

DEVELOPMENT OF SMART & SELF HEALING CONCRETE - A NEW TECHNOLOGY

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ABSTRACT

• Smart concrete is a revolutionary development in civil engineering materials, designed to offer functions beyond traditional load-bearing capabilities. It integrates sensing and responsive features such as self-monitoring, self-healing, and thermoelectric behavior. This paper provides an overview of the materials, functional mechanisms, and applications of smart concrete in modern infrastructure. It also discusses the benefits and limitations, alongside emerging trends and research directions. The paper emphasizes the potential of smart concrete in transforming future construction practices into safer, more resilient, and more efficient systems.

1.INTRODUCTION

• As the demand for intelligent infrastructure grows, innovations in construction materials have become imperative. Smart concrete is an advanced material that combines traditional concrete with technologies that allow it to detect changes in its environment. These changes can include structural stress, temperature shifts, moisture levels, or the formation of cracks. By incorporating sensors, conductive materials, and responsive agents, smart concrete can offer real-time data that significantly enhances structural maintenance and safety.

Concrete that can mend itself It has long been known that concrete cracking can shorten a structure's service life, yet it still occurs in new construction. There are some inherent autogenous healing qualities to concrete. Cracks may eventually mend as a result of the continuous hydration of clinker minerals or the carbonation of calcium hydroxide (Ca(OH)₂). However, autogenous healing is hard to manage because it only works on small fissures and only works when water is accessible. Self-healing autonomous concrete Adding engineered (autonomic) self-repair systems to structural elements that can mend cracks as they appear is one possible way to address this issue. Numerous methods, including the following technologies, have been developed to give concrete

Self-healing cementitious materials; implanted vascular networks to provide healing agents to injury zones; embedded bacterial spores; and micro- and macro-encapsulation of healing agents.

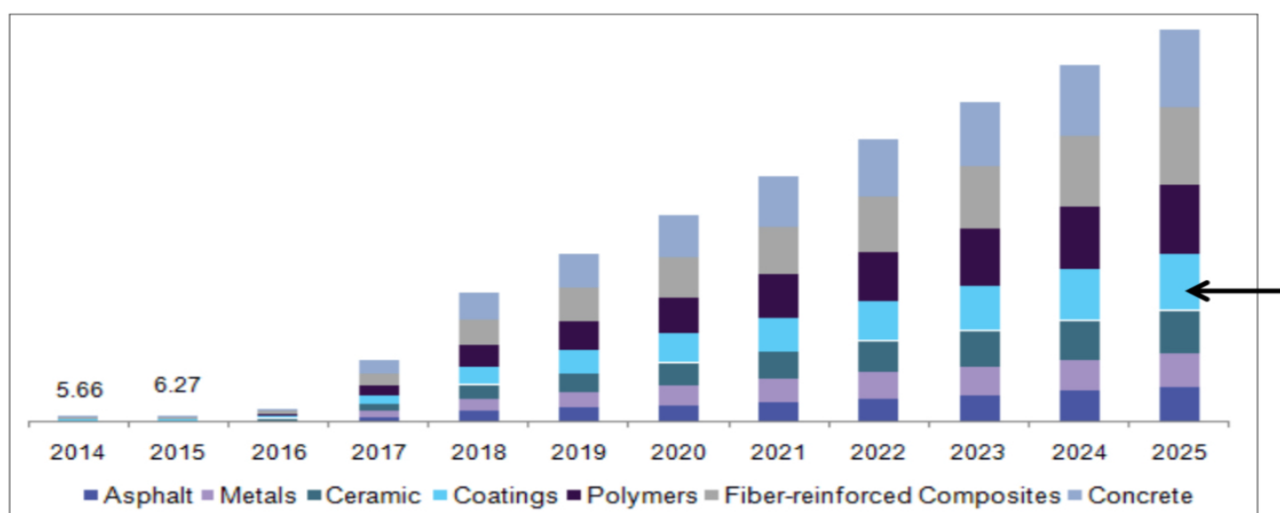
• Incorporate tendons or form memory bars into structural components that, when triggered, release a shrinkage potential that serves as a mechanism for crack closure.

Types of Smart Concrete

• Smart concrete can be categorized into several types based on its functionality:

• Self-Sensing Concrete: This variety includes conductive materials like carbon nanotubes or fibers. These additives help the concrete measure resistance changes under stress, allowing it to sense structural integrity and damage.

