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BOOK OF ABSTRACTS

COST CA15202 SARCOS

SELF-HEALING AS PREVENTIVE REPAIR OF CONCRETE STRUCTURES

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Polymer Flexible Joints as an Alternative External Repair Method in RC Structures

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Advancements in technology and material sciences lead new materials to be used in civil engineering, too. Polymer based new material called Polyurethane PM is one of these newly developed solutions, which primarily designed to be used as flexible joints in various types of constructions. In my studies, the usage of polymer flexible joints (PFJ) between masonry and concrete elements is currently being investigated.

The idea of using Polyurethane PM as flexible joints is not very new, the story is started almost a decade ago at Cracow University of Technology (CUT). Many researches are already done in the past regarding the material properties and its possible usage areas [1-4]. My research focuses on the usage of PFJ between different structural elements, namely concrete and masonry, in order to mitigate hazardous seismic effects on these elements as well as on entire building. It is observed that during seismic excitations an ordinary solution of using classical type mortars lost their bonding features easily, thus in-plane and out-of-plane failures occur as shown in Fig. 1. This causes loss of lives and properties, and therefore affecting governments and societies adversely. The mechanism is emerged due to the stress concentration increment around the boundary zones between concrete elements and masonries. When lateral loads demand high deformations, classical mortar approaches fail and either crushing or debonding damages occur, see Fig. 1.

a) 

Figure 1: In-Plane (a) and Out-of-Plane (b) failures and their schematic visualisation (c).

In order to overcome this obstacle, an innovative solution of using PFJs is thought. The polymer material has strong bonding and hyper-viscoelastic features that enable large elongation capability, besides, it is also durable under high compression affects thus it protects different structural elements against crushing failures. In terms of self-healing perspective, the material is preventing the expansion of micro cracks that might occur at concrete boundary zones. These cracks are due to the cyclic loads and they tend to expand during seismic excitations. Strong bonding features of the PFJs lead crack widths to be minimized. Details are shown in Fig. 2 [5].

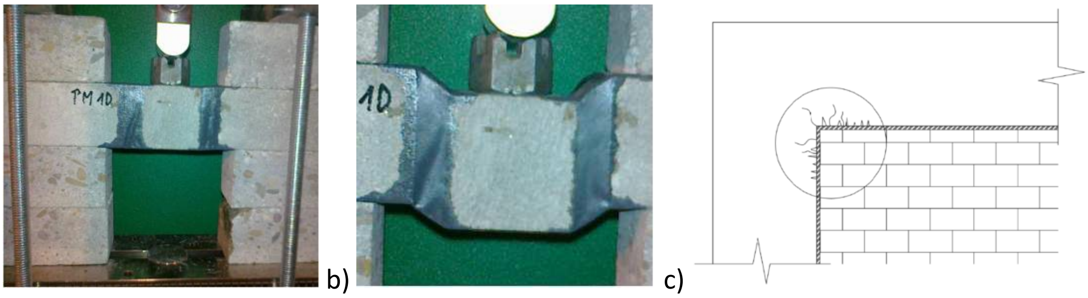

Figure 2: Shear test of PFJ: before (a), after (b) [5] and symbolic micro-cracks on concrete (c).

The research in the scope of my PhD studies is started approximately two years ago. Literature scanning and reviewing past researches were the fundamental steps. Following that, some numerical analyses are done in order to comprehend the behaviour of PFJ both in small and large size structures. The research so far aims to understand the effectiveness of material in terms of damping, frequency and stress mitigation areas. The primary results give promising outcomes that PFJs can be used in real structures.

Self-healing features are not deeply investigated for the concrete members, yet. Primarily focus so far is on the protection of infill masonries. On the other hand, performed laboratory tests on the real size specimens have exhibited very positive outcomes in regards to the RC frame energy dissipation capacity. PFJ leads RC members to withstand high drift demands (over 4%) without any substantial crack. The material will also be tested as an external repair solution for filling the cracks. Some test images are given in Fig. 3. According to the results, it is highly expected that PFJs might provide sufficient and long-term protection for the structural elements including concrete, hence permanent and durable solution can be found.

Figure 3: Laboratory test samples at Slovenian National Building and Civil Engineering Institute (ZAG).

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Durability Assessment Based Design of Ultra High Durability Concrete Structures

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This research is part of framework H2020, European commission under ReSHEALience project [1]. The Ultra High Performance Concrete structures (UHPCS) will be upgraded to the concept of Ultra High Durability Concrete Structures (UHDPCS) by implementing some nano-scale materials such as silica and alumina constituents. These nano-scale materials will work as a self healing agents inside the concrete structures. In this project, long-term flexural behavior of UHPC structures under extremely aggressive environments characterized by chlorides and sulfates will be investigated. The new structural design approach in term of durability will be evaluated based on materials and structural behavior. The real life structure shown in Fig.1. below is used as a tank for the collection of cold water from the cooling towers of a geothermal plant. The structure is primarily designed to verify and compare the performance based on different materials (ordinary reinforced concrete, high -performance fiber reinforced concrete, and ultra high durability concrete). The basin is internally divided into three basins characterized by the same plan dimensions (7.5m* 7.0m). the first basin is made of ordinary concrete, while the other two are made of high performance concrete mix. The vertical walls, which characterized the three basins, have different thicknesses depending on the material used and the geometry of the structural elements as shown in figure below. Unlike basin #1 and #2, basin #3 is designed with UHDC columns section of 20*20 cm with a center distance of 1.5m on the long side and 1.4m on the short side. The high performance cement mix. (UHDC) used for the other two basins have fibrous reinforcement inside without using the traditional steel reinforcement steel bars. The main mechanical properties are as shown below [2].

The average compressive strength F_{cm}=100MPa.
the average resistance to direct traction F_{ctm}=7 MPa.
average tensile strength for bending F_{cfm}=12 MPa.
instantaneous elastic modulus E_{cm}=45 GPa

This basin will be filled with water collecting from the geothermal plant. This water contains a lot of sulfates and chlorides which will be as a hydrostatic load with aggressive exposure at the same time. Full scale slabs of 3cm and 1.8*1.5 m will also be pre-casted and tested in the lab under long term exposure to the aggressive materials.

These different materials (traditional concrete and UHDPC) have different level of durability performance and strength. The water of the geothermal plant contains sulfates and chloride which consider as aggressive exposure for the tank's wall. in certain time, degradation occurs for both materials traditional and UHPC concrete. The traditional material will need an action of repair to restore its capacity and performance which normally comes with costs and efforts. However, UHD concrete relies on the self healing agents to repair its self without any additional costs and efforts. These agents would activate some repairing actions immediately or over a reasonably short time as the degradation takes place and gain the same previous level of performance. The economical and essential aspect of these material is that the repairing action should happen repeatedly over the time as the degradation occurs over time. This repairing could just be closing of the cracks (self sealing) or could be some mechanical recovery and ability to transfer stress during the degradation and healing of the material and structures (self healing) Therefore, in this project durability based design concept will be developed based on the tests of materials level, real life structure level, and laboratory full scale structure level. In the scope of this research, Crack opening and closing, flexural strength recovery, stiffness and ductility will be monitored and analyzed. From the results of UHDC structures, durability assessment will be evaluated to determine the parameters needed for durability assessment based design methods and then validate them with real service conditions [1].

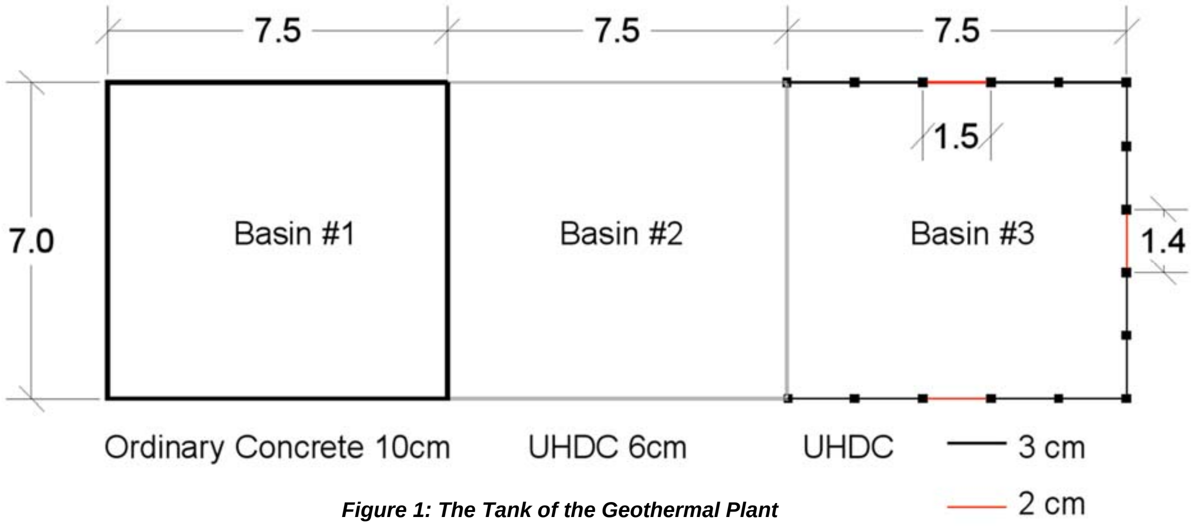

Figure 1: The Tank of the Geothermal Plant

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Quantitative evaluation of self-healing capacity in cementitious materials

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OBJECTIVES

The present post-doctoral research project is taking place within the framework of the collaboration of NCSR "Demokritos" research centre and TITAN S.A. Cement Company, under the auspices of ISN foundation.

One of the main objectives of my project is the design and development of methodological approaches for the assessment of self- healing efficiency of the cement composites, as the lack of specific standard methodologies for the assessment and quantification of the self-healing capacity constitutes a major drawback [1-2].

Specifically, the strength recovery of OPC mortars due to the autogenic self-healing mechanism was examined following two experimental approaches: Compression tests and Ultrasonic Pulse Velocity (UPV) measurements. The focus was given on the evaluation of the inflicted damage degree and the healing capacity as expressed by their strength recovery.

To achieve that, compression tests were performed in conjunction with Ultrasonic Pulse Velocity (UPV) measurements in OPC mortars. Reference samples were prepared and tested at the age of 7 days. Simultaneously, another batch of samples was subjected to controlled damage. Following, the damaged specimens were immersed in water for autogenous healing and tested after 28d healing period to evaluate their healing capacity. The results were compared with the reference ones (without damage) after curing for the same time in the same conditions. Finally, the interpretation and quantification of the experimental results lead to the development of two analytical equations that are proposed for the quantification of both the damage degree and healing capacity after controller damage under compressive strength.

An important aspect of this research was the control of damage degree, and it was shown that in order to achieve a repeatable degree of damage, several attempts of loading of the samples were necessary. In order to achieve this without sacrificing the samples, the feasibility study of UPV was performed providing successful results.

This methodology can be implemented for future research focusing on the study of significant parameters of the self-healing mechanism, such as the effect of damage degree and the duration of the healing period.

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Repairing of civil engineering structures using low environmental impact mortars characterized by self-healing capacities

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OBJECTIVES

Today, the need to repair concrete structure is intense as reinforced concrete buildings are rather old. Moreover, the cracks accelerate their degradation process. In order to reduce maintenance costs and avoid complicated external repair of concrete, the used solutions and techniques are closely related to the available technologies for repairing [1-3]. So, the main objective of my PhD Thesis is to propose innovative repair materials characterized by a low environmental impact and self-healing capacities.

To reach this objective, several cement-based materials incorporating crystalline admixtures (CA) are firstly studied. The effects of these admixtures on the sound material properties (mechanical properties, shrinkage, permeability, porosity) are evaluated, as well as their capacity to improve healing capacity of the repair mortar. These research works were performed during the first year of my PhD thesis. Shrinkage and permeability measurements are performed on specimens kept under two types of environmental conditions: water immersion and wet/dry cycles. Healing kinetics is studied by means of water permeability tests on cracked specimens at 28-day-old. The crack width and area are also monitored by means of optic microscope during 6 months. After, healing products are characterized for each studied mixture. We would like to present these experimental results at the 3rd Rilem Spring Convention 2020 in Guimarães, Portugal.

During my second year of my PhD thesis, the durability of the mortar repair is studying as well as the effect of CA and mineral additions combination on the healing and repair capacities of mortars. We focused particularly on blast-furnace slag and fly ash. Their healing capacities will be evaluated at the micro- and macro-scales and the durability of the repair system (repair mortar + support) are studied by means of several experimental techniques: pull-out test, chlorides penetration test, acoustic emission, etc.

In parallel, I actively participate at the round robin test organized by the Cost SARCOS to study the effect of mineral additions on healing process (RRT1). The self-healing capacities and the healing kinetics is measured by means of several tests such as sorption, permeability and chlorides penetration tests. The measurements started on a 70-day-old specimens, and were followed after 1, 3 and 6 months of water curing.

