SELF-HEALING CONCRETE PRODUCTS AND TECHNOLOGY

IS IT:

- [X] *Product*
- [X] *Technology*
- [ ] *Equipment*

APPLICABLE FOR:

- [X] *Restoration*
- [X] *Rehabilitation*
- [ ] *New Construction*

APPLICABLE ON:

- [ ] *1. Foundations and underground structures*
- [X] *2. Vertical structures*
- [ ] *3. Horizontal structures and vertical connections*
- [ ] *4. Roof and terraces*
- [ ] *5. Façade and building envelope*
- [ ] *6. Finishes and completion elements*
- [ ] *7. Integrated services*
- [ ] *8. General strategies for building recovery*

Related companies: *No companies; university research; structural study.*

DESCRIPTION

Concrete will continue to be the most important building material for infrastructure, but most concrete structures are prone to cracking. Tiny cracks

on the surface of the concrete make the whole structure vulnerable because water seeps in to degrade the concrete and corrode the steel reinforcement,

greatly reducing the lifespan of a structure. Concrete can withstand compressive forces very well but not tensile forces. When it is subjected to tension it starts to crack, which is why it is reinforced with steel; to withstand the tensile forces. Structures built in a high-water environment, such as underground basements and marine structures, are particularly vulnerable to

corrosion of steel reinforcement. Motorway bridges are also vulnerable because salts used to de-ice the roads penetrate into the cracks in the structures and can accelerate the corrosion of steel reinforcement. In many

civil engineering structures tensile forces can lead to cracks, and these can occur relatively soon after the structure is built. Repair of conventional concrete structures usually involves applying a concrete mortar which is bonded to the damaged surface. Sometimes, the mortar needs to be keyed

into the existing structure with metal pins to ensure that it does not fall away. Repairs can be particularly time consuming and expensive because it is often very difficult to gain access to the structure to make repairs, especially if they are underground or at a great height.

WHY TO USE

Self-healing concrete could solve the problem of concrete structures deteriorating well before the end of their service life.

HOW TO USE AND APPLY

Self-healing concrete is a product that will biologically produce limestone to heal cracks that appear on the surface of concrete structures. Specially selected types of the bacteria genus Bacillus, along with a calcium-based nutrient known as calcium lactate, and nitrogen and phosphorus, are added to the ingredients of the concrete when it is being mixed. These self-healing agents can lie dormant within the concrete for up to 200 years.

However, when a concrete structure is damaged and water starts to seep through the cracks that appear in the concrete, the spores of the bacteria germinate on contact with the water and nutrients. Having been activated, the bacteria start to feed on the calcium lactate. As the bacteria feeds oxygen is consumed and the soluble calcium lactate is converted to insoluble limestone. The limestone solidifies on the cracked surface, thereby sealing it up. It mimics the process by which bone fractures in the human body are naturally healed by osteoblast cells that mineralize to re-form the bone.

The consumption of oxygen during the bacterial conversion of calcium lactate to limestone has an additional advantage. Oxygen is an essential element in the process of corrosion of steel and when the bacterial activity has consumed it all it increases the durability of steel reinforced concrete constructions.

The two self-healing agent parts (the bacterial spores and the calcium lactate-based nutrients) are introduced to the concrete within separate expanded clay pellets 2-4mm wide, which ensure that the agents will not be activated during the cement-mixing process. Only when cracks open up the pellets and incoming water brings the calcium lactate into contact with the bacteria do these become activated. Testing has shown that when water seeps into the concrete, the bacteria germinate and multiply quickly. They convert the nutrients into limestone within seven days in the laboratory. Outside, in lower temperatures, the process takes several weeks.

TECHNICAL CHARACTERISTICS

The starting point of the research was to find bacteria capable of surviving in an extreme alkaline environment. Cement and water have a pH value of up to 13 when mixed together, usually a hostile environment for life: most organisms die in an environment with a pH value of 10 or above.

The search concentrated on microbes that thrive in alkaline environments which can be found in natural environments, such as alkali lakes in Russia, carbonate-rich soils in desert areas of Spain and soda lakes in Egypt. Samples of endolithic bacteria (bacteria that can live inside stones) were collected along with bacteria found in sediments in the lakes. Strains of the bacteria genus Bacillus were found to thrive in this high-alkaline environment. Back at Delft University the bacteria from the samples were grown in a flask of water that would then be used as the part of the water mix for the concrete.

