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Use of Egg Shell Powder as Partial Replacement of Cement in Concrete

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Abstract- ***Concrete is widely used throughout the world for the construction of most buildings, bridges, and other structures. The construction industry is one of the largest consumers of natural resources and contributes significantly to environmental pollution through cement production. At present, the entire construction sector is exploring suitable and effective waste materials that can minimize the use of cement and ultimately reduce construction costs. One such alternative material is egg shell powder. A large amount of egg shell waste is disposed of in landfills without any pre-treatment since it is conventionally considered unusable, which creates serious environmental issues. Therefore, a proper alternative method is required to manage these wastes in an eco-friendly manner. The aim of this investigation is to utilize egg shell powder as a partial replacement for cement. In this study, cement is replaced by egg shell powder at levels of 5%, 10%, and 15% by weight of cement. Experimental research was conducted to determine the mechanical properties such as compressive strength, split tensile strength, and flexural strength of egg shell powder-based concrete. The results indicate that the strength of the concrete increases with the addition of egg shell powder, and the comparison shows improved performance in egg shell-modified concrete compared to conventional concrete.***

Keywords: Egg shell powder (ESP), Cement replacement, Concrete, Compressive strength, Split tensile test, Flexural strength test, Waste utilization, Sustainability.

I. INTRODUCTION

Concrete is the most widely used construction material across the world. Cement, being the primary binding material in concrete, is highly energy-intensive to produce and is a major contributor to greenhouse gas emissions. To overcome these environmental challenges, researchers have been exploring the use of supplementary or alternative materials such as fly ash, silica fume, rice husk ash, and more recently, egg shell powder (ESP). Eggshells are an abundant form of waste generated from households, bakeries, and the food industry. Improper disposal of eggshells leads to odor, bacterial growth, and landfill pollution. Studies have reported that eggshells contain about 2.2 grams of calcium in the form of calcium carbonate ($CaCO_3$), which constitutes nearly 94% of their composition. The remaining portion primarily consists of phosphorus and magnesium, along with trace amounts of sodium, potassium, zinc, manganese, iron, and copper.

Since the disposal of eggshell waste does not generate any economic benefit and instead incurs handling costs, there is a need to identify cost-effective and sustainable methods for its utilization. Recycling eggshell waste into construction materials such as cement substitutes presents an environmentally and economically viable solution.

II. EXPERIMENTAL

This experimental program involves all the preliminary tests which are carried out in the material and the concrete. These tests help us to know the properties of the material being used for the process of concreting and in the derivation of the mix ratio.

A. Material Used

1) Cement: Cement is one of the most essential materials required for the production of concrete. It is a widely known construction material that holds a vital role in almost all types of construction work. Various types of cement are available in the market, and each type is used under specific conditions depending on its unique properties such as color, composition, and performance characteristics. Although cement constitutes only about ten percent of the total volume of a concrete mix, it serves as the most active component and acts as the binding medium that ensures strength and durability. It is also the only component of concrete that is scientifically manufactured and quality-controlled. The physical properties and chemical composition of cement are presented in Table-1 and Table-2, respectively.

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Table-1: Physical properties of cement

Material Property	Test Value
Specific Gravity of Cement	3.14
Fineness of Cement	3%
Consistency of Cement	34%
Initial Setting Time of Cement	35 minutes

Table-2: Chemical composition of Cment

Oxide contents	Percentage (%)
CaO	60-67
SiO_2	17-25
Al_2O_3	3-8
Fe_2O_3	0.5-6.0
MgO	0.1-4.0
K_2O, Na_2O	0.4-1.3
SO_3	1.3-3.0

2) Egg shell:- Eggshell waste generated from the poultry industry has gained significant attention due to its potential for recovery and reuse. Large quantities of eggshell waste are produced by the food processing, egg-breaking, and packaging industries. The food industry, in particular, requires further research to identify effective and eco-friendly methods for processing and utilizing this waste material. There is a growing need to develop low-cost and sustainable solutions for managing eggshell waste. Since the disposal of such waste does not generate profit and instead adds to operational costs, minimizing disposal expenses becomes a crucial consideration. Therefore, available options for waste management must be critically evaluated to determine the most cost-effective and environmentally responsible recycling methods. Eggshells were collected regularly from nearby local schools and packed in bags for processing. The collected shells were thoroughly washed with clean water to remove impurities and then sun-dried for a day. This drying process helped to prevent the formation of a paste during grinding and made crushing easier. Figure-1 shows the raw and dried eggshell samples. Blackened or damaged shells were separated, and any unwanted dust or foreign materials were removed before the grinding process. After cleaning and drying, the eggshells were manually crushed to a coarse form and then further ground using mechanical equipment such as mixers and grinders. On average, each eggshell yielded approximately one teaspoon of eggshell powder, weighing around 5 grams. Additional samples were also collected from other nearby schools and processed similarly to ensure sufficient material for the study. However, the powder produced using an electronic mixer was observed to be coarser than cement. Therefore, a ball mill was used to grind the eggshell particles to a finer size, ensuring uniformity. The finely ground powder was then sieved through a 90-micron sieve and packed for use as a partial replacement material for cement.

