

## **PERFORMANCE OF EGGSHELL POWDER AS AN ADDITIVE ON WORKABILITY AND COMPRESSIVE STRENGTH OF M20 CONCRETE**

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### **ABSTRACT**

In the context of sustainable construction, the utilization of waste materials has gained attention as an approach for mitigating environmental impacts. Eggshells, an underutilized biogenic waste in Bangladesh, contain calcium carbonate, which is chemically comparable to limestone and clinker. Although many studies have examined eggshell powder (ESP) as a partial substitute for cement, very few studies have explored its use as an additive to improve both compressive strength and workability of M20 concrete. An experimental program was undertaken using OPC, 20 mm nominal maximum size Sylhet stones, and Sylhet sand with a nominal mix ratio of 1:1.5:3 and a fixed w/c ratio of 0.50. ESP was incorporated at 0%, 2%, 4%, 6%, and 8% by cement weight. The workability of the mix was assessed using the slump test, and compressive strength was determined on cylindrical samples after curing durations of one, two, and four weeks. The concrete mix containing 0% ESP achieved a 28-day compressive strength of 18.65 MPa, while an optimum strength of 22.17 MPa was obtained at 6% ESP, representing an improvement of approximately 19%. Beyond this dosage, strength slightly declined but remained above that of the control mix. With increasing ESP content, workability gradually decreased from 90 mm at 0% to 63 mm at 8%, while remaining within acceptable limits up to 6%. The study concludes that ESP can be effectively utilized up to 6% as an additive for optimum strength and acceptable workability. Future research should address durability, chemical performance, and combined use with supplementary materials.

**Keywords:** Additive, Workability, Compressive Strength, Eggshell Powder (ESP), M20 Concrete

## **1. INTRODUCTION**

Concrete is currently among the most popular construction materials, which are used all over the world, and it is primarily composed of Ordinary Portland Cement (OPC), fine aggregate, coarse aggregate, and water (Paruthi et al., 2023). Among the concrete grades, M20 concrete is widely used in residential buildings and low-rise commercial buildings in Bangladesh since it offers a good balance between compressive strength and workability. However, only a few studies have explored sustainable methods to optimize the effectiveness of M20 concrete.

Eggshell powder (ESP) derived from discarded eggshells contains calcium carbonate and has pozzolanic properties when incorporated into concrete (Mehmood et al., 2025; Othman et al., 2021; Mustapha et al., 2020; Hamada et al., 2020). Being an additive, ESP may enhance compressive strength by fostering further calcium-silicate-hydrate (C-S-H) development and densifying the concrete matrix without altering the cement content and conventional mix proportions (Shcherban, 2022; Abbasi Dezfouli et al., 2020). ESP also valorizes biogenic waste, which provides environmental and economic advantages, which is crucial in Bangladesh, where eggshell disposal is typically neglected (Zhang et al., 2024; Chong et al., 2023).

Although several studies have examined ESP in concrete, the majority of them have dealt with partial cement replacement in various grades of mixes, while very few studies have examined the use of ESP as an additive. A study on M25 concrete with eggshell powder and micro silica partially replacing cement showed that a moderate dosage of ESP (approximately 5%-10% by weight) increased compressive strength at 28 days but decreased workability (Rao et al., 2024). The experimental research on M30 concrete with the addition of the eggshell powder has shown that the compressive and tensile strength gains are measurable in comparison with the traditional mixes, indicating that ESP-type biogenic powders can be used in the construction of high-grade concrete (Imran et al., 2019; Reddy et al., 2023). Another study discovered that maximum compressive strength was achieved in M40 concrete after adding 10% ESP by weight of cement, and the smaller ESP content worked better (Jhatial et al., 2019). The addition of more than 10% ESP in cementitious systems frequently results in a decrease in strength because of the dilution of clinker phases (Mehmood et al., 2025). Notably, there is a lack of research on M20 concrete specifically as an additive, although M20 is commonly applied to various construction projects. Addressing this gap is essential since concrete grade influences both workability and strength, and the results of other grades may vary for M20 concrete.

The goal of the study is to determine the effect of ESP as an additive on the compressive strength and workability of M20 concrete. ESP was added in varying percentages, based on the weight of cement, and standard tests were conducted in one, two, and four weeks of curing. The results will be used to determine the optimum dosage of ESP that improves mechanical performance without impairing the workability in M20 concrete, and can be used in Bangladesh to apply it in sustainable and high-performance concrete in the near future.

