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Application of the use of waste eggshell in concrete: A review

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ABSTRACT

One of the most often consumed foods, eggs generate tons of eggshell trash daily. Eggshell waste can be used as a powder to partially substitute cement in concrete in place of natural lime, which has the advantage of consuming the waste product. Also, it can be used as aggregate as a partial substitute for natural aggregate. This study reviewed the research on the application of waste eggshells. The benefits are related to the eggshell powder's (ESP) high calcium content and effective filling properties. Improved toughened characteristics, a quicker setting time, and better resistance to carbonation and water infiltration are just a few examples of this. Eggshell speeds up the hydration process as well. Eggshell reduces the concrete's flow ability. Several studies demonstrate that workability decreases when eggshell content rises. This is because eggshell has a high-water absorption rate early in the casting process. The water needed to create high workability is absorbed by the eggshell. Eggshell concrete (ESC) sets up considerably faster than regular concrete. In most studies, the time of setting for ESC is reduced by 30–60% compared to concrete without eggshell powder. When eggshell is added to concrete, its compressive strength rises by 6-35%.

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1. Introduction

Calcium is a mineral that is common in eggshells (ES). ES is employed as a calcium source used in animal feed in several nations because of their content importance (Faridi and Arabhosseini, 2018). About 5.5 grams of calcium carbonate, often known as $CaCO_3$, are the main components (Bhaskaran et al.,2016). According to some sources, eggshells' general chemical makeup is comparable to limestone (Chandrasekaran, 2018).
Calcium carbonate ($CaCO_3$) is an interesting one of the four main basic elements used to make cement. Several studies have been done on eggshells' chemical composition, and most have come to similar conclusions. According to certain studies, eggshell is composed of 95% $CaCO_3$ and 5% other minerals (Karthick et al., 2014), (Kiew et al., 2016), (Mohamadet al., 2016). Another one, however, has come to a more precise consensus regarding the constituents, which are 93.70% $CaCO_3$, 0.80% calcium phosphate, 1.3% $MgCO_3$, & 4.20% organic materials (Faridi&Arabhosseini, 2018) (Mishraet al., 2017), (Kannamet al., 2018), (Balamurugan& Santhosh, 2017). Before it may be used to substitute cement or aggregate, raw eggshells must go through a certain process. The eggshells are first washed with water This procedure removes the eggshell's thin membrane and cleans the

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eggshell of impurities. The eggshells are then dried after being cleaned. Before taking the eggshell to the site for grounding, it is advised to dry it as soon as possible (Hama et al., 2019), (Yerramala, 2014), (Yu et al., 2017).
If the eggshells are used as a partial substitute for cement, the powder should pass through sieve No. 200 (Hama et al., 2019). A bigger size of 2.36mm has also been attempted for use as aggregate (Doh & Chin, 2014).

