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Experimental Investigation on Flexural Strength of Concrete Containing Eggshell Powder

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Abstract
The growing demand for sustainable construction materials has encouraged the utilization of agricultural and food industry wastes in cement-based composites. Eggshell waste, primarily composed of calcium carbonate, is generated in large quantities and poses significant disposal challenges. This study investigates the feasibility of using eggshell powder (ESP) as a partial replacement of ordinary Portland cement to enhance the flexural strength of concrete. Concrete mixes were prepared with ESP replacement levels of 0%, 5%, 10%, and 15% by weight of cement. Flexural strength tests were conducted on beam specimens after 28 days of curing in accordance with IS 516:1959. The results revealed that the incorporation of ESP up to 10% improved the flexural strength compared to the control mix, with maximum performance observed at 10% replacement. However, a decline in flexural strength was recorded at 15% ESP due to the dilution of cementitious constituents. The findings indicate that eggshell powder can be effectively utilized as a sustainable cement replacement material at optimum replacement levels, contributing to waste valorisation and reduced environmental impact.

Keywords: *Eggshell powder, flexural strength, sustainable concrete, cement replacement, waste utilization.*

I. Introduction

Concrete remains the most widely used construction material worldwide due to its versatility, durability, and economic feasibility. However, the production of Portland cement is associated with significant environmental concerns, including high energy consumption and carbon dioxide emissions. It is estimated that cement production contributes approximately 7–8% of global CO_2 emissions, prompting the need for alternative and sustainable cementitious materials. In recent years, the incorporation of industrial and agricultural wastes in concrete has gained considerable attention as an effective strategy to reduce environmental impact while improving material performance. Among various waste materials, eggshell waste has emerged as a promising candidate due to its high calcium carbonate content and fine particle size when processed appropriately [1,2]. Large quantities of eggshell waste are generated daily from households, food processing industries, and commercial kitchens, creating disposal and hygiene-related challenges. Eggshell powder primarily acts as a micro-filler material rather than a pozzolanic agent. When finely ground, ESP enhances particle packing density, reduces porosity, and improves the interfacial transition zone between cement paste and aggregates. These characteristics make ESP particularly suitable for improving flexural performance, which is a critical parameter for pavements, slabs, and structural elements subjected to bending stresses. The present study focuses on evaluating the flexural strength behaviour of concrete incorporating eggshell powder as a partial replacement of cement at varying replacement levels [3]. The objective is to identify an optimum replacement percentage that enhances flexural performance without compromising the structural integrity of concrete.

II. Literature Review

Several researchers have investigated the feasibility of using eggshell powder as a supplementary material in cement-based composites. Yerramala (2014) reported that partial replacement of cement with eggshell powder improved the mechanical properties of concrete up to an optimum level, beyond which strength reduction was observed. The improvement was attributed to the filler effect and enhanced microstructural densification. Gowsika et al. (2014) studied the strength characteristics of concrete containing eggshell powder and observed a significant increase in flexural and compressive strength at replacement levels up to 10%. The authors highlighted that the high calcium carbonate content of ESP contributes to improved bonding within the cement matrix. Abdulrahman et al. (2017) examined the mechanical performance of sustainable concrete incorporating eggshell powder and concluded that ESP improves early-age strength and flexural resistance when used in moderate quantities. However, excessive replacement levels resulted in reduced strength due to insufficient cementitious reactions. Balasubramanian et al. (2020) emphasized the environmental benefits of eggshell waste utilization and reported that ESP-modified concrete exhibited enhanced durability and mechanical performance at optimized replacement levels. The study also indicated that ESP primarily acts as a micro-filler and nucleation agent for hydration products. Although previous studies confirm the potential of eggshell powder as a cement replacement material, limited research has specifically focused on its influence on flexural strength under standardized testing conditions. Therefore, the present investigation aims to provide a systematic evaluation of the flexural performance of ESP-incorporated concrete.

III. Materials

3.1 Cement

Ordinary Portland cement conforming to IS 12269 was used in this study. Natural river sand and crushed coarse aggregates were selected in accordance with IS 383 specifications. Eggshell waste was collected from local food establishments, washed thoroughly to remove organic matter, oven-dried, and ground into a fine powder [4]. The processed eggshell powder was sieved to achieve uniform fineness suitable for cement replacement.