- **Self-Healing Concrete:** Designed to repair cracks autonomously, this concrete contains healing agents such as bacteria or polymer capsules. When cracks occur, these agents activate and seal the gaps, restoring strength and durability.
 - **Conductive Concrete:** Integrated with metallic powders or graphite, conductive concrete can pass electricity. It is used for de-icing pavements or electromagnetic shielding.
 - **Thermoelectric Concrete:** This type converts temperature variations into electrical energy using special thermoelectric additives, which can be used to power sensors or devices in remote areas.
- :-Smart Materials in Concrete -Smart Emerging Materials are trending with their cutting-edge synthetic techniques and uses in a variety of fields, including concrete. They are designed to react to environmental factors like temperature, pressure, and violent attacks, as well as cracks and extreme stress.



Market Growth of Self-Healing Materials (a smart material) in USA

Methods Used

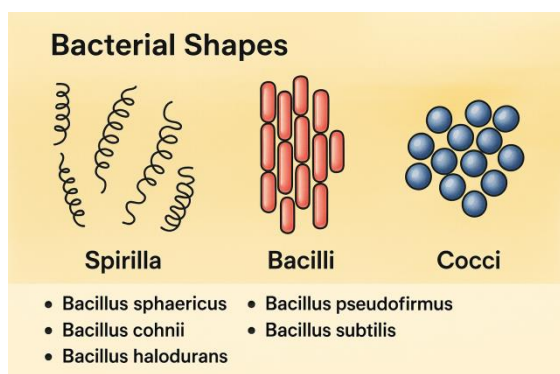
- To achieve the desired smart functions, various materials are mixed with conventional concrete:
 - Carbon-based additives such as carbon black, nanotubes, and fibers for conductivity.
 - Metallic inclusions like steel or iron particles for structural and electrical properties.
 - Smart polymers and microcapsules that release healing agents when cracks form.
 - Embedded electronic sensors like piezoelectric elements to measure vibrations and strain.
- Careful mixing and uniform distribution are essential to maintain effectiveness and structural integrity.

WORKING MECHANISM :

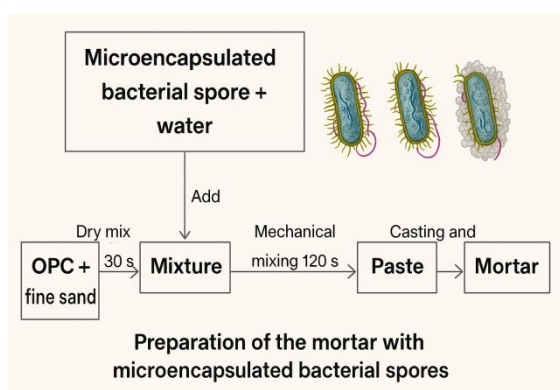
Smart concrete operates by interacting with mechanical, electrical, or thermal stimuli. In self-sensing types, mechanical stress alters the material's electrical resistance, which is monitored through external devices. In self-healing concrete, the presence of water or air initiates a chemical reaction in the embedded agents, leading to the formation of solid materials that seal cracks. Conductive and

thermoelectric concretes work by allowing current flow or generating voltage in response to environmental conditions, enabling multiple practical applications.

Using therapeutic medicines or bacterial spores implanted Calcium lactate, the chemical precursor, and live bacterial spores are added in self-contained pods.



The chemical precursor and microorganisms were injected immediately during the concrete-making process. Alternatively, a portion of the fine aggregate is impregnated with calcium lactate solution and bacterial spores, and the resulting particles are then employed in concrete as the healing agent.



Crack-healing activity in mortar by sodium alginate microencapsulated bacterial spores formed by freeze drying

Source: Pungrasmi et al., 2019

APPLICATION

Smart concrete is being applied in various sectors, particularly in infrastructure requiring high durability and monitoring:

- Bridges: Used for real-time stress and crack monitoring to prevent sudden failures.
- Roads and Highways: Helps in de-icing and structural monitoring in cold climates.
- Buildings: Ideal for earthquake-prone regions, offering structural health data.
- Military and Defense: Enhances survivability of bunkers and protective structures.
- Smart Cities: Forms the base of intelligent transport systems and automated monitoring.

ADVANTAGES :

- Provides real-time structural data.
- Enhances durability and reduces repair costs.
- Enables proactive maintenance and safety measures.
- Can reduce environmental impact with bio-based healing agents.

