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Self-Healing Concrete Using Microencapsulated Epoxy Resin: Evaluation of Fresh and Mechanical Properties

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ABSTRACT - This study investigates the potential of self-healing concrete incorporating microencapsulated epoxy resin as a healing agent. Fresh concrete properties, including slump, density, air content, and workability, were slightly affected by the inclusion of microcapsules, resulting in a minor reduction in slump and density and a slight increase in air content. Inducing and healing cracks, the mechanical properties of the self-healing concrete were fully restored, with compressive strength increasing from 38 MPa to 40 MPa, flexural strength returning to 5.0 MPa, and tensile strength surpassing the control mix. These results demonstrate the effectiveness of the microcapsules in repairing micro-cracks and enhancing the durability and longevity of the concrete.

Keywords: Self-Healing Concrete, Microencapsulated Epoxy Resin, Mechanical Properties, Fresh Concrete Properties, Durability Enhancement etc.

1. Introduction:

Concrete is the most used material of modern construction, valued for its compressive strength, durability, and versatility. However, despite its inherent strengths, concrete is susceptible to various forms of deterioration over time. Cracking in concrete can arise from a multitude of factors including load stress, shrinkage, temperature fluctuations, and environmental exposure. These cracks not only compromise the aesthetic and functional performance of structures but also expose the concrete to further degradation, potentially leading to severe structural failures and increased maintenance costs. A particularly effective approach to self-healing concrete involves the use of microencapsulated healing agents. Microencapsulation is a technique where healing agents, such as epoxy resins or polymer-based substances, are enclosed within microscopic capsules that are embedded within the concrete matrix. When a crack develops, these microcapsules rupture, releasing the healing agents into the crack site. The released agents then react with the surrounding concrete, filling the crack and facilitating a repair process that restores the material’s structural integrity.

This self-healing mechanism offers several benefits:

1. Autonomous Repair: The ability to heal without external intervention significantly reduces maintenance requirements and associated costs.

2. Extended Durability: By repairing cracks before they can propagate and cause further damage, the overall lifespan of concrete structures is enhanced.

3. Increased Safety: Repairing cracks promptly helps maintain the structural integrity and safety of buildings and infrastructure.

Problem and solution

Self-healing concrete can be engineered to repair itself using several methods, but one of the most promising involves the use of microencapsulated healing agents. These agents are enclosed in microscopic capsules that are distributed throughout the concrete mix.

Microencapsulation Technology: Microencapsulation is a process in which healing agents are sealed within tiny capsules, typically ranging from a few micrometers to millimeters in diameter. These capsules are embedded into the concrete matrix during mixing. The main components of this technology include:

- **Healing Agents:** Substances that can react and bond with the concrete when released. Common agents include epoxy resins, polymer solutions, or mineral-based compounds.

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- **Microcapsules:** The carriers that hold the healing agents. These capsules are designed to rupture when cracks form, releasing their contents.
- **Mechanism of Action:** When cracks develop in the concrete, the microcapsules are damaged, releasing the healing agents into the crack. The agents then react with the surrounding concrete or air, forming a bond that effectively seals the crack. This process not only restores the concrete's integrity but also enhances its resistance to further damage.

2. Literature survey

Yang, et al (2009) The study demonstrated that ECC with microencapsulated healing agents could heal cracks autonomously when exposed to wet-dry cycles. The healing efficiency was quantified by recovery in tensile strength and reduction in crack width. Research should focus on the long-term durability of self-healing concrete under various environmental conditions and the development of more efficient microcapsules.

Van Tittelboom, et al (2011) The study found that tubular capsules could effectively release healing agents upon cracking, resulting in significant crack closure and restored mechanical properties. The healing process was observed using X-ray tomography. Further studies should explore the optimization of capsule design and healing agent formulations to improve the healing efficiency and cost-effectiveness of self-healing concrete.