This meeting will open the discussion on self-healing and repair technologies, which are two main fields of my research work. I would be pleased to see others experiences from different laboratories since we are all working in the same fields, especially in repairing concrete in order to get more knowledge on this topic. It will also allow me to present my results at the 3rd Rilem Spring Convention 2020 in Guimarães, Portugal. I would be delighted to get the opportunity to participate in a dynamic and scientifically enriching program with expert researchers and other PhD students.

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Development and characterization of autonomous self-healing cement-based materials using cementitious capsules

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All cementitious materials tend to have defects, resulting from incorrect mix proportion or execution, physical, mechanical or chemical actions. Their low tensile strength, in combination with the presence of such defects, makes them prone to cracking. Under continuing damaging actions, even micro-cracks can propagate and coalesce into macro-cracks, ultimately leading to a reduction of mechanical strength. Moreover, the presence of cracks, along with the intrinsic interconnected porosity of concrete, contributes to create pathways for the penetration of aggressive agents into the bulk material, further reducing its durability.

Capsule-based self-healing has widely been proposed as a promising strategy to improve the durability and resilience of reinforced concrete structures [1,2]. Concerning the macro-encapsulated systems based on tubular capsules, different materials and technologies were tested to produce the shell of the capsules, such as hollow glass [3,4], ceramic [3], extruded plastic [5,6], and cement tubes [7,8]. With specific reference to the cementitious capsules, they were proven effective to protect and release several types of healing agents, namely minerals [7,8], polymers [9] and bacterial [10] healing agents.

In this work, a polyurethane precursor (PU) was selected as a healing agent, due to its ability to polymerize in the presence of humidity and hence to restore good water impermeability performances, while allowing also a satisfactory mechanical recovery as highlighted in previous studies. The cementitious tubes were produced using a polymer-modified cement paste in accordance with previous research [7–10], by means of a new forming process that allowed a good versatility in manufacturing. The PU-filled capsules were then tested in order to characterize: 1) the survival rate of the capsules during the mixing process; 2) the release of the healing agent upon crack occurrence; 3) the self-sealing of the crack and consequent recovery of durability-related properties; 4) the mechanical recovery of the damaged self-healing system.

The survival rate of the cementitious capsules was tested by directly adding them to concrete during mixing, casting it into a large plastic container, manually searching for the capsules and counting the intact and broken capsules.

After producing reference specimens with no capsules, along with self-healing specimens in which the PU-filled capsules were embedded manually before casting, the release of the healing agent upon crack occurrence was tested using a controlled pre-crack procedure.

Upon healing agent curing, the water permeability of the specimens was tested by means of two different water flow tests: the first using a widely used procedure developed in the European project HEALCON [11–13], the second using a newly developed procedure in which the water flow passing through the cracked specimens was not monodirectional.

Finally, the specimens were re-loaded using the same procedure used to introduce the initial damage in order to characterize the mechanical recovery in terms of strength regain [7–9,13].

Positive results were obtained during all the phases of the investigation. A 100% survival rate was obtained. Almost all the self-healing specimens showed a good release of PU from the crack, that allowed to reach a nearly perfect crack sealing, a high reduction in terms of water permeability up to a null water flow and a very good strength recovery, with values close and sometimes higher with respect to the initial load bearing capacity of the specimens.

Further research is still needed in view of the optimization of the system and its scale up. Namely, the manufacturing process should be automated in order to allow a large-scale production of the capsules and optimize the waterproofing, filling and sealing procedures. Besides, design practices should be established to optimize the quantity of capsules needed in a real structure, in order to balance the positive aspects offered by the system with its downsides, such as the cost increase or the change in mechanical properties.

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Resistivity sensors for monitoring water exchange in hardened cementitious materials

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INTRODUCTION

In the field of cement-base materials it is important to highlight durability as an indicator of the state of a structure. The presence of water inside the concrete is necessary for the development of the hydration reactions of the cement and for the formation, therefore, of the solid phases of the cement matrix. However, it is in turn associated with the deterioration of reinforced concrete as a result of the damage associated to the interaction of concrete with the environment: response to ice-thaw cycles, presence of aggressive ions such as chloride and development of carbonation reactions promoting the reinforcement corrosion,... In this context, monitoring the exchange of water through the concrete surface to detect the presence of water in the concrete pores can be proposed as a useful tool for assessing durability performance of cementitious materials [1,2].

In the present study, the development of resistivity sensors for the wireless monitoring of different types of cementitious materials is proposed as non-destructive methods for assessing the presence of water through an indirect indicator as the electrical resistivity is [3].

METHODOLOGY

For the manufacture of the electrical resistivity sensors a PCB (printed-composite-board) of small size has been used, connected to a controller system, all programmed in ARDUINO language. The sensor was encapsulated with a heat shrinkable cable and the interior was resinated with polyurethane resin to avoid contact of the welds with the cement mortar and thus avoiding interference in the readings, as shown in Figure 1-Left.

These sensors were installed inside the cement matrix at the time of manufacturing the mortar samples. The sensors were inserted between the end of the first compaction and the filling of the second mortar layer vertically and looking at the metal tips in the longitudinal direction of the main axis where there is more mortar mass with respect to the edge. In this way it is sought to favor a homogeneous distribution of the mortar around the sensor. For assessing the versatility of the developed sensors, mortars containing different admixtures affecting the water content of the cementitious matrix were studied. The admixtures were a commercial crystalline additive (Krystaline ADD PLUS 2.5, a nanocellulose dispersion, and powder of cellulose). In Table 1 the composition of the mortars is detailed.

Table 1: Mortars Composition

Mortar	Sand	Cement	Water tap	Destiled water	a/c	ADD PLUS 2.5	Nanocellulose	Cellulose powder
K1-R	1350	450	225	-	0.5	-	-	-
K3	1350	450	225	-	0.5	2	-	-
C1	1350	450	200	70	0.6	-	2.26	-
C2	1350	427.5	213.75	-	0.5	-	-	22.5

The mortar samples were exposed to wet-dry cycles considering different exposure conditions: accelerating the drying stage in an oven, drying at laboratory atmosphere, wetting on the surface were the sensor is located and wetting by capillary absorption from the opposite surface.

As can be observed from Figure 1-Right, an increase in the electrical resistance is observed each time the specimens are dried, while the resistance decreases when they are subjected to a wet cycle. It is also observed that this increase in resistance occurs slowly when drying is carried out in laboratory conditions compared to drying in an oven. Furthermore, the decrease of the electrical resistivity is faster when the water entrance is through the surface where the sensor is located than when penetrates by capillary absorption.

Regarding the comparison between specimens of different compositions, different behaviour is observed depending on the composition. Thus, this study allows to conclude that the proposed method is applicable for assessing the water exchange in cement-based structures. Further studies are being carried evaluating the relation between the water content and the resistivity values.

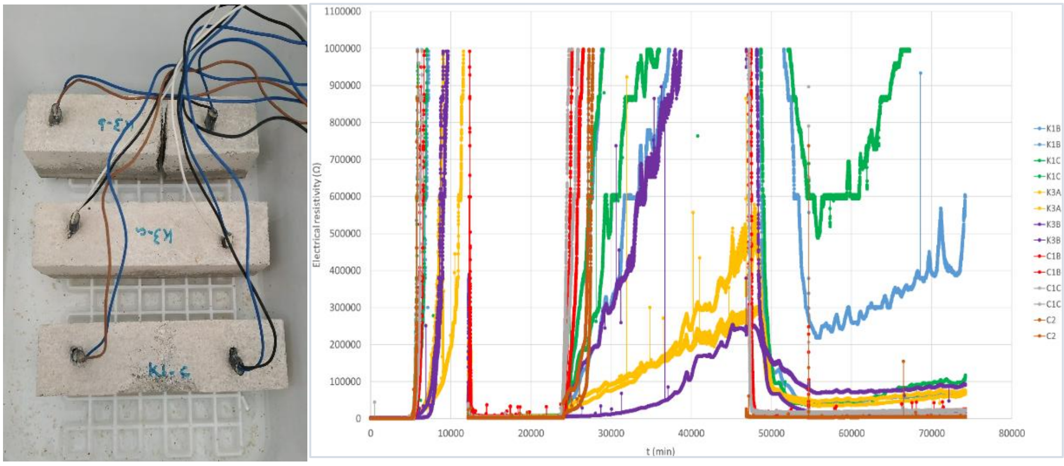

Figure 1. Left-Photography for the sensing systems in the mortar simples. Right-Results of the electrical resistance captured by the sensing system in different conditions.

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Durability of cement-based overlays modified with selected waste mineral powders

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OBJECTIVES

Additives added to cement mixtures have a direct impact on their properties. Depending on the additives, the properties of hardened cementitious composites are different [2,4,5]. Currently, there is a trend in the scientific literature related to the topic of concrete additives that materials are being sought that, when added to the cement mix, will not only allow to maintain the strength parameters of the cementitious composite, but above all increase its durability [1,3]. In addition, waste materials that could be used for cement mixtures are sought, while reducing the amount of cement added to them. This may not only improve the environment (cement production degrades the environment), but also bring recycled materials back to industry [5,6]. Appropriate selection of such materials can cause improvement of cementitious composite properties that are associated with its durability.

In my doctoral thesis, I examine the effect of modifying the composition of cement mixtures used on the overlays on its adhesion with the substrate in concrete floors. Following current literature trends, I selected waste granite powder as the examined additive. Granite powder is formed as a result of the process of cutting granite blocks and crushing of granite rocks. In recent years, there has been a significant increase in the production of waste granite powder, which caused problems in its storage and recycling. In the literature, can be found studies that indicate the possibility of adding granite powder to cement mixes without significantly deteriorating their strength parameters [1,2]. However, there are still many research gaps that should be investigated.

Research carried out for various scales of cement tables: scale of cement pastes, scale of cement mortars, concrete scale. I planned the macroscopic and microscopic research related with properties of cementitious composites. Currently, I have made 22 series of cement sets, which only contain depending on granite powder (11 series of cement pastes and 11 series of cement mortars), and I have performed macroscopic tests. In the coming year, I plan to do the rest of the research, including primarily research related to the durability of overlays in concrete floors.

Figure 1: Photos from preparing samples and doing research

I think, that participate in the 2nd SARCOS PhD Students and ECI meeting can help me plan further research on the durability of concrete structures. In addition, the meeting may allow me to make friends with people who already have experience in conducting this type of research. I also believe that thanks to listening to the prestentation planned as part of the meeting, I will be able to broaden my research horizons and become familiar with the latest research trends related to self-healing / repair technology.

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Preventive repair of concrete substrates using epoxy resin coatings modified with waste mineral additives

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INTRODUCTION

The aim of the PhD ongoing research is to assess the influence of the content of waste mineral additives on the properties of epoxy resin coatings, which make up the finishing layer of floors, especially industrial floors. In order to obtain the appropriate parameters and durability of these floors, the following technological processes must be carried out: surface mechanical treatment, vacuuming, and applying a bonding agent. These processes involve the costs of hiring special equipment, and there is a risk of making mistakes during the treatment. Considering the durability of the epoxy resin coating, it is required that these resins are characterized by a high pull-off strength (min. 1.5 MPa according to [1]). Therefore, there is a need to find an additive, and its amount, that will positively affect the pull-off strength of the epoxy resin coating and this will reduce the risk of negative effects due to mistakes during the treatment. In the literature it is a lack of results regarding this issue.

DESCRIPTION OF PRELIMINARY RESEARCH

One material configuration from the plan of PhD research was tested in the preliminary tests. The results of the preliminary tests were published in Gold Open Access form by Elsevier in the journal listed in the JCR journal list: Applied Surface Science [2]. A substrate was prepared from the cement mortar with dimensions of 1000 x 1400 mm and a thickness of 50 mm. Half of the surface of the substrate was mechanically grinded and then thoroughly vacuumed to obtain ground surface. The other half was only cleaned and vacuumed to obtain a raw surface. A mineral additive with a share of 72% of SiO_2, 0,85% of Al_2O_3, 0,50% of CaO, and with a maximum particle size of 0.063 mm, was used. One square at the ground surface and one square at the raw surface were coated with epoxy resin without the waste mineral additive (0%). The remaining squares were coated with epoxy resin with waste mineral additive in amounts from 7,4% to 44.4% in relation to the weight of the mixture. The measurements of the pull-off strength of the epoxy resin coatings were taken after 7 days, at three points for each square, using the pull-off method according to [3]. The results are illustrated in Fig. 1.

