Road Pavement Forum 2019

Pretoria

Self-Healing Materials

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Introduction

Research & Development: Self-Healing Materials

- Strategic objectives of Transport Infrastructure Engineering unit
  - Provide practical, innovative and cost-effective R&D based solutions that address the current and future pavement infrastructure needs of the country
- Overall strategic objectives of the Smart Logistics & Infrastructure cluster (Built Environment unit):
  - Key Initiatives: (a) Smart infrastructure and (b) Industrialisation of the construction process

Self-Healing Materials: Research Objective & Impact

1. Research Objective

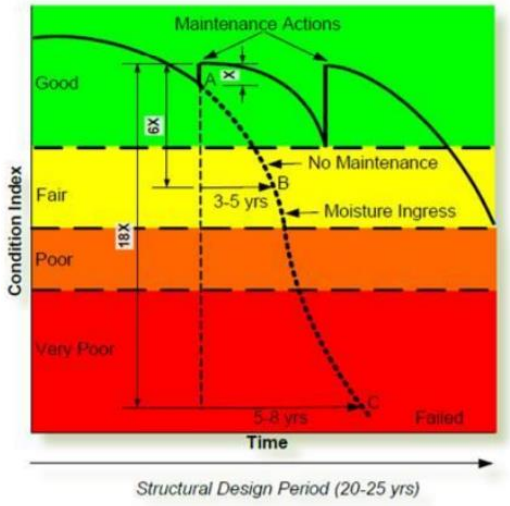
Self-healing pavement system capable of identifying and repairing damage:

- **Automatic initiated response** to damage or failure
- **Reduce** level of damage and **extend** or **renew** functionality and lifetime of pavement

2. Impact

- Significant **economic**, social and environmental benefits

Cost per Kilometre (km): Repair and Reseal of Provincial Roads		
14 mm cape seal + 1 slurry	14 mm + 7 mm double seal	UTRCP
R 1 100 000	**R 1 150 000**	**R 1 500 000**

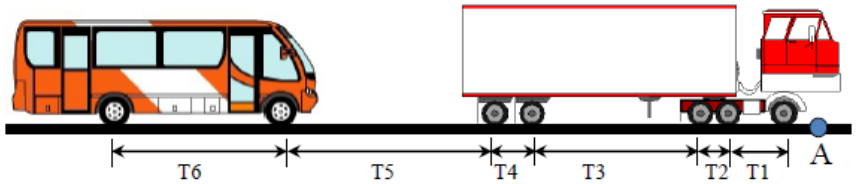


Self-Healing Materials in Focus

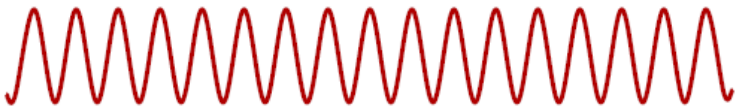
1. **Self-healing asphalt**
   - Advanced heating technology
   - Rejuvenator encapsulation
   - Nanofillers
2. **Self-healing concrete**
   - Bioconcrete
   - Nano materials

Self-Healing Asphalt Pavements

Current Research: Autonomous Self-Healing Properties of Asphalt



Rest times between vehicle axles



Test without rest times

Mechanism

1. Stress relaxation (time-dependant) in viscoelastic material
2. Chemical healing across micro crack surfaces – wetting & diffusion

