

A Review on on “Utilization of Eggshell Powder as Partial Replacement of Cement in Concrete”

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Abstract

The construction industry is facing major environmental challenges due to excessive cement production and disposal of waste materials. Eggshell waste generated from households, hotels, and food industries creates environmental and disposal problems. Researchers have therefore explored the use of eggshell powder (ESP) as a partial replacement of cement in concrete. This review paper presents a study on the properties, preparation, and utilization of eggshell powder in concrete. Previous research related to workability, compressive strength, split tensile strength, flexural strength, and durability characteristics of ESP concrete has been reviewed and analyzed. The reviewed studies indicate that eggshell powder can effectively replace cement up to 5–10% without significantly affecting concrete performance. Improvement in concrete properties is mainly due to filler effects and improved particle packing. However, higher replacement levels may reduce strength because of insufficient cementitious material. The study concludes that eggshell powder is a sustainable and eco-friendly material that can contribute to waste management and green concrete production.

Keywords: Eggshell Powder, Sustainable Concrete, Cement Replacement, Green Concrete, Waste Management.

1. INTRODUCTION

Concrete is one of the most widely used construction materials in the world due to its strength, durability, and versatility. Cement acts as the primary binding material in concrete; however, cement production is associated with several environmental problems such as excessive carbon dioxide emissions, high energy consumption, and depletion of natural resources. It is estimated that cement manufacturing contributes significantly to global greenhouse gas emissions. Therefore, researchers and engineers are continuously searching for sustainable and environmentally friendly alternatives to reduce cement consumption in concrete production.

In recent years, the utilization of industrial, agricultural, and domestic waste materials in concrete has become an important area of research in sustainable construction. Materials such as fly ash, silica fume, rice husk ash, ground granulated blast furnace slag (GGBS), and eggshell powder have been investigated as supplementary cementitious materials. Among these materials, eggshell powder (ESP) has gained increasing attention because of its high calcium carbonate (CaCO_3) content and easy availability.

Large quantities of eggshell waste are generated daily from households, restaurants, bakeries, poultry farms, and food processing industries. Improper disposal of eggshell waste creates environmental and hygienic problems. Since eggshells mainly consist of calcium carbonate, they possess properties similar to limestone, which is one of the primary raw materials used in cement manufacturing. Therefore, eggshell powder can potentially be utilized as a partial replacement of cement in concrete.

The use of eggshell powder in concrete offers several advantages, including reduction in cement consumption, waste recycling, environmental protection, and development of sustainable construction materials. In addition, fine ESP particles contribute to filler effect and improved particle packing, which may enhance concrete properties at optimum replacement levels.

Several researchers have investigated the influence of eggshell powder on workability, compressive strength, split tensile strength, flexural strength, durability, and microstructural characteristics of concrete. Most studies reported that partial replacement of cement with eggshell powder up to 5–10% produces satisfactory mechanical and durability performance.

This review paper aims to critically analyze and summarize previous studies related to the utilization of eggshell powder as partial replacement of cement in concrete. The paper also identifies research gaps, discusses environmental benefits, and highlights future research opportunities for sustainable construction applications.

Objectives of the Study

The main objectives of this review paper are:

1. To study the properties and characteristics of eggshell powder.
2. To review previous research on utilization of ESP as partial replacement of cement.
3. To analyze the effect of ESP on workability and strength properties of concrete.
4. To evaluate durability and sustainability aspects of ESP concrete.
5. To identify research gaps and future scope for further investigation.
6. To promote sustainable and eco-friendly construction practices.

