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Enhancing Sustainability in Concrete Through the Reuse of Expired Calcium-Based Pharmaceutical Waste

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Abstract: *The increasing generation of expired pharmaceutical products and the environmental burden associated with cement manufacturing have encouraged the exploration of sustainable alternatives in construction materials. This study examines the potential application of expired calcium-based medicine powder as a partial substitute for Ordinary Portland Cement (OPC) in concrete production. Finely processed medicine powder was incorporated into concrete mixtures at replacement levels of 5%, 10%, and 15% by weight of cement, while a conventional concrete mix was used as a control specimen.*

The influence of the replacement material on fresh and hardened concrete properties was investigated through workability, setting time, soundness, compressive strength, flexural strength, and split tensile strength tests. Experimental findings revealed a gradual reduction in workability with increasing replacement percentage due to the finer particle size of the medicine powder. Setting time and soundness values exhibited moderate increases but remained within acceptable limits for all replacement levels investigated.

Among the mixes tested, the 5% replacement level demonstrated the most favorable performance, achieving a 28-day compressive strength of 42 MPa compared with 40 MPa for conventional concrete. Improvements were also observed in flexural and split tensile strengths, indicating enhanced particle packing and matrix densification. Higher replacement levels resulted in a gradual decline in mechanical performance because of reduced cementitious content.

The study demonstrates that limited incorporation of expired calcium-based medicine powder can serve as a sustainable supplementary material in concrete, contributing to pharmaceutical waste utilization, reduction of cement consumption, and environmentally responsible construction practices..

Keywords: Sustainable concrete, Expired medicines, Cement replacement, Pharmaceutical waste utilization, Calcium-based medicine powder, Supplementary cementitious material, Mechanical properties, Green construction, Sustainable waste management

I. INTRODUCTION

Concrete is the most extensively utilized construction material worldwide due to its versatility, durability, and ability to meet a wide range of structural requirements. Ordinary Portland Cement (OPC), which serves as the primary binding component in concrete, plays a crucial role in determining the strength and performance of the material. However, the production of cement is associated with substantial energy consumption and significant carbon dioxide emissions, contributing considerably to global environmental concerns. As infrastructure development continues to expand, the need for sustainable construction materials that reduce dependence on conventional cement has become increasingly important.

In recent decades, researchers have focused on incorporating various waste-derived materials into concrete as partial cement replacements. Industrial by-products and agricultural residues such as fly ash, silica fume, metakaolin, ground granulated blast furnace slag, and rice husk ash have demonstrated considerable potential in improving concrete sustainability while reducing environmental impacts. The utilization of such materials not only decreases cement consumption but also promotes resource conservation and waste management.

Simultaneously, the pharmaceutical sector generates large quantities of expired and unused medicines every year. Improper disposal of pharmaceutical waste through landfilling, open dumping, or wastewater systems can lead to soil contamination, groundwater pollution, and adverse ecological effects. Conventional disposal methods, including incineration and chemical treatment, often involve high operational costs and may create additional environmental burdens. Consequently, identifying alternative applications for pharmaceutical waste has become an important aspect of sustainable waste management strategies.

Among different categories of pharmaceutical products, calcium-based medicines are widely consumed and therefore contribute significantly to expired medicinal waste. These medicines contain calcium-rich compounds that may exhibit characteristics beneficial to cementitious systems. When finely processed, such materials can potentially act as micro-fillers within the concrete matrix, improving particle packing and influencing hydration processes. Their calcium content may also contribute to the development of a denser microstructure, thereby affecting the mechanical performance of concrete.

Although extensive research has been conducted on traditional supplementary cementitious materials, studies investigating the direct utilization of expired calcium-based medicines in concrete remain limited. Existing literature primarily focuses on industrial by-products and recycled construction materials, leaving a noticeable research gap regarding the reuse of pharmaceutical waste in structural applications. Therefore, evaluating the engineering performance of concrete containing expired calcium-based medicine powder is necessary to determine its feasibility as a sustainable construction material.