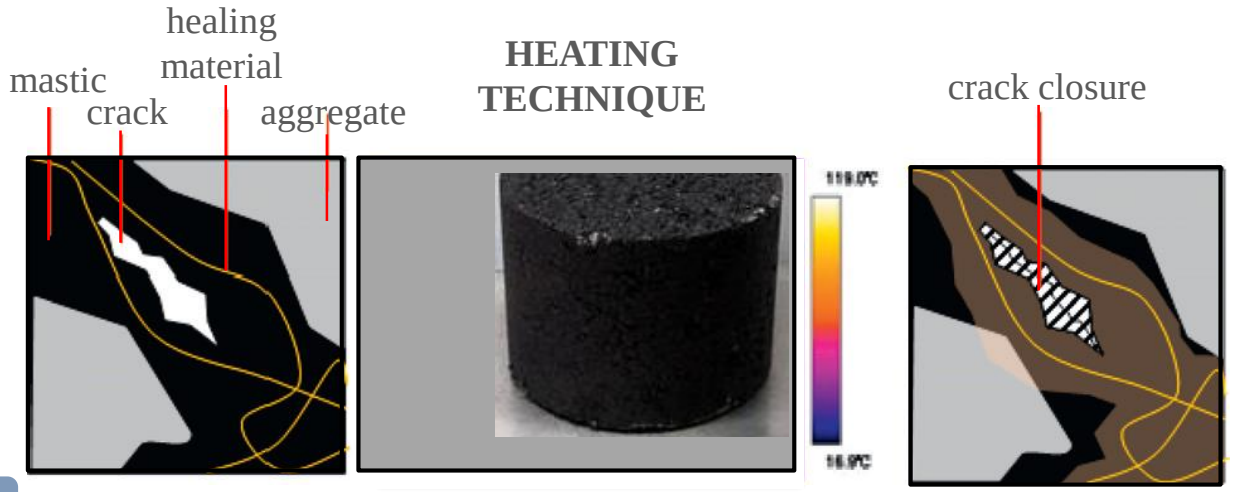
- Advantage: recovery of stiffness and strength, increased fatigue life
- Disadvantage: Healing is slow at ambient temperature

Self-Healing Asphalt Pavements

Current Research: Enhancement of autonomous healing properties through **heating** the asphalt material containing appropriate **healing agents**

- → **TYPE**
- → **SIZE**
- → **SHAPE**

Heating Mechanism



Chemical healing:

- Capillary flow
- Diffusion

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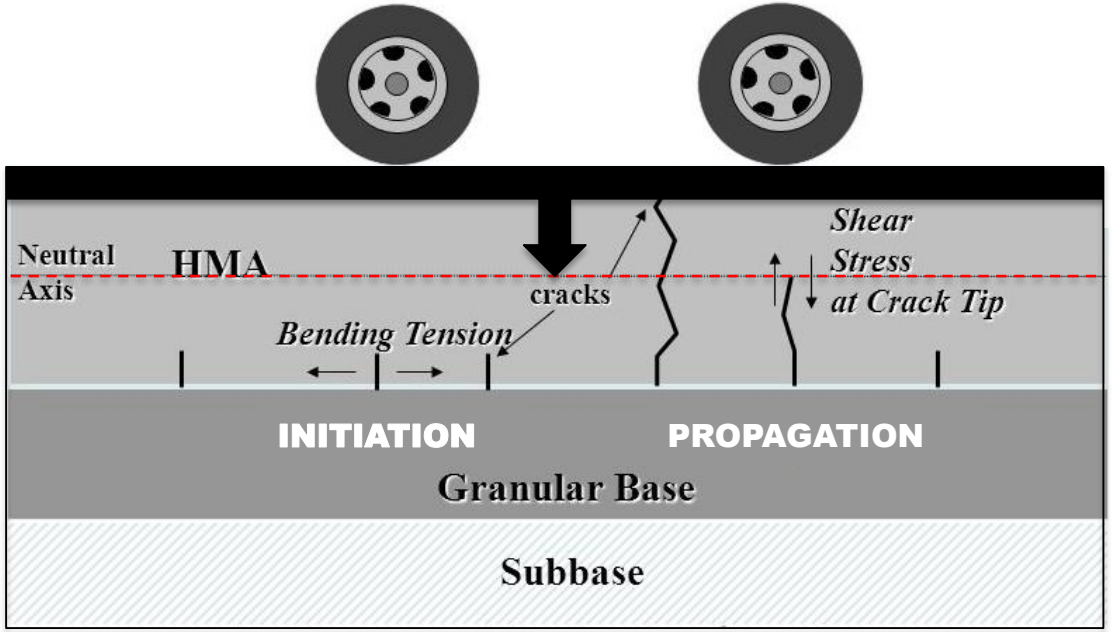
Self-Healing Asphalt Pavements