Eggshell Powder as Sustainable Construction Material:

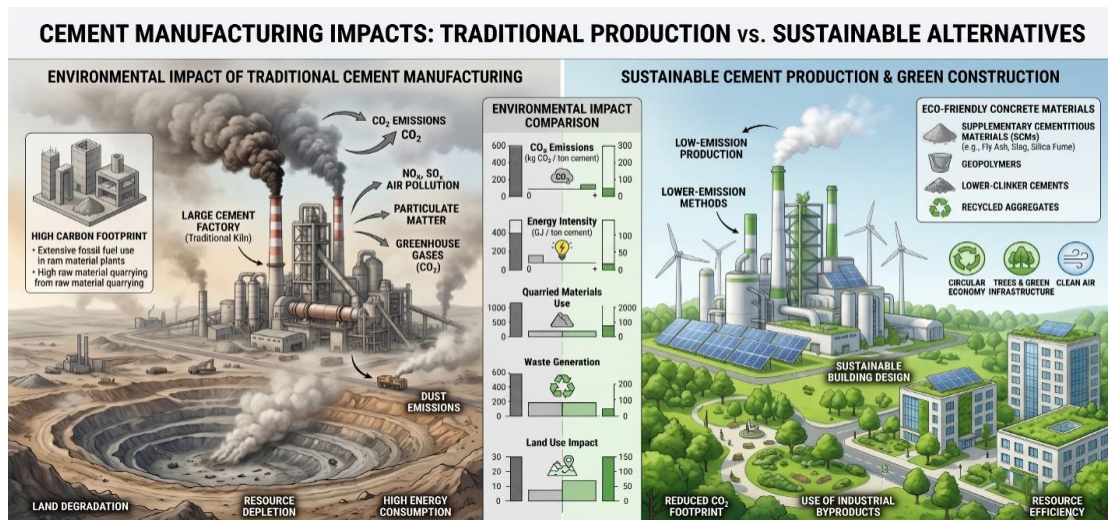
Eggshells are one of the major domestic and food industry waste generated worldwide. They are mainly composed of calcium carbonate along with small quantities of magnesium carbonate, calcium phosphate, and organic matter. Due to the high calcium content, eggshell powder exhibits characteristics like cementitious and filler materials.

The preparation of eggshell powder generally involves collection, washing, drying, crushing, grinding, and sieving processes. Proper cleaning and grinding are important to achieve uniform particle size and improved performance in concrete. Fine ESP particles improve packing density within concrete and reduce micro-voids.

Chemical Composition of Eggshell Powder

Compound	Percentage (%)
Calcium Carbonate (CaCO ₃)	94–97
Magnesium Carbonate	1
Calcium Phosphate	1
Organic Matter	2-4

The calcium-rich composition of ESP contributes to improved hydration and filler action in concrete. Because of these characteristics, eggshell powder is considered a promising material for sustainable concrete production.



2. LITERATURE REVIEW

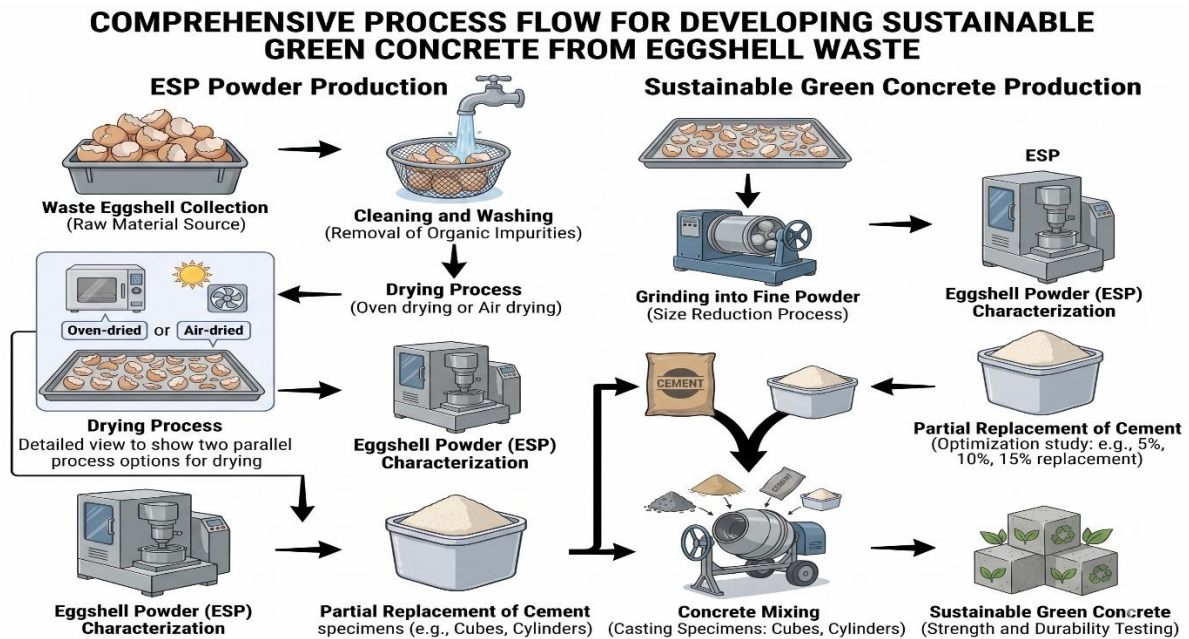
The utilization of waste materials in concrete has become an important area of research in sustainable construction. Among various waste materials, eggshell powder (ESP) has gained significant attention due to its high calcium carbonate content and easy availability. Several researchers have investigated the effect of eggshell powder as a partial replacement of cement in concrete and mortar. Most studies reported that controlled replacement of cement with eggshell powder can improve concrete properties while reducing environmental impact.

