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Development of Self-Healing Mechanism in Concrete using Chemical Agents

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Abstract: *Concrete is a widely used construction material, but its durability is compromised by crack formation due to shrinkage, mechanical loading, or curing defects. This study investigates the self-healing properties of concrete using epoxy resin as a chemical agent. A 10% epoxy resin by weight of cement was incorporated without a hardener to enhance compressive strength, flexural strength, and crack-healing efficiency. Experimental results showed significant improvements in compressive strength (up to 34% at 3 days), flexural strength (7.4% for one-point loading and 43% for two-point loading), and self-healing efficiency. Ultrasonic pulse velocity (UPV) testing further confirmed the superior quality of epoxy-modified concrete. These findings highlight the potential of epoxy resin as an economical and effective self-healing agent for improving the performance of structural concrete.*

Keywords: Concrete.

I. INTRODUCTION

Concrete is one of the most versatile and widely used construction materials due to its strength, durability, and availability. However, its susceptibility to cracking compromises its structural integrity and durability, leading to increased maintenance costs and reduced service life. Traditional repair methods for cracks are labor-intensive and costly, necessitating the development of innovative solutions such as self-healing concrete.

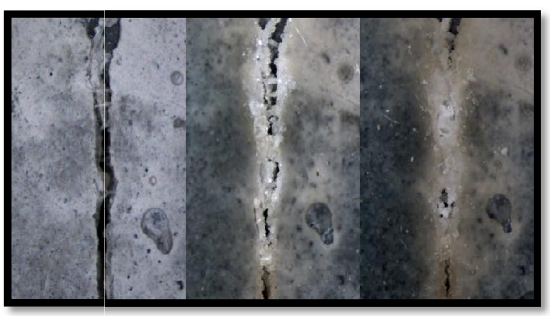

Fig. Delf Healing Concrete

Self-healing concrete has the inherent ability to repair cracks and restore its structural performance without external intervention. This study explores the use of epoxy resin as a chemical self-healing agent. Epoxy resin's unique properties, including high adhesion, chemical resistance, and durability, make it an ideal choice for enhancing concrete's performance. The research aims to evaluate the effects of epoxy resin on compressive strength, flexural strength, and crack-healing efficiency of concrete under various loading conditions.

II. LITERATURE REVIEW

Qi Li et al. 2013, The self-healing capability of dual component microcapsules of resin and curing agent is examine at 5,10,15 and 20 weight %. Comparing the single component system with the dual component system, the 15 weight % dual component microcapsule system shows higher healing efficiency than the single component microcapsule system. The healing efficiency slightly increases with the increase in temperature, as at high temperature due to low viscosity the curing reaction between epoxy and hardener occur in trouble-free manner and the healing agent passes easily on the crack surface. The surface of epoxy contained microcapsule were rough and scraggly whereas the surface of hardener contained microcapsule were smoother. The tensile strength up to 5 weight % of dual component microcapsule increases but beyond this limit it decreases.

Abdul RahmanMohd. Sam et al. 2015,The author made an attempt to study the performance of epoxy resin without hardener as a self-healing agent in concrete. A mortar modified with epoxy resin was developed using 10% of epoxy resin of cement without hardener, resulting in higher compressive strength and lower UPV values. Analysis of SEM shows that self-healing occurs in epoxy resin modified mortar. However, it was found that increasing the epoxy resin content beyond 10% decreased the compressive strength due to the presence of epoxy resin that was not hardened and interfered with the bonding between hydroxyl ions and epoxy resin. These results and the microstructure tests indicate that epoxy resin can be used as a self-healing agent.

Mostavi et al. 2015, A double-walled microcapsule containing sodium silicate as a healing agent and Polyurethane/Urea-formaldehyde as a shell material is synthesis using in situ polymerization. The use of 5% microcapsules by weight of cement enhance the healing rate. The increase in agitation rate reduces the size of capsules. At lower pH the capsule have fewer cracks on their shells, at higher pH the formation of capsules doesn't occur. At higher temperature, the density of pores on the microcapsule surface decreases, and hence the complete formation of capsules take place at high temperature.

Salmabanu Luhar et al.2015, The author carried out an autonomous self-healing mechanism into the concrete that helps repair the cracks by producing calcium carbonate crystals that seal the microcracks and pores in the concrete. Bacteria were selected based on their ability to survive in alkaline environments, such as B. pasteurii, Bacillus subtilis, and B. spharicus, which are mainly used by various researchers for their studies. The growth conditions are different for different types of bacteria. For growth, the bacteria are placed in a medium containing various chemicals at a specific temperature and for a specific period of time. Bacteria improve the structural properties such as tensile strength, water permeability, durability and compressive strength of normal concrete, which was found by conducting different types of experiments on too many specimens of different sizes used by different researchers for their study of bacterial concrete compared to conventional concrete. It is found that use of light weight aggregate along with bacteria helps in self-healing property of concrete. A mathematical model is also introduced to study the stress-strain behaviour of bacteria to improve the strength of concrete.

