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Research

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Experimental Investigation of Partial Substitution of Cement with Eggshell Ash in M20 Grade Concrete

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ABSTRACT

Commonly used for bonding construction materials, cement has influenced not only construction industry, but also environmental design systems. Mass production of cement from rocks of heavy minerals (plaster of Paris) is known to result in large amounts of mineral waste and requires ball mill processing systems. In this research, partial substitution of cement with eggshell ash in M20 grade concrete at 20, 30, and 40% is considered.

Key words: OPC cement, Eggshell ash powder, Coarse aggregate, Fine aggregate.

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1. INTRODUCTION

This research aims at investigating potentials of waste material for enhancing concrete performance (1). Conventionally, limestone is used as a mineral for producing cement concrete. Direct disposal of waste materials to environment may end up with environmental problems. However, incorporating the waste into concrete technology can reduce the use of natural minerals and waste production while improving nominal strength of the resultant concrete less and lowering the load applied by the waste onto the surrounding environment. Application of eggshell ash has reportedly strengthened concrete (2-4). Waste eggshell ash significantly contributes to workability of the concrete when producing hydrated concrete mixes (3, 5, 6). Presently, the large amounts of calcium content in the eggshell ash produced in different industries result in major problems including atmospheric issues as well as problems for living organisms. Accordingly, it has been suggested to incorporate eggshell ash into concrete manufacturing to substitute cement as a major bonding agent (7-9). In India, igneous rocks and limestone form the majority of sources from which cement is produced; however, these are associated with sandstone and limestone grime generation, thereby affecting human and environmental health. Mechanical properties of raw and hardened concrete have been reportedly investigated. Partially substitution of constituents of concrete is known to be associated with cost and energy savings, significantly better performance (2, 3), and weaker environmental impacts. In this research, the main aim is to investigate partial substitution of cement in M20 grade concrete by eggshell ash and to evaluate the resultant mix through compressive and tensile tests. Such a substitution adds to the concrete strength. Today, fine particles of marble and marbonite develop a noxious waste. Accordingly, addition of eggshell ash to concrete was proposed to reduce associated environmental impacts while lowering the production cost and preserving natural mineral assets.

2. EXPERIMENTAL MATERIALS

2.1. Cement

OPC 53 grade cement was used in this research, with its properties mentioned in IS 12269 - 1987. Specific gravity, initial setting time, and final setting time of the cement mortar were 3.15, 55 minutes, and finally, 258 minutes, respectively. Accordding to test results, the corresponding value of SCT for the considered cement was 29.5%.

2.2. Fine aggregates

Figure 1. Sand manufacturing

In this project, fine sand aggregates were substituted with a manufactured sand (M-sand). Specific gravity and fineness modulus of the sand were is 2.75 and 2.93, correspondingly (Figure 1).

2.3. Coarse aggregates

Figure 2. Coarse aggregate

Figure 2 demonstrates the coarse aggregates used in this research. These were 20 mm in size, 2.79 in specific gravity, and 7.2 in fineness modulus. The sharp-edged coarse aggregates were procured from local sources.

2.4. Water

Clear water was used to provide the required hydration for building concrete mixes. For this purpose, water/cement ratio (W/C) of 0.52 (52%) was used. TDS of the water was between 6 and 7.5 ppm.

2.5. Eggshell ash

Depicted in Figure 3, the eggshell ash used in this research was composed of calcium (95%) and magnesium carbonate (5%). Specific gravity and fineness modulus of the eggshell ash were 2.15 and 7%, respectively. The ash was manufactured by drying white eggshell waste in a high-temperature furnace at 1200^{o}C and then suddenly cooling that to room temperature. Finally, upon grinding, the eggshell ash was obtained as a fine powder.

Figure 3. Eggshell ash

3. RESEARCH METHODOLOGY

Partially substituting 20, 30, and 40% of the cement in conventional concrete with eggshell ash, the resultant concrete was cured and then tested. Batching could be done by either weight or volume, but most specifications required weight batching rather than volume batching. For the purpose of this research, OPC 53 grade cement was used at 330 kg of cement per m^3 of concrete (4). Furthermore, M20 grade concrete was introduced into the mix at a ratio of 1:1.5:3.

3.1. Batching

Weight batching was done by substituting 20, 30, and 40% of OPC cement with eggshell ash.