Futuristic Approach

- Self-healing process is still in its early stage of development and demonstration of its full potential is currently underway:
  - Ideal healing agent for optimal healing efficiency
  - Optimal heating temperature
  - Optimal heating speed
  - Initiation point of heating
  - Multiple heating approach in combination with binder rejuvenation

Binder Rejuvenation

Conventional Surface Course Rejuvenation



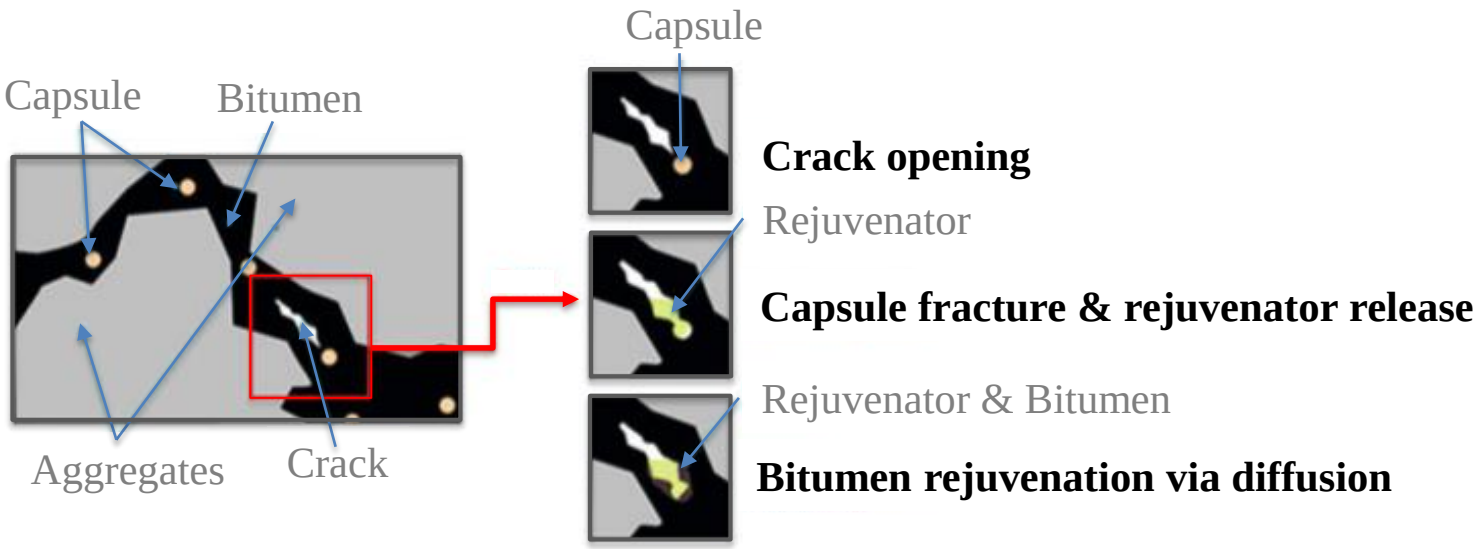
± 20 mm penetration

Onsite Construction:

- Traffic restrictions/ road closures
- Increased CO_2 emissions
- Reduced surface friction

