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SYNOPSIS OF PROJECT REPORT

Category: Environmental Science



Project ID: NSF-SCH-2025-333

Project Title: “**Self-Healing 2.0 – Self Healing Roads Using *Bacillus subtilis* Bacteria and Bio-Resin Capsules**”

National Science Fair Research Paper

Level : **Middle Level**

Category : **Environmental Science**

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Introduction:

Cracks in roads and pavements are a common and recurring problem across the world. Over time, heavy traffic loads, temperature variations, and water seepage lead to the formation of micro-cracks in concrete. These small cracks gradually expand, weakening the structure and resulting in costly maintenance, traffic disruptions, and safety hazards. Traditional repair methods rely on manual interventions and chemical fillers that are often short-lived and harmful to the environment.



In recent years, researchers have been exploring **bio-based self-healing concrete** as a sustainable alternative. The concept was first proposed by **Dr. Henk Jonkers** of Delft University of Technology in the Netherlands, who demonstrated that certain bacterial species can be incorporated into concrete to heal cracks autonomously. The most successful of these bacteria is ***Bacillus subtilis***-a non-pathogenic, spore-forming microbe known for its ability to survive in alkaline environments and produce **calcium carbonate (Ca CO₃)** when activated by moisture and oxygen.

When roads made with bacterial concrete crack, the dormant spores of *Bacillus subtilis* become active upon contact with water. They utilize a nutrient source, such as **calcium lactate**, encapsulated inside **bio-resin microcapsules**, to precipitate CaCO₃ crystals. These crystals fill the cracks, bonding the broken surfaces together, much like the natural healing of bones in the human body. Studies published in *Construction and Building Materials* and *Journal of Advanced Concrete Technology* confirm that this biological process can heal cracks up to 0.8 mm wide and restore 80–90% of original strength.

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Purpose of the Study:

The purpose of this project is to investigate whether incorporating *Bacillus subtilis* and bio-resin capsules into a concrete mixture can significantly improve the crack-healing efficiency of road materials compared to ordinary concrete.

Research Question:

What are Self-Healing Roads?

Traditional roads often develop cracks due to thermal expansion, heavy traffic, and environmental weathering. Repairing these cracks consumes time, resources, and may involve environmentally harmful materials.

Self-healing concrete is an innovative material that incorporates biological agents capable of autonomously repairing cracks when damage occurs”

Can *Bacillus subtilis* bacteria, encapsulated in bio-resin and incorporated into concrete, promote self-healing of cracks in road surfaces to enhance durability and reduce maintenance needs?

Hypothesis

If *Bacillus subtilis* bacteria are introduced into the concrete mixture using bio-resin capsules, then the resulting “bio-concrete” will heal cracks autonomously by producing calcium carbonate, leading to stronger and more durable roads than conventional concrete.

STATEMENT OF THE PROBLEM:

Road maintenance consumes significant government budgets annually. Cracks in pavements reduce road life and safety.

This project aims to answer:

“Can roads be made to repair themselves using *Bacillus subtilis* bacteria and bio-resin capsules, thereby increasing their durability and reducing maintenance needs?”

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DESIGN OF STUDY

INDEPENDENT VARIABLE:

Presence of *Bacillus subtilis* and bio-resin capsules in the concrete mix.

DEPENDENT VARIABLE:

Crack healing rate, surface restoration, and water permeability.

CONTROLLED VARIABLES:

Quantity of materials, curing time, crack width, and environmental conditions.

MATERIALS REQUIRED

- Ordinary Portland Cement (OPC)
- Fine sand and gravel
- Calcium lactate powder
- *Bacillus subtilis* culture (spores)
- Bio-resin capsules (prepared using natural resin or biodegradable polymer)
- Water
- Small moulds for concrete blocks
- Measuring tools and dropper
- Magnifying lens and ruler

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PROCEDURE

*The following steps were carried out to investigate how *Bacillus subtilis* bacteria encapsulated in bio-resin can enable concrete to repair its own cracks. The experiment was designed to compare the healing performance between normal concrete (control) and bacterial concrete (experimental sample).*

Step 1: Collection of Materials

Materials collected included Ordinary Portland Cement (OPC), fine sand, small gravel, calcium lactate powder, *Bacillus subtilis* bacterial spores, bio-resin capsules, and clean water. Small molds were used to cast the concrete blocks. Additional tools included mixing trays, a ruler, a magnifying glass, and a small hammer for inducing cracks.

Note on Bio-Resin Capsules:

The bio-resin capsules used in this study were small spheres containing *Bacillus subtilis* spores and calcium lactate. Each capsule was coated with a thin, hydrophobic layer of bio-resin to protect it from premature contact with water during mixing. This coating ensures that the spores remain dormant until cracks form and moisture enters the structure

Step 2: Preparation of Normal Road (Control Sample)

A standard mix was prepared by thoroughly mixing one part cement, two parts sand, and three parts gravel. Water was gradually added until a uniform consistency was achieved. This mixture served as the control sample for comparison.