3.2. Concrete mix design

Figure 4. Concrete mix

Mixed at the mixture proportion of 1:1.5:4, the concrete was subjected to rotary weight batching. Figure 4 shows fresh M20 grade concrete after rotary weight batching.

3.3. Test specimens

Tests were performed on specimens shaped into cubes, beams, and cylinders. Accordingly, 150 × 150 × 150 mm cubes were subjected to compressive strength tests, cylinders of 150 mm in diameter and 300 mm in length were used for split tensile strength tests, and 150 × 150 × 700 mm beams (5) were used for flexural strength test. Casting and hardening were practiced as per IS codes 516 and 1199.

4. RESULTS AND DISCUSSION

4.1. Compressive strength tests on cubic concrete specimens

Compressive strength of cubic concrete specimens cured in water and then hardened and surface-coated with 4T oil was tested on CTM machine (10). The coating was applied to protect external surface of the specimens against extreme conditions that otherwise may lead to sudden expansion/contractions and inaccurate measurements (11). Before testing each specimen, one should measure its dimensions and weight, and clean surface of the bearing of test machine with a wiping cloth, so as to have the load applied to the cube surfaces gradually (12). Loading was carefully performed along the central axis of the specimen. Cares were taken to avoid any shocking impact to the specimen. Eggshell substituted 20, 30, and 40% of the cement and the modified cubes were loaded increasingly until those failed at 280 kg f_m/min where external surface of the specimen failed via breakage.

Figure 5. Universal testing machines (UTM)

Figure 5 shows the universal testing machine used to undertake compressive strength tests on cubic and beam-shaped specimens.

4.1.1. Calculations

Calculations related to the cubic specimens were performed by dividing maximum load applied to the specimen during the course test by area. According to IS 456-2000, average strength over three specimens were reported. Correction factors were further applied according to dimensions of the specimen, as shown in Figure 6, to obtain stress and strain curves as per IS 456-1959. The new concrete batch compositions exhibited 60 to 70% improvement in strength. In particular, the concrete mixes where cement was substituted with eggshell ash had 60 to 65% higher strength at failure and were economically more efficient at the same time (Table 1).

Figure 6. Compressive failure of concrete cube

Table 1. Results of compressive strength test on concrete cubes

Percentage of cement substituted with eggshell ash	*7-day strength (N/mm^2)*	*14-day strength (N/mm^2)*	*28-day strength (N/mm^2)*
20%	16	22.54	31
30%	15.95	22.30	30
40%	15	21.50	27

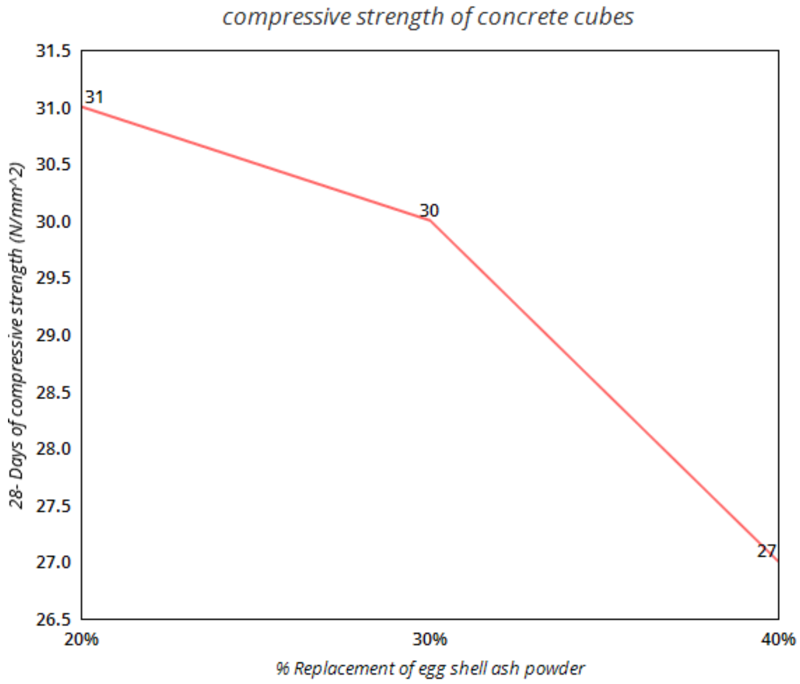

Figure 7. The 28-day compressive strength of concrete cubes for different substitution percentages

Figure 7 presents the results of strength analysis on concrete cubes using 3D Analyzer. For this purpose, test specimens were subjected to compressive strength test once cured for 7, 14, and 28 days, and the maximum load at failure was recorded. In order to maximize curing, mean values of compressive strength at failure were considered.