- ❖ Tie et al. (2022) conducted an experimental study on concrete containing 5%, 10%, and 15% eggshell powder as partial replacement of cement. The study evaluated workability, density, and compressive strength of concrete. The results showed that workability decreased gradually with increase in eggshell powder content due to the finer particle size and higher surface area of ESP. The compressive strength of concrete was found to be satisfactory up to 10% replacement, while higher replacement levels caused reduction in strength because of insufficient cementitious material.
- ❖ Jhatial (2019) studied the influence of eggshell powder with different particle sizes on M40 grade concrete. The investigation used eggshell powder of 50 μm and 100 μm fineness at replacement levels of 5%, 10%, and 15%. The study reported that finer eggshell powder significantly improved compressive strength due to better particle packing and filler effect. Among all mixes, concrete containing 10% ESP showed the best mechanical performance.
- ❖ Ayoade (2024) evaluated the mechanical properties of concrete prepared with 0%, 4%, and 10% eggshell powder replacement. The study observed that compressive strength and split tensile strength increased at 10% replacement level compared to conventional concrete. However, slump value decreased with increase in eggshell powder content because ESP particles absorbed more water during mixing.
- ❖ Mohd Arif et al. (2021) investigated the use of eggshell powder in high-strength concrete. The research included replacement levels of 0%, 5%, 10%, and 15%. The results indicated that the mix containing 10% eggshell powder achieved maximum compressive strength after 28 days of curing. The study concluded that moderate replacement of cement with ESP can improve concrete density and strength due to improved microstructure.
- ❖ Gowsika et al. (2014) studied the effect of eggshell powder in cement mortar with

replacement levels ranging from 5% to 30%. The study found that low replacement percentages produced acceptable strength results, while higher percentages significantly reduced strength because of reduction in cement content. The authors recommended limiting ESP replacement within optimum levels for structural applications.