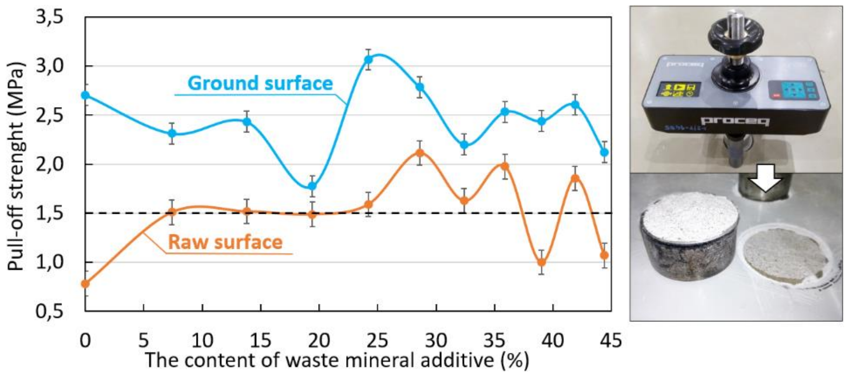

Figure 1: The dependence of the pull-off strength of the epoxy resin coating on the content of the waste mineral additive [2]

Scanning electron microscopy (SEM) tests were carried out for the raw surface for samples: 0%, 19.4%, 35.9% and 44.4% and obtained views of the cross-sections of the sample's height at a x200 magnification. These views have been processed using the ImageJ program according the method described in [4] and thanks to that images of the segmented pores in the form of black pixels were created. From the resulting images, the porosity plots were constructed (Fig. 2).

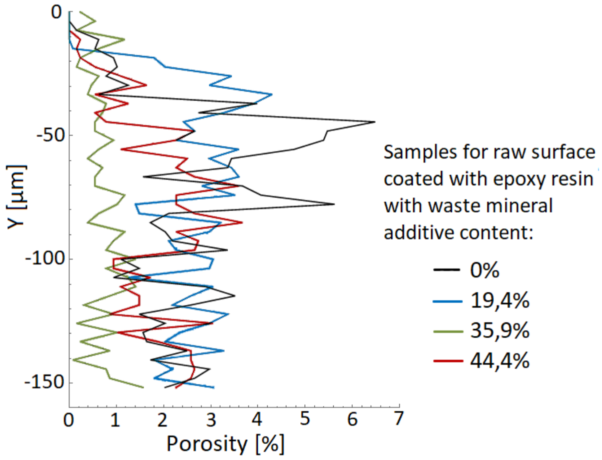

Figure 2: Graphs of the fractional share of pores along the height of the surface area of the substrate [2]

CONCLUSIONS

Based on results from the pull-off test (Fig. 1), it can be seen that the increase in pull-off strength of the epoxy resin coating corresponds to the increase in the amount of waste mineral additive for the raw surface. In the square with the epoxy resin coating without waste mineral additive, the result was below the required value of pull-off strength (< 1.50 MPa). For the ground surface, the positive effect of the waste mineral additive was less visible. In (Fig. 2) it can be seen that in the control sample 0% there is the largest pore content compared to the other samples. A lower percentage of pores in the subsurface layer of the substrate may result from the penetration of the particles of the additive from the coating to the substrate and the filling of its larger pores. The tests showed that the used waste mineral additive in the amount of 7.4% to 35.9% in relation to the weight of the mixture, positively affects pull-off strength of epoxy resin coating.

RESEARCH PLAN FOR THE NEXT YEARS

During the PhD research, several waste material additives, will be selected, that can potentially have a positive effect on the properties of epoxy resin coatings. The properties of the fresh resin modified with the additive will be tested, e.g. viscosity, density. Their properties after hardening will also be tested e.g. hardness, impact resistance, as well as compressive, tensile and flexural strength. The surface morphology of the concrete substrate will be examined using a 3D laser scanner. The epoxy resin coating and the contact surface of the coating with the substrate will be subjected to analysis using SEM in order to obtain their chemical composition and porosity.

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Towards a proposal to model the autogenous healing-induced regain in strength for Ultra High-Performance Fibre-Reinforced Cementitious Composites (UHPFRCCs)

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The ongoing Ph.D. research is part of the project ReSHEALience (Horizon 2020), which has the aim to develop an Ultra High Durability Concrete (UHDC) and a Durability Assessment-based Design (DAD) methodology for structures, to improve durability and predict their long-term performance under Extremely Aggressive Exposures (EAE), i.e. chloride induced corrosion and chemical attack.

The improvement will be supported upgrading Ultra High Performance Fibre Reinforced Concrete with new functionalities for marine structures and infrastructures and for geothermal/biomass energy plants. This goal will be achieved, among the other activities, through the development of a theoretical model to evaluate ageing and degradation of UHDC structures in EAE extending the modelling to predict the lifespan. The model development will be part of a new durability-based design approach for the use of UHDC, aimed at assessing the structures durability and Life Cycle Analysis, to achieve an increase service life of 30%, and a long-term reduction of maintenance costs. The modelling activity will be validated against an extensive experimental campaign performed in the framework of the project and will be tested through long-term monitoring in six full-scale proofs of concept that UHDC in real conditions has the expected enhancement in durability [1].

Looking closer and specifically at the PhD research program, during the first year of activity two existing models, concerning both the diffusion (*Hygro-Thermo-Chemical model* [2,3]) and the mechanical (*Lattice Discrete Particle Model* [4,5]) problems have been enriched with the implementation of the self-healing effects. The proposal, stepping from recent scientific works completed at the Politecnico di Milano [6], has been conceived to be numerically implemented discrete-wise. Then, the parameters calibration and the model validation have been successfully accomplished by means of the best fitting, for the former, and a comparison, for the latter, among the numerical outcomes, gained by simulating the tests (unconfined compression and three point-bending test) carried out in the laboratory, and the actual experimental results. The reference laboratory campaign has been entirely completed at the Politecnico di Milano [7]. It has consisted of four phases: (a) 28-day curing after concrete casting, (b) pre-cracking up to a fixed value of crack width, (c) from 1 to 12 month-conditioning in water or open air, and (d) three point-bending test up to failure. Along with the fracture tests, within the curing span,

unconfined compression tests have been carried out at different ages with respect to unconfined compression in order to assess the compressive strength evolution in time.
The model for autogenous healing has been calibrated and validated for regular plain concrete [8], but there are no limitations in simulating the healing process for cementitious materials on the whole. In terms of mixes composition, UHDC are expected to be HPFRCCs with functionalities customised as such to enhance concrete durability when aggressive environmental conditions hold. Since healing-boosting additives have been already accounted for in the validated model, the fibre-matrix interaction is the main aspect deserving further investigation. Apparently, two issues need to be addressed the most:

1. How do the healing products affect the fibre-matrix interaction mechanisms?
2. Are there any substantial differences between the healing of matrix cracks and fibre-matrix interface? Do these differences, if any, affect the overall process modelling?

Currently, I am focused on extending the LDPM formulation for FRCs [9,10] in order to make the model capable of catching the healing effect on fibre-matrix interaction mechanics. This would help to describe what has been experimentally observed so far [11,12]: the self-repairing of the tunnel-fractures surrounding the fibres is faster than the process involving the matrix cracks, due to the larger width of the latter. And the mechanical regain in terms of fracture strength is appreciable even when the matrix cracks are still mostly unhealed.

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Evaluation of the self-healing capability of Ultra-High-Performance Fiber-Reinforced Concrete with Nano-particles and crystalline admixtures by means of permeability

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OBJECTIVES

Our researches are about the self-healing capability of two types of UHPFRCs incorporating Nano-materials and self-healing promoters, also compares them with two references, a conventional concrete, and a high-performance concrete. The samples were cast with specific dosages and pre-cracked at the age of 28 days by four-point bending test at two different strain levels, which represents two situations of damage. The permeability of pre-cracked samples was evaluated by the chloride penetration test to study the results depending on the strain level and the presence of the nanomaterials and the crystalline admixture (CA). In conclusion, the aim of the proposed work is to evaluate the self-healing capability of different families of concrete mixes that suffered a similar level of damage (i.e., similar strain) using chloride penetration test as an indicator of the water permeability tests adapted to the specific properties of UHPFRC.

Introduction

Especially in concrete structures, the guarantee of high durability is a crucial factor in ensuring their safe service life. Consequently, researchers decided to develop the durability requirements of concrete by using Ultra-High-Performance Concrete [1]. The development needs in concrete like a significant increase in compressive strength, ductility improvement, and workability enhancement can be achieved by using Ultra High-Performance Fiber Reinforced Concrete. Using UHPFRC increase deformability and reduction of brittleness due to the improvement in the tensile post-crack behavior. To promote the ability of autogenous healing of cementitious materials, some additives are being added to concretes [2, 3], such as Crystalline Admixtures (CA). Previous research on UHPFRC [2] evaluated the durability and self-healing performances of UHPFRC and tradition concrete and observed higher crack closure and a positive effect on reducing chloride penetration in continues water immersion even in high salinity conditions in samples with CA. Further, other studies performed on traditional fiber-reinforced concrete [3] indicated water presence is critical for self-healing even in control samples, and CA were able to slightly promote the self-healing mechanism obtaining healing ratios up to 95% even in large crack width.

Methodology

Thus, it was decided to investigate the self-healing capability of two types of UHPFRCs incorporating several additions and compares them with two reference concretes. These two references are conventional concrete (C25/30) and high-performance concrete (C80/90). The two UHPFRCs have very similar dosages, only differing in the amounts of fibers and the type of sands (150 MPa and 135 MPa concretes). Additionally, UHPFRCs with Nano-materials and self-healing promoters were prepared, incorporating alumina nanofibers in 0.25% by the cement

weight, Nano-Cellulose (nanocrystals and nanofibers, in a dosage of 0.15%), and 0.8-1.6% of a crystalline admixture.
Reinforced beams were cast with the dosages mentioned earlier. The beams were pre-cracked at the age of 28 days by four-point bending test at two different strain levels: 1) large residual strain between 1.5‰ and 2‰ after uploading at the lower DEMEC line, and 2) small residual strain between 0.5‰ and 1‰ during loading at upper DEMEC row. These pre-cracked beams were sawed in the middle span section to obtain two pairs of samples with very similar crack openings. These two pairs of samples were used to evaluate permeability before and after healing during 28 days in deionized water (one sample was tested before and one after healing).
To detect the effect of cracks during the permeability test, a specific methodology had to be developed to fit UHPFRC mixes, using chloride penetration as an indicator of the water penetration. This modified version consists of exposing cracked samples to a 50-cm water column with sodium chloride for three days. Afterward, the samples are sawed again from the middle section; then, silver nitrate is sprayed on the sections, revealing the crack pattern and depth of water penetration. These sections were photographed and analyzed using photography software to compare the crack pattern of each sample.
The purpose of this procedure is to obtain different results depending on the strain level, showing larger areas of chloride penetration for samples from beams that suffered larger strain levels, as well as depending on the amount of fibers of the mix.

Conclusions and Future Lines of Research

Comparing the behavior of the samples before and after self-healing, those samples that were pre-cracked up to small strain levels healed better than those that suffered larger strain levels. Additional differences were detected depending on the presence of the nanomaterials and the crystalline admixture.

For the subsequent studies of the research, it is decided to focus on the effect of different CA dosages on the traditional, high-performance, and UHPFRC specimens in various healing times. Furthermore, specimens with a disk geometry will be cast and pre-cracked on two specific strain limits. These specimens will be stored to promote self-healing in water immersion to observe the effect of CA on healing in different periods. The healing effect on samples will be compared with un-healed samples utilizing chlorides penetration, depending on their crack size.

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Bacteria-Based Self-Healing in Cementitious Materials

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INTRODUCTION

We, as humans, have always made efforts to imitate nature and replicate its exceptional ability to counteract different challenges with the less energy expenditure possible. Nowadays, we have better tools to understand and implement nature's principles, resulting in significant advances in the biomimetic materials field.

This presentation will focus on the ongoing Bacteria-Based Self-Healing (BBSH) cementitious materials research currently being developed by the University of Bath (UoB) under the umbrella of the Resilient Materials for Life (RM4L) programme grant. The motivation of this RM4L programme comes from the imperious necessity to improve the durability, efficiency, and environmental impact of current cement-based materials, and thereby reduce the significant expenditure on the repair, maintenance, and replacement of existing structures. So, to achieve this vision, a biomimetic approach is employed to create materials that will adapt to their environment, develop immunity to harmful actions, self-diagnose the on-set of deterioration, and self-heal when damaged. A multidisciplinary team of academics and researchers from Bath, Bradford, Cardiff, and Cambridge Universities was formed to accomplish this.

Overall, BBSH in cementitious materials topic has gained a lot of attention in the last decade, during which considerable developments have taken place [1]. However, nowadays, a significant knowledge gap still exists related to the self-healing efficiency and long-term durability of these novel materials under circumstances that are generally different from the laboratory conditions. Here is where the aim of current BBSH research at the UoB is to advance our knowledge to move these self-healing technologies to commercial applications.

