Integrating Self-Sensing in Self-Healing Concrete: Towards a Biomimetic Approach to Repair

Kevin Paine¹, Bianca Reeksting², Hussameldin Taha¹ and Susanne Gebhard²

¹ BRE Centre for Innovative Construction Materials, University of Bath, United Kingdom, k.paine@bath.ac.uk; h.m.taha.abdalgadir@bath.ac.uk
² Department of Biology and Biochemistry, University of Bath, United Kingdom, b.j.reeksting@bath.ac.uk; s.gebhard@bath.ac.uk

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1 Introduction and Concept

Material degradation of our civil infrastructure is inevitable, and regular maintenance is required to mitigate against failure during the service-life. However, understanding and knowledge of composites is now leading to the creation of concretes with autonomic self-healing capabilities. This development will transform our infrastructure by embedding self-immunity and resilience so that structures evolve over their lifespan enhancing durability and serviceability, improving safety and reducing maintenance costs.

This paper reports on current research being undertaken within RM4L by the University of Bath in the areas of bacteria-based self-healing concrete (BBSHC) and self-sensing concrete, and a proposal to integrate them into a smart biomimetic self-healing concrete.

Bacteria-based self-healing is achieved by embedding encapsulated bacterial spores within the concrete and providing them with the nutrients that they need to grow. Whilst the bacteria are in their spore form, they are inactive. However, when conditions become favourable, they germinate into active cells and these multiply. These more favourable conditions occur when a crack forms in the concrete and water and oxygen ingress. The presence of bacteria near a crack will aid the formation of calcium carbonate should the local environment be rich in dissolved inorganic carbon (DIC) and Ca²⁺ ions (Reeksting et al., 2020).

Whilst the encapsulation of bacteria and nutrients in concrete has proven successful in providing crack closure and a recovery of water tightness there are some elements of this technique that could still be improved upon. For example, encapsulation means that the quantities are fixed, limiting bacterial growth and calcium carbonate precipitated. Furthermore, the healing and bacterial growth itself limits the availability of oxygen.

Consequently, it has been considered that there may be some benefit in providing a vascular flow network (VFN) to supply oxygen and nutrients to the crack when healing is required. VFN systems more readily simulate the way flora and fauna heal themselves and permit a wide range of healing agents or supplies to be pumped to the site of damage as and when required. The reservoir of healing agent can be topped up allowing for multiple healing events.

However, a problem with a VFN is that the release of the healing agents is not initiated by the cracking of the concrete. Consequently, research has been investigating the suitability of self-sensing systems that may detect and diagnose the formation of cracks, and their repair, and trigger VFN systems (Taha et al., 2019). For example, it was shown that localized damage in
mortar beams, can be detected by a surface mounted PZT sensor located up to 220 mm away from where the damage has occurred. As damage increased the difference between the initial admittance signature and subsequent signatures increased. Furthermore, upon repair a recovery of properties was detected in the sensor response.

2 Integration of Technologies

Consequently, it is proposed that these three technologies: (i) bacteria-mediated calcium carbonate precipitation, (ii) vascular flow networks (VFN) and (iii) self-sensing could be integrated to form a smart biomimetic self-healing concrete (Figure 1). BBSHC is cast around an embedded VFN, with PZT sensors strategically placed within or on the surface of the concrete. When a crack occurs the bacterial activity precipitates calcium carbonate. Simultaneously, a sensor detects whether the degree of healing is sufficient. If not, it triggers release of oxygen and/or further growth media through the VFN. This could deliver long-term maintenance and repair of concrete buildings and structures without the need for human intervention.

Figure 1. Integration of BBSHC, VFN and sensing technologies for biomimetic smart self-healing concrete.

ORCID

Kevin Paine: http://orcid.org/0000-0001-7455-7002
Bianca Reeksting: https://orcid.org/0000-0003-1219-9574
Hussameldin Taha: https://orcid.org/0000-0002-6167-7598
Susanne Gebhard: http://orcid.org/0000-0003-4783-6115

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