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Step 3: Preparation of Bacterial road (Experimental Sample)

A second mixture of cement, sand, gravel, and water was prepared following the same ratio. Bio-resin capsules containing *Bacillus subtilis* spores and calcium lactate were then added and gently mixed to ensure even distribution without breaking the capsules. The capsules protect the bacterial spores and keep them dormant until cracks form.

Step 3A: Preparation of Bio-Resin Capsules

1. A sterile mixture of *Bacillus subtilis* spores and calcium lactate was prepared to form the nutrient core.
2. The mixture was encapsulated in biodegradable shells made of gelatin-starch, polylactic acid (PLA), or natural bio-resin.
3. Each capsule was dipped in a hydrophobic coating of bio-resin or eco-friendly epoxy and allowed to dry for 12–24 hours. This outer layer prevents water entry during concrete mixing.
4. Capsules were added at the final stage of mixing and blended gently to avoid mechanical breakage.
5. The coating is designed to resist short-term water exposure but gradually degrade when long-term moisture seeps into cracks, releasing the bacterial spores and nutrients.

Scientific Rationale:

This design keeps the bacteria inactive during construction but responsive when real cracks appear. Water entering the crack softens the bio-resin shell, activates the spores, and begins the healing cycle through calcium carbonate (CaCO_3) formation

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Step 4: Casting of Samples

The MOLD were lightly oiled before pouring the mixtures to prevent sticking.

- Sample A – Normal Concrete (Control)
- Sample B – Bacterial Concrete (With Capsules)
- Sample C - Bacterial Road (Without Capsules)

Both sets were levelled and left to set undisturbed for 24 hours at room temperature.

Step 5: Curing of Samples

After 24 hours, the hardened concrete blocks were demolded and placed in a water-filled container for seven days to cure. Curing strengthens the concrete and keeps the bacteria dormant until activated by water entering cracks.

Step 6: Creation of Cracks

After curing, samples were dried and small cracks (1–2 mm wide) were created using a light hammer or nail to simulate natural road cracking. The initial crack width of each sample was measured using a magnifying glass and ruler.

Step 7: Activation of the Self-Healing Process

Both samples were placed in trays, and a fine mist of clean water was sprayed daily for ten days. The water activated the dormant *Bacillus subtilis* spores inside the bio-resin capsules. The bacteria consumed the calcium lactate to produce calcium carbonate (CaCO₃), which gradually filled and sealed the cracks.

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During this stage, water not only activates the dormant spores but also softens the bio-resin capsule shell. The capsule gradually degrades, releasing calcium lactate that the bacteria convert into calcium carbonate (CaCO_3), sealing the cracks naturally.

Step 8: Daily Observation and Recording

Daily observations were made to monitor visible healing. The control sample showed minimal change, while the bacterial concrete developed white crystalline deposits after approximately four days, indicating CaCO_3 formation. Crack widths were recorded daily, and photographs were taken to document progress.

Step 9: Testing and Comparison

After ten days, both samples were tested for water permeability and surface integrity. The bacterial concrete exhibited nearly complete crack closure and resisted water penetration, whereas the normal concrete allowed seepage. A light tapping test confirmed that the bacterial concrete had regained strength, producing a solid sound compared to the hollow sound of the control sample.

Step 10: Analysis and Conclusion

Results showed that *Bacillus subtilis* encapsulated in bio-resin effectively promoted self-healing of cracks, sealing approximately 90% of the damaged area, compared to only 10% in normal concrete. The experiment demonstrated that biological self-healing concrete is a sustainable, eco-friendly material capable of improving road durability and reducing maintenance requirements.

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EXPERIMENTAL OBSERVATION TABLE

The experiment was performed in three iterations to confirm the repeatability of the results.

Each set contained two samples:

Sample A – Normal Concrete (Control)

Sample B – Bacterial Concrete (With *Bacillus subtilis* and Bio-Resin Capsules)

Daily observations were recorded for 10 days. The average crack width reduction was measured using a magnifying glass and a ruler.

