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An Analysis of the Strength and Durability of Eggshell Powder-Modified Concrete Structures

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Abstract

Because concrete is widely used, the need for cement is constantly growing. However, this causes CO2 to be emitted or included in the structural concrete. By adding or partially substituting cement with other materials while maintaining the required qualities of concrete, researchers are attempting to lower the carbon footprints of concrete. One such product is eggshell powder, a home waste

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product from the chicken industry that may partially substitute cement in concrete. It increases durability and strength. The goal of this study is to determine how eggshell powder affects the strength of concrete. A 1:2:4 mix ratios and a 0.5 w/c ratio were used to cast the concrete. Eighty-four standard-sized specimens were cast and tested for one, three, seven, and twenty-eight days. Densities, compressive strength, and workability (slump value) were examined. The differences between concrete with and without ESP were compared. The findings showed that, compared to a typical concrete mix, the workability of concrete reduces when eggshell powder is added. While there is a noticeable decrease in unit weight (density), adding eggshell powder content to ESP concrete sufficiently raises its compressive strength to a certain point.

Keywords: Eggshell Powder, Workability, Slump Test, Density, Compressive Strength

Introduction

One of the materials most frequently utilized in the building sector is concrete. Thanks to scientific and technological developments, concrete can now be modified to suit a wide range of applications, making it the preferred material for many infrastructure projects. Nevertheless, there are drawbacks to this extensive use as well. One important ingredient in concrete, Portland cement, emits carbon dioxide into the atmosphere, harming the environment. There is pressure on cement manufacturing companies because of the negative environmental effects of the cement production process [1]. Approximately 0.8 to 0.9 kg of carbon dioxide (CO_2) is released for every kilogram of cement, making portland cement a major contributor to environmental pollution. Researchers are

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trying to lower the carbon footprints of concrete by using alternative materials in place of or in addition to cement, as long as the concrete's desirable qualities are maintained.

On the other hand, garbage produced by different sectors is pointless and endangers the ecology. An efficient method is to employ waste materials, such as eggshell, fly ash, and silica fume, to replace cement partially. In addition to lowering the amount of cement in concrete, this also helps us recycle trash and maintain a clean environment. Typically, eggshells are discarded trash from the food and poultry industries. Globally, the food and poultry industries generate over 250000 tonnes of eggshell waste per year [2]. In pakistan, the poultry business is a significant part of the livestock economy and employs around 1.5 million people [3]. About 18 billion eggs are produced in pakistan each year [4]. This enormous quantity presents a problem for the disposal of its garbage. The elements of cement and eggshell powder have similar chemical properties. Eggshells contain a lot of calcium oxide (cao), a crucial ingredient in cement concrete [5]. Therefore, it may be beneficial to utilize utilized eggshell waste as a powder in place of cement in concrete; nevertheless, its impact on the concrete's characteristics has to be examined.

Balouch et al. (2017) investigated the effects of using ESP in place of specific cement on the characteristics of concrete. He looked at workability and compressive strength. It was discovered that workability decreased while compressive strength increased with increasing ESP concentration [6]. In their study, Shu Ing et al. (2014) used a 1:1:2 mix ratio and five different concentrations of ESP. The entire slump values of the concrete with ESP were determined to be at a medium level, and the concrete strength

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increased by 10% [7]. By crushing ESP to a fineness of 50 and 100 microns and using three different amounts of ESP, Jhatial et al. (2019) investigated the behavior of concrete in terms of workability and compressive strength of M40 grade concrete. He discovered that using a 10% percentage increases the compressive strength [8].

The compressive strength of concrete with a mix ratio of 1:1.5:3 with ESP in the range of 5 to 20% was investigated by Divya B et al. (2017). It was shown that 15% ESP content increased strength by 8%, whereas 5% to 10% replacement increased compressive strength by 4% [9]. In his research, Ansari M. et al. (2016) also describe how ESP affects compressive strength. His research shows strength increased from 10% to 15% [10]. The use of ESP as a partial cement substitute in manufacturing concrete under both water and air-curing conditions was also studied by Yu Tan et al. (2017). Ordinary Portland cement was partially replaced with eggshell powder in varying quantities. There was a notable 51.1% increase in compressive strength [11]. The primary goal of the research conducted by Gabol et al. (2019) was to ascertain the workability, compression, tensile, and flexural behavior. According to his findings, a 7.5 per cent ESP enhanced the high compressive strength by 8% after 28 days of curing and the tensile strength by 9.6% after 7 days.

Additionally, he discovered that concrete's workability decreased as its ESP increased [12]. The impact of ESP on a single-way concrete slab's flexural strength was investigated by Hama et al. (2019). He examined concrete's density, compression, and tensile strengths with an ESP concentration ranging from 0% to 15%. A modest rise in compressive and tensile strengths was observed, but

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no influence on density was recorded [13]. Similar outcomes were reported by Sharma et al. (2018) using ESP that was passed through a 90-micron sieve [14]. Research by Allie et al. (2018) examines ESP in concrete and provides a brief history of extra cement material. He discovered no discernible impact on concrete's compressive strength [15]. Vaidya et al. (2019) have researched and evaluated the effectiveness of waste eggshell powder (ESP) as a partial replacement of Portland cement to enhance the strength characteristics of concrete. ESP was utilized in several combinations that may be substituted for cement in concrete at a rate ranging from 5% to 20%.