## **2. METHODOLOGY**

This research was designed to evaluate the impact of eggshell powder as an additive on the workability and compressive strength of M20 concrete. To achieve this objective, five laboratory trials were conducted by preparing a control mix and 2%, 4%, 6% and 8% ESP content by weight of cement. The water-cement ratio was kept at 0.50 for all the trials. A standard slump test was conducted to measure the workability of fresh concrete, and a standard compaction procedure was followed. A compressive strength test was carried out periodically, corresponding to curing durations of one, two, and four weeks. Materials, mix design, additive preparation, aggregate gradation, and testing procedures are discussed further in the next sections. After that, data analysis and results were prepared.

## 2.1 Materials

In this section, the materials used in this study are discussed, and they include cement, aggregates, water, and eggshell powder. Their properties have been described in detail.

### 2.1.1 Cement

This research utilized Ordinary Portland Cement (OPC) as the primary binder, CEM I 42.5 N grade, conforming to BSTI: EN 197-1 specification. The specific gravity of the cement was 3.15 and a normal consistency of 32%, satisfying the requirements for normal setting and soundness.

### 2.1.2 Aggregates

Clean river sand served as the fine aggregate in the concrete mix. The sand was clean, and laboratory tests indicated a fineness modulus (FM) of 2.6 and a specific gravity of 2.63. Crushed stone chips from Sylhet quarries with a maximum nominal size of 20 mm were used as coarse aggregate. Coarse aggregates showed a specific gravity of 2.72, and water absorption below 1% was recorded, satisfying ASTM C33 requirements for aggregates.

### 2.1.3 Aggregate Gradation

A well-graded aggregate system with a 20 mm nominal maximum size was used to meet ASTM C33 specifications. The coarse and fine aggregates were blended in a ratio of 60:40 to achieve a uniform particle distribution. The aggregate gradation was kept constant for all the mixes, ensuring that eggshell powder was the only variable affecting the concrete properties. Table 1 shows the percentage of aggregates passing through different sieve sizes, and Figure 1 represents the well-graded curve.

Table 1: Adopted combined aggregate gradation for M20 concrete

Sieve Size (mm)	Percent Passing
20	95
10	82
4.75	62
2.36	47
1.18	36
0.6	27
0.3	17
0.15	8
0.075	3

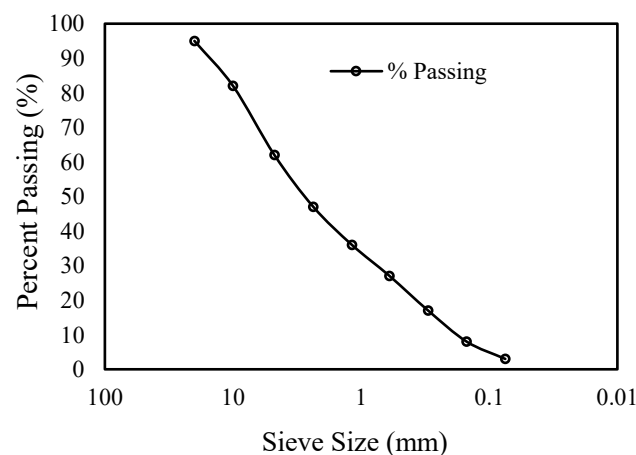


Figure 1: Aggregate gradation for M20 concrete

#### **2.1.4 Eggshell Powder (ESP)**

Eggshell waste was collected from various restaurants in Dhaka. They were washed and oven-dried at approximately 105°C for an entire day. Then they were ground into a fine powder. The eggshell powder was passed through a 0.075 mm sieve.

#### **2.1.5 Water**

Potable water supplied by Dhaka WASA was used for mixing and curing. The mixing water contained no harmful materials like oil, acid, or organic impurities.

#### **2.1.6 Admixtures**

No chemical admixtures were used in this study. Only ESP was incorporated as an additive. However, in practice, the use of plasticizers or superplasticizers may counteract workability reduction at higher ESP contents.

### **2.2 Mix Design and Proportioning**

M20 grade concrete was designed as a nominal mix following IS 456:2000 specifications with a proportion of 1:1.5:3 by weight. A constant water-cement ratio of 0.50 was maintained for all mixes. Eggshell powder was added as an additive at 0%, 2%, 4%, 6%, and 8% by weight of cement while maintaining the same mix proportions. The amount of the ingredients is shown in Table 2.