Rejuvenator Encapsulation

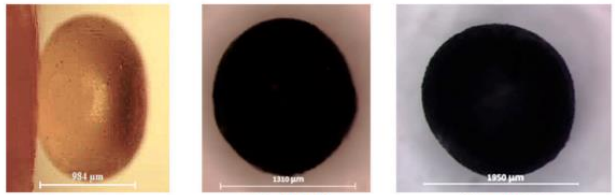
Self-Healing Mechanism



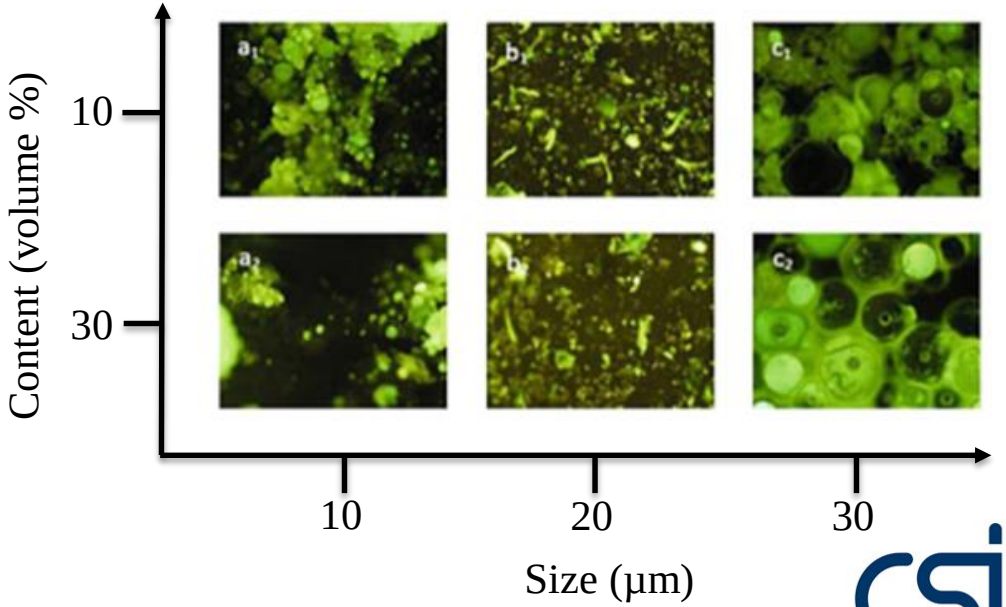
Rejuvenator Encapsulation

Current Research: Thermal and Mechanical Stability

1. Capsule size and content



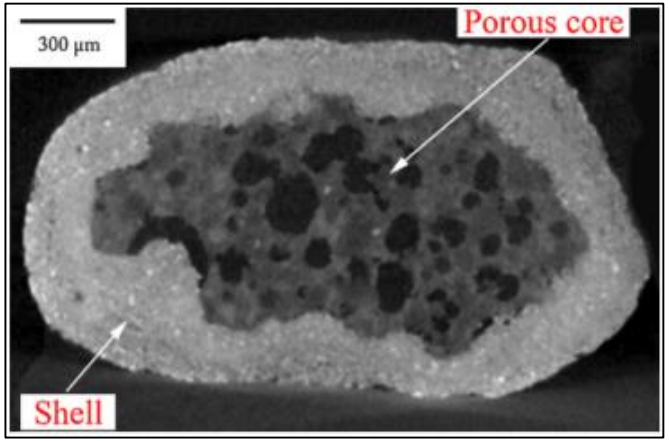
- congregate/attract
- homogeneously distributed
- wider dispersion



Rejuvenator Encapsulation

2. Capsule strength

Engineer the material with **different threshold values for breakage**: design time of breakage such that not all the chemicals are released at the same time.



