MANTECH Publications

Journal of Ceramics and Concrete Technology
Volume 7 Issue 3
ISSN: 2457-0826 (Online)

Partial Use of Eggshell Ash for Cement in Concrete Grade M20: An Experimental Study

Piyush Jindal[1], Alok Kumar[2]

Lecturer[1], Student[2]

Department of Civil Engineering

Savitribai Phule Pune University, Pune, Maharashtra.

Corresponding Author's Email: *kumaralok854@gmail.com[2]*

Abstract

Cement, which is commonly used to connect construction materials, has affected not just the construction sector but also environmental design systems. The mass manufacturing of cement from heavy mineral rocks (plaster of Paris) is known to generate enormous volumes of mineral waste and necessitate the use of ball mill processing devices. Partially substituting cement with eggshell ash in M20 grade concrete at 20, 30, and 40% is investigated in this study.

Keywords: *Eggshell ash powder, OPC cement, Coarse aggregate, Fine aggregate*

INTRODUCTION

The goal of this research is to investigate into the potential of waste materials for enhancing concrete performance (1). Limestone has traditionally been used as a mineral in the manufacture of cement and concrete. Direct waste product discharge into the environment may cause environmental problems. In contrast, incorporating garbage into concrete technology can reduce the consumption of natural minerals and waste creation while increasing the strength of the resultant concrete and lowering the load imposed by rubbish on the surrounding environment. The usage of eggshell ash strengthened concrete, according to reports (2-4). When producing hydrated concrete mixes, leftover eggshell ash significantly enhances the concrete's workability (3, 5, 6). Currently, the high calcium content of eggshell ash produced in many industries poses serious issues such as air pollution and risks to living beings. As a result, it

Page 111-122 © MANTECH PUBLIATIONS 2022. All Rights Reserved

has been recommended that eggshell ash be used in concrete production instead of cement as the major bonding agent (7-9). In India, the majority of cement is made from volcanic rocks and limestone; nevertheless, these are linked to the creation of sandstone and limestone dirt, which has an influence on human and environmental health. The mechanical properties of raw and hardened concrete have been investigated, according to reports. It is well recognised that partially replacing concrete materials results in cost and energy savings, significantly increased performance (2, 3), and lower environmental consequences.

The purpose of this study is to look into the possibilities of waste materials for improving concrete performance (1). Limestone has long been utilised as a mineral in the production of cement and concrete. Direct release of waste products into the environment may generate environmental issues. In contrast, adding garbage into concrete technology can minimise the consumption of natural minerals and waste generation while boosting the strength of the finished concrete and lessening the burden imposed by garbage on the surrounding environment. According to sources, the use of eggshell ash strengthened concrete (2-4). When making hydrated concrete mixes, residual eggshell ash improves the workability of the concrete greatly (3, 5, 6). The high calcium content of eggshell ash generated in many businesses currently creates severe difficulties such as air pollution and dangers to living beings. As a result, it has been suggested that eggshell ash be utilised as the primary bonding ingredient in concrete rather than cement (7-9). The bulk of cement produced in India is generated from volcanic rocks and limestone; nevertheless, these are connected to the formation of sandstone and limestone dirt, which has an impact on human and environmental health. According to reports, the mechanical characteristics of raw and hardened concrete have been studied. It is well acknowledged that partially replacing concrete materials results in cost and energy savings, dramatically improved performance (2, 3), and less environmental impact.

EXPERIMENTAL MATERIALS

Cement

IS 12269-1987 lists the properties of OPC 53 grade cement, which was used in this investigation. The specific gravity, initial setting time, and total setting time of the cement mortar were 3.15, 55, and 258 minutes, respectively. The corresponding

Page 111-122 © MANTECH PUBLIATIONS 2022. All Rights Reserved

SCT value for the cement under consideration was 29.5%, according to test findings.

Fine aggregates

In this project, fine sand aggregates were substituted with synthetic sand (M-sand). The specific gravity and fineness modulus of the sand were 2.75 and 2.93, respectively (Figure 1).



