

Use of the Eggshell Powder as A Partial Replacement of Cement in Concrete

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Abstract - Concrete is the most widely used construction material, but its dependence on cement raises serious environmental concerns. Cement manufacturing accounts for nearly 8% of global carbon dioxide emissions, underscoring the need for sustainable alternatives. Eggshells, which are rich in calcium carbonate, are typically discarded as waste. Processing them into fine powder provides an opportunity to reduce cement consumption while promoting waste recycling.

This study examines the potential of eggshell powder (ESP) as a partial cement replacement in M30-grade concrete. Concrete mixes containing 1%, 3%, 5%, and 7% ESP by weight of cement were prepared and tested. Mechanical properties, including compressive and flexural strength, and durability characteristics, were evaluated. The results are expected to show that ESP can replace 10–15% of cement without significant loss of strength. This approach supports eco-friendly, cost-effective, and sustainable construction practices.

Keywords: Concrete | Cement Replacement | Eggshell Powder (ESP) | Sustainable Construction | Waste Recycling | Calcium Carbonate (CaCO₃) | M30 Grade Concrete | Compressive Strength | Flexural Strength | Durability | Green Materials

1. INTRODUCTION

Concrete is the backbone of modern infrastructure, valued for its versatility, durability, and cost-effectiveness. However, its primary binder—cement—poses a significant environmental challenge. Cement manufacturing is highly energy-intensive and contributes nearly 8% of global carbon dioxide emissions, making it one of the largest industrial sources of greenhouse gases. This environmental burden has prompted researchers worldwide to investigate sustainable alternatives that can reduce cement consumption while maintaining the performance of concrete.

Eggshells, a common household and industrial waste product, are predominantly composed of calcium carbonate (CaCO₃), the same compound that forms the basis of cement. On average, eggshells contain about 95% calcium carbonate along with trace elements such as magnesium,

phosphorus, sodium, and zinc. Despite their abundance, eggshells are often discarded in landfills, where they contribute to waste management problems and environmental hazards. Processing eggshells into fine powder provides a dual advantage: lowering cement demand and promoting waste recycling.

This study explores the potential of eggshell powder (ESP) as a partial replacement for cement in M30 grade concrete. Concrete mixes incorporating 1%, 3%, 5%, and 7% ESP by weight of cement were prepared and tested for mechanical properties such as compressive and flexural strength, as well as durability characteristics. The performance of ESP-modified mixes was compared against conventional M30 concrete. Preliminary expectations suggest that ESP can replace cement up to 10–15% without compromising strength, thereby offering an eco-friendly, low-cost, and sustainable solution for construction practices.

1.1 Objectives:

This study's main goals are to:

- To investigate the feasibility of using Egg Shell Powder (ESP) as a partial replacement for cement in M30 grade concrete.
- To evaluate the mechanical properties (compressive and flexural strength) of ESP-modified concrete.
- To assess the durability performance of concrete mixes containing ESP.
- To determine the optimum percentage of ESP replacement that balances strength and sustainability.

1.2 Scope of study:

- Laboratory-scale experiments using M30 grade concrete.
- ESP replacement levels restricted to 1%, 3%, 5%, and 7% by weight of cement.
- Mechanical and durability properties tested at 7, 14, and 28 days of curing.
- The study provides a foundation for future large-scale applications but does not extend to field implementation.

2. MATERIALS

2.1 Cement

The physical properties of cement play a crucial role in determining its quality, performance, and suitability for construction applications. In India, these properties are standardized and tested according to the guidelines specified by the Bureau of Indian Standards (BIS). The testing procedures are mainly covered under the IS 4031 series, which provides detailed methods for evaluating different physical characteristics of cement.