- ❖ Mahmood et al. (2022) presented a comprehensive review on eggshell powder concrete by analyzing results from different experimental studies. The review concluded that eggshell powder can be effectively used as a supplementary material in concrete at controlled replacement levels. The study also highlighted that curing conditions, water–cement ratio, and particle fineness play important roles in determining concrete performance.
- ❖ Mushtaq et al. (2025) investigated the durability and strength characteristics of concrete containing 5%, 7.5%, and 10% eggshell powder. The study reported that 7.5% ESP replacement provided optimum performance by improving compressive strength and reducing water absorption. However, higher ESP content increased porosity and reduced durability performance.
- ❖ Dissanayake et al. (2023) evaluated compressive strength and porosity characteristics of eggshell powder concrete. The research observed that replacement levels up to 10% produced strength values comparable to normal concrete, while 15% replacement reduced strength significantly. The study also reported that eggshell powder refined pore structure and improved matrix compactness at lower replacement levels.
- ❖ Rajan and Sujatha (2021) studied the combined effect of eggshell powder and nano-silica in concrete. The study concluded that the addition of nano-silica along with eggshell powder enhanced compressive strength and durability characteristics because of improved hydration and denser microstructure.
- ❖ Hassan et al. (2022) investigated the durability performance of eggshell powder concrete through water absorption and chloride penetration tests. The results showed that concrete containing 5–7.5% ESP exhibited lower permeability and improved resistance to chloride attack compared to normal concrete.
- ❖ From the review of previous studies, it can be observed that eggshell powder has significant potential as a sustainable supplementary material in concrete. Most researchers reported optimum performance at replacement levels between 5% and 10%. The improvement in concrete properties is mainly due to filler effect, enhanced particle packing, and calcium-rich composition of eggshell powder. However, excessive replacement of cement leads to reduction in strength and durability because of insufficient hydration products and increased porosity.

Although many studies have focused on compressive strength behavior of eggshell powder concrete, limited research is available on long-term durability, microstructural characteristics, and practical field applications. Therefore, further investigation is required to determine the long-term performance and suitability of eggshell powder concrete in sustainable construction.



3. Experimental Program and Typical Test Results

3.1 Review-Based Experimental Framework

Although this paper is primarily a review study, several published researchers performed experimental investigations on eggshell powder concrete. Based on the reviewed literature, a summarized experimental framework and typical test results are presented to understand the behavior of ESP concrete.

The reviewed studies commonly used M20 to M40 grade concrete with partial replacement of cement by eggshell powder at different percentages such as 5%, 10%, and 15%. The concrete specimens were tested for workability, compressive strength, split tensile strength, flexural strength, and durability characteristics.

3.2 Slump Test Results

Reviewed studies reported slump test results to evaluate the workability of fresh concrete containing eggshell powder.

Slump Test Results

Mix ID	ESP Replacement (%)	Slump Value (mm)
M0	0%	82
M1	5%	78
M2	10%	72
M3	15%	65

The reviewed studies reported gradual reduction in slump value with increase in ESP content. This reduction in workability is mainly due to the finer particle size and higher surface area of eggshell powder, which increases water demand during mixing.

3.3 Compressive Strength Results

Compressive strength is the most important property used to evaluate concrete performance. Most reviewed studies reported improvement in compressive strength up to optimum ESP replacement levels. Strength development was commonly evaluated after 7 days, 14 days, and 28 days curing periods to study the hydration and hardening behavior of ESP concrete.

Typical Compressive Strength Results:

Mix ID	ESP Replacement (%)	7-Day Strength (MPa)	14-Day Strength (MPa)	28-Day Strength (MPa)
M0	0%	22.5	27.4	31.8
M1	5%	24.2	29.6	33.6
M2	10%	25.8	31.8	35.1
M3	15%	21.6	25.3	29.2

The reviewed results indicate that compressive strength gradually increased with curing age for all concrete mixes. The concrete containing 10% ESP achieved maximum strength at 7-day, 14-day, and 28-day curing periods because of filler effect, improved particle packing, and denser concrete microstructure. However, higher replacement levels reduced strength due to lower cementitious content and increased porosity.

3.4 Split Tensile Strength Results

The split tensile strength results from previous studies are summarized below.

Typical Split Tensile Strength Results:

Mix ID	ESP Replacement (%)	Split Tensile Strength (MPa)
M0	0%	2.82
M1	5%	2.96
M2	10%	3.12
M3	15%	2.65

The reviewed studies observed improvement in split tensile strength up to optimum replacement levels. The improvement was mainly attributed to better bonding between aggregate and cement paste due to improved microstructure.

3.5 Flexural Strength Results

Flexural strength behavior of ESP concrete from reviewed studies is summarized in Table.