RESULTS

At the UoB we have made important innovations in BBSH technologies:

- Non-ureolytic bacteria were thought to be less efficient at microbially-induced calcite precipitation (MICP) as they cannot hydrolyze urea and thus to induce rapid increases in pH. However, current research at the UoB has revealed the fundamentally different mechanisms that ureolytic and non-ureolytic bacteria utilize to precipitate calcite. Ureolytic bacteria produce regular inorganic calcite crystals, while non-ureolytic bacteria form calcite precipitates that contain significant organic components and appear to have increased volume and cohesiveness [2].

- A robust strategy for insolating spore-forming, aerobic bacteria (or isolates) with the ability to grow in a high pH and low-temperature environment has been developed [2]. As a result, a range of calcite-producing bacteria, not previously considered for concrete healing, has been isolated, and their efficacy and safety have been proven [2].

- The UoB team has proved that nutrients and additional calcium sources for non-ureolytic bacterial mortars can be added directly avoiding costly encapsulation [3].

- The UoB team has also proved that an essential source of Ca^{2+} ions for BBSH mortars is calcium hydroxide ($Ca(OH)_2$). However, in aged (carbonated) mortars, calcium hydroxide is not available to supply these required Ca^{2+} ions. Consequently, carbonated BBSH systems are totally dependent on the availability of Ca^{2+} ions released from an encapsulated source [4].

- Electromagnetic Interference (EMI) approach has been applied in combination with embedded and surface mounted piezoelectric sensors (PZS) in small-scale concrete beams aiming to investigate the sensitivity of the sensors to the detection of damage and cracks. [5]

CHALLENGES AND FUTURE WORK

The research plan for the next years will range from scaling-up technologies (e.g., the production of bacterial spores and the manufacture of microcapsules to deliver them) to the development of capsule-based BBSH systems that react to rapid damage and heal multiple occurrences of damage arising from cyclic loading. Additional future research areas include: (i) the performance of BBSH systems in aggressive environments (e.g., chlorides, contaminants, etc.); (ii) to exploit the natural regenerative bacterial cycle to heal damage; improving the healing efficiency along the depth of the crack; and, (iii) the validation of BBSH technologies using large-scale field tests. Regarding the latter, we have developed future plans for site trials with external companies (i.e., Network Rail). Furthermore, research will also be oriented to find ways to manufacture and produce these systems at large scale in a cost-effective manner.

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Self-healing Capacity of Structural Size Fiber Reinforced Concrete Beams

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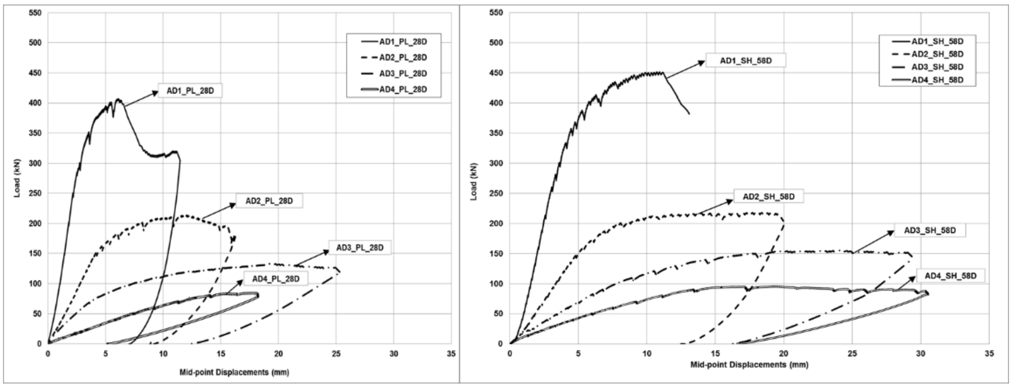
Fiber reinforced cementitious composites due to their deformability under tensile stresses have high damage tolerance and durability [1-3]. In addition to these properties, Engineered Cementitious Composites (ECC) which is a type of fiber reinforced cementitious composites, can show self-healing properties owing to the joint effect of multiple cracking behavior with tight cracks and high amount of binders in their composition [4-5]. However, the self-healing performance of ECC has only been evaluated by using small-scale, laboratory-size specimens tested under laboratory conditions. Yet, on site performance of the self-healing structural material is under question. In order to evaluate the effect of self-healing ability of ECC on the properties of structural-size beam members, reinforced with steel rebars, beams with shear span to effective depth (a/d) ratios ranging from 1 to 4 were produced. 28 days after casting beams were preloaded to 50% of their ultimate load carrying capacity under four-point bending loads. In order to mimic the real life conditions, curing was applied only by using wet burlaps for a duration of 30 days. Then all specimens were tested for load-carrying capacity, deflection capacity, ductility, flexural stiffness, energy absorption capacity in order to gain an understanding of the influence of self-healing.

Figure 1: Reinforced ECC beam specimens under flexural loading

As a result of the experimental study conducted it is revealed that structural parameters enhanced with self-healing. In addition, even though shear reinforcement was not used in the beams specimens failed displaying a ductile bending fracture.



(a) (b)

Figure 2: Test results for damaged (a) and self-healed (b) beams

All of the damaged beams improved their load carrying capacities with respect to pre damaged beams as a result of self-healing process but could not reach the level of sound beams. Nevertheless, beams with an a/d ratio of 4, those subjected to self-healing after initial pre-loading attained load-carrying capacities beyond the values of control specimens. Energy absorption capacity and vertical shear per mid-point deflection values were significantly improved indicating that self-healing is more successful on beams with an a/d ratio of 4, in which the bending mode is more dominant. This conclusion reveals that shorter bending cracks with less surface friction heal better compared to longer shear cracks with higher surface friction. This study shows that for structural size beams, in addition to the enhanced mechanical properties, autogenous healing behavior of ECC is also prominent.

The next step of the study includes the development of economical self-healing fiber reinforced cementitious composites that uses hybrid self-healing mechanism and evaluate its performance when used instead of ordinary concrete in structural sized reinforced beams. It is planned to evaluate the mechanical and self-healing performance under torsional loading in addition to flexural loading.

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Impact of Super Absorbent Polymers on High Performance Concrete Under Severe Conditions

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ABSTRACT

Early-age behavior prediction of cementitious materials is not an easy task, because many properties of the material are subtle to curing conditions, as it is the case for High Performance Concrete (HPC), which have a low water to cement ratios ($0.2 < w/c \leq 0.35$), small aggregate size and supplementary cementitious materials (silica fume, fly ash..) with admixtures [1], [2]. Due to their exceptional mechanical properties and durability, HPCs are highly demanded these days especially for structures under severe conditions. Early-age cracking is their challenge, since high performance concrete goes through a lot of autogenous shrinkage (AS) which develops fast within the first days of age due to cement hydration reactions. The lack of enough water for a full hydration and the reduced porosity in the low w/c concrete matrix result in a drastic decrease of the relative humidity (RH) in the pore structure, and an increase of the pressure within the pore structure which in turn cause the appearance of autogenous shrinkage [3], [4]. However, to avoid the crack development initiated by AS at early age, internal curing is a solution. The release of water into the matrix coming from the curing agent, will maintain the RH high enough for further hydration to avoid self-desiccation. In HPCs, Super Absorbent Polymers (SAP) are commonly used as curing agents, since they were proven to be more effective than other products such as light weight aggregates [5].

In this research, the main goal is to mitigate the shrinkage using SAPs in infrastructure under severe conditions. Therefore, an early age crack assessment was done to approve on the design for a reference HPC wall without SAP which would show early age cracking. It will then be compared to a SAP wall in order to mitigate shrinkage cracking. Two demonstrator walls were built (Figure 1), and commercially available SAPs were used with a diameter of 100 µm. Chemical shrinkage tests were used in order to calculate the amount of SAPs and extra water needed to be added to the mix.

Autogenous shrinkage measurements on concrete were investigated through different methods: corrugated tubes, fibre optic (SOFO) sensors embedded inside walls to follow real time deformations behaviour, and through demountable strain gauges (DEMEC) points placed on the walls at the same position of SOFOs after demoulding in order to compare these values with SOFO measurements. Restrained shrinkage tests were also performed on the mix using ring method, to further study the behavior of SAPs towards mitigating shrinkage under restrained condition since the walls are restrained at the bottom (attached to a slab). A high reduction of AS and no cracks were seen in the SAP wall which indicates that SAPs are indeed a promising material towards mitigating the shrinkage under restrained condition and enhancing the early age behavior of concrete for a better durability. Different tests will then be performed on cracked HPC-SAP specimens to check the sealing capacities of the concrete such as water permeability and capillary absorption using different methods.

Figure 1: Large scale testing walls, on the left is the reference HPC mixture wall (REF) and on the right HPC wall with SAPs

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An investigation of the effect of concrete mix design methods on their properties for potential applications as a preventive repair method

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In the manufacture of recycled aggregate concrete (RAC) using the existing conventional mix design (CMD) methods, a degradation of the mechanical properties of RAC as well as chloride penetration, carbonation coefficient, and shrinkage increase as a function of replacement rate of recycled aggregate (RA), which cause fatal adverse effects on the properties of concrete [1, 2]. However, the equivalent volume mortar (EMV) method has been proposed, which considers the attached mortar to RA as mortar to be newly added for making concrete, unlike in the past when RA was treated as single-phase material. In order to equalize total mortar volume of RAC and natural aggregate concrete (NAC), newly added materials such as cement, sand, and water are reduced by the volume amount of attached mortar in RAC. Through the application of the EMV method, mechanical properties can be comparable to the level of NAC while reducing the use of natural resources [4]. In addition, it showed better durability performance than RAC with CMD method [5]. The effectiveness of the EMV method, which can be one of the methods of preventive maintenance of concrete, is still being studied, but the majority of the studies focuses on the mechanical properties at later ages. Therefore, an investigation on the early age properties of RAC designed with EMV method need to be carried out for potential applications as a preventive repair method.

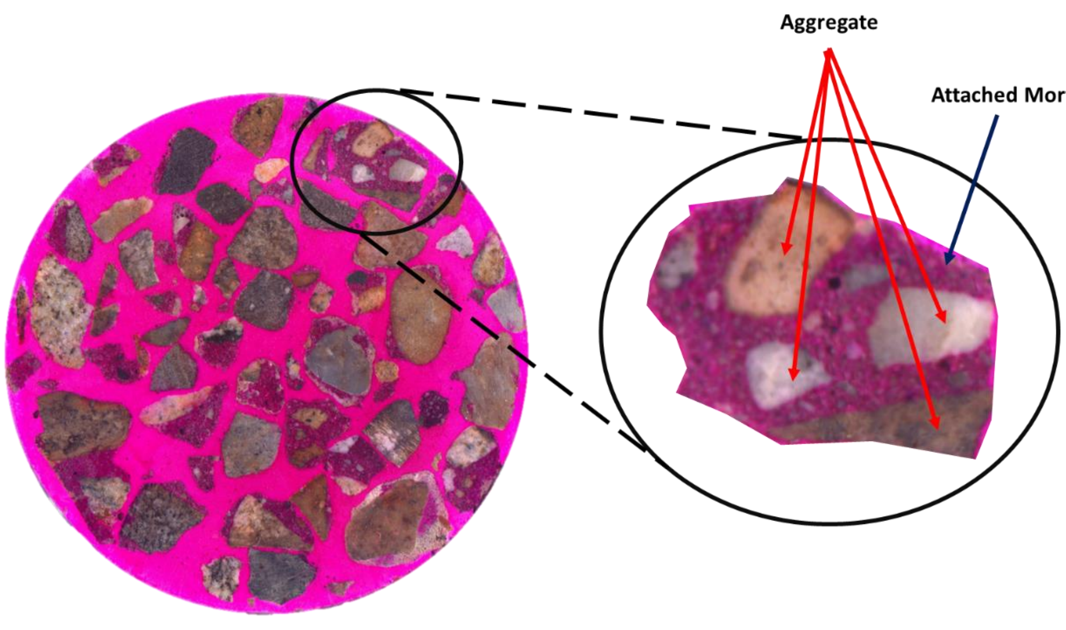

***Figure 1:** RA mixed with white-colour cement (L), actual composition of recycled aggregate (R)*

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Self-Healing capacity of concrete composites due to combination of different exposure conditions – freeze/thaw cycles under chloride penetrations combined with mechanical loads