The present study investigates the suitability of expired calcium-based medicine powder as a partial replacement for Ordinary Portland Cement in concrete. Replacement levels of 5%, 10%, and 15% by weight of cement were examined to assess their influence on workability, setting characteristics, soundness, compressive strength, flexural strength, and split tensile strength. The research aims to identify an optimum replacement level that balances mechanical performance with environmental benefits, thereby contributing to sustainable construction practices and responsible pharmaceutical waste utilization.

II. LITERATURE SURVEY

The increasing emphasis on sustainable construction has encouraged researchers to investigate alternative materials that can partially replace cement while maintaining acceptable engineering performance. Numerous studies have demonstrated that the incorporation of waste-derived materials into concrete not only reduces environmental impacts but also contributes to resource conservation and waste management.

Alaa A. Abdul Hamead (2020) examined the possibility of utilizing expired pharmaceutical products in cement-based materials. Various types of discarded medicines were finely processed and incorporated into mortar mixtures as partial cement replacements. The investigation revealed that the presence of pharmaceutical waste influenced hydration behavior and microstructural development, leading to satisfactory mechanical performance at lower replacement levels. The study highlighted the potential of pharmaceutical waste as a value-added material in construction applications.

Kaptan, Cunha, and Aguiar (2024) reviewed the application of recycled concrete powder as a supplementary cementitious material. Their findings indicated that the physical and chemical properties of recycled powder, including particle size distribution and mineral composition, significantly affect concrete performance. The authors emphasized that appropriate processing techniques such as grinding, thermal activation, and carbonation treatment can improve material reactivity and enhance its contribution to cementitious systems.

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Singh, Kushwaha, and Rana (2024) investigated the effect of metakaolin as a partial replacement for cement in concrete. The results demonstrated improvements in compressive strength, durability, and resistance to aggressive environmental conditions. The study reported that replacement levels ranging from 5% to 15% produced beneficial effects due to enhanced pozzolanic activity and refinement of the concrete microstructure.

Several researchers have also explored the utilization of industrial by-products such as fly ash, silica fume, and ground granulated blast furnace slag. These materials have been found to improve long-term strength, reduce permeability, and enhance durability characteristics while decreasing the environmental footprint associated with cement production. Their successful application has encouraged further research into unconventional waste materials for sustainable concrete development.

Recent studies have highlighted the importance of calcium-rich waste materials in cementitious composites. Such materials can act as micro-fillers and contribute to improved particle packing, resulting in a denser matrix and enhanced mechanical properties. The presence of calcium compounds may also influence hydration reactions, thereby affecting strength development and overall concrete performance.

Despite extensive research on industrial and agricultural waste materials, limited attention has been given to the direct utilization of expired calcium-based medicines in concrete. Most available investigations focus on traditional supplementary cementitious materials or pharmaceutical waste incorporation in mortar systems rather than concrete. Furthermore, information regarding the influence of calcium-based medicinal waste on workability, setting characteristics, compressive strength, flexural strength, and split tensile strength remains scarce.

Therefore, there is a clear need for experimental studies aimed at evaluating the feasibility of using expired calcium-based medicine powder as a partial cement replacement. Such investigations can contribute to the development of environmentally responsible waste management practices while supporting the production of sustainable and resource-efficient construction materials..

III. MATERIALS AND METHODOLOGY

Ordinary Portland Cement (OPC) conforming to IS 12269 specifications was used as the primary binding material for preparing concrete mixes. Expired calcium-based medicines collected from local medical stores and healthcare facilities were selected for the study. The collected medicines were carefully segregated to remove external packaging materials and unwanted impurities before processing. The medicines were then crushed and ground into a fine powder using a grinding machine to achieve a particle size comparable to cement.