In comparison to regular mix concrete, it was discovered that replacing up to 10% and 15% of ESP with cement increased the compressive strength by 7.15%, the flexural strength by 11.62%, and the split tensile strength by 3.5% [16]. In 2017, Bandhavya et al. conducted research on ESP in concrete. He concluded that replacing more than 10% of ESP resulted in a little increase in strength compared to regular mixed concrete [17]. The effects of using white eggshell powder as a partial replacement for ordinary Portland cement (OPC) in concrete were investigated in a laboratory study conducted by Gowsika et al. (2014). The compressive strength of ESP concrete is evaluated, and the eggshell powder's chemical structure (composition) has been determined. The white eggshell powder was used to partially substitute cement in a 1:3 mixed cement mortar, accounting for 5 to 30% of the cement weight. The compressive strength was measured after 28 days of age curing.

The present study's objectives are to examine how ESP affects concrete's characteristics. Different mix ratios and ESP amounts are

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used in this project to determine the concrete's qualities. In Nawabshah City, its impacts on the development of concrete's strength under various curing conditions, such as room temperature, are examined.

Materials and Methods

Methodology

The below figure shows the detail of the methodology adapted for this study.

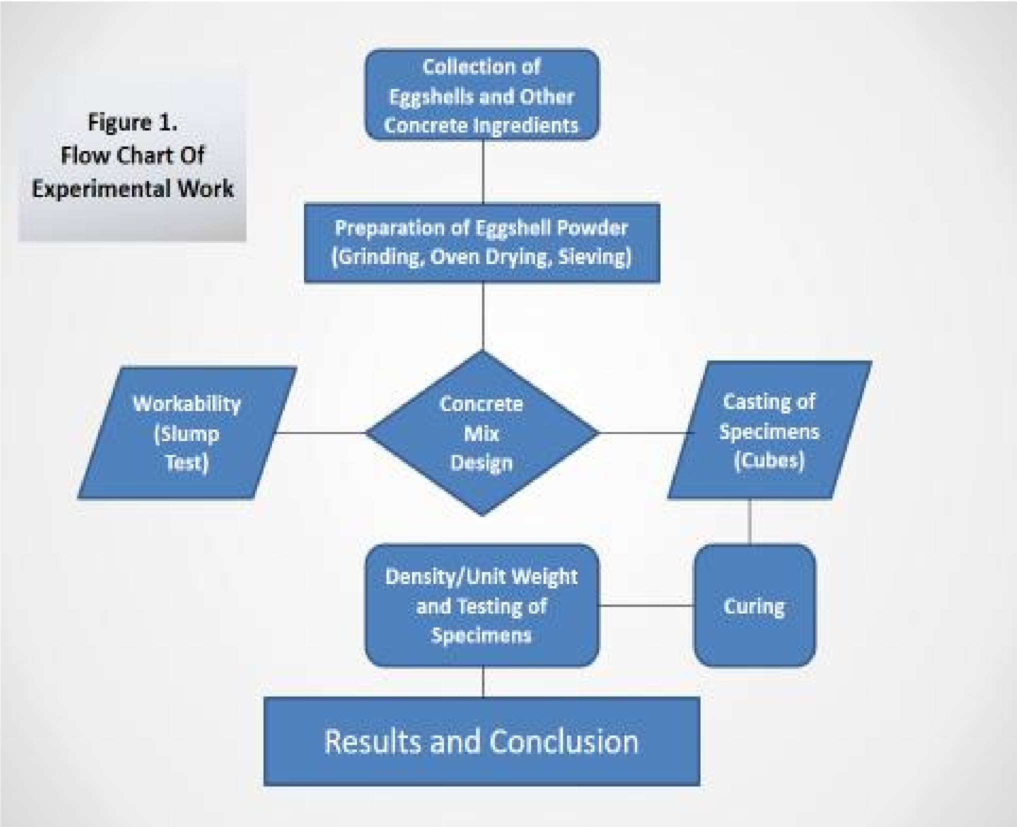

Figure 1: Methodology

Material

The following are the materials used during this study.

Cement

OPC (Ordinary Portland cement) of Type-I following ASTM C150-05 (2005) [20] and BS 12 (1991) was used. It was purchased from the

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local market of Nawabshah under the trade name 'Lucky Cement' and manufactured by 'Lucky Cement Industries.

Coarse Aggregates

Throughout this study, the crushed aggregate of a maximum of 12 mm and minimum size of 4.75 mm was used as the coarse aggregate for manufacturing the concrete.

Fine Aggregates (Sand)

Bolhari sand, locally available, passed through #16 sieves, is used. The sand was washed to remove sticky particles and dried to SSD (Saturated Surface Dry).