Table -1: Physical properties of Cement

S.no	Properties	Result obtained	IS Codes
1.	Fineness test	4%	31:1988 -(P-1)
2	Standard consistency	32%	31:1988 -(P-4)
3	Initial setting time	42 min	31:1988 -(P-5)
4	Final setting time	600 min	
5	Specific gravity	3.17	IS 4031:1988 - (P-11)

2.2 Fine aggregates

Natural river sand was used as the fine aggregate in this study, conforming to the specifications of Bureau of Indian Standards under IS 383:2016. This standard ensures that the aggregate used in concrete meets the required quality, grading, and performance criteria. The selected sand was **clean and free from impurities**, which is essential for achieving good bonding between cement paste and aggregates. The absence of harmful materials such as clay, silt, and organic matter prevents issues like reduced strength, poor workability, and durability problems in concrete.

Table-2: Physical properties of Fine Aggregate

S.no	Properties	Result obtained
1.	Fineness Modulus	2.96
2	Blanking of fine Aggregates	52%
3	Specific gravity	2.71

2.3 Coarse aggregates

Crushed granite with a maximum size of 20 mm was used as coarse aggregate. The aggregates were angular, hard, and free from dust or deleterious materials. They conformed to IS 383:2016 standards and had a specific gravity of about 2.7.

Table-3: Physical properties of Coarse Aggregate

S.no	Properties	Result obtained
1.	Specific gravity	2.78
2	Aggregate impact value	3%
3	Fineness Modulus	7.36

2.4 Water

Potable water free from impurities such as oils, acids, and salts was used for mixing and curing. The water quality satisfied the requirements of IS 456:2000. pH Level: To guarantee ideal hydration and curing, the water's pH level should be neutral or slightly alkaline (usually between 6.5 and 8.5).

2.5. Egg Shell Powder (ESP)

Eggshells were collected from local sources, thoroughly washed to remove membranes, dried, and ground into fine powder. The powder was sieved through a 90-micron sieve to ensure uniform particle size. Chemical analysis confirmed that ESP contained approximately 95% calcium carbonate (CaCO_3), along with trace elements such as magnesium, phosphorus, sodium, and zinc.



Fig.1:- Egg Shell Powder (ESP)

Table-4: Physical properties of Egg Shell Powder

S.no	Properties	Result obtained
1.	Specific gravity	2.44
2	Standard consistency	39%
3	Initial setting time	3mins

3. METHODOLOGY

3.1 Preparation of Eggshell Powder (ESP)

The preparation of Eggshell Powder (ESP) is a crucial step to ensure its suitability as a partial replacement for cement in concrete. Proper processing helps in achieving uniformity, removing impurities, and improving its performance in the concrete mix. The procedure adopted in this study is described below:

a. Collection:

Eggshells were collected in bulk from local food outlets, hotels, and domestic kitchen waste. During collection, care was taken to avoid contamination with other waste materials such as plastics or organic residues. This ensures the purity of the raw material and reduces the need for excessive cleaning.

b. Cleaning:

The collected eggshells were thoroughly washed with clean water to remove dirt, dust, and adhering egg membranes. Any residual egg content was also removed during this process. Proper cleaning is essential to eliminate unpleasant odour, prevent bacterial growth, and avoid the presence of organic impurities that may negatively affect the properties of concrete.

c. Drying:

After cleaning, the eggshells were first sun-dried for 2–3 days to remove surface moisture. To ensure complete removal of internal moisture, the shells were further dried in an oven at a temperature of 105°C for 24 hours. This step is important because the presence of moisture can affect grinding efficiency and the quality of the final powder.

d. Grinding:

The dried eggshells were then crushed and ground into a fine powder using a mechanical grinder. Grinding was carried out until a uniform and smooth texture was obtained. Finer particles improve the reactivity and filler effect of ESP in concrete, enhancing strength and workability.

e. Sieving:

The ground powder was sieved through a 90-micron IS sieve to obtain particles of uniform size comparable to cement fineness. This ensures better mixing, proper dispersion in the cement matrix, and improved bonding within the concrete.

f. Storage:

The prepared Eggshell Powder was stored in airtight containers to prevent moisture absorption and contamination from external impurities. It was kept in a dry and controlled environment until it was used in concrete mix preparation. Proper storage helps in maintaining the quality and consistency of ESP.



