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A new vision to repair damages in composite concretes via using the self-healing concrete technologies

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COMMENTARY

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Abstract

Concrete, as a widely used material in the construction industry, despite its high compressive strength, is prone to cracking due to its weak tensile strength, which leads to a reduction in the durability and lifespan of structures. Self-healing concrete technologies have created a new perspective in improving the sustainability and reducing the maintenance costs of concrete structures by providing innovative and intelligent solutions for automatic crack repair. These technologies, by utilizing natural and engineering mechanisms, promise to increase the lifespan and durability of composite structures. This commentary explores the issue and outlines the promise of self-healing concrete technologies.

Cracks in concrete especially microcracks tend to expand over time, allowing water, chloride ions, and other harmful substances to penetrate the material. This degradation significantly reduces the service life and structural reliability of concrete infrastructures. Traditional repair and retrofitting methods are expensive, time-consuming, and often fail to reach internal damage zones. Therefore, innovative, autonomous repair systems are needed to prolong service life and improve sustainability [1]. For example, fiber-reinforced polymer-polyvinyl chloride (FRP-PVC) composite tubular columns filled with concrete offer high compressive strength, durability, and corrosion resistance. Their cost-effective design effectively enhances stiffness and strain capacity in reinforced concrete structures exposed to harsh environments [2].

In this context, self-healing concrete technologies have emerged as promising solutions. Autogenous self-healing occurs naturally via ongoing hydration of unhydrated cement particles or carbonation of calcium hydroxide, which seals cracks smaller than 0.3 mm. This mechanism can be further enhanced by external factors such as moisture exposure, compressive stress, and wet–dry cycles [3, 4].

Beyond autogenous reactions, engineered self-healing methods integrate additional materials and smart systems to actively close cracks. Fiber-reinforced cementitious composites (FRCCs) and Engineered Cementitious Composites (ECCs) show superior self-healing potential because fibers maintain tight crack widths and act as nucleation sites for healing products. Various fibers, such as polypropylene coated with nano–calcium carbonate or ethyl cellulose films, further promote healing by restricting crack propagation. The use of superplasticizers in ECC mixtures also helps minimize water content and reduce microcrack generation [3].

In addition to fiber-based systems, polymeric compounds are considered one of the most promising agents for self-healing. Their interactions with crack surfaces enable filling and restoration of the damaged zones. Moreover, geo-material-based self-healing systems, as developed by Ahn and Kishi (2010) [5] presented a practical example of self-healing concrete based on geomaterials that enhances self-healing through swelling, expansion, and recrystallization of elements such as aluminosilicates and calcium compounds. This process requires the presence of moisture, which is generally readily available in underground environments and structures exposed to precipitation. New technologies, such as the use of microcapsules and calcite-forming bacteria, have opened new horizons in self-healing concrete. These approaches enable the automatic repair of cracks, increase the useful life of structures, and can be purposefully integrated into the design and implementation of future infrastructure [6].

Recent research divided self-healing mechanisms into two major categories: (1) engineered self-healing, where materials are designed to autonomously trigger healing reactions, and (2) self-repairing, which relies on embedded capsules or systems capable

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of sensing and actuating repair functions. The growing integration of these technologies in composite concretes represents a new vision for creating intelligent, sustainable, and long-lasting infrastructure materials capable of self-diagnosis and autonomous recovery from damage [7]. Today, new approaches in the field of self-healing composite concretes have made significant advances toward improving the durability and reducing the maintenance costs of infrastructure. The study by Yang et al. (2005) [8] is a leading example in the development of engineered cementitious composites ECCs. It investigated the self-healing process under wet and dry cycles in the presence of a significant amount of fly ash and PVA fibers. Their results showed that controlling crack widths below 80 microns not only increased durability but also restored mechanical properties such as resonance frequency.

Given the growth of the research field, future research needs to address the practical integration of self-healing technologies with design codes and structural life assessment to witness a significant transformation in improving sustainability and reducing repair costs [9]. Despite significant advances in self-healing composite concrete technologies, there are still challenges and limitations on the path to full realization of these technologies. Reduced performance at larger cracks, the constant need for moisture to activate the repair mechanisms, high costs of materials and technology, and the lack of comprehensive design and quality control standards are important obstacles [1]. Also, environmental concerns and varying performance under varying environmental conditions necessitate further research and development. However, the prospect of self-healing composite concrete technology holds promise for reducing maintenance costs, increasing the lifespan of structures, and creating smart and sustainable infrastructures. future solutions should focus on integrating these technologies with design codes, optimizing materials, and ensuring performance durability in real-world environments to create a real transformation in the construction industry [3].

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Conflict of interest

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Data availability

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