LIMITATIONS:

- Higher initial investment compared to conventional concrete.
- Requires specialized materials and equipment.
- Complicated manufacturing and application process.
- Limited field data for large-scale projects.

FUTURE SCOPE:

As technology advances, smart concrete will likely integrate with AI and IoT, enabling automatic data collection and predictive maintenance. Wireless sensor networks embedded within structures will communicate performance data in real-time. Further developments in nanotechnology and material science may result in smarter, more efficient, and affordable options for both urban and rural infrastructure.

BENDING TOUGHNESS:

The bending toughness of smart concrete was assessed using the ASTM C1609 method[23] and a specimen of 100 mm by 100 mm by 400 mm. The four point bending method was used to get the load section curve. The image below depicts the test setup. The pure bending section is 100 mm, and the net span length is 300 mm.

:- Bending toughness test results:

The bending toughness of the smart concrete beam specimens was examined using the four-point bending test, as detailed in Section 3.1.2. Table 8 displays the matching deflection at the beginning load, flexural strength, and the initial peak load of the smart concrete beams after the load and deflection data gathered during the test were analyzed. Five groups of representative load-deflection curves for each of the smart concrete mixes are displayed.

(Graphs a to d with different fiber and nanoparticle combinations are displayed here.)

Steel fiber that has been single-doped

0.25 percent carbon black nanoparticles in steel fiber
c) Steel fiber and carbon black nanoparticles (0.5%)

d) Steel fiber and carbon black nanoparticles (0.75%)



ELECTRICAL CONDUCTIVITY TEST OF SMART CONCRETE :

SMART CONCRETE ELECTRICAL CONDUCTIVITY TEST: Self-monitoring smart concrete is a multipurpose type of concrete. By tracking the resistance change rate through its overall conductivity, the concrete structure's deterioration and crack width can be evaluated. The incorporation of conductive elements is essential to smart concrete's good monitoring performance. The conductive qualities of concrete are influenced differently by various conductive material kinds

and additive doses, and their efficacy in smart concrete varies as well. Consequently, research into different kinds and concentrations of conductive

In smart concrete, efficacy varies as well. Researching the various conductive material types and dosages that are added to the concrete matrix is essential to identifying the right kinds of conductive materials and their optimal concentrations. This will guarantee that the final concrete not only satisfies the essential mechanical property criteria, but also establishes the foundation for smart concrete's future self-monitoring performance.

CONDUCTIVE MECHANISM OF SMART CONCRETE :

Song [24] and Forde M [25] et al. have shown that concrete is not an insulator in the strictest sense. According to Layssi H [26] and Sengul O [27] et al., ordinary concrete has a high resistance despite having a conductive channel provided by the pore solution in its matrix.

CURVES:

The findings in Table 6 and Figure 7 demonstrate that the flexural strength and initial peak load of the smart concrete mixes both dramatically increase as the steel fiber percentage rises, and strain-hardening properties become apparent when the steel fiber content approaches 2%. It is seen that the steel fiber content also significantly improves the region beneath the load-deflection curve, which is a measure of toughness. The specimens may fail ductilely even if there is only a 0.5% SF addition in the concrete mix.

The deflection is in line with

Number of specimens P_1 (kN), f_1 (MPa), and δ_1 (mm)

SF-05 14.87 4.461 0.0257

PC 12.88 3.864 0.0244

SF-10 15.79 4.737 0.0311

SF-15 17.89 5.367 0.0341

SF-20 19.58 5.874 0.0376

Smart concrete's compressive strength after adding separate conductive components

Figure 5 plots the compressive strength findings of smart concrete that has individual conductive elements added.

Details of the compressive strength in MPa bar graph:

Compressive Strength (MPa) of Specimens PC ~32.5 SF-05

SF-05 ~33.5

SF-10 ~35.5

SF-15 ~37.5

SF-20 ~36.5

NC-25 ~31.0

NC-50 ~31.5

NC-75 ~32.0

NC-100 ~30.5

CONCLUSION

Smart concrete is set to redefine the future of construction by adding intelligence and adaptability to structural elements. Though challenges remain in terms of cost and deployment, the long-term benefits in durability, safety, and sustainability make it a worthwhile investment. Continued research and interdisciplinary collaboration will accelerate its adoption across the globe.

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