2. Eggshells powder (ESP) as cementitious material

ESP's impact on the characteristics of light proclinate aggregate concrete is studied by Hama (2017). She deduced from the study's findings that 5.0% ESP produced a concrete with performance better than control one. When Gowsikaet al. (2014) replaced cement with ESP obtained from industry in various ratios, they discovered no loss of compressive strength or flexural strength. Concrete with up to 10.0% ESP had sorptivity and split strength values similar to control concrete according to Yerramala (2014). After 7 and 28 days of curing, 5% ESP substitution provided compressive strength higher than the control mix (Yerramala, 2014).
Eggshell powder concrete (ESPC) has worse workability than conventional concrete that doesn't contain ESP. The workability of ESC is similarly decreased when the percentage of cement is increased by eggshell (Parkash & Singh, 2017).
Based on Jhatial et al. (2018), ESP has a strong water absorption, which absorbs the water needed to achieve high workability that led to reduce of ESC. In addition, ESP's particle size influenced the slump. Finer ESP particles absorb a higher amount of water because it has a bigger surface area. This negatively affects the mix's capacity to be worked. Additionally, as more cement is replaced with ESP, the workability of cement mortar declines (Ramathilagam et al., 2018).
When the different eggshell powder is used, the slump of ESC increased but the factor of compaction falls, according to research made by Imran etal. (2019) on the workability of concrete with ESP and CS (copper slag). The concrete produced through conjuration with eggshell and rice husk is found to have very low slump (Afizah et al., 2017). At proper replacement %, ESC is usable for use as road pavement and mild reinforcing. Overall, ESPC's new properties are comparable to those of the traditional mix (Yerramala, 2014).
Eggshell typically acts as an accelerator to speed up the setting of cement (Ramathilagam et al., 2018) (Afolayan&Sani, 2017). Mtallib &Rabiu (2009) conducted a detailed investigation on the function of eggshells as an accelerator despite the fact that the chemical mechanism of hydration is complex. Eggshell powder has a similar effect on setting time as limestone does (Moon et al., 2017),where tri-calcium silicate (C3S) was used to speed up the hydration reaction. The initial setting time and the final setting time are the two data that make up the setting time (Mansoor et al., 2022).
Balamurugan and Santhosh's (2017) used a 5% ESP that resulted in a reduction of 49 to 60% in the final setting time. The consistency test of the combination was 37% consistent across all of the aforementioned experiments.
By substituting eggshells for cement up to 5% of the time, Sharma (2018) investigated impact eggshells when used in mortar. The results showed a consistency of 29.7% at 5% eggshell. The initial and final setting times decreased from 53 and 582 minutes to 21 and 286 minutes at 5% eggshell. Time spent setting fell from 50.86% to 60.38%.
As long as the ESPC has a particular amount of eggshell, it has greater compressive strength than conventional concrete. After reaching the optimum proportion, eggshell content rises but loses strength. Compressive strength and % eggshell replacement have a curvilinear connection, to put it simply. For a large number of studies, 10% ESP is the ideal amount when it is the only replacement material in the mixture (Kannam et al., 2018), (Doh & Chin, 2014) (Kanaka et al., 2019).
ES in concrete increased the water demand for keeping the same level of workability, but the water/cement (w/c) ratio weaken the concrete (Kannam et al., 2018). Parkash (2017) investigated ESPC with eggshell contents of 0, 6, 12, 18, and 24% and found that 12% was the ideal level. A study also showed that 15% of ESP replacement is ideal for the best mechanical characteristics.
A study of ESP using GGBS (ground-granulated blast-furnace slag) was conducted. It was determined that combining 15% ESP with 25% GGBS resulted in an increase in strength of 33% to 35%, depending on the age of the concrete and the testing procedure (Gajjar & Zala, 2018).
However, Yadav and Eramma (2017) found that the optimum percentage of concrete with ESP and GGBS was 10%, resulting in a slightly different optimum content.
However, research into eggshell powder high-performance concrete (ESPHPC) is less common. Comparable to other types of the mix, ESPHPC has a lower optimal content. HPC experiments were carried out by Francis and Eldhose (2017) using ESs with SCBA (sugar cane bagasse ash) as substitutes from cement. The strength peaked