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OBJECTIVES

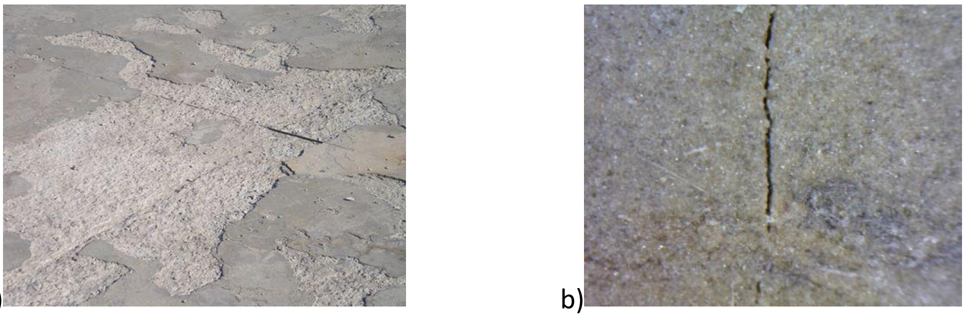
Due to concrete research activity, our department has been active to different topics including self-healing capacity of concrete and smart material properties. Most of my research activity has been investing in self-healing capacity of concrete. It is important to mention that there was collaboration with important academic institutions that was carried out, such as Politecnico di Milano, Federal University of Rio de Janeiro etc. This activity has commenced in 2010 with one of promoters of self-healing research activity in concrete – Prof. Liberato Ferrara, whose work was presented in numerous well known conferences and journal papers.
Educational and research activities organized by SARCO's have created great opportunities for us to showcase our work, exchange the experiences gained throughout our academic journeys and understand the ongoing research at Round Robin Tests results which have undeniably highlighted the significance of self-healing research activity.
One of the underlying issues at our institution which was discussed in the last UBT Conference is related to "smart materials", where the challenges of future research activities concerned with self-healing were deliberated.
The main challenge in Kosovo's concrete constructions lies in their durability and service life due to extreme conditions in different seasons throughout the year. Considering the fact that most of the country's infrastructure buildings are made of concrete, and the fluctuation of temperatures from - 20 °C in winter and + 35 °C in summer (leading to $\Delta T=55°C$), this challenge does raise a serious need for action.
According to the latest RILEM Technical Committee 246-TDC, "service life of reinforced concrete structures can be considerably shortened under the influence of combined actions, as for instance ination of freeze-thaw cycles, applied mechanical load, and chloride penetration shall be investigated".
Hence, we together with colleagues of the upper-mentioned institutions have agreed to elaborate on the following: self-healing capacity of concrete composites combined between different environmental conditions; freeze/thaw cycles that are directly related with the chloride penetration in the outside infrastructure buildings during the freezing periods; combination of different environmental conditions with mechanical loads due their capacity to heal the cracked specimens; reference specimens of the mentioned conditions etc.
The latter would contribute in quantifying the healing capacity, as well as providing answers to the study requested by the latest Rilem Technical Committee regarding durability and life cycle of concrete structures.

First type of concrete that will be studied is the traditional one, out of which most of regional buildings are made of, following with the innovative high strength concrete, self-compacting concrete, and even the Kosovo fly ash as a cement substitution which is highly present as a waste production of coal power plant. Consequently, the last issue tends to fulfill another aspect of SARCOS and COST Action future developments, which is the environment.

Apart from challenges that were previously mentioned, different environmental challenges that are occurring and becoming an integral part in Europe, including Kosovo, also represent a very stimulating case study for materials and concrete performance in particular conditions.

We consider that a crucial step into being part of Europe involves implementing European codes, enhancing the understanding of innovative concrete types such as self-healing concrete, and working alongside institutions and programs founded by European Community.

Moreover, knowing that Kosovo's government invests the most in infrastructural sector, we hope to establish networking between SARCOS and future COST Actions with government institutions, UBT and civil engineering companies in the near future.



a) b)

Figure 1: a) Concrete damage by freeze/thaw cycles and b) ongoing self-healing of cracks

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Dr. Visar Krelani Dr. Muhamet Ahmeti

Preventive repair of the epoxy resin coatings obtained by utilization of the recycled fine aggregate from construction and demolition

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Preventive repair of the buildings elements is nowadays very commonly seen approach. However, the coatings as a non-structural elements are mostly not properly design. Thus, there should be taken actions which could solve this problem and enable to ensure a suitable floor for more significant loads. Among many methods which can prepare floor on chemical compound aggression and mechanical loads, epoxy resin is commonly used as a coating layer [1]. Recently, this method has developed as an alternative preventive repair method in contrast to limited pure concrete which can be only grinded or brushed [2]. Moreover, the worldwide development is currently accompanied with a fast growing construction industry that is responsible for generating the highest amount of wastes in the EU. On the other hand, the extraction of natural aggregate is also high, with sand and gravel extraction coming out on top, generating a huge amount of pollutants. This extraction has a negative influence on the environment and does not provide a renewable material. In some countries, this resource is almost finished. By 2020 the majority of the EU countries want to achieve at least 50 per cent recycling of construction and demolition waste due to its negative impact on the environment. Thus, the main aim of this paper is to present the positive impact of use of the recycled fine aggregate (RFA), as a substitute for conventional fine aggregate (CFA; river sand), which was used as an extender in epoxy resin coatings, on the properties of the epoxy resin coating with preventive repair benefits. For that purpose, samples with different partial substitution of the CFA with RFA: 0%, 20%, 40%, 60%, 80% and 100% were prepared and macro tests for pull-off strength, compressive strength and flexural tensile strength were performed. In addition, X-ray micro-computed tomography, SEM and nanoindentation analyses were performed to investigate the influence of the replacement of the CFA with RFA on the properties of the epoxy resin coating. Based on the obtained results, it can be concluded that RFA has a beneficial impact on the pull-off strength of the epoxy resin coating. The summary evaluation of mechanical performance shows that substitution of RFA by CFA in epoxy resin coatings has visible impact on reduction of dispersion of strength results. The coating modified with RFA wastes become more homogenous material in comparison to the specimens with CFA. Moreover, reuse of the wastes could have significant impact on environment with additional economic benefits. The disposal of the industrial wastes, with high benefits for the properties of epoxy resin coating, can be obtained for the composition with 20% of CFA and 80% of RFA, and for sample with 100% of RFA.

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USE OF BIOPOLYMERS IN RECYCLED AGGREGATES

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INTRODUCTION

The growing demand for construction materials in many countries around the world where there is an intense growth in the rate of industrialization and urbanization, it has caused an important burden on the environment during the last decades, both for the amount of natural resources used, and for the large flow of waste generated.

Therefore, the search for a greater degree of sustainability in the construction sector, raising the use of their own waste as materials likely to be reincorporated in the sector such as concrete made with construction and demolition waste.

For this reason, the research group called IMMATECO (Ingeniería de Materiales y Eco-eficiencia), with more than 10 years of experience. Formed by seven researchers (five permanent staff). The experience of this group in international collaboration have been developed with Magnel Laboratory of the University of Ghent in Belgium, IST of Lisbon (Portugal) and Nova University of Lisbon (Portugal).

Our field of interest is focused on the development, characterization and testing of new stony recycled materials, obtained by recovering and recycling of construction and demolition waste.

Furthermore, the group's research is aligned with the current environmental policy on waste reduction, recycling, material recovery, carbon footprint reduction, obtaining more environmentally efficient building materials and increasing the sustainability of a sector so important for the development of society as construction.

Recycled building materials have been studied and supported by hundreds of publications to on replacing natural aggregates by recycled aggregates satisfactorily [1-5]. However, one of the drawbacks it is the high water absorption values that characterize mixed ceramic recycled aggregates, which it is detrimental to these concretes that have limited workability levels.

Several techniques have been studied to solve this problem as, use of water-reducing admixtures [6], pre-saturation of recycled aggregates [7], chemical treatment [8], two-stage mixing approach [9]. This research suggests the use of biopolymers (polyhydroxyalkanoates, PHA) on the mixed and ceramic recycled aggregates as a new technique to reduce the water absorption drawback, before these are incorporated into the concrete mix.

The first tests are based on use of 100% concrete recycled aggregates on one hand, and 100% ceramic recycled aggregates on the other hand, being obtained by crushing of construction and demolition waste (CDW) in recycling plant (TEC-REC sample: Tecnología y Reciclado S.L., Madrid). These recycled aggregates samples were chosen mainly due to their composition and it separated manually from a mixed recycled aggregate, characterizing by nature; concrete and ceramics and for its granulometry (4-12.5mm).

The study of different biopolymer over recycled mixed aggregates carries out in an air-conditioned room (20ºC, 60% RH) under static and non-sterile conditions (open to the air). In the first step, dry recycled aggregates are immersed for 24 h in one day. After this period, aggregates are removed from the culture solution, and it dried in an oven at a temperature of 70 degrees for 48 hours, to later determine its dry weight gain and its decrease in water absorption.

So far, we only carry out a starting test, in the future we will do a more development study, using four different types of biopolymers that allows us to compare and to contribute with new methods to improve the qualities of recycled aggregates.

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Crack self-healing ability of bio-mortar

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OBJECTIVES

Innovative and sustainable solutions for self-healing concrete structures are at the highest demand in these days as their repair and maintenance can reach very high costs [1]. It is known that bacteria promote a self-healing phenomenon in the existing cracks in a concrete structure [1,2]. However, an elevated pH value of the cement-based concrete matrix affects negatively the life span of bacteria and consequently, the self-healing effect. Therefore, a method for encapsulation of bacteria healing agent in a polymer hydrogel system is needed in order to protect the bacteria from surrounding. The ureolytic bacteria especially Sporosarcina pasteurii have generated a lot of interest in the field of crack repair in concrete and calcareous materials, and have been studied extensively. The use of these bacteria leads to accumulation of insoluble $CaCO_3$ in a calcium rich environment through the hydrolysis of urea; this produces dissolved ammonium, inorganic carbon and CO_2, and the ammonia released in the surroundings subsequently increases pH [3].

In order to investigate the healing capacity of the employed bacterial colony and the effectiveness of the proposed encapsulation methods, systematically varied mortar specimens were prepared. The prepared samples were characterized by X-ray diffraction (crystal phases revealed), X-ray fluorescence analysis (chemical content), mercury intrusion porosimetry (pore size distribution) as well as examined by scanning electron microscopy (surface morphology). Microstructure and textural analysis were performed.

The mortar specimens were notched at mid-span and then pre-cracked in 3-point bending in CMOD-control mode (Crack Mouth Opening Displacement) [4]. After unloading, the water sorptivity test was performed and then the specimens were kept in a moisture room (90% RH). Their healing ability was measured by crack opening displacement change examined by optical microscopy immediately after the crack formation and after two months of healing. Moreover, at the end of the scheduled exposure periods (one and two months) the water sorption test was performed and the specimens were finally tested in 3-point bending up to failure, in order to assess the effect of the healing. The obtained results were compared with those of the reference samples.

OBTAINED RESULTS

The presence of microorganisms encapsulated in hydrogel particles inserted in the cement matrix, proved by SEM investigation, shows a positive effect on mechanical characteristics and water sorption of the mortar specimens. The CMOD mechanical test of the fresh mortar specimens designed with hydrogel and the specimens with bio-mortar show less brittle behaviour in comparison to the standard ones. After two months of curing, the resistance to the maximum load force changed in favour of the specimens with hydrogel and bio-mortar.

The mechanical characteristics of the two months cured specimens could be directly related to the water sorption values. Evidently, the hydrogel ability to retain water affects positively the self-healing phenomenon of the bio-mortar specimens. Figure 1 shows a result of self-healing after 60 days for the mortar samples kept in the moisture room (t=20 °C, RH=90%). The best results were obtained for the sample B – mortar with hydrogel encapsulated bacteria.

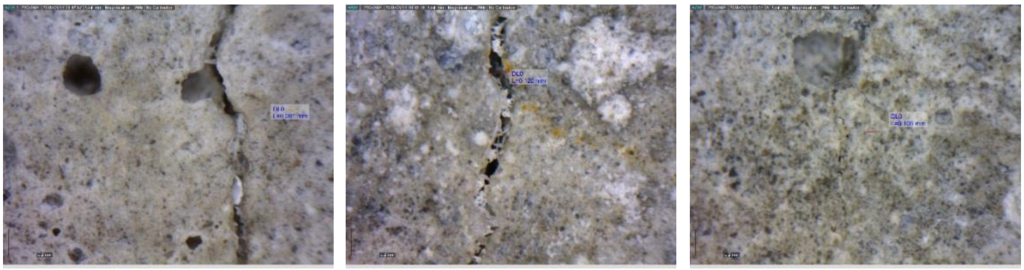

Figure 1: Optical microscopy results of the crack closure after 60 days of pre-cracking with controlled crack mouth opening displacement of 200 μm for the mortar samples S-reference (left), G- with hydrogel (middle) and B-with hydrogel encapsulated bacteria (right).

PLANED INVESTIGATION

A success of the crack healing will be evaluated by the SEM measurements on the mortar specimens' cross-sections. The structure and chemical content of the healing material are planned to be investigated by XRD and by combined XRF/EDS mapping of the crack surface, respectively. The already obtained results will be complemented with the results of SEM-EDS, XRD and XRF characterization. A cross-comparison analysis of the obtained results will be provided.