Different types of bacteria were incorporated into a small block of concrete. Each concrete block would be left for two months to set hard. Then the block would be pulverized, and the remains tested to see whether the bacteria had survived.

It was found that the only group of bacteria that were able to survive were the ones that produced spores comparable to plant seeds. Such spores have extremely thick cell walls that enable them to remain intact for up to 200 years while waiting for a better environment to germinate.

They would become activated when the concrete starts to crack, food is available, and water seeps into the structure. This process lowers the pH of the highly alkaline concrete to values in the range (pH 10 to 11.5) where the bacterial spores become activated.

Finding a suitable food source for the bacteria that could survive in the concrete took a long time and many different nutrients were tried until it was discovered that calcium lactate was a carbon source that provides biomass. If it starts to dissolve during the mixing process, calcium lactate does not interfere with the setting time of the concrete.

RECOMMENDATIONS AND OTHER INFORMATION

There are two key obstacles that need to be overcome if self-healing concrete is to transform concrete construction in the next decade.

The first issue is that the clay pellets holding the self-healing agent comprise 20% of the volume of the concrete. That 20% would normally comprise harder aggregate such as gravel. The clay is much

weaker than normal aggregate and this weakens the concrete by 25% and significantly reduces its compressive strength. In many structures this would not be a problem but in specialized applications

where higher compressive strength is needed, such as in high-rise buildings, it will not be viable.

The second disadvantage is the cost of self-healing concrete is about double that of conventional concrete, which is presently about €80 euros per cubic meter.

Jonkers says: "At around €160 per cubic meter, self-healing concrete would only be a viable product for certain civil engineering structures where the cost of concrete is much higher on account of being much higher quality, for example tunnel linings and marine structures where safety is a big factor – or in structures where there is limited access available for repair and maintenance. In these cases, the increase in cost by introducing the self-healing agents should not be too onerous."

Added to this, if produced on an industrial scale it is thought that the self-healing concrete could come down in cost considerably.

If the life of the structure can be extended by 30%, the doubling in the cost of the actual concrete would still save a lot of money in the longer term. The Delft team is currently working on the development of an improved and more economic version of the bacteria-based healing agent which is expected to raise concrete costs only by a few euros.

EXAMPLES

The ancient Romans already developed a self-healing concrete. Some of their concrete structures survive until this day, most famously of course the Pantheon. And piers, objects that nowadays are infamous for concrete degradation under the influence of sea water. That these Roman structures still exist is a 2,000-year achievement that will not easily be met by modern-day structures. The secret seems to be a 'pozzolanic' reaction of the material with intrusive water that takes place after construction and produces calcium/aluminum silicate crystals that fill voids and cracks.

REFERENCES / SOURCES AND LITERATURE

https://www.biobasedpress.eu/2018/02/self-healing-concrete/

V. Wiktor, H.M. Jonkers. Quantification of crack-healing in novel bacteria-based self-healing concrete. Cem. Concr. Compos., 33 (2011), pp. 763-770, 10.1016/j.cemconcomp.2011.03.012

