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Experimental Investigation on the Effect of Eggshell Powder as a Partial Replacement of Cement in Concrete Cubes

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ABSTRACT

The environmental impact associated with cement production has encouraged research into alternative materials for sustainable concrete. This study investigates the effect of eggshell powder (ESP) as a partial replacement for Portland Pozzolana Cement (PPC) in M20-grade concrete. Eggshell waste was cleaned, dried, ground and sieved before being incorporated into the concrete mixtures. Cement replacement levels of 5%, 7% and 10% by mass were considered. The workability of fresh concrete was assessed using the slump test, while compressive strength was evaluated using 150 mm × 150 mm × 150 mm concrete cubes after 14 days of curing. The reported slump value was 78 mm. The average 14-day compressive strengths of the 5%, 7% and 10% mixtures were 14.33 MPa, 16.83 MPa and 12.90 MPa, respectively. Among the investigated mixtures, the 7% replacement level achieved the highest average measured compressive strength. The findings indicate that concrete strength varied with the proportion of eggshell powder incorporated. However, the absence of a conventional control mixture and experimentally measured 28-day results limits the conclusions. Further testing is required to establish the suitability of eggshell powder for concrete applications.

Keywords: Eggshell powder, partial cement replacement, M20-grade concrete, compressive strength, workability, sustainable construction.

1. INTRODUCTION

Concrete is widely used in construction because of its strength, versatility, availability and ability to be moulded into different structural forms. Cement is the principal binding material in conventional concrete, but its production consumes energy and contributes to carbon dioxide emissions. The use of alternative materials to reduce conventional cement consumption has therefore become an important research area in sustainable construction (Hamada et al., 2020; Chong et al., 2020).

The reuse of agricultural and food-processing waste in construction materials offers a possible approach to waste management and resource conservation. Eggshells are generated by households, restaurants, bakeries and food-processing industries. When processed into a fine powder, this waste material may be suitable for investigation as a constituent of cement-based materials. Eggshells consist predominantly of calcium carbonate, a compound also present in limestone, which has encouraged research into their potential use in concrete (Chong et al., 2020; Zhang et al., 2024).

The performance of eggshell powder depends on several factors, including its particle size, processing method, replacement percentage, and interaction with the other constituents of the mixture. Previous studies have reported different effects on workability and mechanical properties, indicating that a replacement percentage suitable for one cementitious system may not necessarily be suitable for another (Hamada et al., 2020; Mohd Arif et al., 2021).

Experimental research has demonstrated that eggshell powder can produce different strength responses depending on the material proportions and testing conditions. The present study investigates the use of eggshell powder as a partial replacement for PPC in M20-grade concrete. Replacement levels of 5%, 7% and 10% were considered. The reported slump value and measured 14-day compressive strengths were analysed to compare the performance of the three mixtures.

2. REVIEW OF LITERATURE

2.1 Eggshell Powder as a Cement Replacement Material

Eggshell powder has been investigated as a waste-derived material for use in concrete and other cement-based systems. Its calcium-carbonate-rich composition makes it relevant to research on fine fillers and alternative constituents in cementitious mixtures. However, its suitability depends on the material's properties and the quantity used in the mixture (Hamada et al., 2020; Chong et al., 2020).

Research reviews have also identified workability and durability as important considerations when incorporating eggshell powder into concrete. A reduction in workability has been reported in some mixtures, while mechanical performance may vary according to the replacement level and mixture composition. Consequently, the material should be assessed using both fresh- and hardened-concrete tests rather than compressive strength alone (Chong et al., 2020; Hamada et al., 2020).

2.2 Experimental Studies on Compressive Strength

An experimental investigation of high-strength concrete containing eggshell powder considered replacement levels of 0%, 5%, 10% and 15%. The 10% mixture achieved a reported 28-day compressive strength of 68.4 MPa, which was the highest among the mixtures examined in that study. Workability decreased as the eggshell powder replacement percentage increased. These findings demonstrate the potential influence of replacement level, although the results apply to the high-strength concrete system investigated and cannot be directly transferred to M20-grade concrete (Mohd Arif et al., 2021).

Research on cement-based materials containing eggshell powder has also shown that increasing the replacement proportion can reduce compressive strength. In one investigation, the reported 28-day strengths were 54.8 MPa for the control mixture, 43.4 MPa for the 7.5% replacement mixture and 35.5 MPa for the 15% replacement mixture. The findings indicate that replacing a larger proportion of cement does not necessarily improve strength (Zhang et al., 2024).

2.3 Summary of the Literature

The available literature indicates that eggshell powder has potential for use in cement-based materials, but its influence on concrete performance is dependent on its characteristics and replacement percentage. Research has identified both potential benefits and limitations related to workability, strength development and durability (Hamada et al., 2020; Chong et al., 2020).