Table 2. Physical Properties of OPC and Medicine Powder

Property	OPC	Medicine Powder
Color	Grey	Off-white
Specific Gravity	3.15	2.23
Fineness	92.3%	96.3%
Particle Size	75 µm	65 µm

Preliminary characterisation of the processed medicinal powder was conducted to assess its suitability as a supplementary cementitious material. The physical properties considered in the investigation included standard consistency, setting time, and soundness. The results indicated that water demand increased gradually with higher replacement levels, while setting time decreased because of the calcium-rich nature of the medicine powder. Soundness values also increased with increasing replacement percentage; however, mixes up to 15% replacement remained within acceptable limits, whereas the 20% replacement level showed excessive expansion and was considered unsuitable for concrete applications.

3.1 Concrete Mix Design

The concrete mix design adopted in this study was developed in accordance with standard concrete mix proportioning procedures to achieve the desired strength and workability characteristics. Ordinary Portland Cement (OPC) was

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partially replaced with finely ground expired calcium-based medicine powder at replacement levels of 5%, 10%, and 15% by weight of cement. A control mix without medicine powder was also prepared for comparison. The total cementitious material content was maintained at 400 kg/m³ for all mixes, while a constant water-cement ratio of 0.45 was used throughout the experimental program to ensure consistency in performance evaluation. Natural fine aggregate and crushed coarse aggregate conforming to standard grading requirements were used in all concrete mixtures. The medicine powder replacement quantities were fixed at 20 kg/m³, 40 kg/m³, and 60 kg/m³ for 5%, 10%, and 15% replacement levels, respectively. The concrete ingredients were thoroughly mixed to obtain a homogeneous mixture before casting. Fresh concrete properties were evaluated using slump tests, and hardened concrete specimens were tested after 7 and 28 days of curing. The adopted mix proportions enabled a comparative assessment of the influence of medicine powder incorporation on the mechanical and workability properties of concrete.

Table 3. Concrete Mix Proportions

Mix ID	Cement (%)	Medicine Powder (%)	Cement (kg/m³)	Medicine (kg/m³)	Powder Water-Cement Ratio
M0	100	0	400	0	0.45
M1	95	5	380	20	0.45
M2	90	10	360	40	0.45
M3	85	15	340	60	0.45

3.2 Experimental Procedure

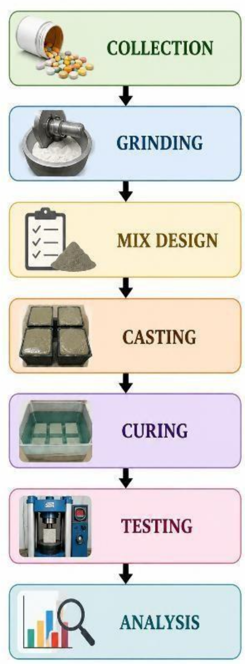

Figure 1 Experimental Procedure Adopted in the Present Study

The flowchart in Figure 1 outlines the experimental methodology for testing the use of expired calcium-based medicine powder as a partial replacement for cement in concrete. It started with collecting medicines from stores, crushing them into fine powder, and then preparing concrete mixes with different replacement levels. The mixes were cast into molds, compacted, and cured under standard conditions. The specimens underwent mechanical tests, including compressive, flexural, and split tensile strength tests. Results were compared to control mixes to assess the influence of medicine powder on concrete's properties.

3.3 Fresh Concrete Properties

The properties of fresh concrete were notably affected by adding expired calcium-based medicine powder as a partial cement replacement. Results showed a slow, steady rise in both initial and final setting times as the replacement percentage increased. The control mix had an initial setting time of 45 minutes and a final time of 600 minutes. In comparison, the 15% replacement mix had setting times of 60 and 667 minutes, respectively. This extension in setting time likely results from changes in hydration behavior caused by the presence of the medicine powder in the cement matrix. Soundness values also increased gradually with higher replacement levels, but all mixes remained within acceptable limits, confirming that the blended cement maintained sufficient dimensional stability.

