Bacteria-based Self-healing Concrete in Cold Climates

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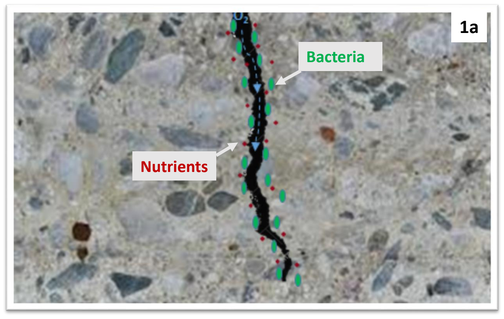
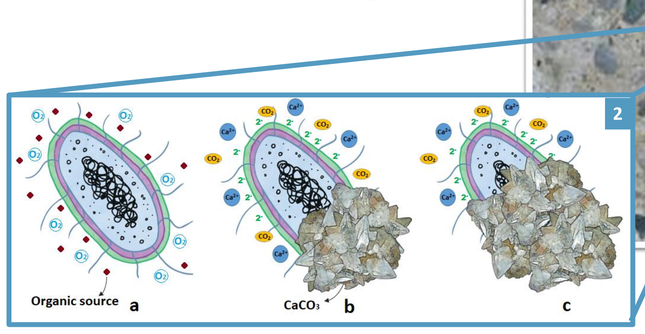
Concept

Maintenance and repair of concrete structures account for approximately 34% of the total budget in the UK construction industry. Dealing with the problem of cracking in concrete is, therefore, crucial.

Bacteria have the ability to precipitate calcium carbonate in the form of calcite, $CaCO_3$, through their metabolic activities, which act as a sealant for cracks as shown in Fig. 1a and 1b.

Certain bacteria promote the oxidation of organic compounds, provided to them as a nutrient source (Fig. 2a). The oxidation leads to the production of $CaCO_3$ and CO_2 (Fig. 2b). The negatively charged bacterial cell wall attracts calcium cations, Ca^{+2}, which react with the CO_2, resulting in more calcite precipitated around the bacteria (Fig. 2c).



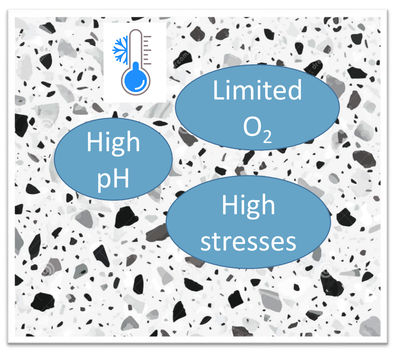


Aim of the project

Extend the use of the bacteria-based self-healing concrete (BBSHC) in cold and temperate climates.

Challenges

- Protection of the bacteria inside the concrete matrix
- Access of bacteria to nutrients and oxygen
- Preservation/improvement of the concrete's strength properties.



Initial Findings

Influence of bacteria cells and nutrients on the properties of concrete.

Isothermal calorimetry was used for studying the hydration rate of cement pastes containing 1% (per cement dry mass) of various organic nutrients (Fig. 3a). The hydration of cement pastes with live and dead bacteria cells (named as BC and DBC, respectively in Fig. 3b) of the B. Cohnii type in different concentrations (10^5, 10^7, 10^9) was also examined. In both cases, control samples, without nutrients or bacteria, were used as points of reference.

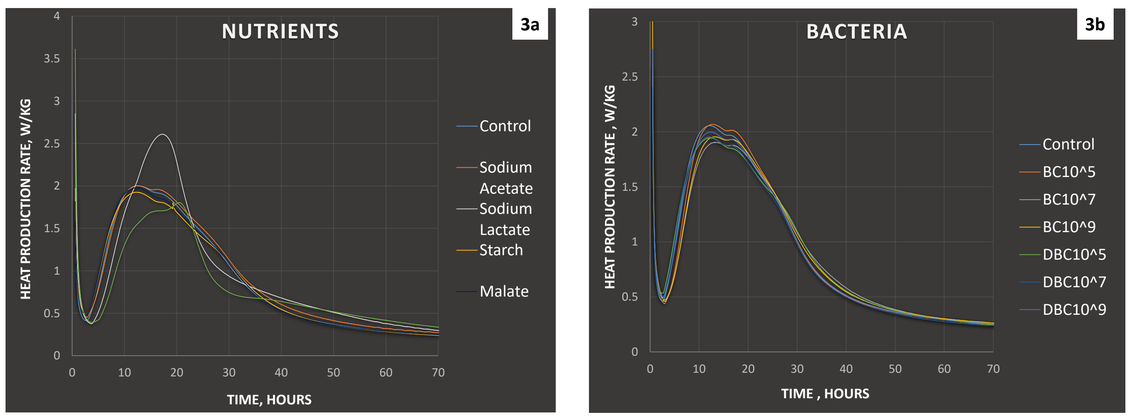


Fig. 3: Heat of hydration for cement pastes containing nutrients (left) and bacteria (right).

As shown in Fig. 3a, sodium acetate, starch and malate are promising candidates as nutrients since they do not affect the hydration of cement significantly. The same applies to the bacteria cells, live and dead (Fig. 3b).