Figure 1. Sand manufacturing

Coarse Aggregates



Figure 2. Coarse aggregate

Figure 2 depicts the coarse aggregates used in this study. These were 20 mm in diameter, with a specific gravity of 2.79, and a fineness modulus of 7.2. The coarse aggregates with sharp edges were acquired locally.

Water

Clear water was used to provide the essential hydration for the creation of concrete mixes. For this aim, a water/cement ratio (W/C) of 0.52 (52% was used. TDS levels in the water ranged between 6 and 7.5 ppm.

Eggshell Ash

As indicated in Figure 3, the eggshell ash used in this investigation was composed of calcium (95%) and magnesium carbonate (5%). The specific gravity and fineness modulus of eggshell ash were 2.15 and 7%, respectively. The ash was made by drying white eggshell waste in a high-temperature furnace at 1200 °C and then rapidly cooling it to room temperature. The eggshell ash was eventually pulverised into a fine powder.



Figure 3. Eggshell ash

RESEARCH METHODOLOGY

After replacing 20%, 30%, and 40% of the cement in conventional concrete with eggshell ash, the resultant concrete was cured and tested. Although either weight

Page 111-122 © MANTECH PUBLIATIONS 2022. All Rights Reserved

or volume batching can be employed, most needs call for weight batching rather than volume batching. OPC 53 grade cement was used in this investigation at 330 kg of cement per m3 of concrete (4). Furthermore, M20 grade concrete was added to the mix at a 1:1.5:3 ratio.

Batching

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

Concrete Mix Design

The concrete was rotational weight batching after being mixed at a ratio of 1:1.5:4. Figure 4 depicts freshly mixed M20 grade concrete following rotating weight batching.



Figure 4. Concrete mix

Test specimens

Specimens fashioned into cubes, beams, and cylinders were tested. As a result, compressive strength tests were performed on 150 × 150 × 150 mm cubes, split tensile strength tests were performed on cylinders 150 mm in diameter and 300 mm in length, and flexural strength tests were performed on 150 × 150 × 700 mm beams (5). Casting and hardening were carried out in accordance with IS standards 516 and 1199.

RESULTS AND DISCUSSION

Compressive strength tests on cubic concrete specimens



Figure 5. Universal testing machines (UTM)

Page 111-122 © MANTECH PUBLIATIONS 2022. All Rights Reserved

The compressive strength of cubic concrete specimens that had been cured in water, hardened, and surface-coated with 4T oil was measured using a CTM machine (10). The coating was applied to protect the specimens' external surfaces from severe conditions that may otherwise cause fast expansion and contraction and incorrect results (11). Measure each specimen's dimensions and weight before grading it, and then wash the surface of the test machine's bearing with a cleaning cloth to ensure that the load delivered to the cube surfaces is applied gradually (12). Loading was done slowly and carefully along the specimen's central axis. To prevent frightening the specimen, every care was taken. The modified cubes were gradually loaded until they failed at 280 kg fm/min, when the external surface of the specimen split, and eggshell was used to replace 20, 30, and 40% of the cement, respectively.

The universal testing machine shown in Figure 5 was used to conduct compressive strength tests on cubic and beam-shaped specimens.

Calculations

The cubic specimens were calculated by dividing the greatest force applied to the specimen throughout the course test by the area. The average strength of three specimens was reported in accordance with IS 456-2000. Correction factors were then added based on the specimen dimensions, as illustrated in Figure 6, to provide stress and strain curves in accordance with IS 456-1959. The revised concrete batch compositions improved strength by 60 to 70%. Concrete mixtures containing eggshell ash, in instance, demonstrated 60 to 65% better strength at failure while also being more economically efficient (Table 1).



