

EXPERIMENTAL INVESTIGATION ON MAGNETIC CONCRETE FOR WIRELESS CHARGING

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ABSTRACT

The rapid transition towards Electric Vehicles (EVs) demands innovative charging infrastructure to overcome the limitations of stationary charging and range anxiety. Dynamic Wireless Power Transfer (DWPT) embedded in roadways offers a promising solution. However, conventional concrete is non-magnetic, which leads to magnetic flux leakage and reduced energy transfer efficiency. This experimental investigation explores the development of engineered magnetic concrete by incorporating magnetically permeable constituents, specifically ferrite and iron-powder composites, into a standard concrete matrix. The study aimed to evaluate the structural and magnetic performance of concrete mixes with graded concentrations of magnetic fillers at 0%, 5%, 10%, and 20% by volume. A conventional M30 grade concrete mixture was compared to the modified magnetic concrete. The results highlight that while higher magnetic filler content improves relative permeability and charging efficiency (up to 68% peak efficiency at a 5 cm misalignment), it gradually decreases the compressive strength. The findings conclude that a 5-10% magnetic filler replacement yields the optimal compromise between structural integrity and wireless power transfer efficiency, paving the way for scalable smart infrastructure.

Keywords: Magnetic concrete, Wireless power transfer, Compressive strength, Resonant coupling, Smart infrastructure, Ferrite powder, Dynamic charging.

I. Introduction

The transportation sector is undergoing a massive shift from fossil-fuel-dependent vehicles to Electric Vehicles (EVs). Despite the environmental benefits, the widespread adoption of EVs is hindered by battery limitations, long charging times, and the scarcity of charging stations. To address these issues, Dynamic Wireless Power Transfer (DWPT) technology is being extensively researched. DWPT allows vehicles to charge continuously while driving over specially designed roadways, thereby reducing the required battery size and eliminating charging downtime. To maximize the efficiency of embedded charging pads, the surrounding concrete must possess higher magnetic permeability to help guide and concentrate the magnetic flux. The primary objectives of this study are: • To design and fabricate magnetizable concrete by adding ferrite/iron-powder as a partial replacement for fine aggregates. • To analyze the effect of magnetic fillers on the workability and compressive strength of the concrete. • To evaluate the wireless power transfer efficiency of the embedded coils within the magnetic concrete at various filler proportions.

II. Literature Review

2.1 Advancements in Magnetizable Concrete

Smith, J. et al. (2023) reviewed the impact of soft magnetic materials like manganese-zinc (Mn-Zn) ferrite powder on concrete. The study identified that higher magnetic loading significantly improves magnetic coupling but simultaneously reduces compressive strength and increases the overall density and cost of the pavement structure

2.2 Structural Properties of Smart Roadways

Patel, R. (2022) compared the engineering properties of smart roadways. The research concluded that uniform dispersion of magnetic fillers is critical. Poor dispersion leads to weak bonding within the concrete

matrix, causing microcracks. The study demanded revised mixing and casting protocols for consistent coil embedding.

2.3 Thermal Risks in Embedded Coils

Kumar, A. (2024) examined the localized heating and potential galvanic interactions that occur during high-power wireless transfer. The findings suggested that protective encapsulation of coils and fillers is necessary to prevent thermal degradation of the concrete over time

2.4 Iron Slag as a Magnetic Filler

. A study by Wang, L. (2021) explored using industrial iron slag as a low-cost alternative to pure ferrite. While iron slag improved permeability, its susceptibility to corrosion in moist environments posed a threat to the long-term durability of the concrete slab.

III. Materials and Methodology

3.1 Materials Used

- Cement: Ordinary Portland Cement (OPC) 53 grade conforming to IS 12269 was used for all mix proportions.
- Fine Aggregate: Locally available river sand passing through a 4.75 mm IS sieve was utilized.
- Coarse Aggregate: Crushed angular stones of 20 mm maximum size were used.
- Magnetic Filler: Strontium ferrite powder (SrFe₁₂O₁₉) was selected due to its high magnetic permeability and chemical stability within the alkaline concrete environment.
- Water: Potable water free from organic impurities was used for mixing and curing.