Water

The water to cast specimens should be free from any organic particles. It should not contain any chemical or mineral dissolved particles. Normally, drinking water is considered suitable for the manufacturing of concrete. This study also used drinkable water to produce the concrete with and without eggshell powder.

Eggshell Powder

After being purchased at the local food market in Nawabshah, Sindh, Pakistan, eggshells were cleaned to remove dust and other organic materials. After that, they were left in the sun for three to five days to dry. To create the shells in powder form, they were then pulverized in a grinder [5-7]. The ESP was dried in an oven at 105°C for 24 hours [7]. The eggshell powder was then sieved using a No. 170μ sieve to produce a powder with tiny particles.

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Figure 2: Eggshells used in the study

Figure 3: Grinding of eggshells

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Figure 4: Oven drying of ground eggshell powder

Figure 5: Eggshell powder

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Figure 6: Eggshell powder after sieving

Mix Proportion (Cement: Sand: Aggregates)

Throughout this study, the concrete mix proportion was fixed at 1:2:4 (cement: sand: aggregates). The batching was performed in terms of weight, using a W/C ratio of 0.5.

Eggshell Powder Dosage

ESP partially replaced the cement as a proportion of the total weight of cement and binder. To compare the outcomes, a batch of regular concrete without eggshell powder was also cast. Different percentages of the eggshell powder dose were used to cast each of the seven batches of concrete.

Shape and Size of Specimens

The specimens of standard size specified for each study parameter were cast and tested during this study. The standard size and Shape for compressive strength were cubes of 100mmx100mmx100mm (4"x4"x4") for compressive strength of concrete.

Casting of Specimens

Very careful batching was done, and the materials were well combined in a dry condition. The mixing process was done by

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hand. After that, water was added, and the mixture was continually mixed until it was consistent. After a slump test, the mixture was poured into the designated moulds (cubes) in three layers. The concrete was compacted using a table vibrator. The specimens were held for curing after the moulds were unsealed after being covered and allowed to firm for a full day.

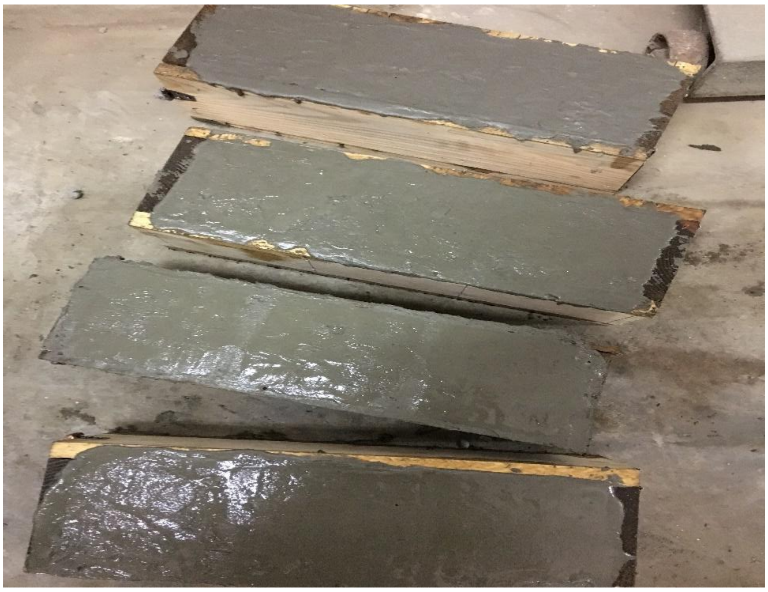

Figure 7: Specimens during Casting

Table 1: Batches of all the Specimens

S. No.	Batch Designation	Eggshell Powder	Description
01	CM	0	Normal concrete without ESP
02	ESPC1	2.5	Concrete with 2.5% ESP by
03	ESPC2	5	Concrete with 5% ESP by
04	ESPC3	7.5	Concrete with 7.5% ESP by
05	ESPC4	10	Concrete with 10% ESP by
06	ESPC5	12.5	Concrete with 12.5% ESP by
07	ESPC6	15	Concrete with 15% ESP by

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Table 2: Concrete Mix Proportion (0.5 w/c ratio)

Sr.	Batch Designati	ESP	Cement	Fine Aggreg	Coarse Aggreg	ESP (kg/m	Water (kg/m
1	CM	0	3	6	12	0	1.5
2	ESPC1	2.5	2.925	6	12	0.075	1.5
3	ESPC2	5	2.85	6	12	0.15	1.5
4	ESPC3	7.5	2.775	6	12	0.225	1.5
5	ESPC4	10	2.7	6	12	0.3	1.5
6	ESPC5	12.	2.625	6	12	0.375	1.5
7	ESPC6	15	2.55	6	12	0.45	1.5

Figure 8: Specimens during Casting

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Curing

Curing is an integral part of constructing concrete specimens as it directly affects the strength. In this investigation, the specimens were cured solely by water curing. To do this, the specimens were immediately submerged in water after being removed from the moulds until the testing was completed.