Mortar samples with bacteria at the previously mentioned concentrations were made and tested under compression. Compressive strength was notably improved for most of the samples containing bacteria, especially for the ones with dead cells (Fig. 4). The sample with dead cells at a concentration of 10^5 cells/ml, DBC10^5, had the highest strength, even at 28 days.

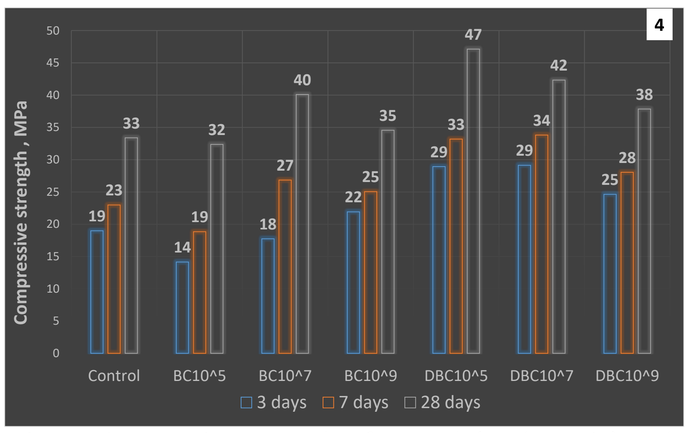


Fig. 4: Compressive strength of control (no bacteria) and bacterial mortar (BC for live and DBC for dead cells) in different concentrations (10^5, 10^7, 10^9 cells/ml) at 3, 7 and 28 days.

Scanning Electron Microscopy (SEM) images of the control and DBC10^5 sample (Fig. 5 and 6, respectively) show a denser and more cohesive surface of the latter, which explains its higher strength. The high magnification images show ettringite (AFt) needles in the control sample (Fig. 5b) and monosulfate (AFm) in the bacterial sample (Fig. 6b).

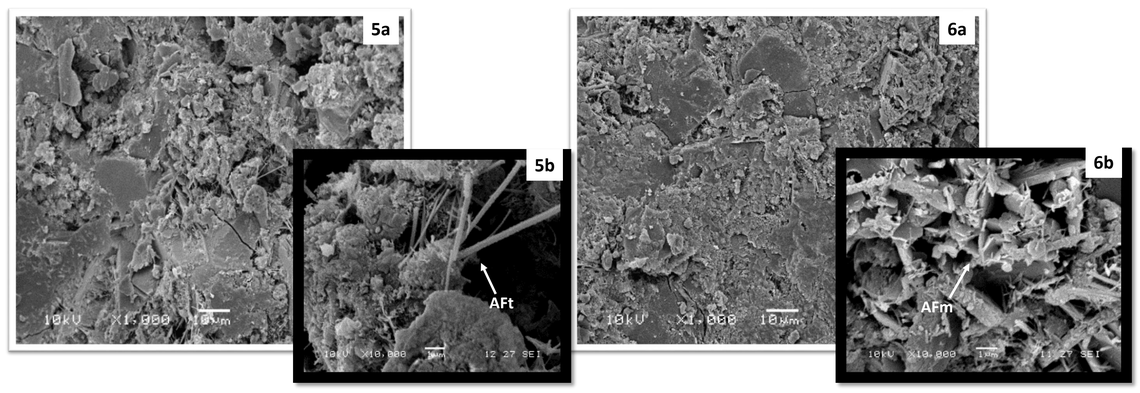


Fig. 5, 6. SEM images of the control (5a,b) and the bacterial DBC10^5 (6a,b) sample at 7 days in two magnifications: x10^3 (5a, 6a) and x10^4 (5b,6b) .

Thermogravimetric analysis (TGA), shown in Fig. 7, showed that the control and the bacterial sample have similar calcite content. This means that the strengths are not improved due to calcite formation by the bacteria. A different mechanism related to their surface properties and composition seems to be a possible explanation.

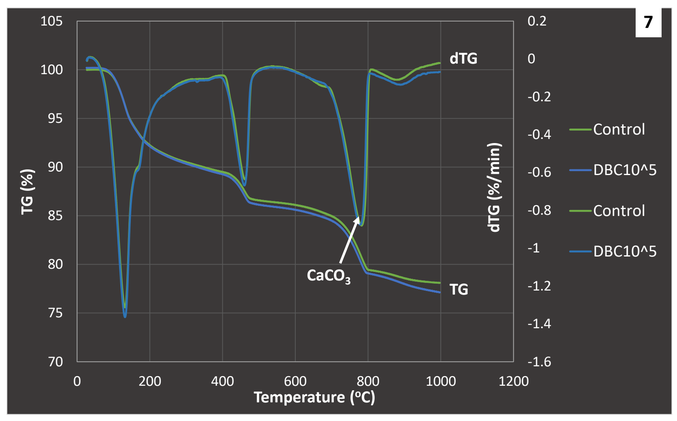


Fig. 7. TG and dTG curves of the control and the bacterial DBC10^5 sample at 7 days.

Future steps

Protocol

- Establish a protocol on the self-healing procedure (curing conditions, cracking, healing evaluation) using B. Cohnii in room (20 °C) and low (10 °C) temperature.

Self-healing

- Examine the self-healing ability of different bacteria types (cryophilics) in the above-mentioned temperatures. Test alternative nutrients and importation methods for the bacteria.

Combination

- Combine different types of bacteria for achieving self-healing in a wide range of temperatures. Attempt repetitive healing.

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