WEBSITE OF THE COMPANY

N/A

IMAGES AND CAPTIONS

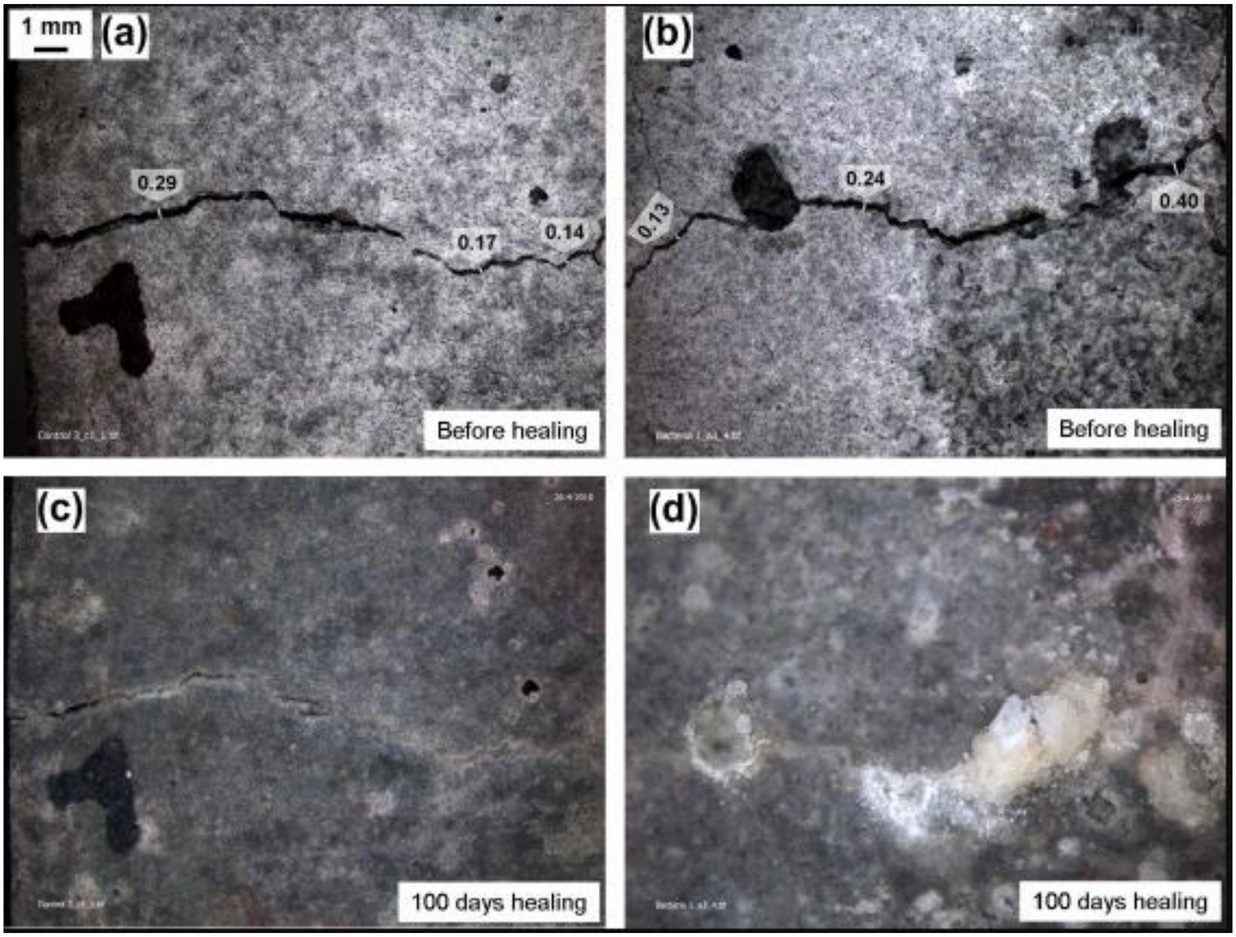
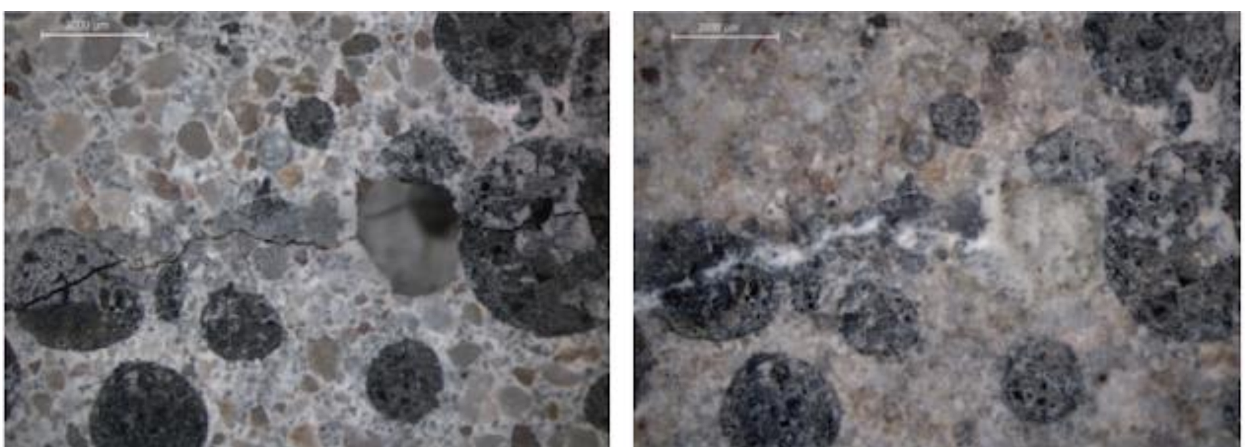