4.2. Split tensile strength test on cylindrical concrete specimens

Split tensile test is a standard procedure for identifying tensile strength of cylinder concrete specimens indirectly according to IS 5816-1970 (13). The cylindrical concrete specimens (300 mm in length by 150 mm in diameter) were mounted in a CTM for the tests. Accordingly, compressive loads were gradually applied to horizontal surfaces of the specimen (14). In order to keep the load uniformed, at higher compressive loads, diameter of the cylinder changed without failure (15). In order to address such high compressive stress near the point of load application, strip rods were placed between the concrete cylinder and load-bearing pressurized plates (16). This not only protected concrete cylinder and load-bearing pressurized plates against slipping, but also kept the concrete cylinder from slipping in load-carrying stages. Due to the gradual increase in the applied load, higher compressive stress was applied to the sample along vertical axis, while uniform tensile stress was applied horizontally. This was mainly based on differences in Poison’s ratios.

Figure 8. Compressive failure of concrete cylinder

Table 2. The result of split tensile strength of concrete cylinder

Percentage of cement substituted with eggshell ash	*7-day strength (N/mm^2)*	*14-day strength (N/mm^2)*	*28-day strength (N/mm^2)*
20%	3.9	4.2	4.3
30%	3.5	3.9	4.2
40%	3.3	3.6	4

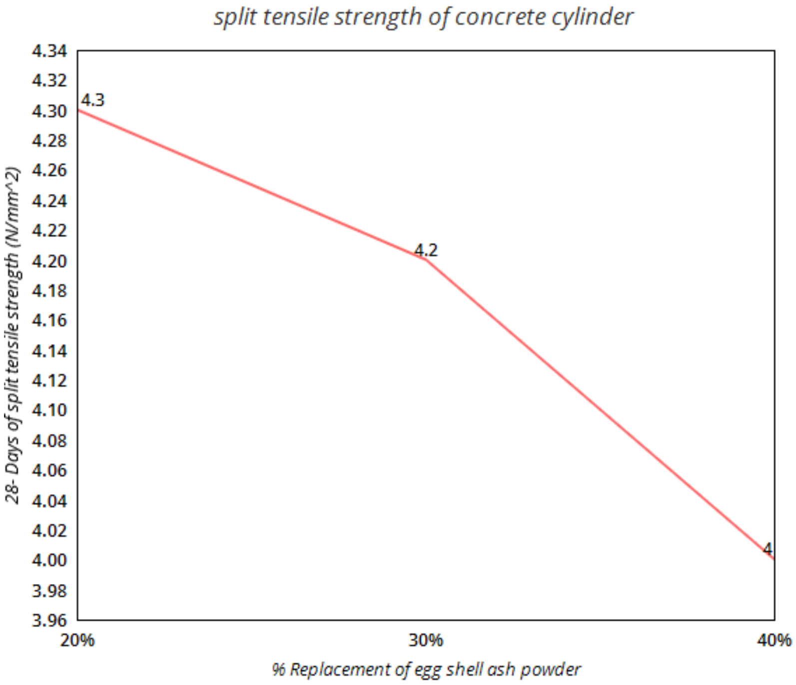

Figure 9. The 28-day compressive strength of cement cylinder for different substitution percentages

Table 2 and Figure 9 present the results of strength analysis on concrete cylinders using 3D Analyzer. For this purpose, test specimens were subjected to compressive strength test (using a UTM) once cured for 7, 14, and 28 days, and the maximum load at failure was recorded (Figure 8). In order to maximize curing, mean values (%) of compressive strength at failure were considered.

4.2.1. Calculations

$F_t = 2P/\pi DL$

F_t = Vertically acting force

P = Compressive load at failure

L = Length of the cylinder

D = Diameter of the cylinder

The following calculations were performed for the 28-day cured cylindrical concrete specimens to calculate its strength:

$20\% = 2 \times 4.3/(\pi \times 150 \times 300)$

$= 0.00006$ N

$30\% = 2 \times 4.2/(\pi \times 150 \times 300)$

$= 0.000059 \approx 0.00006$N

$40\% = 8/(\pi \times 150 \times 300)$

$= 0.000056 \approx 0.00006N$

In the 28-day cured specimens, when the cement was substituted by eggshell ash at 20, 30, and 40%, better strength was obtained under the same set of conditions with the load acting on a vertical plane.

