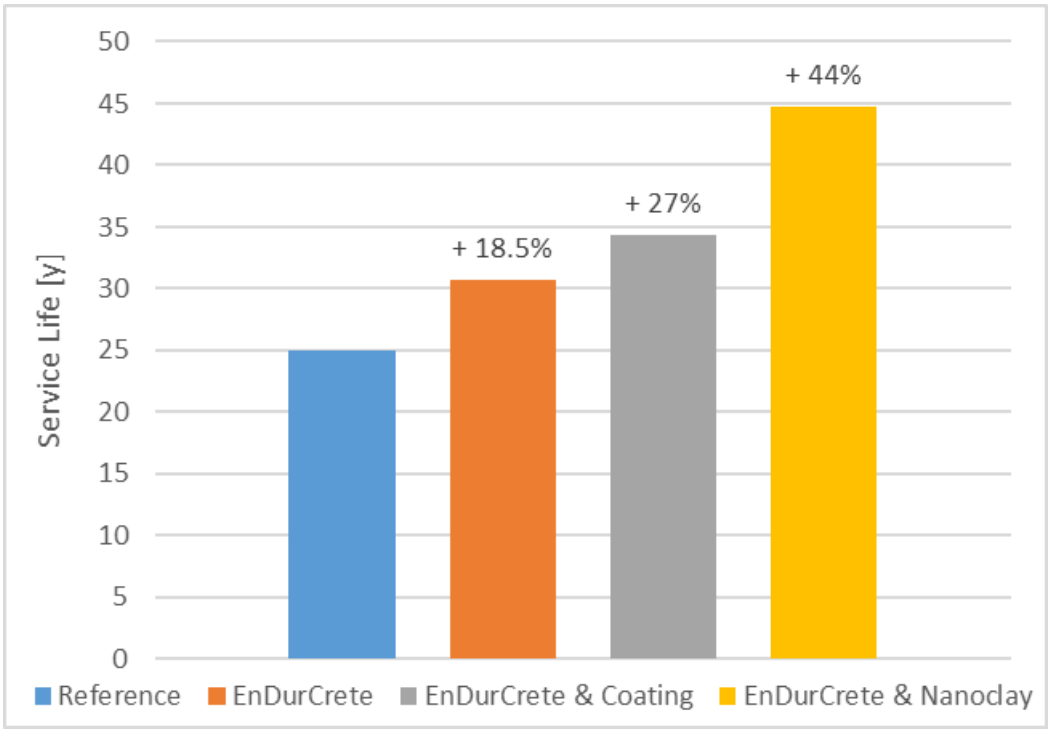
The SERVICE LIFE of the SEASIDE EXTERNAL WALL is going to represent the STRUCTURE SERVICE LIFE

Service life evaluation – Chloride (2)

REINFORCED CONCRETE PIER in Marine environment



REINFORCED CONCRETE DISSIPATION BOX in Marine environment



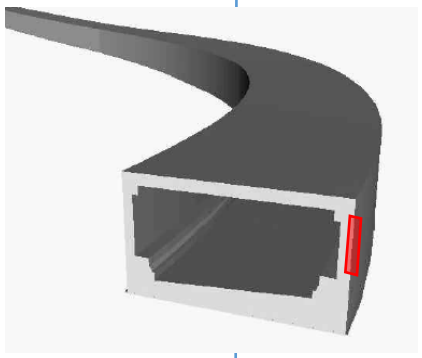
From Reference to EnDurCrete Concrete **16% increase of Service Life**

From Reference to EnDurCrete + Coating **24% increase of Service Life**

From Reference to EnDurCrete + Nanoclay **42% increase of Service Life**

Service life evaluation – Carbonation (1)

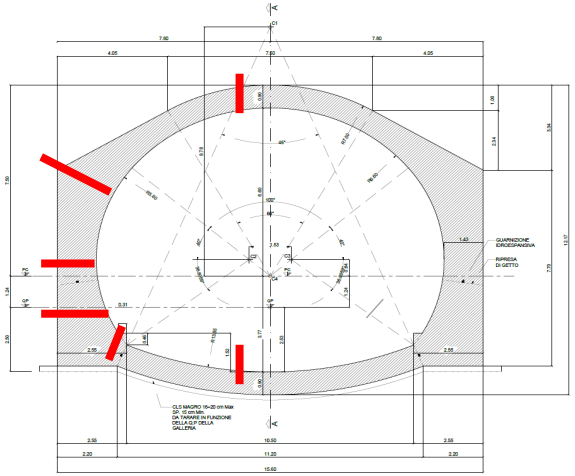
REINFORCED CONCRETE TUNNEL in Continental environment



The Vertical WALLs are the critical element of this kind structure

The SERVICE LIFE of the CRITICAL WALL SECTION is going to represent the STRUCTURE SERVICE LIFE

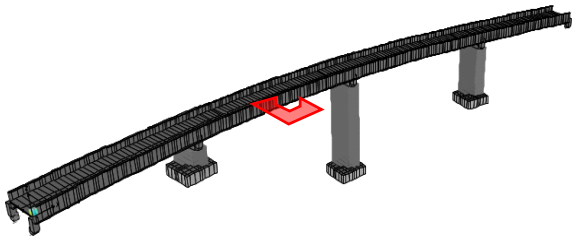
REINFORCED CONCRETE TUNNEL PORTAL in Continental environment