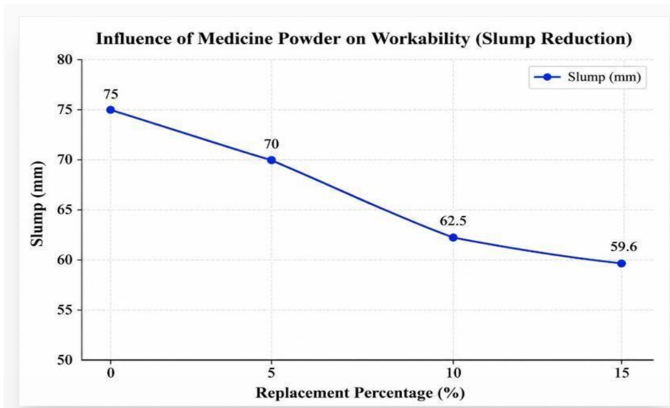

Figure 2: Influence of medicine powder on workability

Workability, measured by the slump test, decreased with increasing medicine powder content, from 75 mm in the control to 59.6 mm at 15% replacement. This decrease is due to the powder's finer particles and increased water demand. Compressive strength remained satisfactory at lower replacement levels but decreased at higher replacement levels. Overall, small amounts of expired calcium medicine powder can be used without greatly affecting the concrete's properties and performance.

Replacement Level	Setting Time (minutes)	Soundness (Le Chatelier Expansion, mm)	Workability (Slump, mm)	Remarks
0% (Control)	Initial: 45 Final: 600	1.0	75	Reference mix with conventional cement properties
5%	Initial: 50 Final: 620	1.2	70	Slight increase in setting time and soundness with acceptable strength
10%	Initial: 60 Final: 640	1.5	62.5	Moderate reduction in strength and workability observed
15%	Initial: 60 Final: 667	2.0	59.6	Increased expansion and reduced workability require careful monitoring

Table 4. Fresh Concrete and Cement–Medicine Blend Properties

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IV. RESULTS AND DISCUSSION

Comparative Analysis of Mechanical Properties

Table 5. Mechanical Properties of Concrete Mixes

7-Day Mix ID	Replacement Level (%)	Strength (MPa)	28-Day Strength (MPa)	Flexural (MPa) (4.8)	Split Tensile Strength Strength (MPa)
M0	0	28	40	4.8	3.9
M1	5	30	42	5.2	4.2
M2	10	27	38	4.5	3.6
M3	15	23	32	3.8	3.0

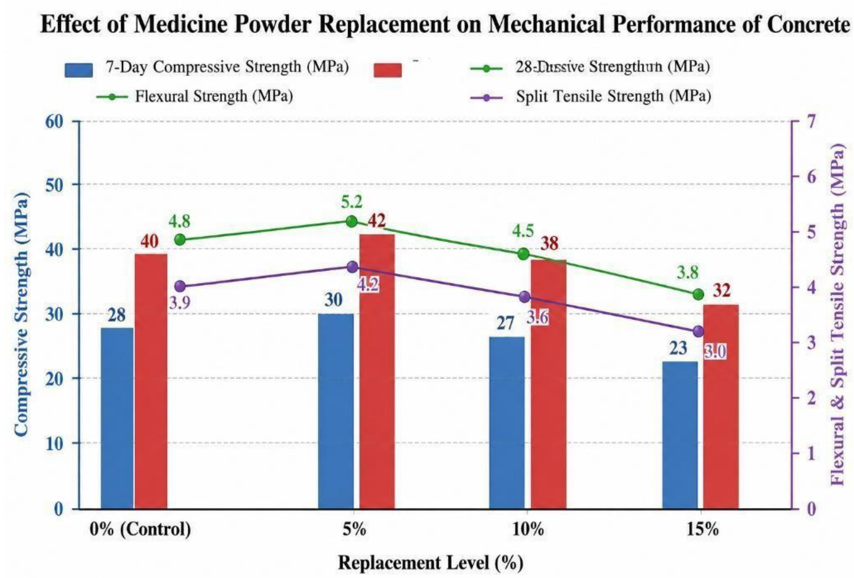

Figure 3: Effect of medicine powder replacement on the mechanical performance of concrete