Figure 6. Compressive failure of concrete cube

Page 111-122 © MANTECH PUBLIATIONS 2022. All Rights Reserved

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

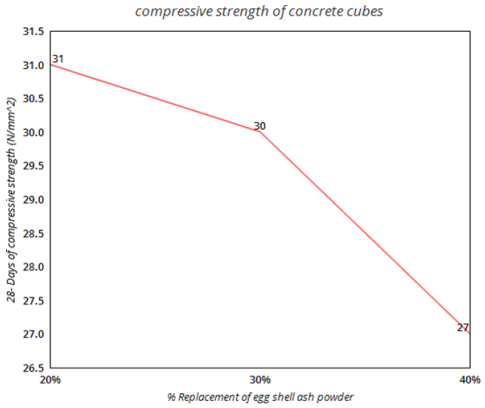


Figure 7. The 28-day compressive strength of concrete cubes for different substitution percentages

Figure 7 depicts the results of a strength analysis on concrete cubes performed using a 3D Analyzer. To that end, test specimens were compressed after being cured for 7, 14, and 28 days, and the maximum load at failure was recorded. Mean values of compressive strength at failure were examined in order to maximise curing.

Split tensile strength test on cylindrical concrete specimens

The split tensile test is a standard procedure for indirectly evaluating the tensile strength of cylinder concrete specimens, according to IS 5816-1970. (13). A CTM was used to examine the cylindrical concrete specimens (300 mm long by 150 mm in diameter). As a result, compressive loads were gradually applied to the horizontal surfaces of the specimen (14). At higher compressive stresses, the cylinder's diameter changed while keeping the load consistent (15). To handle such high compressive stress near the point of load application, strip rods were installed between the concrete cylinder and load-bearing pressure plates (16). This not only

Page 111-122 © MANTECH PUBLIATIONS 2022. All Rights Reserved

kept the concrete cylinder and load-bearing pressure plates from slipping, but it also kept the concrete cylinder from slipping during load-carrying stages. As the applied load rose, more compressive stress was given to the sample along the vertical axis, whereas uniform tensile tension was applied horizontally. This was caused mostly to changes 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

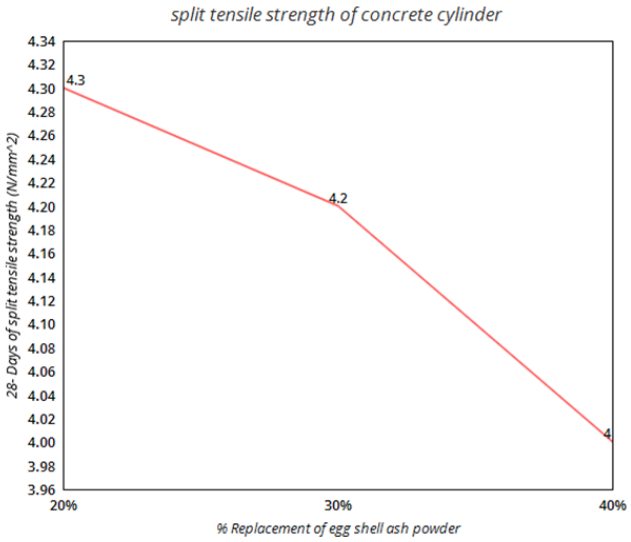


Figure 9. The 28-day compressive strength of cement cylinder for different substitution percentages

Page 111-122 © MANTECH PUBLIATIONS 2022. All Rights Reserved

Table 2 and Figure 9 show the results of a strength analysis on concrete cylinders performed using a 3D Analyzer. For this reason, test specimens were compressed (using a UTM) after being 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.

Calculations

$Ft = 2P/\pi DL$

Ft = 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%

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

$= 0.000056 \approx 0.00006$N

When the cement was replaced with eggshell ash at 20, 30, and 40% in the 28-day cured specimens, greater strength was obtained under the identical set of circumstances with the load operating on a vertical plane.

Concrete beam flexural strength test results Flexural strength tests, like split tensile tests, are used to validate beam performance in line with BS 1881: part 118:1983. (16). It is most commonly used on standard beam sizes (150 150 500 mm).

To create two equivalent weight-carrying supports, the concrete beam is mounted on a one-third-supported roller bearing; then load is gradually applied to the beams (17). To prevent the beams from sliding in response to load, steel channel sections were inserted in the centre of the beams (18). Beam materials are routinely examined without reinforcement, and composite materials are tested.

The ability of a material to generate no shear force into components is referred to as flexural strength (19). When no shear force was applied, the bending moment of the beam was highest at Pd/2. The ultimate load applied to the material prior to deformation is denoted by flexural strength (20).

