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# Self-healing concrete: Current and potential future technologies.

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Concrete is the most used building material internationally, in spite of its limited lifespan. There are various deterioration mechanisms that reduce the life of this important material and many researchers have investigated different ways to extend the life of concrete buildings and infrastructure. One recent option for prolonging the life of concrete is self-healing concrete which has been investigated for a number of years. Different types of self-healing concretes have been investigated and this paper presents some performance results and areas where additional research is needed.

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## 1 Introduction

Civil engineering structures are designed so that elements were able to have sufficient load bearing capacity and durability to withstand design loading and environmental conditions. Because of its high compressive strength and low tensile strength, cracking is a common feature in reinforced concrete and does not necessarily indicate a deficiency in a structure, but it can bring about premature failure through other means. Failure is often through cracking causing premature corrosion of reinforcement or other

mechanisms. Different reinforced concrete defect types and their typical time to appearance are presented in Table 1. As shown in Table 1, the majority of defects are either direct cracking, or other forms of defects which are linked to cracking (e.g, freeze-thaw damage and damage due to structural loading or temperature movements).

Self-healing is one option to extend the life of concrete structures and this is based on replicating the human body in its response to self-healing a cut or other wound.

*Table 1: Defect types (after Fookes. and Collis, 1976)*

Type of defect	Typical time to appearance
Plastic settlement cracks	10 mins – 3 hrs
Plastic shrinkage cracks	30 mins – 6 hrs
Construction defects	On removal of formwork
Crazing	1-7 days – sometimes much later
Early thermal contraction cracks	1 day – 3 weeks
Long-term drying shrinkage cracks	Several weeks or months
Chemical attack (including sulfate attack)	Few months to years, depending on materials
Freeze-thaw damage	After first severe winter
Damage due to structural loading	Probably several months or later
Damage due to temperature movements (seasonal)	Probably up to a year, but possibly longer
Materials related	Several years
Reinforcement corrosion	Several years, but may be sooner

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## 2 Types of self-healing

As shown in Table 1, the timespan for self-healing must cover the range of defect times, although if some early-age defects are “healed” (e.g. plastic shrinkage cracks), they may limit later defects (e.g. reinforcement corrosion).

The size of cracks is also key to self-healing and the damage rating of concrete and links to crack widths and other damage severity is presented in Table 2. It is not intended that self-healing will be successful for larger defects (e.g. large spalled areas) and will instead focus on smaller cracks which will then prevent larger damaged areas from forming.

A recent RILEM technical committee report into self-healing identified the following main categories of self-healing (RILEM, 2013):

1. Autogenous self-healing where “the recovery process uses materials components that could also be present when not specifically designed for self-healing (own generic materials).” There is some confusion over how wide a crack this is effective for, but autogenous healing is likely to be less effective for cracks over 0.25 mm.
2. Autonomic self-healing where “the recovery

process uses materials components that would otherwise not be found in the material (engineered additions).” This could be used for larger cracks and is the area where most research is now concentrated.

## 3 Autonomic self-healing

The Universities of Bath, Cardiff and Cambridge are currently collaborating on the development of self-healing systems for concrete, focused on different technologies:

1. Microcapsules for cargo delivery. For this form of self-healing, various cargos (e.g. sodium silicate) are encapsulated in a shell which ruptures when a crack forms. The cargo is then released, sealing the crack (Figure 1).
2. Microbially induced calcite precipitation which uses bacterial spores and a medium containing nutrients and a soluble calcium precursor in different coated perlite capsules. When a crack forms, the bacteria spores germinate to form bacteria and convert the soluble precursor into insoluble calcite, sealing the crack as shown in Figure 2.

Table 2: Defect types (after RILEM, 1991)

Damage	Damage rating				
	1 (very slight)	2 (slight)	3 (moderate)	4 (severe)	5 (very severe)
Cracks in prestressed concrete due to overloading	Width <0.05mm	Width 0.05-0.1 mm	Width 0.1-0.3mm	Width 0.3-1mm	Width 1-3mm with some spalling
Cracks in reinforced concrete due to overloading	Width <0.1 mm	Width 0.1-0.3mm	Width 0.3-1mm	Width 1-3mm with some spalling	Width >5mm with widespread spalling
Cracks in unreinforced concrete	Width <1 mm	Width 1-10mm	Width 10-20mm	Width 20-25mm	Width >25mm with spalling
Shrinkage or settlement cracks	Single small crack	Several small cracks	Many small cracks	Few large cracks	Many large cracks
Effects of reinforcement corrosion	Barely noticeable	Light rust stains	Heavy rust stains	Heavy rust stains and cracking along line of bars	Heavy rust stains and spalling along line of bars
Pop-outs	Barely noticeable	Noticeable	Holes up to 10mm in diameter	Holes 10 - 50mm in diameter	Holes >50mm in diameter
Spalling	Barely noticeable	Clearly noticeable	Larger than coarse aggregate	Areas up to 150mm across	Areas larger than 150mm