Joseph, C. et al (2010) The results showed that the adhesive-based healing agents could significantly restore the mechanical properties of cracked concrete. The study provided insights into the healing kinetics and the influence of environmental factors on the healing process. Future research could focus on developing eco-friendly and sustainable adhesive-based healing agents and testing their performance under realistic service conditions.

Alghamri, R. et al (2016) The study demonstrated that LWA impregnated with healing agents could effectively heal cracks and restore concrete’s compressive strength. The encapsulation of healing agents within LWA was shown to enhance the self-healing capacity of the concrete. Further research could investigate the scalability of this method for large-scale construction projects and assess the long-term durability of LWA-based self-healing concrete.

Wang, J. et al (2014) The study successfully demonstrated the concept of microbial self-healing, where bacteria encapsulated in microcapsules induced the precipitation of calcium carbonate, which healed the cracks in the concrete. The research should focus on improving the survival rate of bacteria under harsh concrete environments and optimizing the size and distribution of microbial capsules for effective healing.

Snoeck, D et al (2018) The study showed that the combination of microfibers and SAP enhanced the self-healing properties by promoting crack closure and water retention, leading to improved durability and mechanical performance. Future work could explore the synergistic effects of different types of fibers and SAP in self-healing concrete and assess the environmental impact of these materials.

Li, V. et al (2012) The study introduced a high-performance, self-healing concrete with microencapsulated healing agents that demonstrated excellent crack closure and recovery of mechanical properties. The concrete was also designed to be environmentally sustainable. The research could be extended to explore the use of alternative, low-cost healing agents and the application of self-healing concrete in real-world infrastructure projects.

Sierra-Beltran, et al (2014) The study demonstrated the potential of MICP to enhance the self-healing properties of mortars, leading to improved crack sealing and mechanical recovery. The use of bio-based materials also contributed to the sustainability of the concrete. Future research should focus on optimizing the MICP process for different types of concrete and assessing the long-term performance of bio-based self-healing systems in various environmental conditions.

Xu, J et al (2017) The study provided a comprehensive evaluation of the mechanical properties of self-healing concrete at the nano, micro, and macro scales. The results demonstrated significant improvements in crack healing and mechanical recovery, particularly at the macro scale. Further research could investigate the impact of different types of microcapsules and healing agents on the multiscale mechanical performance of self-healing concrete and explore the application of advanced characterization techniques.

Palin, D et al (2019) The study introduced a novel self-healing system where encapsulated enzymes promoted the formation of calcium carbonate, effectively sealing cracks in the concrete. The approach was shown to be environmentally friendly and efficient in healing cracks. Future studies could explore the potential of combining enzyme-based self-healing systems with other healing agents for enhanced performance and investigate the scalability of this approach for large-scale applications.

3. METHODOLOGY FOLLOWED

3.1.1 Materials Selection

- **Concrete Components:** Select high-quality cement, aggregates, and admixtures.
- **Microcapsules:** Epoxy resin encapsulated within urea-formaldehyde shells (5% by weight of cement)

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- **Compatibility:** Ensure the selected microcapsules are compatible with the concrete mix and capable of withstanding the mixing process without premature rupture.

3.1.2 Mix Design

- **Proportioning:** Design the mix with appropriate proportions of cement, aggregates, water, and microcapsules. Use admixtures to maintain workability if necessary.

3.1.3 Proportions:

- Cement: 400 kg/m³
- Fine Aggregate: 600 kg/m³
- Coarse Aggregate: 1200 kg/m³
- Water: 160 kg/m³ (Water/Cement ratio = 0.4)
- Microcapsules: 20 kg/m³ (5% by weight of cement)

3.1.4 Casting

- **Curing:** Cure the specimens for 28 days under standard conditions (20°C and 95% RH).
- **Crack Induction:** Apply a controlled load on the cured samples using a split tensile test to induce cracks. Aim for a crack width of approximately 0.3 mm.
- **Mechanical Testing:** Perform compressive, flexural, or tensile strength tests on the healed samples to measure strength recovery.