Max. resistance of capsule > maximum stress caused by vehicle passing post construction

→

AGEING PROCESS

→

Higher traffic induced load stresses on capsule

→

Continuous loading cycles results in rupture of capsule and release of rejuvenator

Rejuvenator Encapsulation

Current Approach

- Advantage: Rejuvenation of aged binder
- Disadvantage: Once-off mechanism i.e. Capsule cannot be replenished upon release of healing material

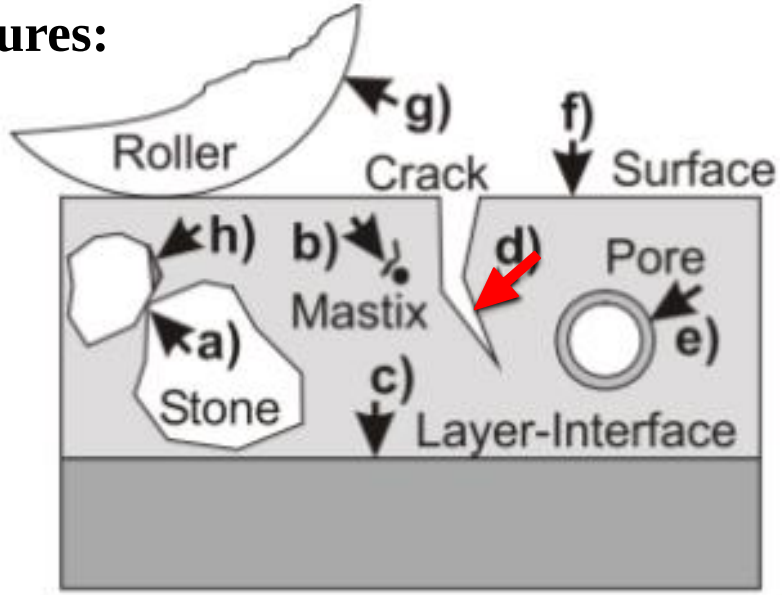
Futuristic Approach

- Self-healing process is still in its early stage of development and demonstration of its full potential is currently underway:
  - Appropriate content of capsules to achieve optimum dispersion
  - Multiphase self-healing process

Nanoparticles

Focus areas for nanoscience and technology with respect to asphalt pavement structures:

a. Bond between stones
b. Mastic
c. Bond between layers
d. Self-repair (healing)
e. Oxidation of binder films and binder inhomogeneity
f. Surface properties
g. Anti-adhesion surface for rollers during compaction
h. Bond, adhesion between stone and mastic



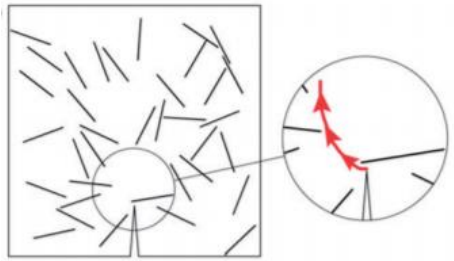
Nanoparticles

Future Research: Nanofillers - Nanoclay

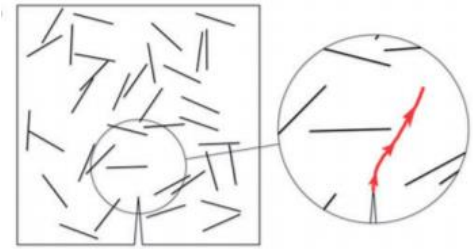
Self-healing mechanism:

- Crack deflection & pinning

A



B



A

- Crack deflection due to nanoclay in path of crack propagation
- Energy absorption by deflected crack results in delay of crack growth

B

- Absence of nanoclay near crack tip results in more space for crack to propagate easily

Healing dependant on **dispersion** and **orientation** of clay particles around crack tip

Nanofillers

Futuristic Approach

- Detailed investigations to determine most adequate methodology to obtain good dispersion
- Long-term effect of nanoclay particles on the performance of self-healing asphalt mixtures

Self-Healing Concrete Pavements

Carbon nanotubes (CNTs)

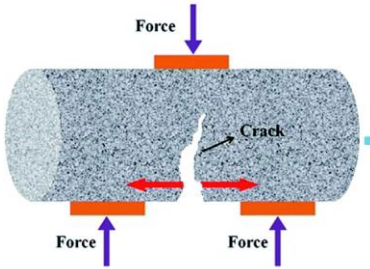
CNT's – ideal nano reinforcement materials due to distinct properties of atomic structure:

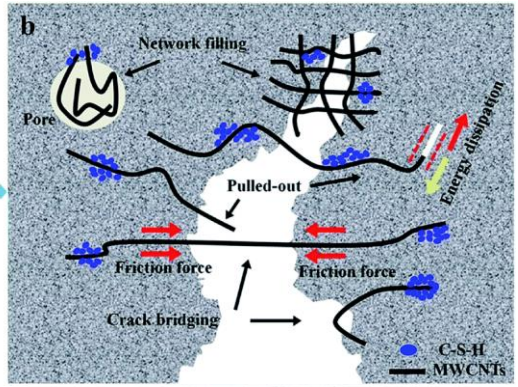
- high aspect ratio
- small size

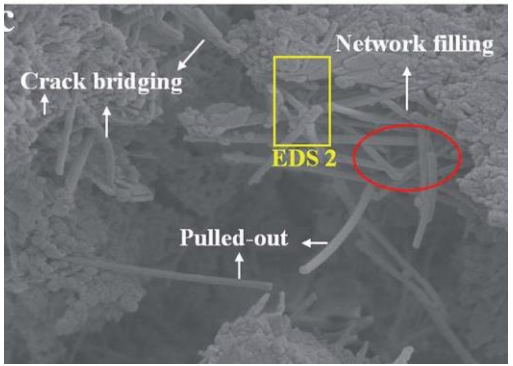
} distributed on a much finer scale

- low density
- unique physical and chemical properties
  - ➢ Force applied - nanotube bends; Force removed - recovers original shape
  - ➢ Interfacial interactions between CNTs and cement hydrates produce high bond strength-new composite material equivalent to rebar-frame reinforced concrete

Mechanism







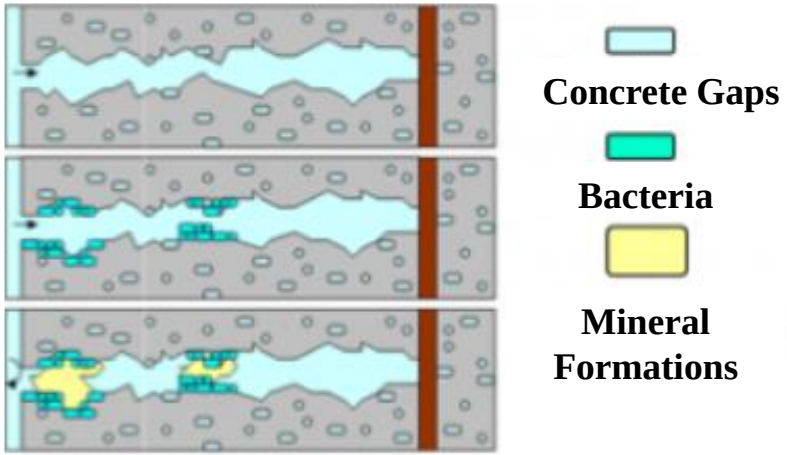
Self-Healing Concrete

Bioconcrete: Direct Application of Bacterial Spores

Use of bacteria that thrive in alkaline environments:

- Bacteria of genus Bacillus
- Spores with extremely thick walls remain intact > 50 years
- Suitable chemical precursor – “calcium lactate”