Table 2: Mix proportions of M20 grade concrete incorporating eggshell powder at different percentages of cement weight

<b>Mix ID</b>	<b>Cement (kg/m<sup>3</sup>)</b>	<b>Fine Aggregate (Kg/m<sup>3</sup>)</b>	<b>Coarse Aggregate (Kg/m<sup>3</sup>)</b>	<b>Water (Kg/m<sup>3</sup>)</b>	<b>ESP (% weight by cement)</b>	<b>ESP (Kg/m<sup>3</sup>)</b>
M0	383	575	1150	191	0	0
M2	383	575	1150	191	2	7.66
M4	383	575	1150	191	4	15.32
M6	383	575	1150	191	6	22.98
M8	383	575	1150	191	8	30.64

### **2.3 Mixing and Casting Procedure**

All materials were weighed separately using a digital balance with an accuracy of  $\pm 1$  g. Mixing was carried out in two stages:

**1. Dry Mixing:** Cement, ESP, and sand were first mixed until a uniform colour was obtained. Coarse aggregates were then added and mixed thoroughly.

**2. Wet Mixing:** Around 70% of the total mixing water was initially added, and the remaining portion was introduced gradually until a uniform mixture was achieved.

The slump test of fresh concrete was conducted immediately before casting. Concrete was placed into cylindrical molds (100 mm  $\times$  200 mm) in three layers, and each layer was tamped 25 times with a tamping rod as specified by ASTM C31.

## 2.4 Curing of Specimens

Specimens were demolded 24 hours after casting and subsequently submerged in water at room temperature. Curing was done at one, two, and four weeks to evaluate the development of compressive strength.

## 2.5 Testing Procedure for Laboratory Tests

Two major tests were performed in this study. The slump test was performed to determine the workability of fresh concrete based on ASTM C143. For each ESP percentage, slump test results were obtained. The compressive strength test was performed using a Universal Testing Machine (UTM), properly set up based on ASTM C39. Three samples for every ESP level were tested after one, two, and four weeks of curing duration, and their mean compressive strength was recorded.

## 2.6 Experimental Flow Chart

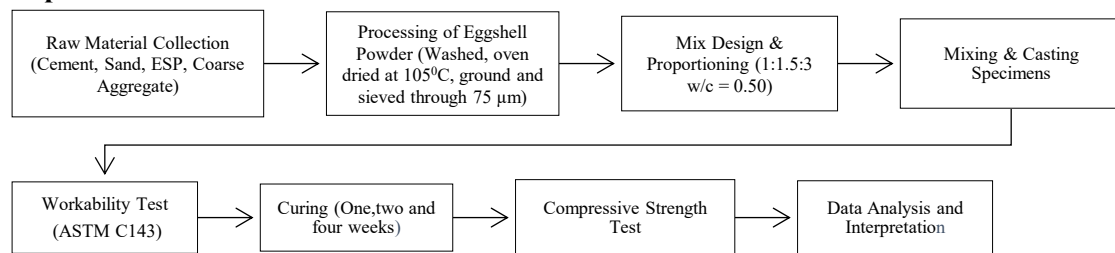


Figure 2: Flowchart of the experimental procedure

## 3. RESULTS & ANALYSIS

This section shows the results of the laboratory study. The analysis includes the changes in slump values, compressive strength at various curing ages, and the percentage-based trade-off between the gain in strength and the loss of slump.

### 3.1 Slump Test Results

The maximum slump of the control mix (0% ESP) was 90 mm. As ESP was gradually incorporated, the slump values decreased to 86 mm, 80 mm, 77 mm, and 63 mm at 2%, 4%, 6% and 8% ESP, respectively. However, the slump values were still within the acceptable range (typically 75-100 mm) for M20 concrete up to 6% ESP. The results are shown in Figure 3.

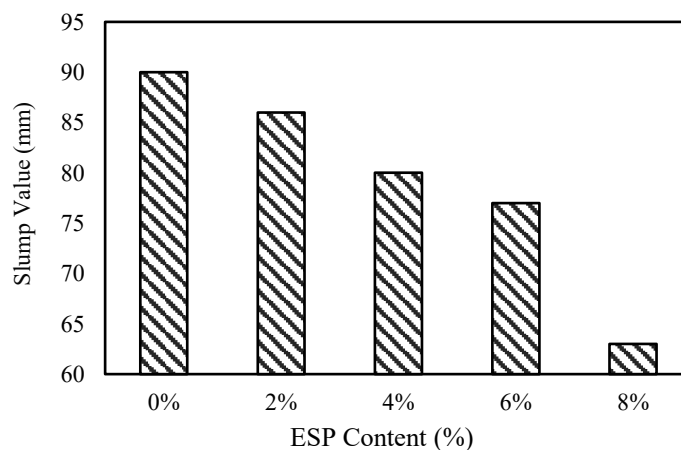


Figure 3: Variation of slump values

### 3.2 Compressive Strength Test Results

The mean compressive strength values obtained for curing periods of one, two, and four weeks at different ESP contents are shown in Table 3. Compressive strength increased up to 6% ESP addition. After that, the strength slightly decreased at 8% ESP. The compressive strength of the control mix was found to be 18.65 MPa at four weeks, while the maximum strength of 22.17 MPa was obtained with 6% ESP. This indicates an approximately 19% increase in strength. The trend of compressive strength at one, two, and four weeks is shown in Figure 4.