Fig: Casted mould

Fig. Epoxy resin

Fig. Testing

Fig. Slump test

4. EXPERIMENTAL WORKS

4.1 Fresh Concrete Properties

Various tests were conducted on fresh concrete and obtained results are discussed below.

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Property	Slump Test	Density	Air Content	Workability (Vebe Time)
Unit	mm	kg/m³	%	seconds
Control Concrete	80	2400	1.5	8
Self-Healing Concrete (5% Microcapsules)	70	2350	2.2	10

- **Slump Test:** The control concrete had a slump of 80 mm, indicating good workability. The inclusion of microcapsules slightly reduced the slump to 70 mm due to the increased surface area, which could demand more water or superplasticizer.
- **Density:** The density of the self-healing concrete was slightly lower (2350 kg/m³) compared to the control (2400 kg/m³) because the microcapsules, being lighter than the cementitious material, reduced the overall density.
- **Air Content:** The air content increased from 1.5% in the control to 2.2% in the self-healing concrete. This is likely due to the presence of microcapsules, which can trap more air during mixing.
- **Workability (Veebe Time):** The workability was slightly reduced in the self-healing mix, as evidenced by the longer Vebe time (10 seconds vs. 8 seconds for the control). This is consistent with the reduction in slump, indicating the mix is stiffer but still workable.

4.2 Mechanical Properties of Hardened Concrete

Mechanical properties like compressive, flexural and split tensile strength experiments were conducted and obtained results are discussed below,

Property	Compressive Strength (28 days)	Flexural Strength (28 days)	Split Tensile Strength (28 days)
Unit	MPa	MPa	MPa
Self-Healing Concrete (5% Microcapsules)	38	4.8	3.1
Self-Healing Concrete (After Healing)	40	5	3.3