Figure 9: Specimens kept in water tank for curing

Testing Age

All the specimens were tested at 1-, 3-, 7-, and at 28-days of curing age.

Experimental Program

Tests performed on the concrete are workability, density and compressive strength.

Workability Test

The workability of concrete for all the batches cast during this study was determined before casting the specimens. Workability was determined using a slump test by ASTM C143-2003 [21].

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Density Test

Densities were determined by measuring the weights and dimensions of concrete cube specimens before testing them after 1, 3, 7, and 28 days of curing age.

Compressive Strength Test

Three cube specimens of 150 mm by 150 mm by 150 mm were cast, tested, and crushed at standard curing age for all mixes to estimate the average compressive strength of concrete with varying ESP levels. Compressive strength tests were conducted in a digital automated compression machine with a progressive load that produced a constant strain rate until the specimens failed. Each specimen's ultimate capacity load was noted at the point of failure [22].

Results and Discussions

General Appraisal

The purpose of this study is to experimentally examine and comprehend how eggshell powder affects the growth of eggshell powder concrete's strength. From 0% to 15%, eggshell powder was utilized as a partial substitute for cement, with increments of 2.5% by cement weight. Concrete's workability, density (unit weight), and compressive strength are all examined for the impact of esp. Standard protocols were followed when taking the tests, and several computation methods were used to collect the findings thoroughly.

Workability

To evaluate the effect of ESP on concrete's workability, slump experiments were conducted. Table 3.1 and Figure 9 show the outcomes of these examinations. According to the statistics, the workability (slump value) of the concrete mix is impacted when

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some cement is substituted with ESP. The workability falls as the percentage of ESP rises. Normal concrete had the maximum slump value of 34 mm, which gradually decreased when eggshell powder was added in 2.5% increments up to 15% by cement weight. The slump value of the concrete containing eggshell powder dropped by 4.6 mm on average basis. This decrease might be explained by ESP's high water absorption capacity, which lowers the mix's flow ability. To obtain the required workability, adding ESP to the mixture may thus require more water, mechanical effort, or admixtures.

Table 3: ***Average Workability of Concrete with & Without ESP***

S. NO.	ESP (%)	Slump Value (MM)
1	0	34
2	2.5	29
3	5	24
4	7.5	20
5	10	15
6	12.5	11
7	15	6

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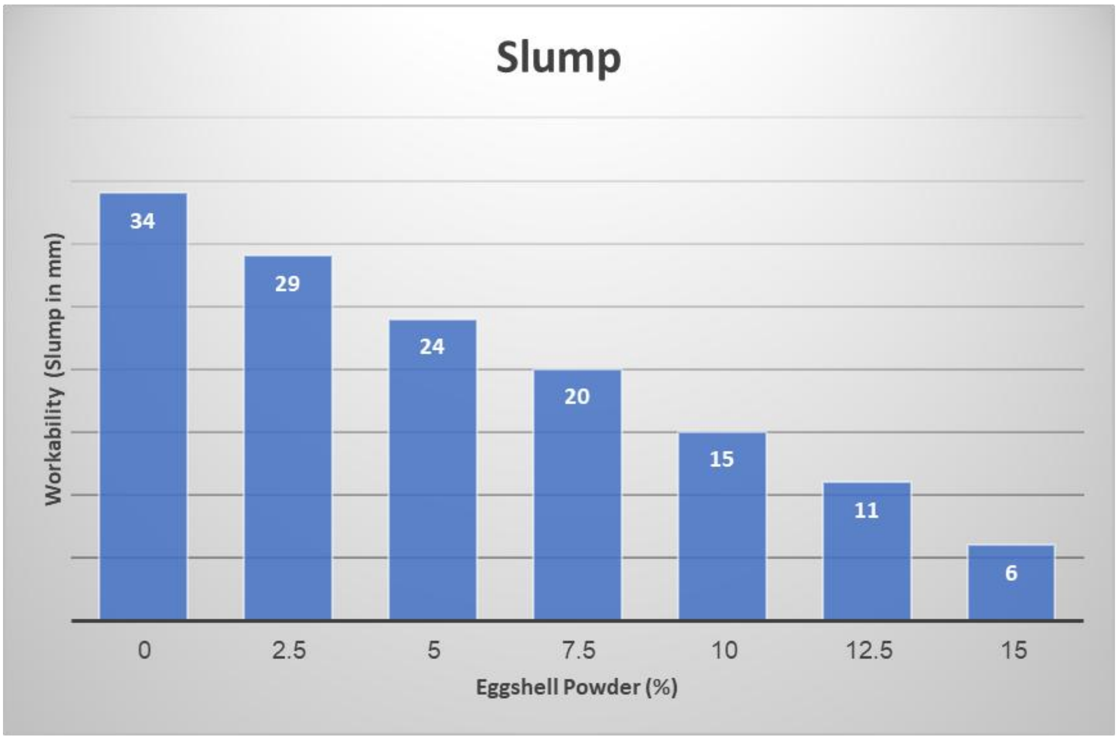

FIGURE 10: COMPARISON OF WORKABILITY OF CONCRETE WITH AND WITHOUT ESP.