The TUNNEL SECTIONs themself are the critical element of this kind structure

The SERVICE LIFE of the CRITICAL SECTION is going to represent the STRUCTURE SERVICE LIFE

REINFORCED CONCRETE BRIDGE in Continental environment

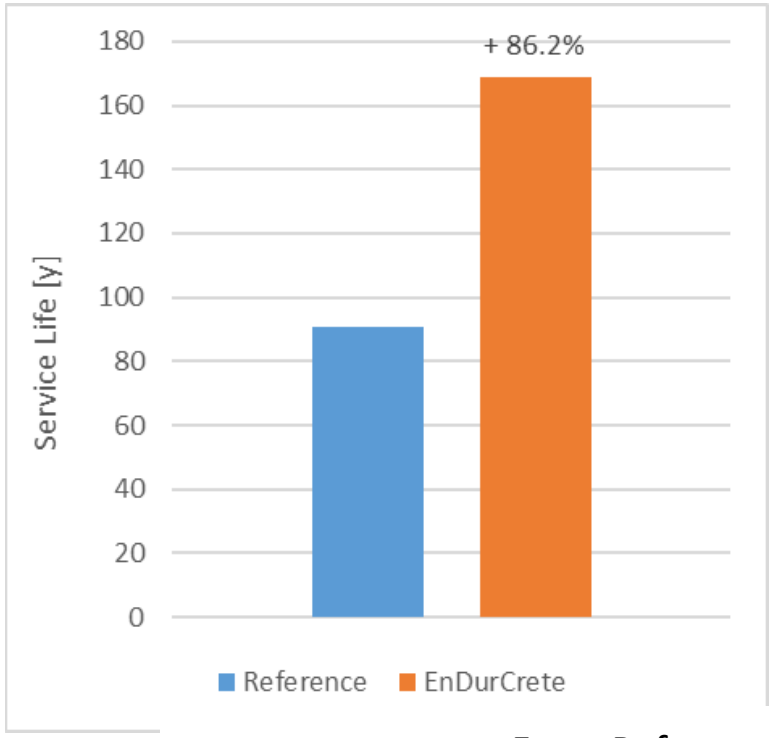


The R/C PILES are the critical element of this kind structure

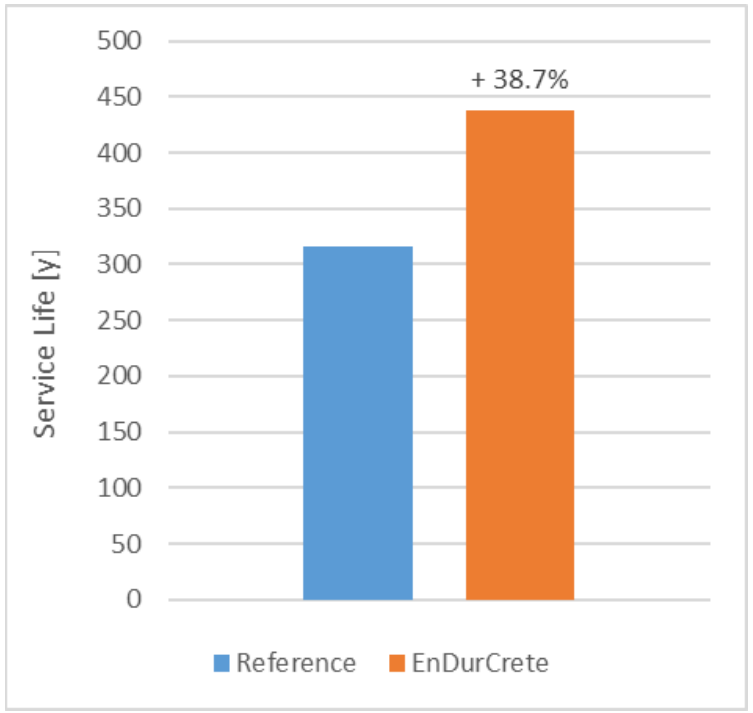
The SERVICE LIFE of the CRITICAL PILE ELEMENT is going to represent the STRUCTURE SERVICE LIFE

Service life evaluation – Carbonation (2)