Table 3: Average compressive strength of concrete mixes at different curing ages.

ESP Content %	7 days (MPa)	14 days (MPa)	28 days (MPa)
0	8.58	12.59	18.65
2	9.47	13.22	19.18
4	10.21	15.00	20.16
6	11.60	16.17	22.17
8	10.83	14.80	20.77

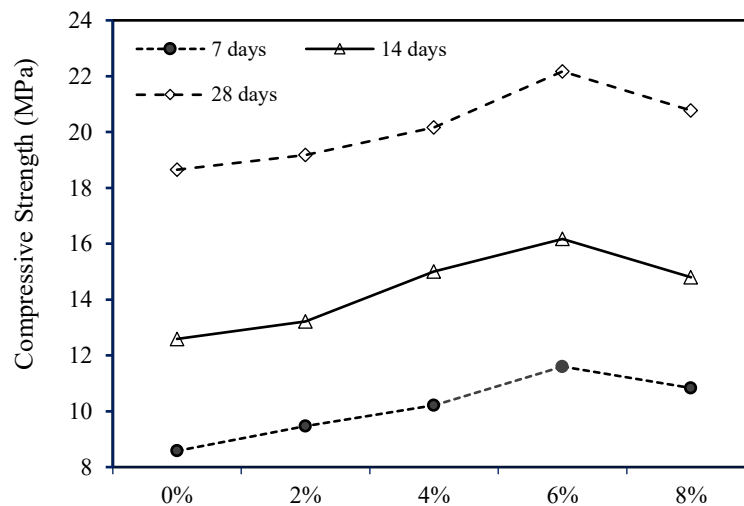


Figure 4: Variation in compressive strength at One, two and four weeks with different ESP percentages

### 3.3 Combined Performance Analysis

For practical application, it is better to analyze both strength and workability parameters together. While strength determines the load-bearing capacity, workability ensures proper compaction and placement. Concrete with excellent strength but poor workability could result in segregation or voids within the hardened mix. Thus, the combined performance analysis allows for determining the most efficient ESP content that ensures both structural performance and construction efficiency.

Figure 5 illustrates that slump values decreased steadily with increasing ESP content and were no longer within the acceptable range at 8%. Compressive strength increased up to 6% ESP and then slightly declined at 8%. This shows that 6% ESP provided the best combination of mechanical performance and acceptable workability.

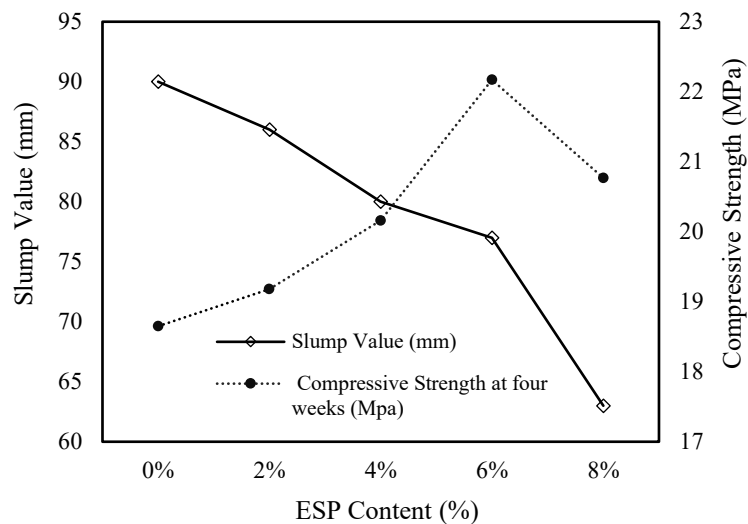


Figure 5: Combined results of slump value and compressive strength at different ESP content

### 3.4 Percentage-Based Trade-Off Analysis

A percentage-based evaluation was conducted in order to bring out the relative increase in compressive strength and loss in workability when compared to the 0% of the ESP mix. The strength trend in Figure 6 revealed a strength gain of up to 19% at 6% ESP, and the slump decreased steadily to reach about 30% loss at 8% ESP. This plot effectively illustrates the practical trade-off between workability and strength.

