BioConcrete: A novel bio-based material

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2010 EU-US Frontiers of Engineering Symposium, 1-3 Sept 2010
Outline:

• Introduction: Sustainability in Civil Engineering
• Self-healing materials research program
• Bio-based Geo- Civil- Engineering research program
• Example: Bio-based self-healing concrete
Civil engineering highlights
Comes however at a price...

- 8% of human CO₂ emission due to cement production
- Raw materials consumption
- Landscape mutilation
Comes however at a price...

# 8 % of human CO$_2$ emission due to cement production

# Raw materials consumption

# Landscape mutilation

True innovation required!
Sustainable solutions:

1. Shift from non-renewable to renewable resource use
   (Mimic Nature: full material cycling)

2. Change material characteristics:
   Less maintenance / repair, longer service life
   (Mimic Nature: Self-healing mechanisms)

Two Delft University of Technology research programs:

1. Bio-based Geo- and Civil Engineering (BioGeoCivil)
2. Development of Self-healing materials (DCMat)
1. The BioGeoCivil Program:

Develop **bio-based technology** which enables us to **reduce** the amount of **resources** consumed by geo & civil engineering

**Examples:**

- **Bio-concrete**
- **Bio-grout**
- **Living walls**
- **Wood fiber concrete**
2. The Self-healing Materials Program

Delft Centre for materials (DCMat) established in 2004:

Central research theme: Development of Self-healing materials

A consortium of 22 TU Delft research groups

Lessons from Nature: Skin / Bone-healing

2005 / 2006: Start of 7 innovative projects; 2010: > 40 research projects

Self-healing capacity of:

- Concrete
- Aluminum alloys
- (Plastic) polymers
- Composite materials
Example of both programs:

Development of Bacteria-based Self-healing Concrete

Bio-concrete

Introduce self-healing mechanism particularly to constructions which are very liable to damage:
Problems with concrete:

Crack formation / porosity

1. Loss of strength
2. Ingress of aggressive chemicals
   → Degradation of concrete matrix
   → Risk of reinforcement corrosion

Acid sulfate soils
Spalling, e.g. freeze/thaw cycles
Ettringite formation / sulfate

Strength loss
Problems with concrete:

Crack formation / porosity

3. Leakage problems

→ Repair / maintenance needed!
Manual inspection and repair

- Time consuming / costly
- Traffic delay / high additional costs!
- Not always possible (accessibility)
Mechanisms for self-healing: Bacteria

Development of SH bacterial concrete to prevent leakage and reinforcement corrosion
DCMat & SHM8704

H.M. Jonkers & V. Wiktor

Principal: Concrete incorporated viable bacteria convert precursor chemical (‘bacterial ‘food’) to bio-minerals (crack-filling material)

Bacteria as self-healing agent:

Bio-mineral production: reduces permeability
The bacteria: ‘Concrete-compatible’

Endolithic communities

Spore-forming bacteria

1. > 50 years viable

2. Concrete compatible

Playa, rock

Soda-lake communities

Wadi Natrun, Egypt  pH ~ 10

Alkali-resistant

Endospore
Two-component self-healing agent:

1. Bacteria (catalyst)
2. Mineral precursor compound (chemical / 'food')

→ Packing of agents in porous aggregates

Reservoir for healing agents (bacteria + chemicals)
Concrete composition

Self-healing concrete:

Replace (fraction of) aggregate material for SH aggregates

Volumetric

Paste → Aggregate

→ Aggregate

W/C ratio (weight) 0.5

18% 50%
Healing mechanism:

Bacteria-based specimens:

\[ 2 \text{Ca}(\text{CHO}_2)_2 + 2 \text{O}_2 \rightarrow 2 \text{CaCO}_3 + 2 \text{CO}_2 + 2 \text{H}_2\text{O} \]

(Copious and fast \(\text{CaCO}_3\) production on crack surface)

(Increased calcite production from concrete matrix Portlandite:)

\(\text{Ca(OH)}_2\)

Copious and fast \(\text{CaCO}_3\) production on crack surface
Procedure permeability testing

- Expanded clay balls + bacteria + food
- Concrete cylinder: cut in slabs
- Specimens with varying healing agent proportions
- Controlled slab-cracking
Procedure permeability testing

Glue in ring

To permeability setup

Automated permeability determination
Results permeability testing

Control specimens

A Before healing 20 x After healing

B Before healing 40 x After healing

Precipitate: No crack-sealing

0.15 mm crack width
Results permeability testing

Bacterial specimens

A Before healing 20 x After healing

B Before healing 40 x After healing

Perfect Crack-sealing

0.15 mm crack width
Results permeability testing

Bacterial concrete (bacteria, food)

Before 0.15 mm crack width After
Results permeability testing

Control specimens after healing

Permeability at 0.51 bar (ml/h)

- 0
- 0 - 0.2
- 0.2 - 2
- > 2

33% Healed

Bacterial specimens after healing

Permeability at 0.51 bar (ml/h)

- 0
- 0 - 0.2
- 0.2 - 2
- > 2

100% Healed
Conclusions

Bacteria-based self-healing concrete

1. High crack-sealing capacity

2. Healing agent bio-based = ‘Sustainable’

Applications:

Crack sealing / water proofing

Potential:

Porosity decrease: improved durability
Limits to self-healing?