Experimental studies further demonstrate that the strength response can differ between cementitious systems. Therefore, replacement levels need to be evaluated under the particular mixture and curing conditions adopted in each investigation (Mohd Arif et al., 2021; Zhang et al., 2024). This provides the basis for examining 5%, 7% and 10% eggshell powder replacement in the present M20-grade concrete study.

3. RESEARCH GAP

Previous investigations have examined eggshell powder in different concrete grades and cementitious systems, reporting variations in workability and compressive strength. The findings indicate that the effect of eggshell powder depends on the replacement percentage, material characteristics and mixture composition (Chong et al., 2020; Mohd Arif et al., 2021; Zhang et al., 2024).

The present investigation focuses on M20-grade concrete prepared using PPC and compares three eggshell powder replacement levels: 5%, 7% and 10%. The study evaluates the reported workability and measured 14-day compressive strength to identify the best-performing mixture among the replacement levels investigated.

4. OBJECTIVES

The objectives of this investigation are

1. To investigate the workability and compressive strength of M20 grade concrete incorporating eggshell powder as a partial replacement for PPC cement at 5%, 7% and 10% proportions.
2. To determine the optimum replacement percentage of eggshell powder based on the experimental results and assess its potential for sustainable concrete production.
3. To promote sustainable use of eggshell waste in construction

5. MATERIALS AND METHODOLOGY

5.1 Materials

Cement: Portland Pozzolana Cement (PPC) was used as the cementitious material for preparing the M20-grade concrete mixtures.

Fine aggregate: Fine aggregate was used as the fine granular component of the concrete. Its grading and physical properties should be reported according to the laboratory test results.

Coarse aggregate: Coarse aggregate was incorporated to form the granular framework of the concrete. Its properties influence the workability and strength of the mixture.

Eggshell powder: Discarded eggshells were processed into a fine powder for use as a partial cement replacement. Eggshell powder is predominantly calcium-carbonate-based, although its precise composition depends on its source and processing conditions (Chong et al., 2020; Zhang et al., 2024).

Water: Water was used for concrete mixing and curing according to the laboratory procedure.

5.2 Preparation of Eggshell Powder

Eggshells were collected and cleaned to remove adhering impurities. The shells were dried, ground into a powder and sieved to obtain a finer and more uniform material. The resulting powder was incorporated into the concrete mixtures as a partial replacement for cement by mass.

The preparation of eggshell powder is important because particle size, residual membrane, moisture and contamination may influence the properties of the resulting concrete. The characteristics of the processed powder should therefore be documented when assessing its suitability for cement-based applications.

5.3 Concrete Mix Proportions

M20-grade concrete was selected for the investigation. Three replacement levels were considered, with eggshell powder replacing cement by mass. The complete quantities of cement, eggshell powder, fine aggregate, coarse aggregate and water should be reported from the actual mix-design calculations used in the laboratory.

Table 1. Eggshell powder replacement levels

Mixture designation	Eggshell powder replacement
M1	5%
M2	7%
M3	10%

5.4 Slump Test

The slump test was used to assess the workability of fresh concrete. The test was conducted using a slump cone and the applicable testing procedure. After the concrete was placed and compacted in the mould, the cone was lifted vertically and the subsidence of the concrete was measured.

5.5 Casting and Curing of Concrete Cubes

Concrete cubes measuring 150 mm × 150 mm × 150 mm were prepared for compressive-strength testing. Fresh concrete was placed in the moulds and compacted to reduce entrapped air. Following initial hardening, the specimens were demoulded and cured under the specified laboratory conditions.

Three cube specimens were reported for each replacement level. The specimens were tested after 14 days of curing and the average compressive strength was calculated from the individual results.

5.6 Compressive Strength Test

The compressive strength of concrete was calculated by dividing the maximum load at failure by the loaded cross-sectional area.

$$f_c = P/A$$

Where,

- f_c = compressive strength (N/mm² or MPa)
- P = maximum load at failure (N)
- A = loaded cross-sectional area (mm²)

6. RESULTS AND DISCUSSION

6.1 Workability of Fresh Concrete

The reported slump value was 78 mm. Slump provides an indication of the consistency and workability of fresh concrete. Previous studies have reported that the incorporation of eggshell powder may reduce workability, depending on the mixture proportions and the characteristics of the powder (Chong et al., 2020; Mohd Arif et al., 2021).