Typical Flexural Strength Results:

Mix ID	ESP Replacement (%)	Flexural Strength (MPa)
M0	0%	4.12
M1	5%	4.34
M2	10%	4.58
M3	15%	3.96

The studies reported improvement in flexural strength at lower ESP replacement levels because of improved interfacial transition zone and denser matrix structure.

3.6 Water Absorption Results

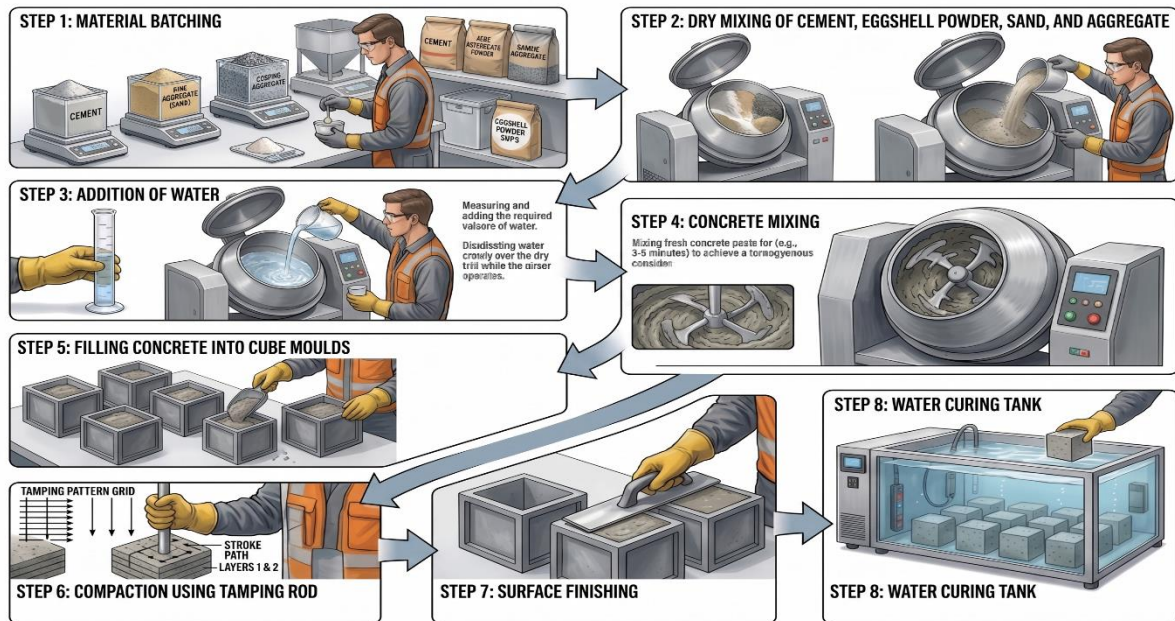
Water absorption behavior of ESP concrete from reviewed studies is presented below.

Typical Water Absorption Results:

Mix ID	ESP Replacement (%)	Water Absorption (%)
M0	0%	4.2

M1	5%	3.9
M2	10%	3.6
M3	15%	4.8

The reviewed studies showed reduction in water absorption up to optimum replacement levels because of improved matrix compactness and reduced pore spaces. However, higher replacement levels increased porosity and water absorption.



4. DISCUSSION

The reviewed literature confirms that eggshell powder has strong potential as sustainable supplementary material in concrete production. Most researchers reported improvement in concrete properties up to an optimum replacement level of 5–10%.

The improvement in strength is mainly due to filler effect produced by fine ESP particles. These particles fill micro-voids within the concrete matrix and improve particle packing density. In addition, the calcium-rich composition of ESP contributes to better hydration and formation of denser concrete microstructure.

Several researchers observed that compressive strength increases at lower replacement levels because of improved bonding between cement paste and aggregates. Split tensile strength and flexural strength also showed improvement at optimum ESP content.

However, excessive replacement of cement with eggshell powder negatively affects concrete performance. Higher ESP content reduces cementitious material available for hydration, leading to insufficient formation of hydration products and increased porosity.