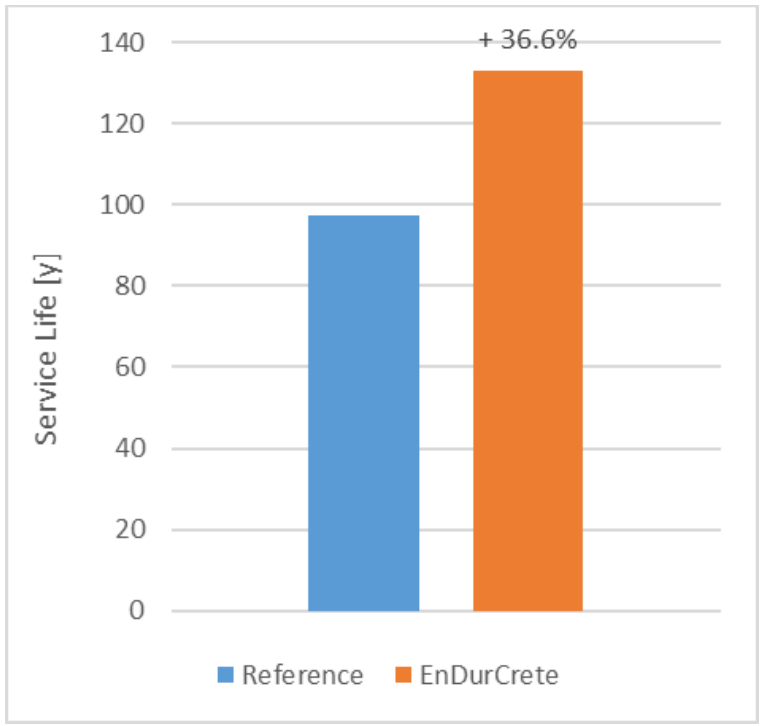
REINFORCED CONCRETE TUNNEL in Continental environment



REINFORCED CONCRETE TUNNEL PORTAL in Continental environment



REINFORCED CONCRETE BRIDGE in Continental environment



From Reference to EnDurCrete Concrete **45% increase of Service Life**

Question on parameters sensitivity

Which parameters have the highest influence on the Service Life evaluation?

Service life parametric analyses

EVALUATION OF THE INFLUENCE OF THE MAIN PARAMETERS ON THE RESUTLS

for CARBONATION PENETRATION		***for CHLORIDE PENETRATION***
HIGH INFLUENCE *(more for lower FS)* ←	***The oversizing of the reinforcement [Factor of Safety variation] HAS A***	→ ***NEGLIGIBLE INFLUENCE*** *(since corrosion rate is a negligible component of service life)*
FUNDAMENTAL INFLUENCE ←	***The choose of the RELATIVE HUMIDITY HAS A***	→ ***NEGLIGIBLE INFLUENCE*** *(since corrosion rate is a negligible component of service life)*
FUNDAMENTAL INFLUENCE ←	***The CONCRETE COVER variation HAS A***	→ ***FUNDAMENTAL INFLUENCE***

Life Cycle Assessment of EnDurCrete cements

Jakub Heller, Geonardo Ltd.

How environmentally friendly are the new cements developed in EnDurCrete project?

Global Warming Potential (kg/CO2/ton of cement produced)

CEM I 52.5R (REFERENCE)	CEM II/C-M (S-LL) (EDC-D)	CEM II/C-M (S-V) (EDC-PL)	CEM VI (S-V) (EDC-PL)
826 kg	469 kg	472 kg	425 kg
100%	57%	57%	52%

- Lower clinker content (clinker is replaced by alternative or secondary materials – fly ash, calcium sulfates and slag) leads to reduced release of CO_2 ($CaCO_3$ + heat → $CaO + CO_2$)
- Cement production is responsible for up to 8% of worldwide man-made emissions of CO_2!

And what about other environmental impact categories?

LCIA results: Cements

Impact category		CEM I 52.5R (REF)	CEM II/C-M (S-LL) (EDC-D)	CEM II/C-M (S-V) (EDC-PL)	CEM VI (S-V) (EDC-PL)
ODP (Depletion potential of the stratospheric ozone layer)	kg CFC 11eq.	0,000014	0,000010	0,000009	0,000009
	% of CEM I	100%	76%	68%	68%
AP (Acidification potential of land and water)	kg SO_2 eq.	1,73	1,17	1,13	1,06
	% of CEM I	100%	67%	65%	61%
EP (Eutrophication potential)	kg Neq.	0,51	0,36	0,34	0,32
	% of CEM I	100%	70%	67%	63%
POCP (Formation potential of tropospheric ozone photochemical oxidants)	kg O_3 eq.	0,14	0,08	0,08	0,07
	% of CEM I	100%	59%	59%	54%
ADPE (Abiotic depletion potential for non-fossil resources)	kg Sbeq.	0,00023	0,00018	0,00016	0,00016
	% of CEM I	100%	76%	69%	68%
ADPF (Abiotic depletion potential for fossil resources)	MJ	2201,11	1489,24	1428,00	1357,08
	% of CEM I	100%	68%	65%	62%
PENRT (Total use of non-renewable primary energy resources)	MJ	2798,06	1945,65	1821,88	1766,73
	% of CEM I	100%	70%	65%	63%

What is the impact of novel admixtures and coatings?

- Slightly higher impacts during the production phase
- Extended durability of the construction will lead improvement of the total environmental performance considering the whole life cycle
- Recyclability of EnDurCrete concretes is similar to conventional ones

For further information visit our website and social media pages:

endurcrete

http://www.endurcrete.eu/
https://twitter.com/Endurcrete_eu
https://www.linkedin.com/company/endurcrete/
https://www.instagram.com/endurcrete/

Thank you for your attention.

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