3. Inserting shape memory polymers in the concrete which can contract with a stimulus applied (current applied to heating element around them), and these then contract closing a crack (large vertical elements in Figure 3)
4. A vascular system of plastic tubes in the concrete, mimicking the veins in a human body. These are cast in concrete and removed, leaving a network through which healing agents are pumped (diagonal elements in Figure 3). If there is a crack, healing agents flow from the network into the crack, sealing it.



Figure 3: Shape memory polymers inserted at the base of a concrete wall (large vertical elements) and vascular network of tubes (diagonal elements) which will be removed after casting

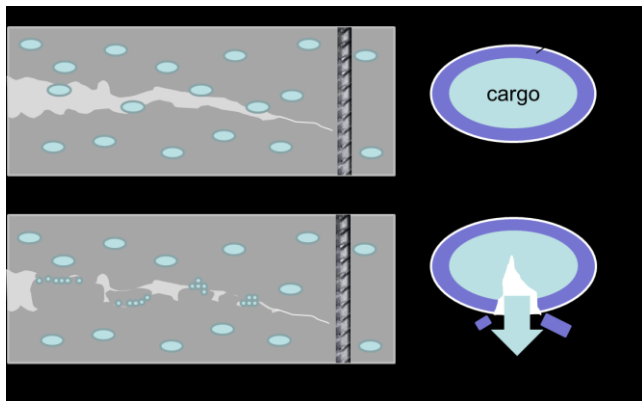


Figure 1: Embedded microcapsules. When a crack forms (top), the cargo is released sealing the crack (bottom).

#### 4 Site trials

Site trial were constructed with different vertical cantilever walls, with the reinforcement pattern in Figure 3. A finished wall is shown in Figure 4. In this the concrete contains perlite impregnated with bacteria and nutrients in separate capsules, covered with sodium silicate and cement paste.

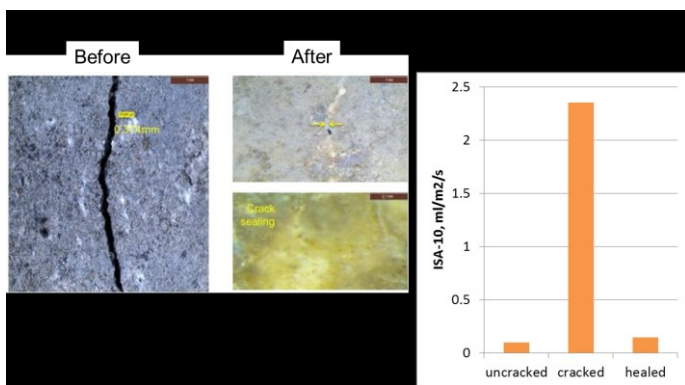


Figure 2: MICP healing of concrete showing visual crack closure and the effect on initial surface absorption.



Figure 4: Finished wall with bacterial self-healing agents.

The walls were then loaded at the top to induce a nominal 0.5 mm crack at the bottom of the wall

(moderate structural cracking from Tables 1 and 2) and the healing of the walls is being monitored. As temperatures have been cold (generally below 15°C) since construction in late 2015, it is not anticipated that there will be MICP self-healing until the warmer UK months of July/August 2016 as this works best at temperatures around 30°C.

## 5 Further research

While there has been research on self-healing concrete for a few years, the site trials described here are the first where there have been different self-healing agents mixed with concrete.

At this point, the cost-benefit and long term performance of the systems need to be evaluated, but this is difficult as all material and bacteria production has been on a laboratory scale and scaled up costs are difficult to predict. It is likely that self-healing concrete will be used for situations where repair is very difficult, expensive or unsafe (such as for high bridges).

Further research is needed into different aspects, including repeatability of healing, healing under cyclical loading (e.g. for concrete roads or rail) and how the healing agents perform against chemical attack. Some work has been conducted on the healing agents to confirm that they do not have a detrimental effect on the concrete.

## 6 Conclusions

This paper has presented some initial research into self-healing concrete and shown that different types of self-healing concretes are possible, but extensive research is needed for these innovative construction products to be used with confidence by a conservative construction industry.

## 7 Acknowledgements

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