Density

By weighing and measuring cube examples before testing at 1, 3, 7, and 28 days after curing, the densities of hardened concrete were ascertained. The volume of each specimen was consistently 0.001 m^3. The specimens' densities varied between 2530 and 2362 kg/m^3. The findings show that the density of the concrete decreases as the replacement amount of cement with ESP is increased. The lowest specific gravity of ESP in comparison to cement is responsible for the greatest density drop, which was noted at 15% ESP substitution.

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Table 4: *Average Weight (densities) of all Cube Specimens*

S. No.	Batch/ Concrete	Eggshell Powder (%)	1-Day Unit weight (kg/m³)	3-Day Unit weight (kg/m³)	7-Day Unit weight (kg/m³)	28-Day Unit weight (kg/m³)
1	CM	0	2420	2410	2530	2515
2	ESPC1	2.5	2410	2400	2510	2500
3	ESPC2	5	2400	2400	2400	2490
4	ESPC3	7.5	2400	2400	2490	2485
5	ESPC4	10	2395	2390	2480	2480
6	ESPC5	12.5	2390	2380	2470	2475
7	ESPC6	15	2380	2362	2470	2470

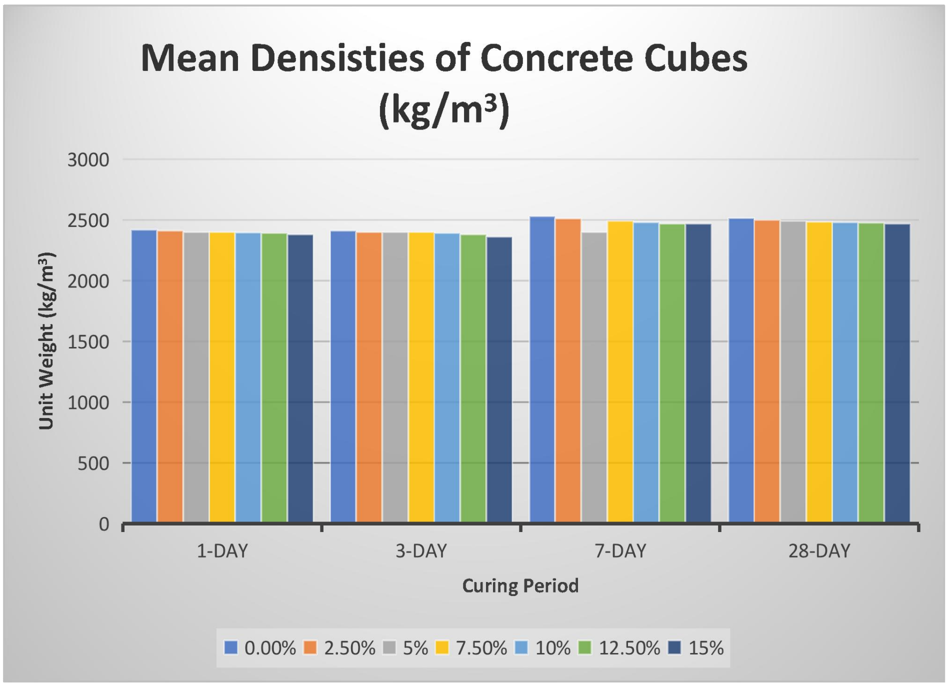

Figure 11: Comparison of average densities of concrete cube specimens at all curing days

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Compressive Strength

The compressive strength of concrete incorporating different percentages of eggshell powder (ESP) was assessed by casting, curing, and testing three cube specimens measuring 150 mm × 150 mm × 150 mm for each dosage at standard curing ages. The compressive strength tests utilized a digital automatic compression machine, which applied a progressive load at a consistent strain rate until specimen failure occurred. The ultimate load capacity was measured at the failure point for each specimen. The influence of esp on the compressive strength of concrete was examined about dosage and curing durations of 1, 3, 7, and 28 days. Tables 4.3–4.6 present the average compressive strength values for concrete, comparing samples with and without ESP.

The compressive strength of control mixes concrete increases with curing age [23-27]. The behavior of eggshell powder concrete significantly differed from that of the control concrete specimens. No strength improvement occurs at the early age of concrete. The one-day compressive strength of eggshell powder concrete specimens is lower than that of the control mix concrete, and this strength decreases as the eggshell powder content increases. A marginal increase in compressive strength is observed for 2.5% and 5% content of esp at a 3-day curing period.

Additionally, there is an increase in early strength of 2.5% and 5% at 7 days of curing, while a 10% dosage of ESP results in the highest strength gains of 8.5%. Over 28 days, strength increased by 7.5% and 10% for ESP content, while it decreased for the other contents and the strength of concrete increases over time. An optimal content exists for the development of compressive strength at each age, beyond which compressive strength declines.