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B. Composition Of Egg Shell Powder

Oxide contents	Percentage (%)
CaO	50.7
SiO_2	0.09
Al_2O_3	0.03
MgO	0.01
Fe_2O_3	0.02
Na_2O	0.19
P2O5	0.24
SrO	0.13
NiO	0.001
SO_3	0.57
Cl	0.219

Mix Variation	Replacement (%)	Slump (mm)	Workability
CM	0%	92	Medium
V1	5%	86	Medium
V2	10%	82	Stiff
V3	15%	73	Stiff
V4	20%	62	Low





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III. PROCESSING OF EGG SHELL POWDER

1) Collection of waste eggshells from restaurants, bakeries, and households.
2) Washing to remove membranes and impurities.
3) Drying under sunlight or in an oven.
4) Grinding in a ball mill/pulverizer to achieve fine powder (<90 microns).
5) Sometimes calcination at 900°C is done to improve reactivity.

IV. TESTING AND OBSERVATIONS

The experimental investigation forms the core of this research. To validate the hypothesis that Egg Shell Powder (ESP) can effectively replace a portion of Ordinary Portland Cement (OPC), several tests were conducted on fresh and hardened concrete. All testing procedures were carried out in strict accordance with the relevant Bureau of Indian Standards (BIS) to ensure accuracy, reliability, and reproducibility.

A. Slump Cone Test (IS 1199:1959)

The workability of fresh concrete determines how easily it can be mixed, transported, placed, and compacted without segregation. The slump test measures the consistency and flowability of the concrete mix before it begins to set.





Slump Cone Test

B. Compressive Strength Test (IS 516:1959)

Compressive strength is the primary parameter used to evaluate the mechanical performance of structural concrete. This test determines the maximum load-bearing capacity of the concrete cube under uniaxial loading.

Mix	ESP (%)	7 Days (N/mm²)	28 Days (N/mm²)
Control	0%	17.8	26.5
V1	5%	18.2	27.2
V2	10%	19.5	28.1
V3	15%	20.6	29.4
V4	20%	16.2	24.5



Compressive Strength Test

C. Water Absorption Test

This test evaluates the porosity and durability of the hardened concrete matrix. A lower water absorption percentage implies a denser microstructure, which makes the concrete more resistant to deterioration from chemicals and moisture.

Water Absorption (%) = ((W2 - W1) / W1) × 100

V. RESULTS AND DISCUSSION

The objectives of all the tests are to find the mechanical properties the concrete (Grade M20) with Egg Shell Powder as the replacement of cement. The strength properties such as compressive strength and split tensile strength test results are presented in the tabular form and also in graphical form for better understanding. The results are analyzed, compared between the various mix proportions.

VI. ENVIRONMENTAL AND ECONOMIC BENEFITS

1) Waste Management: Utilization of eggshell waste reduces landfill problems.
2) Sustainability: Reduction in cement usage lowers CO_2 emissions.
3) Cost-effectiveness: ESP is a low-cost material compared to cement, beneficial in large-scale construction

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VII. LIMITATIONS

1) Availability of ESP depends on collection and processing facilities.
2) Need for proper cleaning and grinding process.
3) Long-term durability data is still limited.

VIII. FUTURE SCOPE

1) Large-scale pilot projects should be conducted to validate lab results.
2) Combination of ESP with other pozzolanic materials like fly ash or silica fume.
3) Research on self-compacting concrete and high-performance concrete with ESP.
4) Life cycle assessment (LCA) of ESP concrete.