at about 60 MPa after 28 days. The results showed that 5% was the ES percentage at which compressive strength increased by 5.5%. However, 10% SCBA replacement added as part of an environmentally friendly blend with nearly comparable strength to control was likewise acceptable. Another study showed that replacing cement with 2.5% ESP enhanced the bond strength between steel reinforcing and surrounding concrete, but increasing the amount of ESP to 7.5% led to a decline in bond strength (Hamdullah et al., 2019). Mansoor et al. (2022) found that 5% ESP powder is the best and higher content cause to decline in strength.
According to numerous studies, the ideal eggshell content for maximal flexural strength ranges from 6% to 10%. According to another study, the ideal eggshell content is 7.5% (Dhanalakshmi et al., 2015).
Because compressive strength should be preferred over flexural strength, increased ideal content for flexural strength does not impair the viability of ESC.
According to age, Ramya et al. (2019) found that split tensile strength was 3 to 16% greater than the control when about 50% QD (quarry dust) was added with 10%ESP. In a related experiment, copper slag and ESP (0–20%) were used in place of cement. The study found that a 10% replacement of both materials resulted in the highest compressive strength and splitting strength. At its highest point, the rise in splitting strength was 14.7%.
At all ages up to 28 days, adding 20% glass powder (GP) on top of 10% ESP results in about identical split strength with the reference split strength (Chandrasekaran, 2018). It can be demonstrated that an eggshell replacement of 5 to 10% generally improves the split tensile strength of ESC.
Concrete demonstrated that when ESP content increased, both the depth of penetration and the rate of absorption reduced. Tan et al. research's (2018) demonstrated that the absorption proportion reduced with increasing eggshell content for both ovens- and air-dried ESC. Another interesting result of the experiment was that ESC had a lower rate of absorption due to a higher concentration of calcium oxide and a superior filling effect.Another study agreed with the hypothesis (Balamurugan & Santhosh, 2017). Doh and Chin (2014) found a dramatic drop in penetration value at 20% ESC in a broader water penetration test.

3. Influence of Crushed Eggshell Content as Fine Aggregate Replacement

Sam and Raji (2015) investigated the use of used egg shells as a potential component for concrete. In concrete, leftover egg shells were utilized as a fine aggregate. The commonly used fine aggregate was entirely substituted in the laboratory test. Cast, cured, and tested 18 cubes. Sand was used as the fine aggregate in normal concrete mixes, and the strength development of those mixes was compared to mixtures employing eggshell particles. As a result, the compressive strength of the concrete dropped, although it is still within the range of lightweight concrete. When lighter concrete is required and a reduction in the structure's dead load is desired, they advise utilizing eggshells to produce concrete.
Another experiment was conducted to look into the feasibility of using eggshells as an alternative fine aggregate in the concrete mixture. In the experimental program, eggshells were substituted for the usual concrete formulation's sands in amounts of 10%, 20%, 30%, and 40%. (by volume). The eggshells were calcined at 900 °C to produce calcium oxide (CaO), often known as quicklime. The samples underwent 28 days of wet curing. The results show that the addition of calcium oxide to the aggregates has a substantial effect on the carbonation rate (up to 42%) and compression strength (up to 58.4%).
The addition of more calcium oxide is thought to have enhanced the bond's mechanical component. Between CEP and traditional concrete, there are no appreciable variations in the pH and sorptivity values. Compressive strength and carbonation acceleration rate benefit from the maximum replacement percentage of 40%. If the specifier wants to improve the performances of pH and sorptivity, formulation adjustment is not necessary. Gunasekaran (2015) discovered that 20% of the eggshell can be used to replace some of the fine aggregate (River Sand) (Nadia et al., 2020).

4. Conclusion

1. Eggshell reduces the concrete's flow ability. Several studies demonstrate that workability decreases when eggshell content rises. This is because eggshell has a high-water absorption rate early in the casting process. The water needed to create high workability is absorbed by the eggshell.

2. Eggshell concrete sets up considerably faster than regular concrete. In most studies, the control mix time is 30–60% longer than the time of setting for ESC.

3. Concrete's compressive strength increases by 6-35% when eggshell is added. In tests for water absorption, penetration, and carbonation, ESC’s performance was better. Research on the optimal eggshell content differs. However, the vast majority concurred that the optimal mechanical characteristics fell between the range of 10-15%. Others discover that up to 5% of eggshells is the ideal amount.

4. The eggshell also be used as fine aggregate to produce concrete with good properties

5. According to the findings, the aggregates' additions of calcium oxide significantly impact the compression strength (up to 58.4%) and carbonated ratio (up to 42%).

6. A 20% of fine aggregate can be partially replaced with an eggshell to produce concrete with good properties.

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