Page 111-122 © MANTECH PUBLIATIONS 2022. All Rights Reserved

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

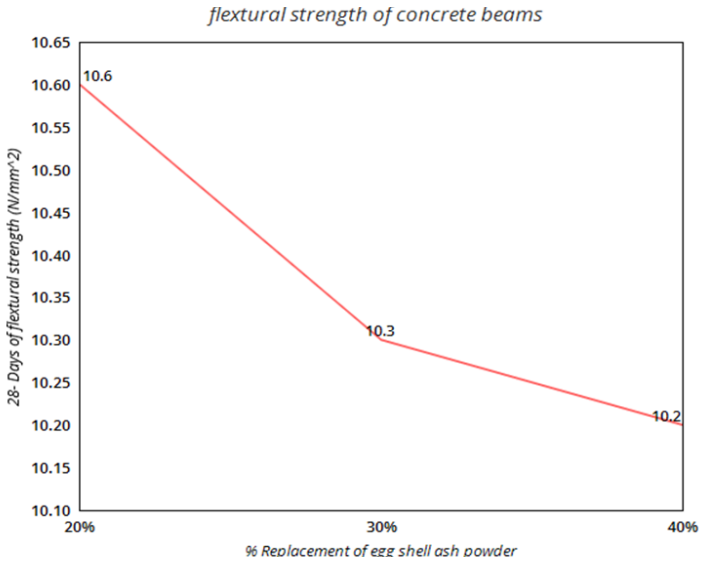


Figure 10. The 28-day compressive strength of cement cylinder for different substitution percentages

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).

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:

Page 111-122 © MANTECH PUBLIATIONS 2022. All Rights Reserved

20% = 10.6 × 500/150 × 1502
= 0.00157 N/mm^2
30% = 10.3 × 500/150 × 1502
= 0.00152 N/mm^2
40% = 10.2 × 500/150 × 1502
= 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.

Hydraulic shrinkage: testing hardened concrete

These tests detect axial or exterior changes in specimen dimension (shrinkage of concrete specimen during a hardening process at room temperature) (21). In the testing procedure, the following standards were used: UNI 1130: 2008 and UNI 6555, which is identical to ASTM [426]. The UNI 1130 takes measurements at a specific stacking pin, whereas the UNI 6555 takes set measurements into a mould on a dial gauge scale (22). The mold's dimensions are 100 100 500 mm. In these experiments, new composite concrete is poured into a mould and allowed to cure for 24 hours (23). The composite concrete was placed in a curing tube in order to take blocks. The same process was used on three sample blocks, which were then cured for 7, 14, and 28 days. After curing, the test specimens were transformed into concrete blocks at normal temperature (18oC or 68oF). As seen in Figure 11, the procedure started with a wet mix and concluded with a dry concrete block (24). Following the measurement of the block dimension, the block size was compared to the mould size (25). The dimensions should ideally be equal, however shrinkages of 0.5 to 0.8 mm were acceptable (Table 4).

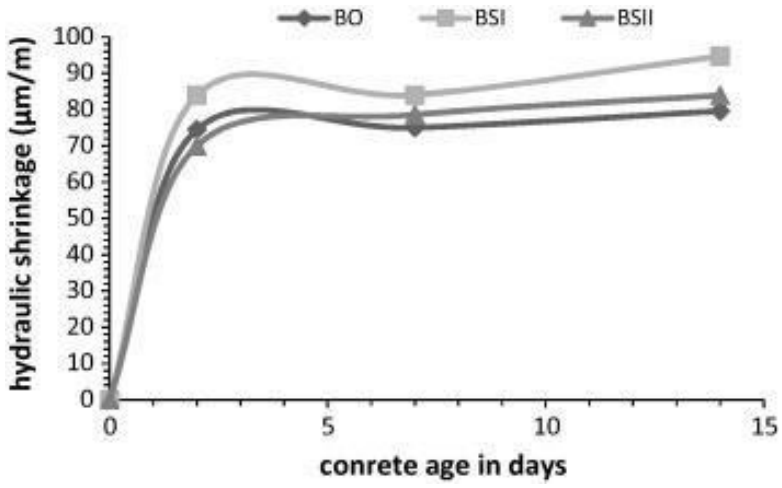


Figure 11. Results of hydraulic shrinkage test on three blocks samples

Page 111-122 © MANTECH PUBLIATIONS 2022. All Rights Reserved

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)

Recommendations

The optimum cement substitution ratios employing eggshell ash, according to the test results, were 30% and 40%. Local resources like eggshell and pozzolans should be promoted for use in concrete production. Concrete beams and slab sections should undergo similar study to establish flexural behaviour and bonding strength with this material. Concrete cubes should be tested for durability using partially substituted eggshell for cement.