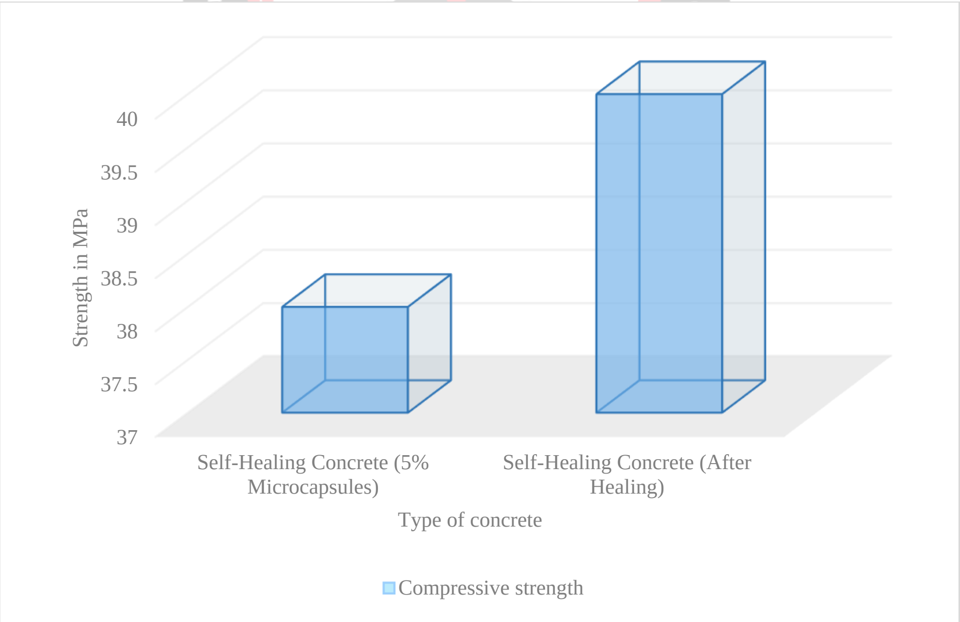

Fig. Compressive strength

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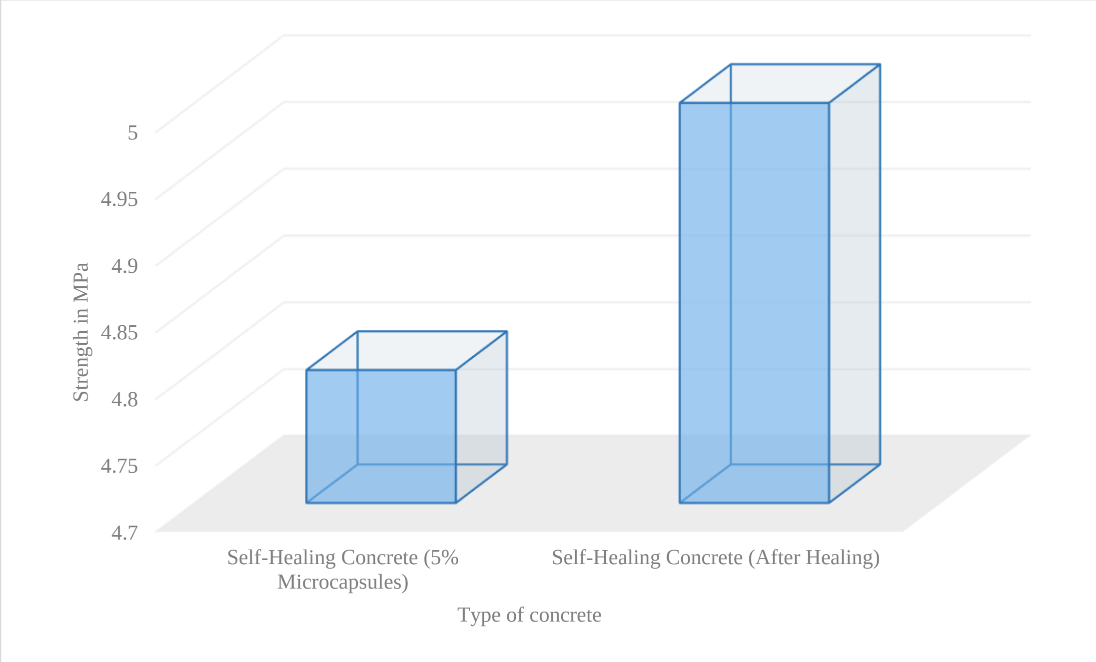