Fig.1: Stereomicroscopic images of crack-healing process in control mortar specimen before (a) and after 100 days healing (c), in bio-chemical agent-based specimen before (b) and after 100 days healing (d). *©V. Wiktor, H.M. Jonkers*



Before-and-after pictures of the surface of a slab of self-healing concrete. The crack is visible in the left-hand image and on the right, the white limestone has filled up the gap

Fig.2: Production of calcium carbonate in crack. *© https://sites.duke.edu/hayliemoore/files/2019/08/EPHY-450-Report.docx.pdf*

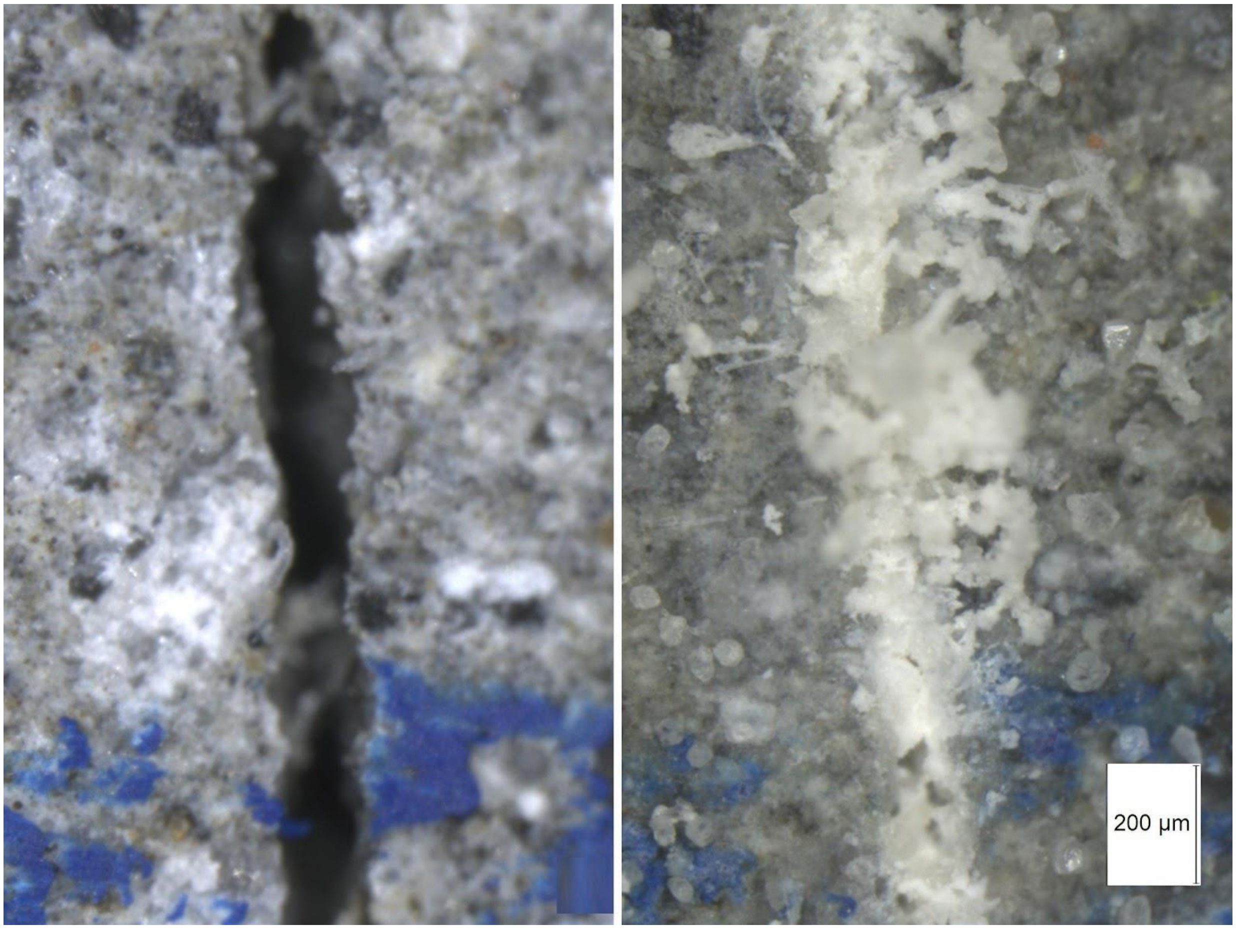


Fig.3: By adding a slight excess of calcium hydroxide to the concrete, it may perform autogenous repair in small cracks.
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