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Table 5: *Average Compressive Strength at 1-Day Curing Age*

S. No.	Batch/ Concrete	Eggshell powder (%)	1-Day Compressive Strength (MPa)	Diff. w.r.t control specimen (%)
1	CM	0	18.35	---
2	ESPC1	2.5	18.12	-1.30%
3	ESPC2	5	17.25	-6%
4	ESPC3	7.5	16.81	-8.40%
5	ESPC4	10	16.39	-11.70%
6	ESPC5	12.5	15.92	-13.30%
7	ESPC6	15	15.33	-16.50%

Table 6: *Average Compressive Strength at 3-Day Curing Age*

S. No.	Batch/ Concrete	Eggshell powder (%)	3-Day Compressive Strength (MPa)	Diff. w.r.t control specimen (%)
1	CM	0	21.55	---
2	ESPC1	2.5	21.61	0.28%
3	ESPC2	5	21.95	1.85%
4	ESPC3	7.5	20.39	-5.40%
5	ESPC4	10	20.11	-6.70%
6	ESPC5	12.5	19.36	-10.10%
7	ESPC6	15	19.15	-11.20%

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Table 7: *Average Compressive Strength at 7-Day Curing Age*

S. No.	Batch/ Concrete	Eggshell powder (%)	7-Day Compressive Strength (MPa)	Diff. w.r.t control specimen (%)
1	CM	0	25.7	---
2	ESPC 1	2.5	25.97	1.05%
3	ESPC 2	5	26.88	4.60%
4	ESPC 3	7.5	24.57	-4.40%
5	ESPC 4	10	27.89	8.50%
6	ESPC 5	12.5	23.14	-9.96%
7	ESPC 6	15	22.09	-11.04%

Table 8: *Average Compressive Strength at 28-Day Curing Age*

S. No.	Batch/ Concrete	Eggshell powder (%)	28-Day Compressive Strength (MPa)	Diff. w.r.t control specimen (%)
1	CM	0	30.98	---
2	ESPC 1	2.5	29.23	-5.70%
3	ESPC 2	5	28.31	-8.61%
4	ESPC	7.5	32.71	5.60%

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	3			
5	ESPC 4	10	34.22	10.50%
6	ESPC 5	12.5	28.15	-9.13%
7	ESPC 6	15	27.51	-11%

Figure 12: Average compressive strength at 1-day curing age

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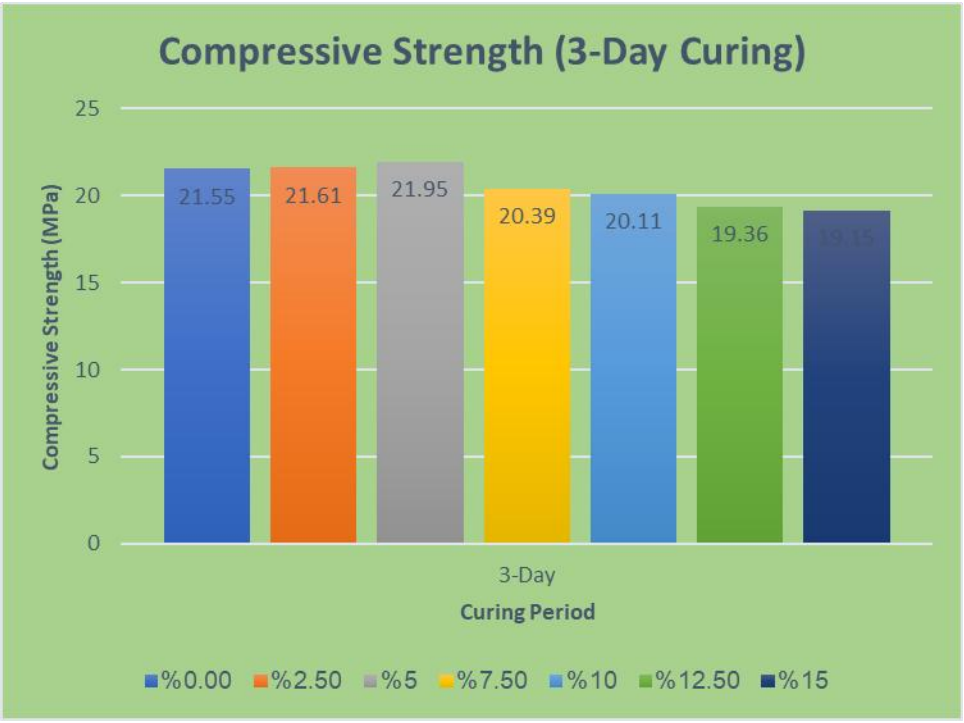