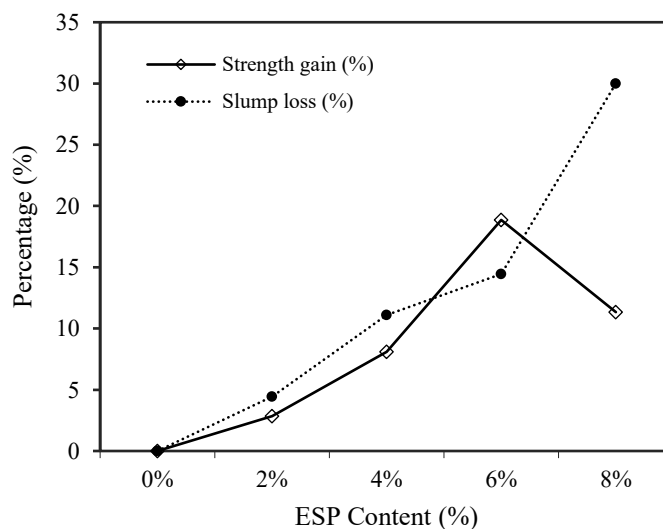


Figure 6: Percentage of compressive strength gain and slump loss at each ESP content

### 3.5 Discussion and Findings

The test results of the slump showed a gradual decrease in workability with an increase in ESP content. This decrease in workability was largely related to the high surface area and fine particle nature of the ESP, which consequently increased the water demand of the mix. However, the slump values up to 6% ESP were still within the acceptable range of M20 concrete, which means that ESP to that extent does not cause significant challenges in concrete handling and placement. On the other hand, the results of compressive strength showed a gradual increase with the addition of ESP up to 6% after which there was a marginal decrease. The increase in strength was found to be mainly due to the micro-filler effect

of finely ground ESP that compacted the matrix, filled the interstitial voids, and enhanced the bond between the aggregates and cement. When the ESP content exceeded 6%, excessive fines increased the water demand and reduced the strength slightly. The findings aligned with earlier studies on calcium-carbonate-derived materials, reaffirming ESP as an eco-friendly and sustainable additive. Overall, 6% ESP content can be considered as the optimum dosage that ensures an increase in strength and acceptable workability in M20 concrete.

#### **4. CONCLUSIONS AND RECOMMENDATIONS**

It was evident from the study that the addition of 6% ESP by weight of cement maintained a balance between strength and workability in M20 concrete. The addition of 6% ESP can increase strength up to 19% and keep the slump value within the acceptable limit. For concrete mixes with more than 6% ESP, superplasticizers should be used.

In this study, eggshell powder was used as an additive rather than a direct replacement for cement, so it does not immediately reduce cement consumption. However, its sustainability relevance can still be understood from a life-cycle performance point of view. The increase in compressive strength achieved at the same cement content indicates that similar structural performance could potentially be obtained with lower cement usage in future optimized mix designs of M20 concrete. This would reduce the potential carbon emissions per unit of concrete. In addition, the fine particle size of eggshell powder appears to improve matrix densification, which may contribute to better durability and a longer service life. From a life-cycle perspective, improved durability can reduce the need for frequent maintenance or repair, leading to lower cumulative carbon emissions over time. Furthermore, the use of eggshell waste provides an added environmental benefit by diverting biogenic waste from disposal and promoting resource reuse, which aligns with broader sustainability and circular economy objectives.

The results were positive, but there were certain limitations. The parameters used in this study were compressive strength and workability. Other parameters such as tensile strength, durability, permeability, and resistance to chemical attack should also be taken into consideration. Moreover, the experiment did not incorporate any chemical additives, and therefore, the experiment was restricted to the isolated influence of ESP. Other microstructural measurements, such as SEM or XRD analyses, were not carried out to confirm the densification process at the microscopic level. The long-term consequences were not taken into consideration as well. These shortcomings provide opportunities for future studies. The future studies should focus on the durability of ESP concrete through tests on sulphate resistance, chloride permeability, and carbonation. Microstructural characterization using SEM and XRD techniques would help gain further knowledge about hydration behavior and pore refinement. It is also possible to carry out a cost-benefit and life-cycle analysis to determine the environmental and financial benefits of ESP concrete. The performance and sustainability could be further enhanced by combining ESP with advanced materials.

#### **DECLARATION OF USE OF AI**

The authors used different AI tools during the writing process. They were only used to improve the clarity of the language, perform simple calculations, and avoid typographical mistakes. Data Analysis, result interpretation, technical content, and graphs are prepared by the authors. No AI tool was used while generating the research idea.

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