Self-Healing Mechanism

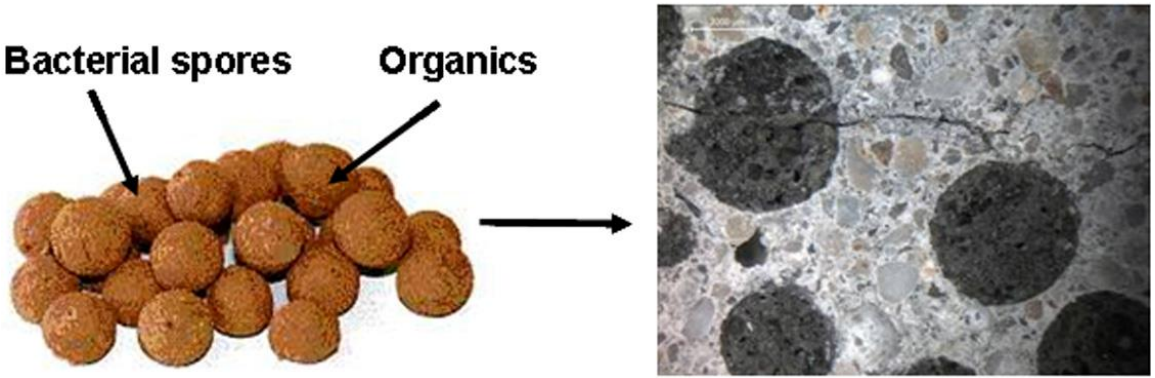


Self-healing mechanism of **unprotected bacterial spores** embedded in concrete matrix was restricted to approx. two months

Self-Healing Concrete

Bioconcrete: Encapsulated Bacterial Spores

Bacterial spores and chemical precursor (calcium lactate) are packed in porous expanded clay particles and added to the concrete mixture.

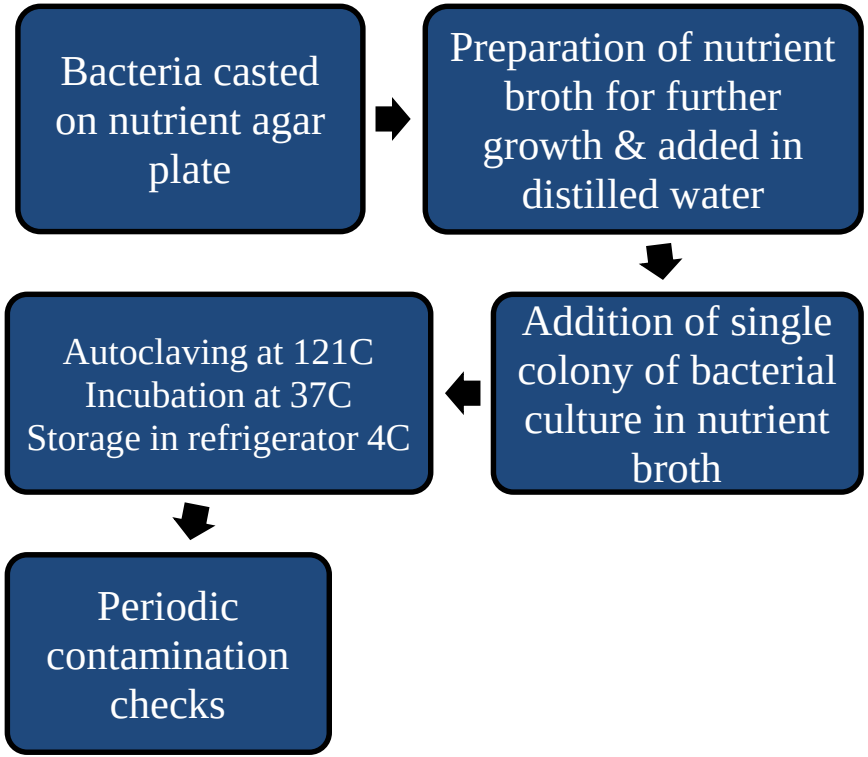


Protection of bacterial spores within porous light weight aggregates extends functionality period when embedded in concrete matrix

Self-Healing Concrete

Bioconcrete: Cultured Bacteria

Preparation of Cultural Bacteria



Self-Healing Concrete Pavements: Challenges

- Selection and isolation of specific Bacillus species from soil samples in which many other spores of Bacillus species predominate
- Costly production process of calcite precipitate
- Preparation of cultural bacteria – appropriate nutrient medium, temperature, humidity for germination and growth

Thank you

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