CONCLUSION

The eggshell ash performed admirably. It was observed that eggshell ash may be used to partially replace cement in concrete mixtures at a rate of 30 to 40%, hence improving strength. Eggshell ash added to concrete boosted its compressive, flexural, and split tensile strengths, as well as its durability. The trials also shown that partial substitution at 30 or 40% can have other benefits, such as improving concrete construction and making structures more earthquake resistant.

REFERENCES

1. Poon CS, Shui Z, Lam L. Effect of microstructure of ITZ on compressive strength of concrete prepared with recycled aggregates. Construction and Building Materials. 2004;18(6):461-8.
2. Ganjian E, Khorami M, Maghsoudi AA. Scrap-tyre-rubber replacement for aggregate and filler in concrete. Construction and building materials. 2009;23(5):1828-36.
3. Sagoe-Crentsil KK, Brown T, Taylor AH. Performance of concrete made with commercially produced coarse recycled concrete aggregate. Cement and concrete research. 2001;31(5):707-12.
4. Lepage S, Baalbaki M, Dallaire É, Aïtcin P-C. Early shrinkage development in a high performance concrete. Cement, concrete and aggregates. 1999;21(1):31-5.
5. Steinberg M, Kukacka L, Colombo P, Kelsch J, Monowitz B, Dikeou J, et al. Concrete-Polymer Materials,

Page 111-122 © MANTECH PUBLIATIONS 2022. All Rights Reserved

First Topical Report, BNL 50134 (T-509) and USBR Gen. Rep. 1968;41:83. 15

6. Li Q, Meng H. About the dynamic strength enhancement of concrete-like materials in a split Hopkinson pressure bar test. International Journal of solids and structures. 2003;40(2):343-60.
7. Kumar MM, Maruthachalam D. Experimental Investigation on Self-curing concrete. International journal of advanced scientific and technical research. 2013;2(3).
8. Whiting D, Blankenhorn P, Kline D. Effect of hydration on the mechanical properties of epoxy impregnated concrete. Cement and Concrete Research. 1974;4(3):467-76.
9. Blankenhorn P, Kline D, Whiting D. Compressive strength of concrete impregnated with epoxy systems that do not contain a curing agent. Cement and Concrete Research. 1980;10(6):809-22.
10. Aminabhavi TM, Cassidy PE, Kukacka LE. Use of polymers in concrete technology. Journal of Macromolecular Science, Part C: Polymer Reviews. 1982;22(1):1-55.
11. Kukacka LE, Sugama T, Fontana J, Horn W, Amaro J. Alternate materials of construction for geothermal applications. Progress report No. 12, January-- March 1977. Brookhaven National Lab., Upton, NY (USA), 1977.
12. Fowler DW, Houston JT, Paul DR. Polymer-Impregnated Concrete Surface Treatments for Highway Bridge Decks. American Concrete Institute, Journal of. 1973;70(Proceeding).
13. Blankenhorn PR, Weyers R, Kline DE, Cady P. Enclosed Soak System for Deep Polymer Impregnation of Concrete Bridge Decks. Journal of Transportation Engineering. 1975;101(ASCE# 11102 Proceeding).
14. Cree D, Rutter A. Sustainable bio-Inspired limestone eggshell powder for potential industrialized applications. ACS Sustainable Chemistry & Engineering. 2015;3(5):941-9.
15. Lee H, Neville K. " Book Review-Handbook of Epoxy Resins". Industrial & Engineering Chemistry. 1967;59(9):16-7.

Page 111-122 © MANTECH PUBLIATIONS 2022. All Rights Reserved