4.3. Results of flexural strength test on concrete beams

Resembling split tensile test, flexural strength test is conducted to determine beam performance as per BS 1881: part 118:1983 (16). It is commonly implemented on standard beam sizes (150 × 150 × 500 mm). For this purpose, the concrete beam is placed on a one-third-supported roller bearing to apply two identical load- carrying supports; then load was applied to the beams gradually (17). Steel channel sections were placed in the middle of the beams, so as to keep the beam from slipping in response to load (18). Beams materials are commonly tested without any reinforcement, with the tests performed on blended materials. Flexural strength refers to the ability of a material for inducing no shear force into components (19). The beam exhibited maximum bending moment at Pd/2, wherein no shear force was applied. Flexural strength indicates ultimate load applied to the material before a deformation occurs (20).

Table 3. Results of flexural strength test on concrete beams.

Percentage of cement substituted with eggshell ash	*7-day strength (N/mm^2)*	*14-day strength (N/mm^2)*	*28-day strength (N/mm^2)*
20%	6.2	10.2	10.6
30%	5.8	9.75	10.3
40%	5.3	9.2	10.2

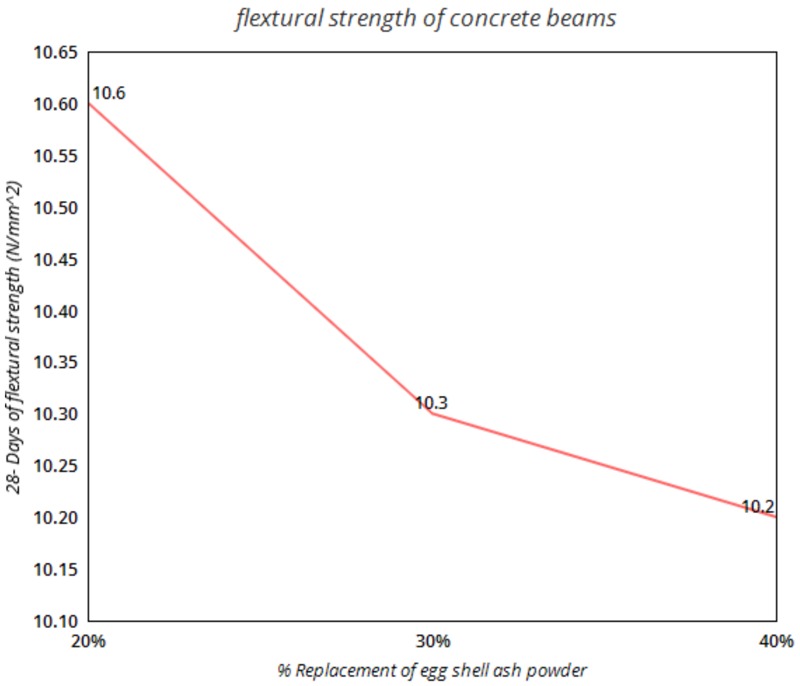

Figure 10. The 28-day compressive strength of cement cylinder for different substitution percentages

Figure 10 presents the results of strength analysis on concrete cylinders using 3D Analyzer. For this purpose, test specimens were subjected to compressive strength test (using a UTM) once cured for 7, 14, and 28 days, and the maximum load at failure was recorded. In order to maximize curing, mean values of compressive strength at failure were considered (Table 3).

4.3.1. Calculations

For a rectangular sample under a four-point loading scheme, where the loading span is 1/3, the followings hold true:

$\sigma = FL/bd^2$

F = Load (force) at failure

L = Length of the span

b = Width of the beam

d = Thickness of the beam

For a 28-day curing period, curing strength of the beams were calculated as follows:

$20\% = 10.6 \times 500/150 \times 150^2$

$= 0.00157\ N/mm^2$

$30\% = 10.3 \times 500/150 \times 150^2$

$= 0.00152\ N/mm^2$

$40\% = 10.2 \times 500/150 \times 150^2$

$= 0.00151\ N/mm^2$

Average stress value over the substitution ratios of 20, 30, 40% for the 28-day curing concrete cylinder was 0.002 N/mm^2.