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Self-Healing Capability Of Composites Nano-Tailored Cementitious Cementitious

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OBJECTIVES

The study of author includes enhanced self-healing properties of engineered cementitious composites (ECCs) that are capable of repairing their cracks. To do this, single and binary use of nano-silica (NS) and carbon nanotubes (CNT) were utilized and ECC specimens were assessed based on electrical resistivity (ER), freeze and thaw, rapid chloride permeability, resonance frequency and unit weight tests. Besides, basic engineering recoveries of different ECC specimens were also evaluated by conducting mechanical experiments on pre-loaded and sound specimens. Engineering properties of nano tailored ECC specimens were taken into account in terms of flexural strength, deflection capacity, ductility ratio, initial stiffness and energy dissipation capacity. Microscopic analysis was also performed to understand the microstructural self-healing mechanism within ECC matrices. The investigations indicated that an effective combination of NS and CNTs in conventional ECC matrices triggered a higher level of self-healing both in crack width closure and mechanical recoveries. However, single-use of CNT in ECC mixtures was also promising for achieving self-healing attributes compared to only NS bearing and control ECC specimens.
The improving of self-healing/repair in following next years to ensure longevity of infrastructres is mainly related to robustness of nanomaterials in cement based materials since nanomaterials still present high variations for the studies in civil enginering literature. The key objective of this Ph.D study was to bring new insights to self-healing oriented building design and applications so that construction industry can perform sustainable transformation in the forthcoming years. It would be great chance to be an attendee of this Ph.D meeting for future studies of author, especially planned for the investigation of synergistic effect of nanomaterials to reduce costs at given self-healing efficiency.

INSTRUCTIONS

Concrete technology has dealt with many problems over years and high performance reinforced cementitious composites were developed to offset different types of problems. For example, engineered cementitious composites (ECCs) favoring inherent tight microcracking behavior under excessive loading were introduced to the construction market by Victor Li. To further tailor cement-based materials, efforts have been made on the self-healing performance [1]. One of the practical and effective methods to lower the necessity for repetitive repair/maintenance applications is autogenous self-healing mechanism. Present study reflects one part of the Ph.D. thesis of author that recently presented. Details can be also found in research paper published recently [2]. Current study undertakes the self-healing properties of ECCs tailored through extensive preliminary research with homogeneous NS, CNT and binary NS/CNT additions (Figure 1a). Many types of permeability and mechanical test procedures, physical microcrack sealings of pre-loaded specimens were evaluated by a video microscope recorder. Self-healing responses of nano tailored ECC mixtures were further discussed through SEM, TGA and XRD investigations. Recovery of basic engineering properties of preloaded ECC specimens was assessed in detail by qualifying their engineering properties. Sound 28 day-old ECC specimens modified with nanomaterials were also characterized through evaluating their flexural strength, deflection capacity, ductility ratios, initial stiffness and energy dissipation capacities based on stress-deflection curves (Figure 1b).

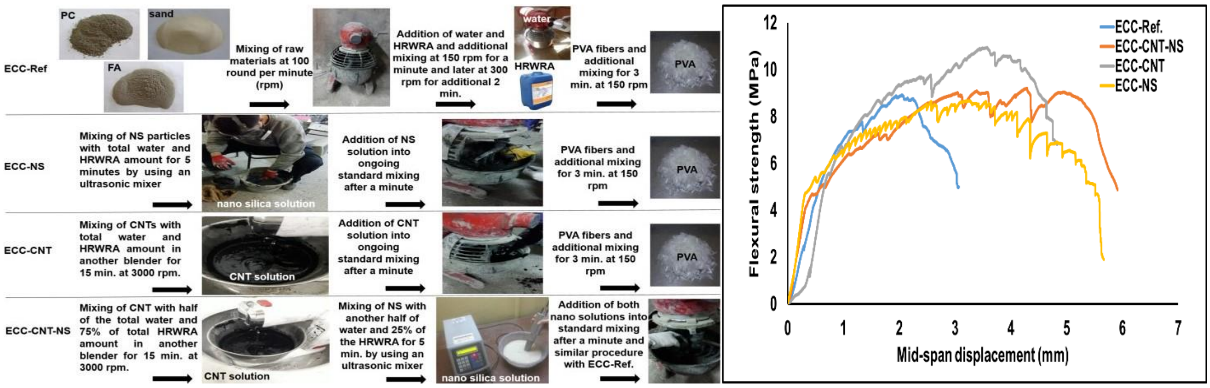

Figure 1. homogeneous distribution of nano-materials (a) and stress-deflection curves of produced specimens (b)

The potential of autogeneous self-healing ability at possible widest cracks was studied in the presence of nano materials (Figure 2). Accordingly, recorded largest cracks widths from each mixture (691 µm-ECC-Ctr, 208 µm-ECC-NS, 605 µm-ECC-CNT and 810 µm-ECC-CNT/NS) resulted in complete or partial crack closure after a limited period. After just 7 days of self-healing period, mixtures tailored with CNT and NS particles showed complete closure of surface microcrack (810 µm). This result was the first time encountered by researchers in the literature considering autogenous self-healing phenomenon. However, it is worth noting that the attribute of early-age ECC-CNT/NS (7-day-old) to exhibit fully self-healing response in a very limited recovery period may differ for aged specimens due to reduction in the amount of products having healing capability and moisture at long curing. The uniform distributed NS and CNTs have led to increment of energy dissipation capacity, ductility ratio and initial stiffness in comparison with other mixtures. Microscopic analysis exhibited that bridging capability of CNTs on the self-healing products yielded effective reinforcement at nano/micro-scale.

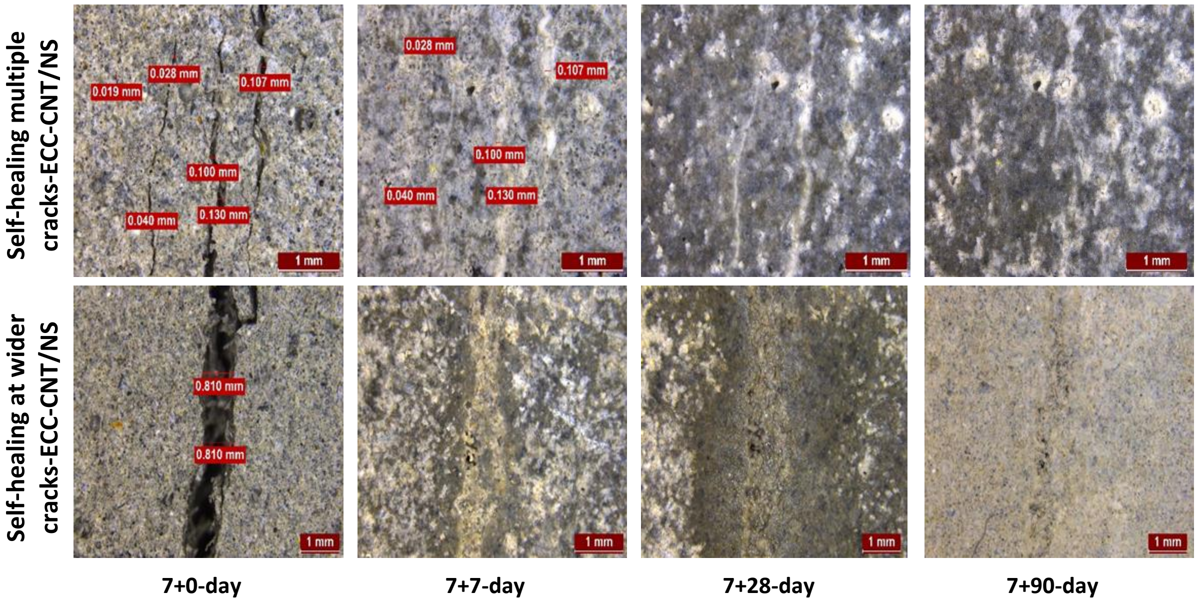

Figure 2. Autogenous self-healing capability of nano-tailored ECC specimens

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Synthesis and characterisation of core/shell particles for developing self-healing mortars

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OBJECTIVES

The objective of my PhD research is to study the development, characterization and performance of encapsulated healing agents, for the development of self-healing mortars. Encapsulated healing agents are a promising solution for extending infrastructures' lifetime because of the long term protection of the active components inside their durable shell [1].

My research is divided in three sections: i) the development of a synthetic methodology for encapsulated healing agents (core/shell particles), ii) the incorporation of these particles in a cementitious matrix and the study of the composite cement's performance, and iii) the evaluation of the composite cement's healing efficiency.

Concerning the first section, a modification of the Stöber method has been studied [3, 4] in order to develop a durable Si-based shell. This method is well known for the production of spherical silica particles in the nano-scale. The effect of the reactants concentration and the reaction conditions on the size distribution of the silica particles was studied and evaluated using scanning electron microscopy (SEM) (Fig. 1) and image analysis techniques.

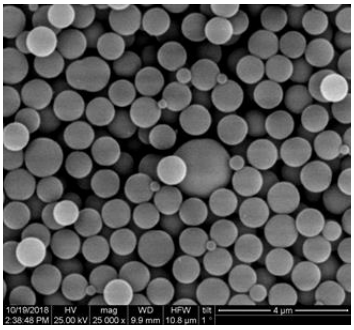

Figure 1. *Silica particles observed in SEM*

Figure 2. *Controlled damage of prismatic specimen*

According to the results, using this method, the particles' diameter ranges from 550-5000nm, while the autonomous self-healing with encapsulated healing agents aims to heal cracks with crack width >100μm [5]. Consequently the lower size of the produced silica particles is considered restrictive for this application due to the low amount of healing agent that could be encapsulated.

Except from the particles' size, the performance requirements of the particles are: i) the mechanical strength of the shell that should be appropriate in order to survive the mixing process but rupture during crack propagation, and ii) the porosity of the shell that should ensure water tightness of the capsule and long term reactivity of the healing agent [6].

The future steps of this section will be the development of a synthetic methodology for encapsulating the healing agents in the micro-macro scale and, the optimization of the mechanical performance and water tightness of the silica-based external shell.

Finally, a set of preliminary tests have been conducted in the frame of the last section of this research, in order to develop methodologies for the assessment of the self-healing efficiency of composite cements, in terms of water permeability, water absorption and characterization of healing products [7]. A critical parameter of the abovementioned methodology, that requires further investigation, is the controlled damage of the specimens in order to ensure repeatability and comparability between the specimens (Fig. 2).

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Monitoring and Identifications of Early Cracking in the Cement Road Pavements; Lab, Field and numerical study

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OBJECTIVES

Ground Penetrating Radar (GPR) as a non-destructive geophysical method was applied in concrete monitoring applications; evaluation of concrete cracks in term of width and depth, water content in cement pavement roads, cultural heritage, and seismic performance and strengthening of the RC Structure including beams and columns (corrosion and concrete problems). The aim of the research has similarity of the Cost Action SARCOS CA1520 objectives. Characterization and monitoring of crack healing working group 2, and GPR as non-destructive method will be a very recent technique to monitor and evaluate early cracking and water content in the concrete road pavements (rigid pavement).

In upcoming year, the research objectives will be self-healing concrete in rigid pavements damages as well as the inspection of the early cracking and detection of moisture on the early stage cracks in the rigid pavement will be investigated.

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Self-healing processes using biopolymers in recycled concrete and mortars

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Introduction

A lot of studies have demonstrated the concrete permeability is related to the ingress of various ions, liquids and gases from the environment, responsible for the deterioration of concrete directly and indirectly [1,2] what in the end supposes a decrease of structure useful life.

Construction and demolition waste (C&DW) represent more than 10 billion tons in all the word [3] It accounts for approximately 25-30% of all waste generated in the European Union [4] of which the largest fraction of this waste is concrete at the end of its useful life.

For this reason, this project seeks to experiment with polyhydroxyalkanoates (PHA), natural polymers produced by microorganisms, capable of acting as additives promoting the surface protection of building elements, thereby contributing to the durability and useful life of concrete structures.

In addition, this project is carried out on recycled concrete, with a 50% replacement of natural aggregate by recycled aggregate from concrete.

The PHA used in this study is a product of the suspension of mixed microbial cultures (MMC), in two different carbon substrates: crude glycerol and pine wood bio-oil. Both of these residual products, the pine wood bio-oil, product resulting from the food industry and the crude glycerol, considered a waste stream of the biodiesel industry [5] which It is a major problem to manage this waste because of the high cost of purification for use in other industries.

A portion of MMC cell walls were disrupted by sonication, resulting in four different types of treatments (Glycerol without sonication =GNS, Pine wood bio-oil without sonication =PNS, glycerol with sonication =GS, Pine wood bio-oil with sonication =PS).

Methods

For this research with PHA, tests have been proposed to prove the degree of protection provided by this biopolymer against the passage of time and the climatic conditions to which concrete will be subjected during its useful life.