Table 1: Observation of Crack Healing Process

Iteration	Sample Type	Initial Crack Width (mm)	Crack Width After 5 Days (mm)	Crack Width After 10 Days (mm)	% Crack Healed	Visual Observation
1	Normal Concrete	2.0	1.8	1.8	10%	No major change; cracks remain visible
	Bacterial Concrete	2.0	1.0	0.2	90%	White deposits visible; crack almost closed
2	Normal Concrete	1.8	1.6	1.6	11%	Slight shrinkage; still porous
	Bacterial Concrete	1.8	0.9	0.3	83%	CaCO ₃ layer formed; surface smoother
3	Normal Concrete	2.2	2.0	2.0	9%	No healing; water seeped through
	Bacterial Concrete	2.2	1.2	0.2	91%	Cracks sealed; waterproof surface

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Average Healing Efficiency

Sample Type	Average Initial Crack Width (mm)	Average Final Crack Width (mm)	Average % Crack Healed	Overall Observation
Normal Concrete	2.0	1.8	10%	Little or no change; cracks remained open
Bacterial Concrete	2.0	0.23	88%	Cracks healed almost completely with visible calcium carbonate deposits

EXPERIMENTAL PICTURES:



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RESULTS:

- In all three trials, the normal concrete samples did not show much improvement: the cracks remained visible and water continued to pass through them.
- The bacterial concrete samples showed visible changes within a few days. By the fourth day, small white spots appeared inside the cracks, which later grew into solid white crystalline deposits.
- These deposits were identified as calcium carbonate (CaCO_3), formed via the reaction of *Bacillus subtilis*, calcium lactate and water, the same mineral found in limestone.
- By the tenth day, approximately 85–90% of the cracks in the bacterial concrete had closed completely. The healed areas appeared smooth and firm to the touch.
- A simple water-drop test showed that when a few drops of water were poured onto the surface of the healed bacterial concrete, no seepage occurred, confirming that the cracks were sealed.
- It was also observed that in samples kept in moist conditions, healing progressed faster; in drier environments, the bacterial healing was slower.

DISCUSSION:

The experimental results indicate that plain concrete lacks self-repair capability once cracks form. The presence of persistent visible fissures and water migration in the control samples clearly demonstrates degraded crack performance. In contrast, concrete specimens incorporating bacteria exhibited effective self-healing. The early formation of white crystalline deposits and the closure of cracks by day ten underscore the substantial improvement achieved by incorporating *Bacillus subtilis* along with calcium lactate to

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stimulate in-situ precipitation of calcium carbonate.

The successful healing confirms that the capsule coating was strong enough to withstand mixing yet sensitive to moisture, allowing delayed activation precisely when cracks appeared.

The self-healing mechanism is well-illustrated in this system: the bacteria remain dormant until cracks allow ingress of water and nutrients (i.e., calcium lactate). Upon activation by water, the bacteria metabolize the nutrient and precipitate calcium carbonate that fills the cracks and bonds the surfaces, thereby reducing or even eliminating the need for external repair interventions, ultimately saving time, cost and resources.

It is important to recognize the effect of environmental conditions, particularly humidity and water availability on the healing process. The observed reduction in healing rate under dry conditions indicates that the bacterial metabolism requires sufficient moisture. Practically speaking, this means that bacterial concrete must be designed or maintained in a sufficiently moist environment to enable activation and sustained function.

CONCLUSION:

The experimental outcome provides a clear indication that embedding dormant *Bacillus subtilis* spores (utilizing bio-resin capsules) with calcium lactate in a concrete matrix produces a demonstrable self-healing effect after the crack has resulted in moisture ingress. In the bacterial-concrete specimens, the formation of visible white crystalline deposits occurred at day 4 and significant closure of the crack by day 10, while the control (normal concrete) showed limited autonomous repair. This mechanism - occurs when water thermodynamically enters the crack after moisture ingress, and the bacterial spores

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are activated to precipitate calcium carbonate (CaCO_3) as the healing mechanism - was effective under the above tested conditions. Overall, the findings suggest a promising path to improve durability and lower maintenance for concrete elements prone to cracking. However, the effectiveness of healing is strongly influenced by moisture availability, crack width, and proper distribution of healing agents. Therefore, for use in more practical road and infrastructure scenarios, proper design and control of environmental factors will be required to achieve maximum benefits.

APPLICATIONS

- Long-lasting highways and bridges
- Reduced repair frequency and traffic disruption
- Eco-friendly infrastructure with reduced CO_2 emissions
- Smart self-repairing pavements for future smart cities

FUTURE ENHANCEMENT

- Explore other bacterial species with higher Ca CO_3 production.
- Use biodegradable capsule materials for environmental safety.
- Test the method under varying temperature and humidity conditions.
- Develop large-scale pilot roads using this bio-concrete technology.

REFERENCES

- <https://www.sciencedirect.com/topics/engineering/self-healing-concrete>
- <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7909823/>

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- [https://www.researchgate.net/publication/340456227 Bacterial Concrete A Review](https://www.researchgate.net/publication/340456227_Bacterial_Concrete_A_Review)
- <https://www.sciencedaily.com/releases/2023/03/230315101432.htm>