Figure 13: Average compressive strength at 3-day curing age

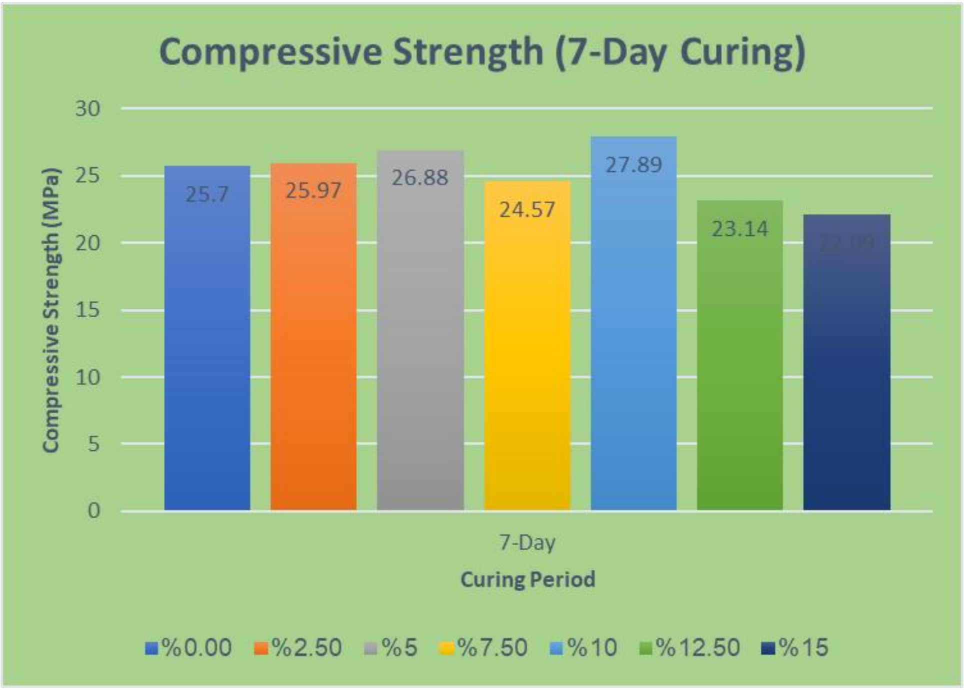

Figure 14: Average compressive strength at 7-day curing age

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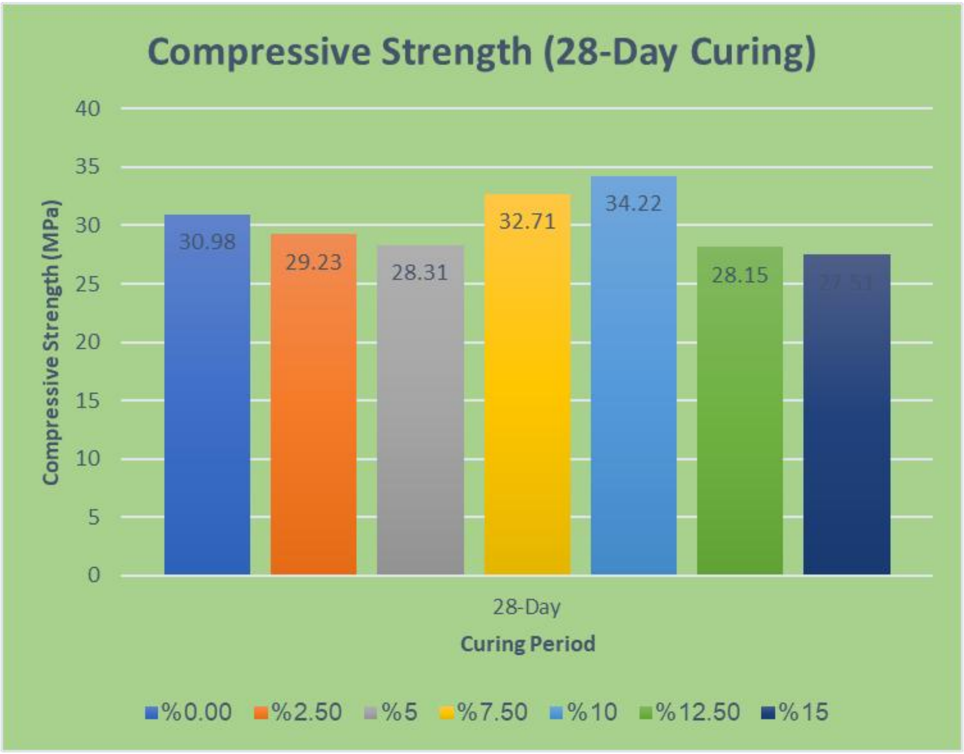