First of all, I have started with the water drop absorption test, being applied the different treatments by capillarity. This test allows evaluating the permeability variation of the biotreated surfaces by monitoring the time required to absorb a water drop under open air conditions. This test facilitates comparing for each biotreated concrete samples and the reference (with water application) samples.

Additional tests will be carried out in the near future to determine further the degree of surface protection provided by the various treatments, including ice-thaw testing, carbonation, water penetration under pressure, water absorption, density and accessible porosity of concrete.

Results

The results of the drop absorption test have been obtained, allowing the comparison of each of the four treatments with each other, as well as with regard to reference. As can be seen from the graph, (Figure 1) a significant superiority of the different treatments over the reference test pieces are maintained throughout the cycles, with particular emphasis on the test pieces treated with Pine wood bio-oil with sonication.

another common factor that is perceived in the four treatments, is the decrease of the absorption time over the cycles, due to the washing of the biopolymers.

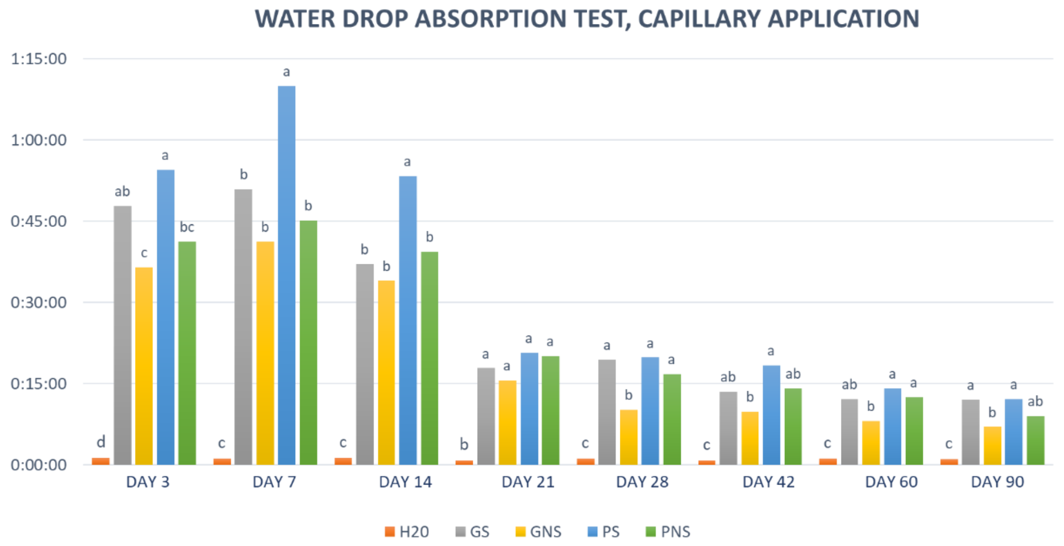

Figure 1 comparison of the results of water drop absorption test.

<u>Problems</u>

One of the main problems associated with this project is the difficulty involved in the production and purification of PHA, which obliges us to limit to a large extent the number of tests to be carried out, as well as the number of test pieces with which we can work within each test.

In addition, one of the problems we foresee is the lack of penetration of this biopolymer, which can be an inconvenience when talking about the durability of these treatments on concrete.

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Bacteria-based self-healing concrete in cold climates

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OBJECTIVES

Monitoring and repair of the cracks is crucial for expanding the service life of concrete structures. However, in some cases rehabilitation can be rather difficult and expensive. In the UK, maintenance and repair works account for approximately 34% of the country's total construction budget which in 2018 represented 57.9 billion pounds. An answer to the problem may be self-healing concrete, an innovative material that has the ability to detect and heal its own cracks, minimizing the need for external human intervention. One way to achieve this is by using bacterial spores inside the concrete. These, in the presence of nutrients and when water flows through the cracked area will germinate and behave as healing agents sealing the crack by inducing the precipitation of calcium carbonate through their metabolic activities. The employment of bacteria that can survive inside the material, meaning in highly alkaline conditions and under severe stresses that take place during the mixing, hydration and hardening process of the concrete, is of great importance.

Although self-healing systems with different bacteria, nutrients and curing regimes have shown encouraging results in the laboratories, where bacteria are grown in ideal temperatures of 20-30^{o}C, the development of the method in more realistic environmental conditions must be considered. In order for this mechanism to be applied in low temperatures, about 7^{o}C, the use of cold-thriving bacteria will be investigated in the present research. As a first step towards this application, the effect of the healing agents, bacteria and nutrients, on the properties of the concrete was studied. A significant increase in the strengths of most of the mortars containing bacteria was recorded, especially of those with dead bacteria cells. This improvement of concrete's strength is promising as a low-cost and environmental-friendly way to enhance the properties of low-strength cementitious materials.

Psychrophilic bacteria will be examined and evaluated for their healing ability in low and room temperatures. The results will be compared with the performance of a non-psychrophilic strain in the same temperatures. Combination of different types of bacteria, psychrophilic and non-psychrophilic will also take place for achieving self-healing in a range of temperatures. Another parameter to be examined is the age of cracking and the healing of cracks created at 28 and 180 days will be assessed. Finally, incorporation of a vascular network through which nutrients can be supplied continuously will also be tested in an effort to attain repetitive healing. The self-healing efficiency of the above-mentioned systems will be first evaluated visually using optical microscopy. Water permeability as well as durability tests (chloride penetration and sulphate attack) will be also performed to assess the effect of the healing on the durability of the self-healing concrete.

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Sprayed Self-healing Engineered Cementitious Composites for Concrete Repair

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Abstract

The repair and maintenance of concrete structures is a serious global concern owing to the significant cost, time and labour involved. In Europe, half of the annual construction budget is spent on repair and maintenance, but still, 50% of repairs fail prematurely[1]. Autonomous self-healing sprayed Engineered Cementitious Composites (ECC) may offer a better solution for concrete repair and increase the durability of structures. In this study, the efficiency of the autonomous self-healing mechanism will be investigated using two different healing agents: crystalline admixture and magnesium oxide. Mechanical properties (compressive and flexural strength), durability (water permeability, water absorption, sulphate attack and rapid chloride migration), and microstructure (via SEM and XRD) will be investigated on cast and sprayed ECC specimens. Cylinders and beams, pre-cracked at 28 days by splitting and 4-point bending test respectively, will be submerged in water for 1 and 3 months to monitor the self-healing efficiency. Change in surface crack widths will be monitored with a digital microscope, ultrasonic pulse velocity and resistivity meter to study the autonomous self-healing rate and development along the crack cross-section. Additionally, the sulphate resistance of cast and sprayed ECC will also be investigated.

The research contributes to the understanding of the self-healing mechanism of cement composites and the effects of the deployment method (very common in repair applications) in the healing. The research also explores the durability of sprayed self-healing ECC when applied in an aggressive environment subjected to sulphate attack, thus informing the potential applications and limitations of the material. Overall, this study contributes to the understanding of self-healing cement composites as an external repair material for reinforced concrete infrastructure and the reduction (or even potential removal) of repair and maintenance operations.

Preliminary Experimental Program

The experimental program is in the initial stage; the development of the pumpable mix is discussed below:

A sprayable ECC has been developed based on the theory of micromechanics and rheology-based design. The former is a technique to tailor the microstructure of the composite based on an understanding of the mechanical interactions between the matrix, PVA fibres and interface phases under load. This technique used herein is mainly focused on achieving strain-hardening in tension because the tensile ductility is representative of the structural performance as well as material ductility. The rheology design exhibit significant pumpability and sprayability in the fresh state and strain hardening behaviour in the hardened state [2][3].

Trail mixes were conducted to obtain a pumpable and sprayable mix. To characterise the pumpability, fresh ECC mixed with and without a self-healing agent in a 15L capacity drum mixer was pumped with a worm screw pump through a 25 mm diameter and 5000 mm long rubber hose without a nozzle (Figure 1 and 2). The pumpability of the fresh ECC varies with the percentage of PVA fibres used. Hence, the required pumpability of the mix was obtained using a moderate amount of fibres (less than 2% by volume).

Figure 1: Screw worm pump

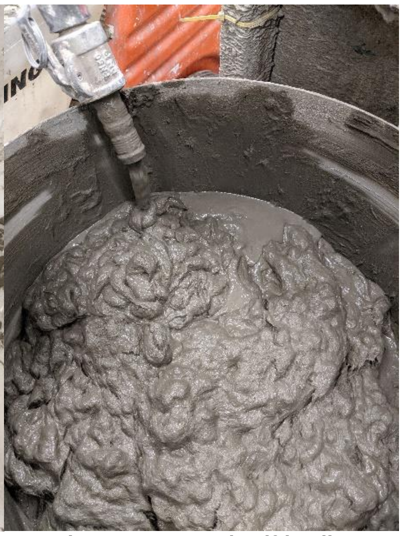

Figure 2: Pumped self-healing ECC

Expected Outcomes

- An understanding of the self-healing efficiency of the sprayed ECC specimens with regards to conventional casting.
- Identification of the most suitable self-healing agent (and optimum content) for sprayed self-healing cement composites in terms of efficiency.
- A conceptual model that explains the evolution of the self-healing mechanism along the crack cross-section and contributes to the understanding of the autonomous self-healing mechanism of the cast and sprayed ECC.
- An understanding of the durability of the cast and sprayed self-healing ECC exposed to sulphate attack.

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SuperAbsorbent Polymers for smart and durable concrete structures

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Most of the deteriorating mechanisms acting on concrete structures are related to the ingress of aggressive agents inside the structures. Even before reaching its hardened state, a cement-based composite is subjected to the formation of cracks especially due to the effects of shrinkage during the early ages. The formed porosity of the material can become the perfect path for the ingress of those aggressive agents. After the crack formation the water intrusion causes a drop in the pH of the concrete that can lead to steel corrosion; the ingress of chlorides causes the de-passivation of the protective film, the intrusion of CO_2 can cause carbonation and both processes can accelerate the corrosion.

Recent research has shown that superabsorbent polymers (SAPs) can be used to reduce crack formation due to autogenous shrinkage by means of internal curing. Besides that, this material has been considered of great interest in the study of smart self-healing materials where the promotion of self-sealing is also investigated [1-3].

Superabsorbent polymers (or hydrogels) are a natural or synthetic water-insoluble 3D network of polymeric chains cross-linked by chemical or physical bonding. They possess the ability to take up a significant amount of fluids from the environment (in amounts up to 500 times their own weight).

In the industry contractors are searching for a way to decrease shrinkage cracks and to obtain a watertight structure. This is especially important for tunnel elements, underground parking garages, basements, liquid containing structures, pavements, etc. Nowadays, contractors are often forced to apply crack repair right after construction, due to the formation of shrinkage and thermal cracks at early age. The shrinkage could be overcome by using SAPs as they may provide internal curing to the construction element: they absorb water in the fresh concrete mix, and provide it to the cement particles at the right moment in the hydration process when they need it, in this way reducing the autogenous shrinkage. In hardened concrete, they may seal occurring cracks, as they swell in contact with intruding liquid/fluid. This will lead to more watertight structures. The SAPs will subsequently promote autogenous healing of the crack since they provide water for further hydration of unhydrated cement particles and calcium carbonate precipitation, leading to even more tight structures and possible regain of the mechanical properties.

In this context, this research aims to reduce shrinkage cracks by means of internal curing resulting from the addition of superabsorbent polymers. In addition, the construction elements will possess self-sealing and self-healing characteristics.

Different polymers (commercially available and in-house produced) have been tested to verify the potential for mitigation of autogenous shrinkage in cement pastes and concretes and also to evaluate their influence in the fresh (setting time, workability, air content) and hardened states (mechanical strength). Two commercially available polymers were found to completely mitigate the autogenous shrinkage of the concrete mixtures studied with limited reduction in the compressive strength [6]. The self-sealing effect is currently being studied by means of low-pressure water permeability tests with cracked and uncracked concrete specimens subject to low pressure water flow. One commercially available SAP and one in-house produced SAP, especially developed for sealing and healing, have shown the ability to reduce the permeability by up to 67% in cracked concrete specimens with a crack width in the range of 250-300 μm.

The next stage of the research will be to test those polymers with regards to the self-healing effect, by studying the regain of mechanical properties in healed specimens.