Fig. 2:- ESP making process for concrete applications

3.2. Mix Design:

The concrete mix design adopted in this study was carried out in accordance with the guidelines specified by the IS 10262:2009 for M30 grade concrete. This standard provides a systematic procedure for determining the appropriate proportions of cement, fine aggregate, coarse aggregate, and water to achieve the desired strength and workability.

Based on the mix design calculations, the quantities of materials required were determined specifically for casting nine concrete cubes. Proper adjustments were made to account for the partial replacement of cement with Eggshell Powder (ESP) at different percentages. The mix proportions were carefully maintained to ensure uniformity and consistency across all specimens.

The concrete specimens were prepared using standard cube moulds of size 150 mm × 150 mm ×

150 mm, which is the standard dimension for compressive strength testing. The total volume of concrete required was calculated by considering the volume of one cube and multiplying it by the number of specimens, along with an additional allowance for handling and wastage.

Table-5: Mix proportion

Material	ement	Fine aggregate	Coarse aggregate	Water
Weights(kg)	437.8	772.6	1009	197
proportion	1	1.76	2.3	0.45

Weighing of Materials and Mix Proportions

Weighing of Materials:

The weighing of materials is a critical step in concrete preparation, as it directly affects the accuracy and consistency of the mix. In this study, the quantities of materials required for casting nine concrete cubes were calculated based on the adopted mix design for M30 grade concrete. Each constituent material—cement, fine aggregate, coarse aggregate, Eggshell Powder (ESP), and water—was measured carefully using a digital weighing balance to ensure precision.

Proper weighing ensures that the designed water-cement ratio and mix proportions are strictly maintained. Any variation in material quantities may lead to inconsistencies in strength, workability, and durability of the concrete. Therefore, special attention was given to accurate batching to achieve reliable and repeatable results.

Mix Proportions:

Concrete mix proportions were determined according to standard mix design procedures for M30 grade concrete. In this study, cement was partially replaced with Eggshell

Powder (ESP) at different percentages, namely 0% (control mix), 1%, 3%, 5%, and 7% by weight of cement.

Each mix was prepared separately by thoroughly blending the dry materials first, followed by the addition of water to achieve a uniform and workable mix. The prepared concrete was then placed into cube moulds and compacted properly to eliminate air voids. After casting, all specimens were kept undisturbed for 24 hours at room temperature. Once the initial setting was completed, the cubes were carefully de-moulded and transferred to a curing tank containing clean water. The specimens were cured for different durations—3, 7, 14, and 28 days—to evaluate the strength development of concrete over time.

Curing is an essential process that ensures proper hydration of cement, leading to improved strength and durability. The variation in ESP percentages allowed for a comparative analysis of its effect on the mechanical properties of concrete at different curing stages.

Table -6: Mix Design of Concrete With ESP

S.no	Cement	F.A	C.A	ESP
1	100%	100%	100%	0%
2	99%	100%	100%	1%
3	97%	100%	100%	3%
4	95%	100%	100%	5%
5	93%	100%	100%	7%

3.3. Casting and Curing:

Mould Preparation:

Moulds were thoroughly cleaned to remove dust and old concrete, then oiled on inner surfaces to prevent sticking, ensuring smooth surface finish and easy removal of hardened concrete specimens.

Mixing:

All materials were mixed in proper proportions as per mix design, first dry mixing then adding water gradually, ensuring uniform distribution and achieving a consistent, workable concrete mix.

Casting:

Concrete was poured into moulds in layers and compacted using tamping or vibration to remove entrapped air, ensuring dense, uniform specimens with proper shape and improved strength characteristics.

Curing:

After 24 hours, specimens were carefully de-moulded and placed in clean water for curing at 3, 7, 14, and 28 days to ensure proper hydration, strength gain, and durability.



Fig- 3 Specimens

4. EXPERIMENTAL INVESTIGATION

4.1. Compressive strength

Compressive strength is a fundamental property of concrete that measures its ability to resist axial compressive loads without failure. It is an important indicator of the material's load-bearing capacity, durability, and overall structural performance. This property is commonly evaluated by testing standard concrete specimens, such as cubes or cylinders, under a compression testing machine after specific curing periods like 7 and 28 days. The results are expressed in megapascals (MPa) and are essential for design, quality control, and ensuring the safety of structures.