6.2 Fourteen-Day Compressive Strength

Table 2. Measured 14-day compressive strength

Eggshell powder replacement	Trial 1 (MPa)	Trial 2 (MPa)	Trial 3 (MPa)	Average strength (MPa)
5%	14.0	15.0	14.0	14.33
7%	16.0	17.5	17.0	16.83
10%	13.0	13.7	12.0	12.90

The 5% eggshell powder mixture achieved an average 14-day compressive strength of 14.33 MPa. The individual specimen strengths ranged from 14.0 to 15.0 MPa. The 7% replacement mixture recorded an average compressive strength of 16.83 MPa, the highest value among the three mixtures. The individual strengths were 16.0, 17.5 and 17.0 MPa. The average strength was approximately 17.4% higher than that of the 5% mixture.



Figure 6.1 Compressive Strength Graph

The 10% replacement mixture achieved an average compressive strength of 12.90 MPa, the lowest value among the mixtures investigated. This was approximately 23.4% lower than the average strength of the 7% mixture. The measured results indicate that compressive strength did not increase continuously with increasing eggshell powder content. Under the experimental conditions adopted, the 7% mixture performed better than the 5% and 10% mixtures at 14 days.

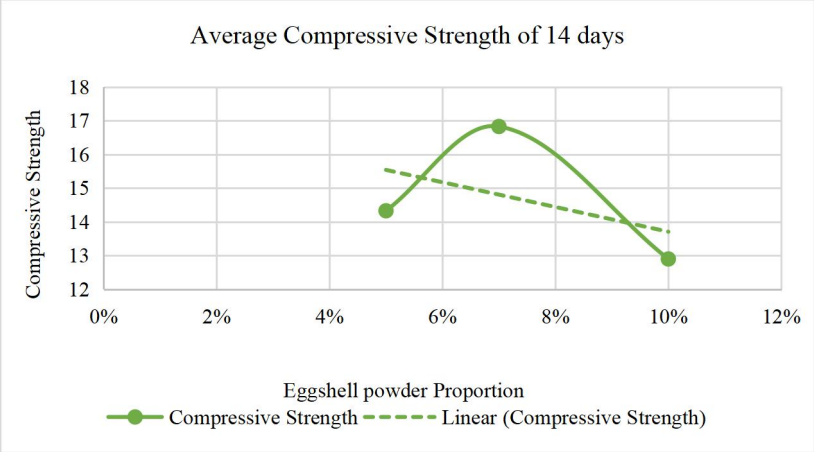


Figure 6.2 Average Compressive Strength of 14 days

An appropriate quantity of fine eggshell powder may influence particle packing within the cementitious matrix. At higher replacement levels, reducing the cement content may limit the amount of cement available for hydration and strength development. These mechanisms are consistent with the importance of replacement percentage discussed in previous studies, but they have not been directly confirmed in the present investigation through microstructural or hydration analysis (Hamada et al., 2020; Zhang et al., 2024).

6.3 Estimated 28-Day Compressive Strength

The thesis includes the following estimated 28-day strengths. These values are estimates rather than experimentally measured results.

Table 3. Estimated 28-day compressive strength

Eggshell powder replacement	Estimated strength (MPa)
5%	16.86
7%	19.80
10%	15.18

6.4 Comparison with Previous Research

The present investigation identified the 7% replacement mixture as the best-performing mixture among the three replacement levels based on the measured 14-day compressive strength. This finding illustrates the importance of evaluating replacement proportions individually rather than assuming that strength increases with increasing eggshell powder content.

The results should not be compared directly with the numerical strengths reported in high-strength concrete or cement-based material studies because the mix designs and testing conditions differ. Previous investigations have reported different strength responses at different replacement percentages, reinforcing the need to assess eggshell powder within the specific material system under consideration (Mohd Arif et al., 2021; Zhang et al., 2024).

Accordingly, the principal finding of the present study is that the 7% replacement mixture achieved the highest average measured 14-day compressive strength among the tested M20-grade mixtures. Further testing is required to determine whether this level remains favourable at 28 days and in comparison with a conventional control mixture.

7. CONCLUSION

This study investigated eggshell powder as a partial replacement for PPC in M20-grade concrete at replacement levels of 5%, 7% and 10%. The reported slump value was 78 mm, while the measured average 14-day compressive strengths were 14.33 MPa, 16.83 MPa and 12.90 MPa, respectively.

Among the mixtures investigated, the 7% replacement level achieved the highest average measured compressive strength at 14 days. The 5% mixture recorded an intermediate value, whereas the 10% mixture achieved the lowest average strength. These findings indicate that increasing the eggshell powder content did not produce a continuous increase in compressive strength under the experimental conditions adopted. The findings provide preliminary information on the performance of eggshell powder in M20-grade concrete.

8. LIMITATIONS AND FUTURE SCOPE

The study was limited to three eggshell powder replacement levels and the available 14-day compressive-strength results. The 28-day strength values were estimates rather than measured results. Future research should include a conventional control mixture and additional replacement percentages. These investigations would provide a stronger basis for evaluating its suitability as a partial cement replacement.

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