The mechanical properties of concrete were significantly influenced by incorporating expired calcium-based medicine powder as a partial cement replacement. The results in Table 4 indicate that the 5% replacement mix (M1) exhibited the best overall mechanical performance among all mixes investigated. At 7 days, the compressive strength increased from 28 MPa for the control mix (M0) to 30 MPa for M1, while the 28-day compressive strength improved from 40 MPa to 42 MPa. Similarly, flexural and split tensile strengths increased from 4.8 MPa and 3.9 MPa in the control mix to 5.2 MPa and 4.2 MPa, respectively. This improvement may be attributed to the filler effect of the finely ground medicine powder and the presence of calcium-rich compounds, which may have enhanced hydration and resulted in a denser concrete matrix. However, further increases in the replacement percentage led to a gradual reduction in strength properties. The 10% replacement mix (M2) showed a slight decrease in compressive, flexural, and split tensile strengths compared with the control mix, although the values remained within acceptable limits for non-structural applications. At 15% replacement (M3), a more pronounced reduction in mechanical performance was observed, with the 28-day compressive strength decreasing to 32 MPa. The reduction in strength at higher replacement levels may be due to the lower availability of cementitious compounds and weaker bonding within the concrete matrix caused by excessive cement replacement.

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Fig 4: Concrete Test Cubes

Overall, the comparative analysis demonstrates that limited incorporation of expired calcium-based medicine powder can improve concrete performance, whereas excessive replacement adversely affects the mechanical characteristics of concrete. Among all the mixes studied, the 5% replacement level was identified as the optimum dosage for achieving improved strength and satisfactory overall performance.

V. CONCLUSION

The present study investigated the feasibility of utilising expired calcium-based medicine powder as a partial replacement for Ordinary Portland Cement in concrete. Based on the experimental investigation and comparative analysis, the following conclusions were drawn:

- The incorporation of expired calcium-based medicine powder influenced both the fresh and hardened properties of concrete, with the extent of variation depending on the replacement percentage.
- Workability decreased progressively with increasing medicine powder content. The slump value reduced from 75 mm for the control mix to 59.6 mm at 15% replacement due to the finer particle size and increased water demand of the medicine powder.
- Initial and final setting times increased gradually with higher replacement levels, indicating modifications in the hydration characteristics of the blended cement system.
- Soundness values also increased with increasing replacement percentage; however, all mixes up to 15% replacement remained within acceptable limits, demonstrating satisfactory dimensional stability.
- Among all the mixes investigated, the 5% replacement mix exhibited the best overall mechanical performance. The 28-day compressive strength increased from 40 MPa in the control mix to 42 MPa with a 5% replacement. Similarly, flexural and split tensile strengths increased from 4.8 MPa and 3.9 MPa to 5.2 MPa and 4.2 MPa, respectively.
- The improvement observed at lower replacement levels may be attributed to the filler effect of the finely ground medicine powder and the presence of calcium-rich compounds that contributed to better particle packing and enhanced hydration reactions.
- Further increase in replacement percentage beyond 5% resulted in gradual reductions in compressive, flexural, and split tensile strengths because of the reduced availability of cementitious compounds and weaker bonding within the concrete matrix.
- The 10% replacement mix maintained acceptable mechanical properties for non-structural applications, whereas the 15% replacement level showed a more noticeable decline in performance and workability.
- Overall, the experimental findings demonstrate that expired calcium-based medicine powder can be effectively utilised as a sustainable supplementary material in concrete at lower replacement levels.

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• Based on the comparative performance evaluation, 5% replacement of cement with expired calcium-based medicine powder was identified as the optimum replacement level for achieving improved strength and satisfactory overall concrete performance while also contributing to environmentally responsible pharmaceutical waste management and reduction in cement consumption.

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