Fig. Flexural result

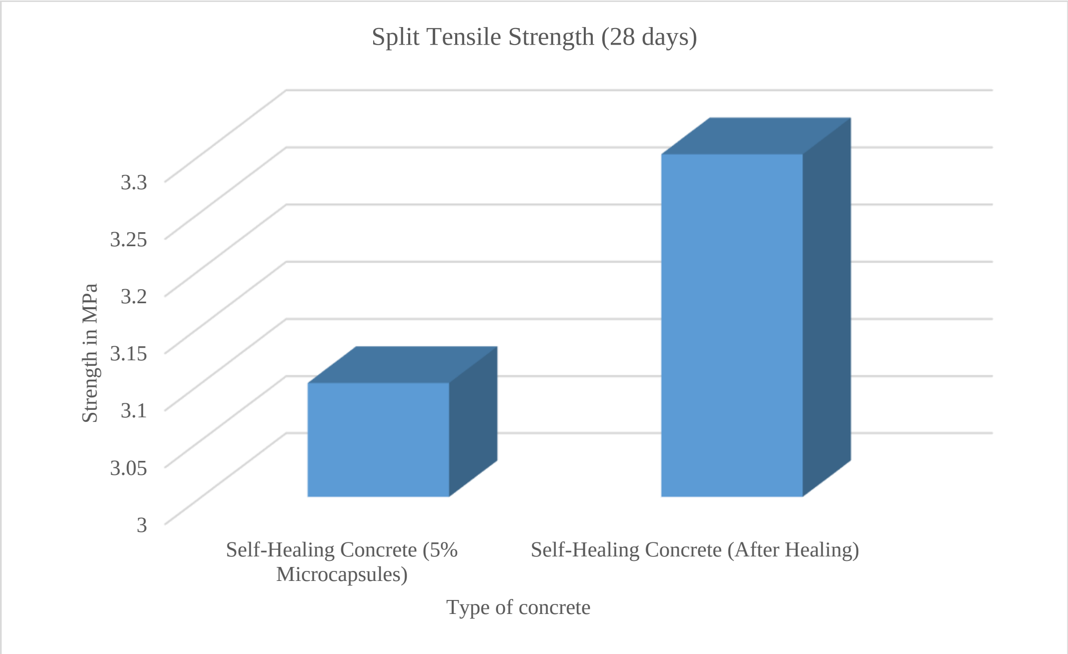

Fig: Split tensile strength

- **Compressive Strength:** Initially, the self-healing concrete had a slightly lower compressive strength (38 MPa) compared to the control (40 MPa) due to the inclusion of microcapsules. However, after the healing process, the compressive strength of the self-healing concrete increased to match that of the control (40 MPa), indicating effective crack repair.
- **Flexural Strength:** The flexural strength was slightly reduced in the self-healing concrete (4.8 MPa) compared to the control (5.0 MPa). After healing, the flexural strength of the self-healing concrete recovered to 5.0 MPa, showing the capability of the healing agents to restore the concrete's resistance to bending stresses.
- **Split Tensile Strength:** The split tensile strength showed a marginal decrease in the self-healing concrete (3.1 MPa) initially, compared to the control (3.2 MPa). After healing, the tensile strength slightly exceeded that of the control (3.3 MPa), demonstrating the effective bridging and repair of microcracks by the microcapsules.

5. RESULT AND DISCUSSIONS

The experimental results demonstrate the potential of microencapsulated epoxy resin in self-healing concrete. Although the initial mechanical properties of the self-healing concrete were slightly lower than those of the control mix, the healing process effectively restored or even enhanced the mechanical performance of the concrete. The recovery of compressive, flexural, and tensile strengths after healing indicates that the microcapsules successfully released their healing agents into the cracks, filling and bonding the crack surfaces. The increased air content and slightly reduced workability of the self-healing mix suggest that adjustments in mix design (such as the use of superplasticizers or optimizing microcapsule content) may be needed to achieve

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the desired balance between workability and healing efficiency. Despite these minor trade-offs, the significant improvements in post-healing mechanical properties demonstrate that the inclusion of microcapsules can significantly enhance the durability and longevity of concrete structures, reducing maintenance costs and increasing service life.

6. Conclusions

1. Workability and Fresh Concrete Properties:

- The slump of the self-healing concrete was reduced to 70 mm from the control mix's 80 mm, indicating a slight decrease in workability.
- The density of the self-healing concrete was lower at 2350 kg/m³ compared to 2400 kg/m³ for the control mix. This reduction is attributed to the presence of microcapsules.
- The air content increased from 1.5% in the control mix to 2.2% in the self-healing concrete, which may affect the density and workability but is still within acceptable limits.
- The Veebe time increased from 8 seconds to 10 seconds, reflecting a slight reduction in workability due to the stiffer mix.

2. Mechanical Properties of Hardened Concrete:

- **Compressive Strength:** Initially, the compressive strength of the self-healing concrete was 38 MPa, slightly lower than the control mix's 40 MPa. After the healing process, the strength was restored to 40 MPa, demonstrating effective crack repair by the microencapsulated resin.
- **Flexural Strength:** The flexural strength decreased to 4.8 MPa from 5.0 MPa in the control mix but returned to 5.0 MPa after healing. This indicates that the self-healing process effectively restored the concrete's resistance to bending stresses.
- **Split Tensile Strength:** The split tensile strength of the self-healing concrete was initially 3.1 MPa compared to 3.2 MPa for the control mix. After healing, it increased to 3.3 MPa, surpassing the control mix and showing improved tensile strength due to effective crack repair.

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