Figure 15: Average compressive strength at 28-day curing age

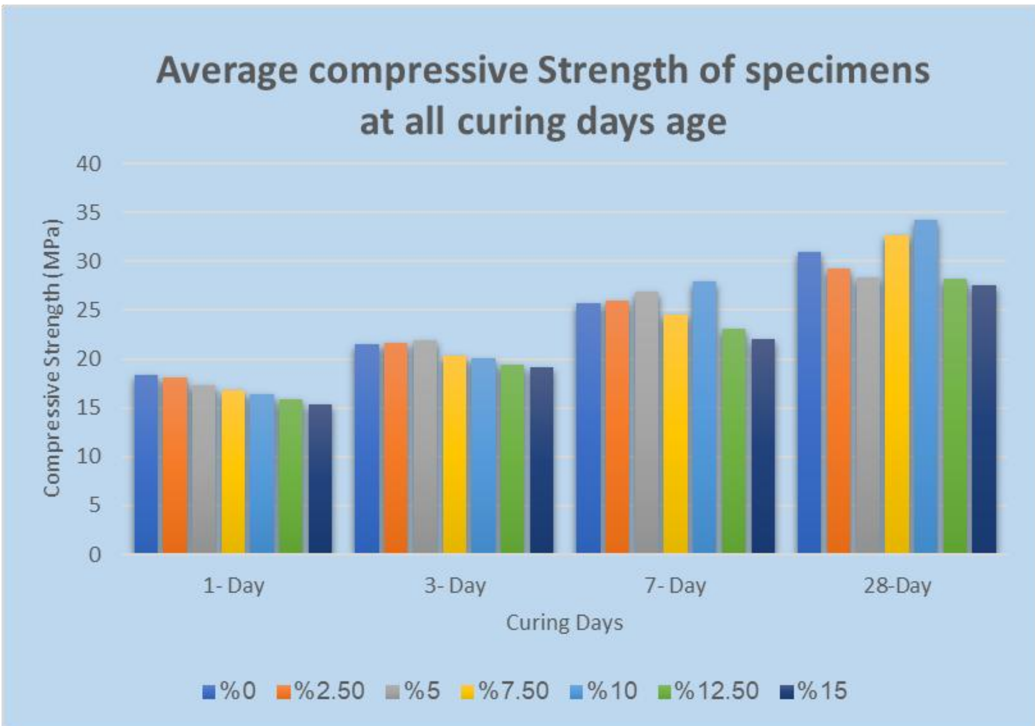

Figure 16: Average compressive strength with eggshell powder

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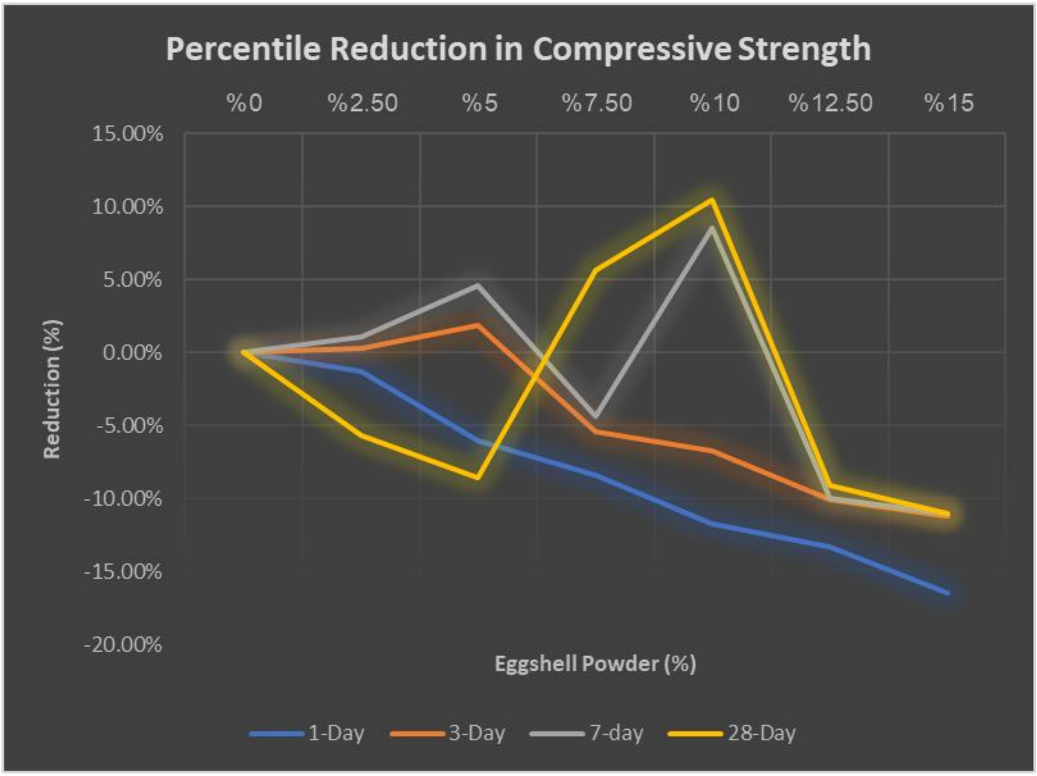

Figure 17: Percentage change in average compressive strength for all curing ages

Conclusion

The workability of concrete diminishes as the quantity of ESP increases. The density of ESP concrete typically declines with the incorporation of eggshell powder. In the early stages, strength shows no improvement; however, in later stages, strength increases with the addition of ESP to a certain degree. The optimal cement replacement at 7 and 28 days of curing was 10%, resulting in the maximum average compressive strength of eggshell powder concrete and an increase in cement replacement leads to a reduction in compressive strength. Future research may explore the effects of ESP on various concrete properties, including water absorption capacity, setting time, shrinkage resistance, fire resistance, permeability, durability, and mortars incorporating

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eggshell powder. Admixtures can be incorporated to enhance performance; additionally, varying the mix proportions and adjusting the water-cement ratio may be employed.

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