4.4. Hydraulic shrinkage: testing hardened concrete

These tests measure axial or external changes in the dimension of specimen (shrinkage of concrete specimen in the course of a hardening process at room temperature (21). The following standards were used in the test process UNI 1130: 2008 and UNI 6555, which is similar to ASTM [426]. The UNI 1130 undertakes measurements at a particularly required stacked pin, while UNI 6555 implies fixed measurements into a mold in a dial gauge scale (22). Dimensions of the mold are 100 × 100 × 500 mm. In these tests, fresh composite concrete is spilled into a mold and left for 24 hours of setting time (23). In order to take blocks of the composite concrete, it was placed into a curing tube. The same procedure was applied to three sample blocks followed by curing for 7, 14, and 28 days. Upon completion of the curing stage, the test specimens turned into concrete blocks at room temperature (18°C or 68°F). A shown in Figure 11, the process began with a wet mix and ended up with a dry concrete block (24). After measuring the block dimension, the block size was compared to the mold size (25). Ideally, the dimensions should be exactly identical, but shrinkages of 0.5 to 0.8 mm were still acceptable (Table 4).

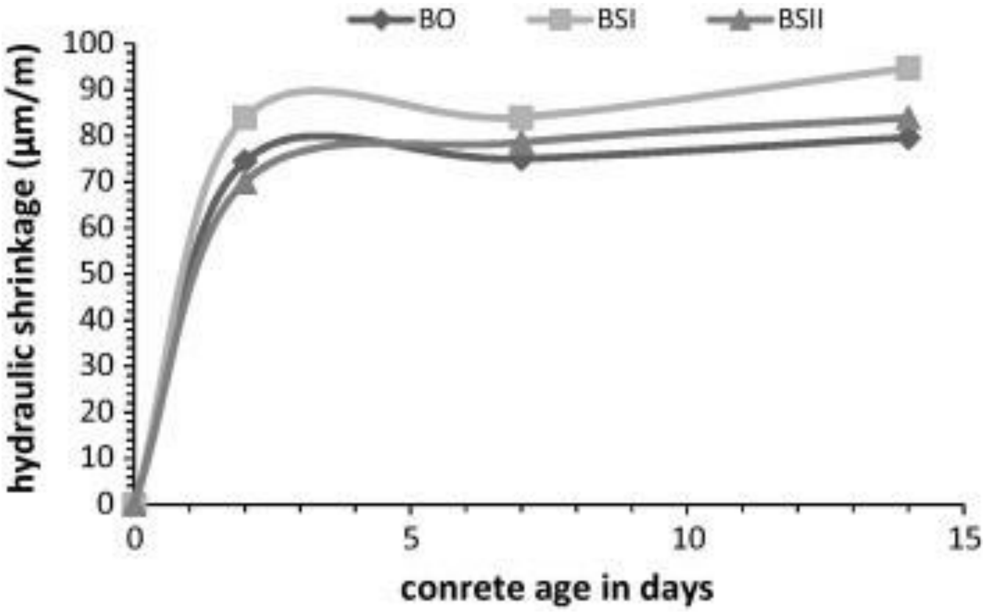

Figure 11. Results of hydraulic shrinkage test on three blocks samples

Table 4. Results of hydraulic shrinkage test on hardened concrete.

Specimens	*No. of curing days*	*Dimensions of shrinkage test mold*	*Measured dimensions of hardened concrete*
1	7- Days	100* 100* 500 mm	Exact size
2	14- Days	100* 100* 500 mm	Exact size
3	28- Days	100* 100* 500 mm	Acceptable size (within 0.5 mm of exact size)

4.5. Recommendations

Based on the test results, optimum values of substitution ratio of cement with eggshell ash were 30% and 40%. The use of local materials like eggshell and pozzolans in concrete production should be encouraged. Similar studies are recommended for concrete beams and slab sections to ascertain flexural behavior and better bonding strength obtained with this material. Durability studies on concrete cubes with partially substituted eggshell for cement should be carried out.

5. CONCLUSION

Outstanding performance was obtained with eggshell ash. It was found that, eggshell ash can partially substitute cement in concrete mix at 30 to 40%, thereby increasing its strength characteristics. Incorporation of eggshell ash into concrete improved compressive, flexural, and split tensile strengths and durability of the concrete. The experimental results further indicated other advantages of such partial substitution at 30 or 40%, including enhanced concrete performance and structural resistance against seismic events.

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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