IX. CONCLUSION

Egg shell powder is a promising supplementary cementitious material for partial replacement of cement in concrete. At replacement levels of 5–10%, ESP improves compressive strength and enhances sustainability by reducing cement consumption and utilizing food waste. Although large-scale applications are still limited, ESP concrete has the potential to contribute to eco-friendly and cost-effective construction practices. After studying the various researches done by various authors, Following conclusions are drawn:-

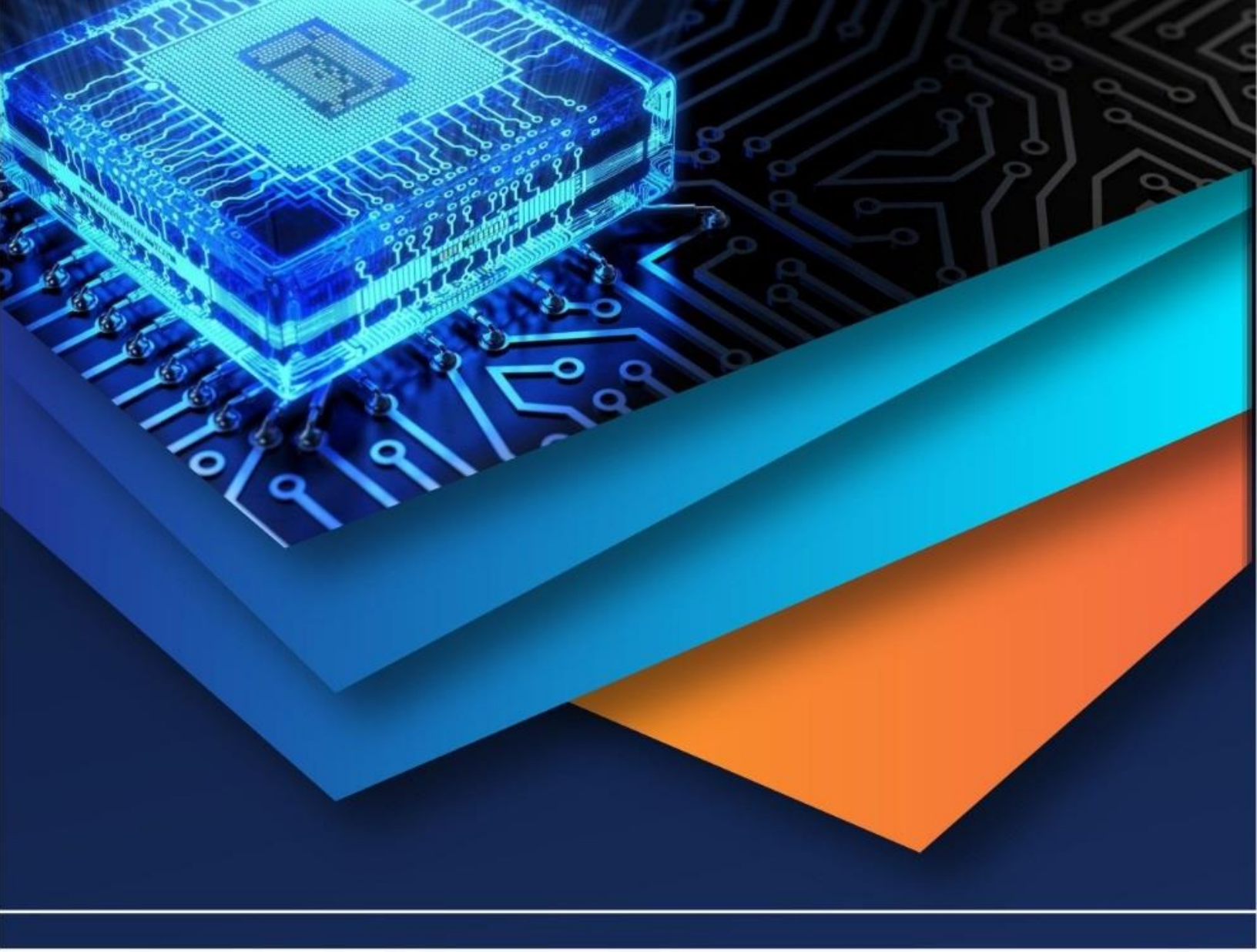
1) The hardness and specific gravity were increased with increasing ESP
2) The workability of concrete is decreased by increasing the amount of Egg shell powder
3) The compressive strength of the concrete with egg shell powder as cement replacement material increases up to 15%
4) The split tensile strength of the egg shell powder concrete decreases with the addition of egg shell powder. This can be increased if the concrete is used with reinforcement.

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