Table-6 Compressive strength results using of ESP

Testing Period	% of Replacement of ESP				
	0%	1%	3%	5%	7%
3 Days	14.44	23.33	18.88	20	19.6
7 Days	19.9	24.22	19.77	22.66	20.11
14 Days	28.5	29.11	27.44	28.22	27.44
28 Days	31.22	30.11	29.55	32.77	29.88

Graphs 1: Compressive strength results of ESP

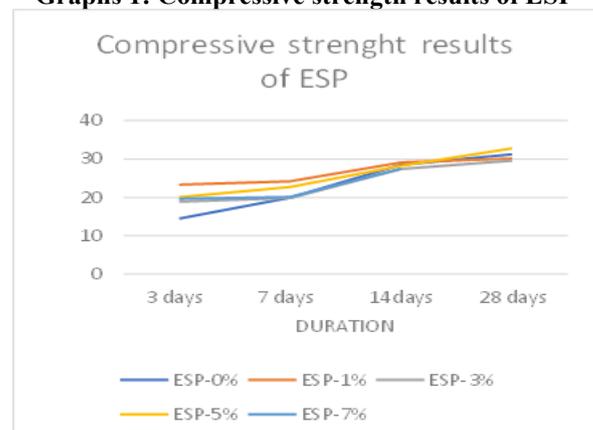




Fig- 4 Compressive Strength Testing On Specimen

5. CONCLUSION

This study focuses on evaluating the feasibility of using Eggshell Powder (ESP) as a partial replacement for cement in M30 grade concrete prepared with OPC 53 grade cement. The primary objective was to reduce cement consumption while maintaining or enhancing the strength characteristics of concrete. To achieve this, cement was replaced with ESP at proportions of 1%, 3%, 5%, and 7% by weight, and the performance of these mixes was compared with a conventional control mix without ESP.

The experimental investigation involved testing the **compressive strength** of concrete at different curing periods, namely 3, 7, 14, and 28 days. The results clearly indicated that ESP has a positive influence on the early strength development of concrete. Among all the mixes, the 1% ESP replacement showed the highest compressive strength at 3 and 7 days, demonstrating that a small percentage of ESP accelerates the hydration process due to its fine particle size and high calcium carbonate content.

At later stages, particularly at 28 days, the mix containing 5% ESP exhibited superior performance compared to the control mix. It achieved a compressive strength of 32.77 MPa, which is higher than the 31.22 MPa recorded for conventional concrete. This improvement can be attributed to the filler effect of ESP, which enhances particle packing and reduces voids in the concrete matrix, leading to increased density and strength.

The mixes with 3% and 7% ESP showed compressive strength values comparable to the control mix, indicating that the inclusion of ESP within this range does not adversely affect the mechanical properties of concrete. However, beyond an optimum level, the replacement may lead to dilution of cementitious content, which can slightly reduce strength.

Overall, the study concludes that ESP can be effectively used as a partial replacement for cement up to 5%–7% by weight without compromising the strength and performance of concrete. This not only contributes to reducing the environmental impact associated with cement production, particularly carbon dioxide (CO₂) emissions, but also promotes the utilization of waste materials like eggshells. Hence, the use of ESP supports the development of sustainable, eco-friendly, and cost-effective construction practices.

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IS: CODES

1. IS 456:2000 Code of practice for plain and reinforced concrete.
2. IS 516:1959 Method of test for strength of concrete.
3. IS: 2386 – methods of tests for aggregate for concrete.
4. IS: 269-2015 – specifications for 33, 43 and 53 grade OPC.
5. IS: 456; 10262; SP 23 – codes for designing concrete mixes.
6. IS 12269-1987 – Specification for 53 Grade OPC.
7. IS 2386 (Part III) 1963 – Methods of test for aggregate for specific gravity, density, voids, absorption and bulking.
8. IS 2386 (Part I) 1963 – Methods of test for aggregate for concrete particle size and shape.
9. IS 383-2016 – Specification for coarse and fine aggregate.