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Self-Healing in Cementitious Materials

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ABSTRACT

My Ph.D. on "Self-healing Cementitious materials" started right after my master in "Physics and technology of materials" at Physics School of AUTH, when I realized that my enthusiasm for expanding my knowledge of material science remains. Initially, I worked with the effect of **nanomaterials** on the self-healing capability, the addition of nano-particles in cement-based materials has been proved beneficiary in terms of pozzolanic reaction and early strength gain. For that purpose, nano-SiO_2 (NS) and nano-CaO (NL) were incorporated in cement pastes in different proportions. According to the results obtained from quantification of self-healing capacity, the significant contribution of nano-materials is evident. The formation of secondary crystals into the nano-modified structure resulted in: porosity refinement, strength increase and the most important, dense structure by the presence of fully compatible products that reinforce the material's structure. In pastes where cement-lime was combined, NS had lower influence due to different mechanisms acting in parallel. CaO nanoparticles not only benefit cement properties, but also the mechanism of their action favors calcite precipitation. Also has a vital role in terms of healing through secondary calcite formation at very early ages, which even in a low percentage (0.5% w/w of binder) was very active. Lime-cement pastes with nanoparticles contain a considerable amount of available portlandite which at later ages can contribute to further calcite precipitation. Even at 28days, healing crystals seem to be formed in wide cracks. Portlandite content increase and healing "bridges" on cracks enforce that claim [1,2].

Then I expanded my research by testing compositions that combine nanomaterials with silicate salts. Despite the wide application of sodium silicate solutions, the mechanism by which they act and improve the performance of the concrete is not fully understood. Has been investigated the influence of silicate salts and nanoparticles as well as the influence of the curing environment on the mechanical and physical properties of cement pastes. The samples with sodium silicate salts were more effective in relation to potassium meta-silicate. The role of nanoparticles needs investigation as they seem to form dense structure and managed to fill empty spaces with an excess of C-S-H phases [3]. SEM imaging revealed a number of flake and needle-like crystals in the pastes which were likely the primary reason for the mechanical properties. Overall, the presence of silicate salts in cement systems seems to play a significant role in self-healing procedure.

After that my interest turned to the effect of crystalline admixtures (CA) on the ability of self-healing. Different types of commercial products of crystallites were tested to observe the different effects and have been exposed to different environments; sea water, water, and wet/dry cycles. CA, aided by the presence of humidity, form idiomorphic crystals that block cracks and pores resulting in reduced porosity. The hydrophilic nature of crystalline admixtures helps the components to react with water and cement particles in the concrete to form C-S-H and pore-blocking precipitates in the existing micro-cracks and capillaries. The resulting concrete exhibits significantly increased resistance to water penetration. High-performance fibre reinforced cementitious composite (HPFRCC) were produced in the laboratory. Specimens were pre-cracked at 28 days and the achieved cracks width were in the range of 0.10–0.50 mm.

Furthermore, microstructure observations and Ultrasonic Pulse Velocity tests have been conducted. According to the healing efficacy the results highlighted the following conclusions: In relation to the curing regimes, was confirmed that continuous wetting was more efficient in relation to cycling curing conditions in all of the cases; According to sealing efficiency, the rates of water absorption through the crack of the concrete with CA were considerably decreased in all the exposure conditions, with a greater reduction in water; Analyzing the results of crack closure for the reference samples, the surface cracks up to about 50 and 150μm width has been closed within 28 days, at Cycles, Water and Sea Water exposure conditions, respectively. The addition of CA increased the crack closure, for surface cracks up to about 250, 400, 500μm, which were completely healed, at Cycles, Water and Sea Water, respectively.

Through the above experimental activity, many questions were raised about the techniques and standards used to measure healing as they have not been standardized. In the journey of this quest, more and more advanced methods of analyzing the efficiency of healing have been employed by many researchers. These methods are intended to clarify and quantify the healing mechanism. My recent study was about techniques either common in the micro and nano-structure study or innovative in this field, which were used in order to identify the healing efficacy. Specifically, the application of SEM analysis, 3-D ultrasound tomographic, nanoindentation, sorptivity and software development in the Python programming environment for healing monitoring have been investigated. The main objective was the quantification of several parameters, such as the geometry of the cracks, the properties of the healing products, as well as the healing depth. The methodology for non-destructive 3D-ultrasound tomography of healed specimens clarifies the ability of healing in depth. Nanoindentation technique enables localized contact response, which allows accurate estimates of the nano-mechanical properties of the tested areas. The software developed in a python programming environment aimed at quantifying surface closure and is an attempt to minimize the parameters that affect the inaccurate results, usually caused by the program's inability to detect only the crack. In addition, the results of each of the above methods are also presented, and their contribution to the study of healing is analyzed.

Through this journey of knowledge of self-healing analysis, I have had the need to analyze the techniques and standards that have been used to measure healing as they have not been standardized. Through that, the success of self-healing in cement-based materials can be ensured through thorough research and repeat measurements. I firmly believe that the exchange of knowledge and the ability to work in other laboratories helps researches to better understand their topic. Therefore, I decided to apply for a position to the Ph.D. Meeting at Guimarães.

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SARCOS Round Robin Test 5: Evaluating test methods for self-healing concrete with macrocapsules

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INTRODUCTION

In recent years the interest in self-healing concrete has been growing and with it the research output. Although a lot of tests have already been carried out by different international labs [1] it is often difficult to compare results, as no standard methods are yet available and there are a lot of factors which can influence the healing behaviour [2]. In the framework of the EU COST Action CA 15202 six different Round Robin Tests are running to evaluate test methods to assess the efficiency of self-healing concrete. Each test focusses on a different healing mechanisms. Round Robin Test 5 (RRT5), which is discussed here, focusses on self-healing concrete with macrocapsules. In total 6 labs participated in RRT5: Ghent University, Politecnico di Torino, Riga Technical University, Cracow University of Technology, Cambridge University, and KU Leuven.

MATERIALS AND METHODS

Unreinforced mortar specimens (40x40x160 mm^3) were made with a cast-in hole (ø 5 mm) positioned with its centre 1.5 cm from the bottom side. Two series were prepared: a reference REF series and a self-healing CAPS series. The CAPS series had 2 glass capsules (ø 3.35 mm) filled with polyurethane which were positioned under the cast-in hole. After curing, one side of the hole of the specimens was slightly enlarged and provided with a tube in order to connect the specimen to the water flow setup. The other side of the hole was sealed using silicone. Additionally, a Carbon Fibre Reinforced Polymer (CFRP) laminate was glued on the top side of the specimens using epoxy resin. At an age of 14 days the specimens were cracked in a three-point bending setup. The CFRP laminate at the top did not act as reinforcement but guaranteed that the two halves of the specimens remained connected upon crack formation. However, due to the lack of tensile reinforcement, the crack between the two halves of the specimens was too big. To reduce the crack width a screw jack was mounted on the bottom of the specimens which allowed the application of a force to push both halves of the specimens back together. By iteratively applying more force and measuring the crack width, the desired crack width of 285-315 µm at the bottom side could be reached with a good accuracy in most specimens.

To evaluate the permeability of the CAPS specimens, relative to the REF series, a water permeability test [3] was carried out. The specimens were connected to a water reservoir at a height of 50±2 cm using the pre-inserted tube in the cast-in hole. Water leaking out of the specimens through their crack was captured in a container which was mounted on an electronic balance which recorded the weight in function of time. The weight was recorded for a minimum of 6 min out of which an average water flow Q could be determined in g/min. Out of the mean water flow of the REF specimens Q_{REF} and the mean water flow of the CAPS specimens Q_{CAPS} it is then possible to calculate the sealing efficiency SE: $SE = (Q_{REF} - Q_{CAPS})/ Q_{REF}$.

RESULTS

The water flow results obtained by the different labs are given in Table 1. Despite the relatively high means of lab 2, the obtained sealing efficiency *SE* is comparable to that of lab 1 and lab 6. Lab 4 and lab 5 have significantly lower, respectively higher, *SE* results. This can be explained by variations on the outflow of the polyurethane. Additionally, lab 4 had less REF specimens to test. Lab 3 obtained a Q_{CAPS} which is comparable to the other labs, but the results of Q_{REF} are diverging, most likely due to a slightly deviating test procedure. This resulted in a diverging *SE* compared to the other labs.

Table 1: Mean results of the water flow test of the 6 participating labs

	Q_{REF} (g/min)	Q_{CAPS} (g/min)	SE
Lab 1	69	39	44%
Lab 2	108	54	50%
Lab 3	34	45	-33%
Lab 4	51	42	17%
Lab 5	61	17	73%
Lab 6	82	48	41%

The methods and results which are presented here are only part of a larger investigation of RRT5, which also includes water absorption tests on concrete prisms, as well as a study on the outflow of healing agent from the capsules. Currently, additional tests are being executed to eliminate any possible inconsistencies, after which a recommendation for the testing of self-healing concrete (with macrocapsules) will be published.

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Construction and Demolition Waste-based Engineered Geopolymer Composites (EGC) with Self-healing Capability

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OBJECTIVES

Geopolymers are produced with the alkaline-activation of a certain aluminosiliceous source material [1]. These source materials can change significantly in origin and wide-range of materials can be used for geopolymerization. In this regard, until now, geopolymers were mainly developed with the use of aluminosiliceous materials (e.g. fly ash, blast furnace slag, calcined clays) which are mostly with already well-known properties and composition/behavior that can be continuously controlled by the manufacturer. These materials, which were formerly called by-products (such as different types of fly ash and slag), are no longer regarded as waste due to their very successful and wide-spread utilization for many years as pozzolanic materials in traditional concrete mixtures and in blended Portland cement production. Therefore, selection of source materials for geopolymerization has broadened significantly recently and special attention started to be paid on materials that are not strongly demanded especially in blends with PC [2]. In this sense, components from construction and demolition waste (CDW) which is regarded to be the largest waste stream in the European Union can be preferably be used in geopolymer production. In addition, CDW-based components can also be used as different types of aggregates.

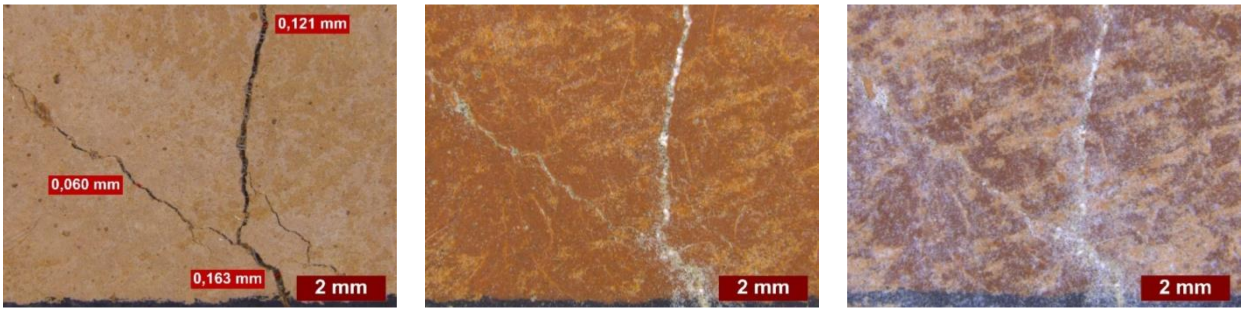
Engineered Cementitious Composites (ECCs) are materials with distinctive tensile properties and strain-hardening response similar to very ductile metals such as aluminium. Tensile strain-hardening response of ECCs comes along with the formation many multiple microcracks. The formation of these tiny multiple microcracks not only bring about superior mechanical properties but also significantly enhance resistance against many commonly encountered durability issues troubling reinforced concrete structures. On top of all, these tiny microcracks can close by themselves without external interference which provides unique attribute to ECCs known as autogenous self-healing. In this study, to multiply the benefits of ECC and account for some of the drawbacks of ECC production (e.g. high volumes of cement usage), main focus was placed on the development of Engineered Geopolymer Composites (EGC) with completely CDW-based matrix and the assessment of autogenous self-healing performance of EGC.

INSTRUCTIONS

Within the context of the study, several trial EGC mixtures were developed. For the development of geopolymeric paste, different proportions of wide range of CDW-based components including the wastes of hollow brick, red clay brick, roof tile, glass and concrete were mixed. This was done to simulate the acquirement of CDW-based materials from a construction and demolition site altogether as in real-life cases. As aggregates, fine portion of waste concrete was utilized after arranging their gradation and maximum grain size in order not to cause any problem related to the ductility and multiple microcracking response of EGC mixtures. As alkaline solution, combination of sodium hydroxide and sodium silicate was used.

Completely CDW-based matrices were reinforced with the combination of polyethylene and nylon fibres. The selection of the fibres was based on their stability in highly alkaline environment and reasonable ductility properties. After the production of the mixtures, they were used in the production of coupon specimens which were subjected to initial preloading under bending and resulted in visible multiple microcracking (Figure 1). These preloaded specimens were then subjected to wet/dry (W/D) cyclic conditioning for 7 and 14 days. As can be seen from Figure 2, microcracks with widths well above than 150 µm were easily healable even after very limited further curing (7 W/D cycles). Further curing even made the healing of microcracks more evident.

Figure 1: Representative views of EGC specimens and microcracks after bending test



After preloading | After 7 W/D cycles | After 14 W/D cycles

Figure 2: Representative microscopic views of EGC specimens after limited periods of further W/D curing

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