The healing touch

As Riccardo Maddalena and Diane Gardner **report, self-healing concrete represents an environmentally-friendly choice, for increasing the service life of a structure, and reducing its overall maintenance and the subsequent usage of concrete**

To tackle climate change and environmental preservation from the very root of the problem, European countries have been looking at 'green' alternatives in every sector of production and technology. Recently, the European Union has encouraged its countries to drastically decrease (and eventually ban) the usage of plastic materials (such as straws, plates and cutlery) and replace them with recycled or reusable materials. Similarly, in the last decade, interest in the carbon footprint of the built environment has been increasing, particularly with respect to Portland cement and other building materials.

A few years back, in the early 2000's, self-healing concrete was considered to be fiction rather science, until researchers proved otherwise. Then, government and policy makers started investing in this innovative infrastructure material and large self-healing research projects were initiated.

In the UK, the first self-healing research project (Materials 4 Life) was funded by EPSRC (Engineering and Physical Science Research Council) in 2013 for three years. The £1.7m project was a collaboration between Cardiff, Cambridge and Bath universities, as well as 13 industrial partners. The project led to the first trial of self-healing concrete in the UK, which was constructed on the site of the new A465 road in Wales in close collaboration with the construction company Costain.

In 2017, the EPSRC funded a new project (Resilient Materials 4 Life, RM4L) to the same consortium, with the addition of the University of Bradford. The five-year long project is the world's longest-funded project on self-healing concrete, with an overall budget of £6m and the support of 22 companies, including Costain, Highways England, HS2, the Welsh Government, and the UK Environment Agency. The project comprises four research themes, which address: self-healing of cracks at multiple scales; self-healing of time-dependent and cyclic loading damage; self-diagnosis and immunisation against physical damage; and self-diagnosis and healing of chemical damage. These themes bring together complementary technologies using laboratory experiments, numerical modelling and site trials which, under the guidance of the project's industrial partners, address a diverse range of applications such as cast in-situ and precast concrete, repair systems, overlays and geotechnical systems.

Self-healing technologies work at different scales and target different types of damages. Self-healing concrete is more generally addressed by RM4L researchers as biomimetic concrete, which mimics the human body with the capability of self-sensing, self-diagnosing and self-healing damage.

Indeed, self-healing concrete can be compared to human tissue/skin – so when a crack or damage (cut, infection, premature aging) occurs, the concrete has will sense the damage (self-sensing, nervous system), send a signal to the brain and diagnose the problem (self-diagnosing). Then the concrete will activate the healing mechanism (self-healing) in the same way that blood platelets prevent from bleeding and heal tissues' damage.

To achieve crack-healing in concrete, we use different technologies. Microcapsules, as small as half millimetre, containing a healing agent are mixed with fresh concrete. When a crack occurs, and intercepts the microcapsule, it ruptures and releases the healing agent, filling and healing the crack. Capsule-shells can be designed to be sensitive to changes in the surrounding concrete environment such that they rupture when there are adverse changes. Another system adopted by our scientists is to incorporate hollow channels (or hollow elements), that will allow the healing agent to be flushed through the concrete element when a crack occursus. These channels (or elements), called vascular networks, are manufactured from brittle plastics using 3D printing techniques.

Bacteria have also been used to heal concrete cracks. They are mixed with the concrete, along with 'nutrients'. When a crack occurs, water penetrates the concrete matrix, and revives the bacterial spores, and they will start using the calcium hydroxide present in the concrete, which subsequently precipitate calcium carbonate in the cracks. Fun fact: bacteria could found in natural building rock and stones can be dormant for hundreds of years without compromising their crack-healing capabilities with time.

Scientists have developed shape memory polymer (SMP) tendons to close cracks in concrete beams. These polymers have the ability to recover their original shape (e.g. shrink) when thermally activated. The SMP tendons are embedded in concrete beams and activated when cracks are detected. The released shrinkage force acts to close the cracks.

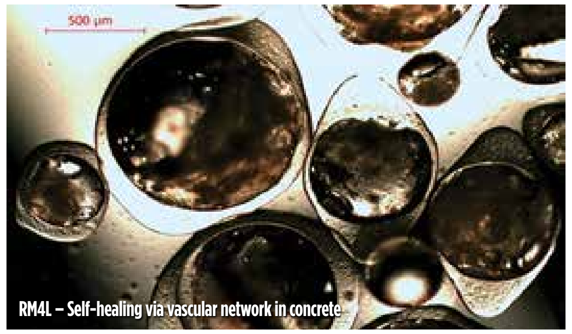
Given the exciting potential of these self-healing technologies, it is no surprise that the European Union and other international and national funding agencies have directly funded research projects on self-healing concrete, and promoted international and interdisciplinary collaborations between academia and industry.

For example, in April 2016, the EU funded a research project to develop materials and construction methods for concrete infrastructure that extended the life-span by up to 100 per cent (LORENCIS). The project, co-ordinated by SINTEF (Norway), in collaboration with nine European universities and research institutions and seven industries, with an overall budget of €7.6m is due to end in March 2020. The LORCENIS project focuses on reinforced concrete under severe operating conditions, such as bridges, dams, offshore wind farms, harbours, and concrete, developing materials with active properties (including self-healing and self-sensing technologies).

With other exciting projects having already completed and many still underway (ENDURCRETE and ReSHEALience for example) it is clear that the industry is keen to pursue the opportunities that self-healing concrete can offer. In order to keep up with the potential future demand, in June 2019 the European Union funded an international training network to train new early-career researchers in the prevention of deterioration of new concrete infrastructure by innovative, multifunctional self-healing strategies and existing concrete infrastructure by advanced repair technologies. The SMARTINCS (Self-healing Multi-functional Advanced Repair Technologies In Cementitious Systems) network will bring together the expertise of research institutes pioneering smart cementitious materials, along with leading EU companies and pre-standardisation agencies. The training network involves over 11 institution and companies of EU countries, and will run until December 2023.

The next decade looks set to be full of new research in the area of self-healing concrete, and the future of building could be changed by the results.

M4L site trial – Self-healing concrete wall in Wales, UK



RM4L – Self-healing via vascular network in concrete

RM4L – crack healed using bacteria

Concrete beam subjected to load. Details of SMP fibres inside

Dr Riccardo Maddalena is a Research Associate & RM4L Programme Manager and Dr Diane Gardner is Senior Lecturer at Cardiff University, Cardiff. The Resilient Materials 4 Life (RM4L) programme has a clear vision to transform the Nation's built environment through the provision of a sustainable and resilient infrastructure, using low carbon, adaptable and sustainable construction materials. This will have an impact on all aspects of our infrastructure.
As part of the research grant, an international conference on smart and autonomous infrastructure materials will be held in September 2020 in Cambridge (UK).

For more information, please see
https://rm4l.com