Zhu et al. 2016, The self-healing of cracks in ECC with a water binder ratio 0.25 and with 50% fly ash is analyzed. ECC self-healing cracks are filled with white self-healing products and chemical composites that resemble the color of the ECC matrix. The self-healing materials in the cracks of ECC include various hydration products, calcium hydroxide, calcium carbonate, and chemical composites that penetrate into the ECC matrix from the self-healing environment. The different propagation of the self-healing products in the microcracks, the degree of self-healing, the broken PVA fibers, and the detachment of the interface between the ECC matrix and the PVA fibers result in lower initial crack stress, slower ultrasonic pulse viscosity, and larger absorption coefficient of the self-healed ECC with increasing preloaded tensile stress. Compared with untreated ECC, the lower initial crack stress, slower ultrasonic pulse viscosity, and larger absorption coefficient of the self-healed specimens decreased at the same preloaded tensile stress, especially at a high strain level.

III. METHODOLOGY

3.1 Materials

- **Cement:** OPC 43 grade.
- **Aggregates:** Coarse aggregates of 20 mm and 10 mm, and natural sand as fine aggregate.
- **Water:** Clean potable water.
- **Epoxy Resin:** Diglycidyl Ether of Bisphenol A-type epoxy resin without hardener.
- **Steel Reinforcement:** Fe415 grade bars.

3.2 Mix Design The mix design was prepared for M25 grade concrete using IS 10262:2019 guidelines. A 10% epoxy resin by weight of cement was incorporated.

3.3 Specimen Preparation

- **Cubes:** Nine conventional and nine epoxy-modified cubes (150 mm × 150 mm × 150 mm) were cast for compressive strength testing.
- **Beams:** Four structural beams (700 mm × 150 mm × 150 mm) were prepared, including conventional and epoxy-modified specimens for one-point and two-point loading tests.
- **Curing:** Specimens were cured for 28 days before testing.

Fig. 2. Casting of Cubes

3.4 Testing Methods

- **Compressive Strength:** Measured using a compression testing machine at 3, 7, and 28 days.
- **Ultrasonic Pulse Velocity (UPV):** Used to assess concrete quality and self-healing performance.
- **Flexural Strength:** Evaluated using one-point and two-point loading setups.
- **Load-Deflection Behavior:** Structural beams were tested under one-point and two-point loading to evaluate their performance.

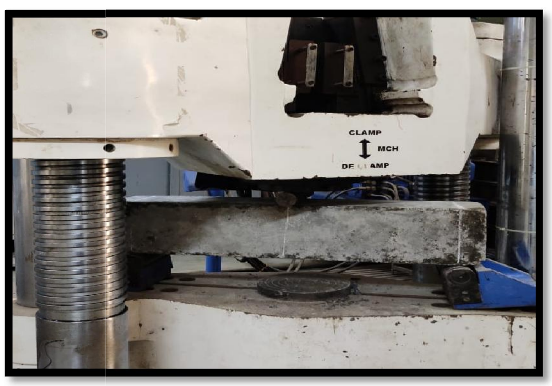

Fig. 3. Test Setup of flexural beam for one point loading

IV. RESULTS AND DISCUSSION

4.1 Compressive Strength Epoxy-modified concrete exhibited increased compressive strength compared to conventional concrete:

3 Days: 34% increase.

7 Days: 20.27% increase.

28 Days: 11.97% increase.

This improvement is attributed to the interaction of epoxy resin with cement hydration products, enhancing the matrix's strength.

4.2 Ultrasonic Pulse Velocity (UPV) UPV results showed significant improvement in concrete quality for epoxy-modified specimens:

- **Without Cracks:** Velocity increased to 4.79 km/s (excellent quality).
- **After Healing:** Velocity improved to 3.88 km/s, indicating effective self-healing.

4.3 Flexural Strength

- **One-Point Loading:** Flexural strength increased by 7.4%.
- **Two-Point Loading:** Flexural strength increased by 43%.

4.4 Structural Performance Structural beams with epoxy resin exhibited higher load-carrying capacities and better crack resistance compared to control specimens:

- **One-Point Loading:** Strength gain of 19.58%.
- **Two-Point Loading:** Strength gain of 30.91%.

V. CONCLUSION

The use of epoxy resin as a self-healing agent in concrete offers significant improvements in compressive strength, flexural strength, and crack-healing efficiency. Key findings include:
Increased compressive strength by up to 34%.
Improved flexural strength by 7.4% (one-point loading) and 43% (two-point loading).
Enhanced self-healing efficiency as demonstrated by UPV testing.
Superior load-carrying capacity of structural beams under both one-point and two-point loading.
Epoxy resin offers a cost-effective and efficient solution for enhancing the durability and performance of concrete structures without requiring a hardener. Future research should focus on scaling up this technology for field applications and exploring its long-term performance under varying environmental conditions.

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