3.2 Fine Aggregate

Natural river sand was used as fine aggregate in this study. The sand was clean, dry, and free from deleterious materials such as clay, silt, organic matter, and salts. It conformed to the grading requirements of IS 383. Properly graded fine aggregate plays a significant role in improving workability and strength of concrete by ensuring better particle packing and reducing void content within the concrete matrix.

3.3 Coarse Aggregate

Crushed angular coarse aggregates obtained from a local quarry were used in the experimental work. The aggregates passed through a 19 mm sieve and were retained on an 11.9 mm sieve, ensuring uniform size distribution. The angular shape of the aggregates provided better interlocking, contributing to improved mechanical strength. The specific gravity of the coarse aggregate was found to be 2.70. All aggregates were washed and air-dried prior to use to remove surface impurities and dust.

3.4 Eggshell Powder

Eggshells were collected from local domestic and commercial sources, including households and food outlets. To remove adhering impurities and organic matter, the collected eggshells were thoroughly washed with clean water multiple times. The cleaned eggshells were then air-dried for a period of 4–5 days at ambient temperature. After drying, the eggshells were crushed and ground into a fine powder using a mechanical grinder. The ground powder was subsequently sieved through a 90-micron sieve to obtain uniform particle size [5]. The prepared eggshell powder primarily consisted of calcium oxide (CaO), with minor quantities of silica, alumina, and magnesium compounds [5]. Due to its fine particle size and high calcium content, eggshell powder acts mainly as a filler material, contributing to improved particle packing and densification of the cement matrix when used as a partial replacement for cement.

3.5 Mix Proportion

Concrete mixes were prepared by replacing cement with eggshell powder at 0%, 5%, 10%, and 15% by weight. A control mix without ESP was used as a reference. The water-to-binder ratio was kept constant for all mixes to ensure consistency in comparison. . Flexural strength tests were conducted at curing ages of 7, 14, and 28 days, with the curing period calculated from the time of water addition to the dry mix constituents [6]. For each curing age, three beam specimens were tested to obtain representative and reproducible values for assessing the flexural performance of the mortar mixes

IV. Results and Discussion

4.1 Tests for Flexural Strength:

Guidelines provided in ACI 549R indicate that the cement-to-sand proportion in mortar, when considered by weight, typically lies between 1:1.4 and 1:2. For Ferro cement applications, mortar mixes with relatively high cement content are commonly employed, and volumetric mix ratios are generally selected within the range of 1:1.5 to 1:4 to achieve satisfactory strength and bonding performance. It is well established that higher sand proportions increase the water demand required to maintain equivalent workability. Taking these factors into account, a cement–sand ratio of 1:2 was selected for the present study, with a portion of the cement replaced by eggshell powder (ESP). To develop a compact and strong mortar possessing adequate workability for proper infiltration through mesh reinforcements, preliminary trial mixes were prepared. Parameters including the fineness modulus of sand, water–cement ratio, and cement–sand proportion were carefully assessed and finalized [7, 8]. Based on the outcomes of these trials, a constant water–cement ratio of 0.40 was adopted for all mixes to ensure consistency throughout the experimental investigation [9].