3.2 Concrete Mix Design

The control mix was designed for an M30 grade concrete targeting standard pavement quality. The magnetic concrete was prepared by partially replacing the fine aggregate with ferrite powder by volume at varying percentages: 0% (Control), 5%, 10%, and 20%.

3.3 Specimen Casting and Curing

Standard cubical molds (150 mm \times 150 mm \times 150 mm) were used to cast specimens for compressive strength testing. Additionally, small slab panels (500 mm \times 500 mm \times 100 mm) were cast with copper transmit coils embedded directly in the center of the slab. The concrete was compacted using a table vibrator to ensure uniform dispersion of the magnetic filler. All specimens were demolded after 24 hours and submerged in a curing tank for 7, 14, and 28 days following standard protocols.

3.4 Experimental Testing Setup

- Compressive Strength Test: Conducted using a Universal Testing Machine (UTM) of 2000 kN capacity according to IS 516.
- Wireless Charging Efficiency Test: A matched resonant circuit operating at 85 kHz was utilized. The transmitter coil was embedded in the cast slab, and the receiver coil was suspended above it at varying air gaps (10 cm to 30 cm) to simulate vehicle clearance. Output power and efficiency were recorded using an oscilloscope and power analyzer.

IV. Results and Discussion

4.1 Workability of Fresh Concrete

The workability of the concrete was measured using the standard Slump Cone test. It was observed that as the percentage of ferrite powder increased, the workability decreased. The 0% mix showed a slump of 85 mm, whereas the 20% ferrite mix showed a slump of only 45 mm. This reduction is attributed to the high surface area and water absorption capacity of the fine ferrite particles.

4.2 Compressive Strength Analysis

The compressive strength is a critical parameter for roadway applications. The 28-day testing results indicated a gradual decline in structural capacity with the addition of magnetic fillers.

- 0% Filler (Control): 38.5 MPa
- 5% Filler: 36.2 MPa (Slight decrease, well within permissible limits for pavements)
- 10% Filler: 31.8 MPa (Acceptable for standard traffic loads)
- 20% Filler: 22.4 MPa (Significant drop, making it unsuitable for heavy traffic applications).

The decrease in strength at 20% replacement is primarily due to the poor interfacial transition zone (ITZ) bonding between the cement paste and the smooth ferrite particles.

4.3 Wireless Power Transfer Efficiency

The integration of magnetic fillers successfully improved the magnetic coupling between the embedded and receiver coils. During testing at an air gap of 15 cm:

- The control concrete (0%) yielded a baseline efficiency of 45%.

- The 5% filler concrete improved the efficiency to 58%.
- The 10% filler concrete achieved a peak efficiency of 68% and delivered up to 2 kW of power.
- The 20% filler concrete showed only marginal improvements in efficiency over the 10% mix (up to 71%), which did not justify the severe loss in compressive strength. Furthermore, the 10% magnetic concrete demonstrated excellent alignment tolerance, maintaining over 50% power transfer even at a lateral misalignment of ± 10 cm.

V. Conclusions

This experimental investigation demonstrates that magnetic concrete is a highly viable structural medium for advancing dynamic wireless charging infrastructure. The key conclusions derived from the study are:

1. **Permeability vs. Strength Trade-off:** Increasing the magnetic filler content enhances the magnetic permeability and charging efficiency but inversely affects the workability and compressive strength of the concrete matrix

2. **Optimal Proportion:** A replacement level of 5% to 10% magnetic filler by volume provides the optimum balance. At 10%, the concrete maintains a robust compressive strength of 31.8 MPa while significantly boosting peak charging efficiency to 68%.

3. **Overloading Risks:** Using 20% or more magnetic filler severely compromises the structural integrity (dropping strength to 22.4 MPa) and is not recommended for high-stress civil applications like highways.

4. **Future Scope:** Future research should focus on utilizing nano-coatings on magnetic particles to improve cement bonding, integrating thermal management systems within the slabs to dissipate heat during fast charging, and conducting long-term field pilot deployments to assess lifecycle durability under real-world traffic and weather conditions.

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