The literature also indicates that finer ESP particles provide better performance because of improved packing effect. Therefore, grinding and sieving processes play an important role in determining concrete behavior.

From an environmental perspective, the utilization of eggshell powder reduces cement consumption and minimizes waste disposal problems. Since cement manufacturing is one of the major contributors to carbon dioxide emissions, replacing a portion of cement with ESP supports sustainable construction and green building practices.

Although many studies demonstrated the positive influence of ESP on concrete properties, limited research is available regarding long-term durability, field applications, and

standardization of ESP preparation methods. Therefore, further investigation is still required to improve practical implementation of ESP concrete.

Research Gap

Based on the reviewed literature, the following research gaps were identified:

1. Limited studies are available on long-term durability performance of ESP concrete.
2. Microstructural behavior and hydration mechanisms require further investigation.
3. Lack of standardization exists in eggshell powder preparation methods.
4. Limited field applications and large-scale practical studies are available.
5. Combined utilization of ESP with other supplementary materials requires more investigation.
6. More research is required on high-performance and self-compacting concrete containing ESP.

Environmental Benefits of ESP Concrete

The use of eggshell powder in concrete offers several environmental and economic benefits:

- Reduction in cement consumption.
- Reduction in carbon dioxide emissions.
- Utilization of waste materials.
- Reduction in landfill disposal problems.
- Development of sustainable construction materials.
- Promotion of eco-friendly construction practices.
- Conservation of natural resources.

The recycling of eggshell waste contributes to circular economy principles and sustainable waste management.

5. Conclusion and Future Scope

5.1 Conclusion

Based on the detailed review of previous studies on the utilization of eggshell powder (ESP) as a partial replacement of cement in concrete, the following conclusions can be drawn:

1. Eggshell powder has significant potential as a sustainable and eco-friendly supplementary material in concrete due to its high calcium carbonate (CaCO_3) content.
2. The utilization of eggshell powder helps in reducing environmental pollution caused by cement production and waste disposal problems associated with eggshell waste.
3. Most research studies reported that partial replacement of cement with eggshell powder improves compressive strength, split tensile strength, and flexural strength up to an optimum replacement level.
4. The optimum percentage of eggshell powder replacement is generally observed between 5% and 10%, where satisfactory mechanical and durability properties are achieved.
5. The improvement in concrete properties is mainly due to:
 - filler effect of fine ESP particles,
 - improved particle packing,
 - reduction in pore spaces,
 - and enhanced concrete microstructure.
6. Higher replacement levels of eggshell powder negatively affect concrete performance because of reduced cementitious material, increased water demand, and higher porosity.
7. Workability of fresh concrete decreases gradually with increase in ESP content due to finer particle size and higher surface area of eggshell powder.
8. Proper processing of eggshell powder, including cleaning, drying, grinding, and sieving, plays an important role in improving concrete performance.

9. The use of eggshell powder in concrete supports sustainable construction practices by reducing cement consumption, lowering CO₂ emissions, and promoting waste recycling.
10. Overall, eggshell powder can be considered an economical, environmentally friendly, and promising alternative material for green concrete production.

5.2 Future Scope

Although many researchers have investigated the use of eggshell powder in concrete, further studies are still required in several areas. The following future research directions are recommended:

1. Detailed investigation on long-term durability performance of ESP concrete under different environmental conditions.
2. Microstructural analysis using advanced techniques such as SEM, XRD, and TGA to study hydration mechanism and pore structure.
3. Investigation on the combined use of eggshell powder with other supplementary cementitious materials such as fly ash, silica fume, and GGBS.
4. Study on the effect of different particle sizes and processing methods of eggshell powder on concrete performance.
5. Evaluation of practical field applications and large-scale construction use of ESP concrete.
6. Investigation on self-compacting concrete and high-performance concrete containing eggshell powder.
7. Life-cycle assessment and cost analysis of eggshell powder concrete for sustainable construction applications.
8. Development of standard guidelines for preparation and utilization of eggshell powder in concrete.

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