$$\text{Flexural Strength } = \frac{P\ L}{B\ D\ 2}\ MPA$$

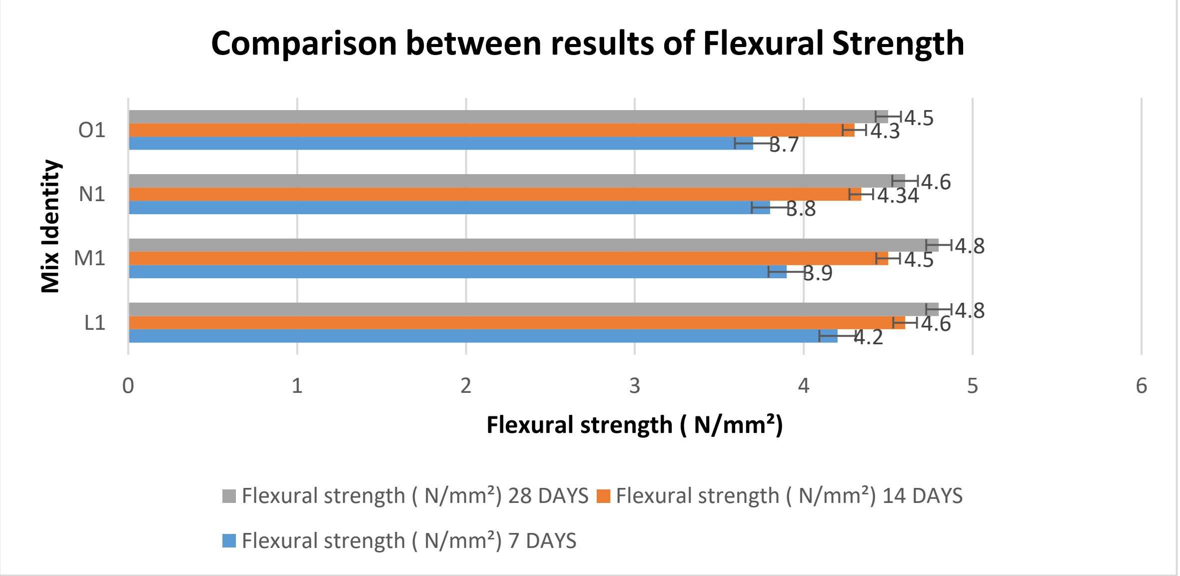
Where,
P = Load
l = length of the specimen
b = width of the specimen d = depth of the specimen

4.2 Test Results for Flexural Strength:

From the test results, it is observed that flexural strength increases with an increase in curing age for all mix identities, indicating continuous hydration and improved bonding between the mortar matrix and reinforcement. Among the mixes, the control mix exhibits comparatively higher flexural performance, while mixes with modified composition show slightly reduced but comparable strength values [10]. However, the overall trend suggests that the inclusion of alternative materials does not adversely affect the flexural behaviour of Ferro cement. The gradual improvement in strength with time confirms the suitability of the selected mixes for Ferro cement applications where bending resistance is a critical requirement.

Table 1: Average Results for Flexural Strength

Sr. No.	Mix Identity	Flexural strength (N/mm²)		
		7 DAYS	14 DAYS	28 DAYS
1	L1 (ESP 0%)	4.2	4.6	4.8
2	M1 (ESP 5%)	3.9	4.5	4.8
3	N1 (ESP 10%)	3.8	4.34	4.6
4	O1 (ESP 15%)	3.7	4.3	4.5



Graph 1: Comparison between results of Flexural Strength

The flexural strength results of the Ferro cement specimens for different mix identities at curing ages of 7, 14, and 28 days are presented in the table. At 7 days, the flexural strength values were observed to be 4.2 N/mm² for L1**,** 3.9 N/mm² for M1**,** 3.8 N/mm² for N1, and 3.7 N/mm² for O1, indicating a gradual reduction with change in mix composition. With an increase in curing period to 14 days, the flexural strength improved to 4.6 N/mm² (L1), 4.5 N/mm² (M1), 4.34 N/mm² (N1), and 4.3 N/mm² (O1) due to continued hydration and better bonding within the Ferro cement matrix. At 28 days, further improvement was observed, with flexural strength values reaching 4.8 N/mm² for L1 and M1, 4.6 N/mm² for N1, and 4.5 N/mm² for O1. Overall, the results indicate that flexural strength increases with curing age for all mixes, and although slight variations are observed among different mix identities, the strength values remain within acceptable limits for Ferro cement applications.

V. CONCLUSION

Eggshell powder can be effectively utilized as a partial replacement of cement in concrete without adversely affecting its flexural performance when applied at controlled replacement levels. The experimental results demonstrate that the flexural strength of concrete increases with the incorporation of eggshell powder up to an optimum replacement level of 10%, beyond which a decline in strength is observed. At higher replacement levels, particularly 15%, the reduction in flexural strength is primarily attributed to the dilution of cementitious constituents and the non-pozzolanic nature of eggshell powder. The enhancement in flexural performance at lower replacement levels is mainly governed by the micro-filler effect of finely ground eggshell particles, which leads to improved particle packing density and refinement of the interfacial transition zone. Overall, the utilization of eggshell powder in concrete contributes to sustainable construction practices by reducing cement consumption and promoting the effective management of eggshell waste.

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