SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V13I5P104

Volume 13 Issue 5, 48-58, May 2026

Original Article

Ascertaining the Feasibility of Using Locally Sourced Chicken Eggshell Powder as A Supplementary Cementing Material: An Example from Ghana

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Received: 2 December 2025 Revised: 3 January 2026 Accepted: 03 April 2026 Published: 29 May 2026

Abstract *- Although the use of locally sourced Chicken Eggshell Powder (CESP) as a Supplementary Cementing Material (SCM) in concrete is a sustainability measure towards reducing the embodied carbon of concrete and promoting eggshell waste valorization, little is known of studies that evaluated the feasibility of locally sourced CESP as an SCM in Ghana. This study assesses the feasibility of chicken eggshell powder, sourced from poultry and food vendors in Takoradi, Ghana, as a supplementary cementing material in concrete production. Concrete specimens were prepared with Portland limestone cement partially replaced with CESP in proportions of 0%, 5%,10%,15%, and 20%. Tests, including XRF, EDS, and compressive strength tests, were the basis for assessing the performance of fresh and hardened CESP concretes. EDS and XRF analyses revealed essential elements in cements for C-S-H formation during hydration, such as Si, Fe, and Ca in CESP also. A low workability slump, S1: 10-40 mm, was recorded for CESP concretes. Compressive and flexural strengths of concrete improved progressively up to 10% partial replacement, beyond which further increases in partial replacement resulted in diminishing performance for ages, in days, 7, 28, and 63. Density decreased as the percentage of CESP in concrete increased. Empirically, the elemental composition of CESP from Takoradi has been established, likewise the characteristics of CESP concrete with CESP from Takoradi, an area with limited prior investigations. Practically, regression equation models were developed to aid construction practitioners in determining the optimal level of partially replacing cement with CESP in concrete mix at ages 7,28, and 63 days.*

Keywords *- Cementing, Concrete, Economy, Materials, Sustainability*.

1. Introduction

One of the means of achieving sustainability in the construction industry is to source materials locally if available. This has the potential of reducing carbon emissions as a result of limiting transportation time for materials, which will limit the use of fossil fuels [1]. It also contributes to growing the local economy as a chain of employment is created for indigenes, among others [2]. Whereas concrete has been the backbone of civil infrastructure development, many developing countries in the world, including Ghana, import cement, the main ingredient in concrete, or materials for manufacturing the cement, such as clinker. The transportation element in the cement production and/or importation chain significantly contributes to carbon emissions in the atmosphere [1]. It is estimated that for every tonnage of cement produced, the process generates about 0.9 tonnage of carbon emissions [2, 3], causing environmental pollution and climate change [3]. Hence, there is growing concern about reducing the carbon footprint of concrete through sourcing materials for cement locally as well as using more environmentally friendly alternative materials as a replacement for cement [1, 2]. It is against this backdrop that many countries in the world, including Ghana, are investigating the feasibility of locally sourced materials as an alternative to cement.

Whereas the feasibility of using some agricultural waste such as coconut shell powder and eggshell powder in concrete production has been established within some national contexts, such as Sri Lanka, Oman, India and Malaysia (see[1, 2, 4, 5]), there is lack of consensus among researchers regarding the characteristics of the SCM, characteristics of the modified concrete, and the optimum level of partial replacement [1, 2, 4, 5]. The varying views among researchers have been attributed to the origin and processes of the SCM, among others [1]. Nonetheless, little is known of studies, if any, that provided empirical evidence of the feasibility of locally sourced chicken eggshell powder (CESP) as a supplementary cementing material (SCM) in concrete production with Ghana as its focus. Also, there is a lack of prior studies that have reported on the characteristics of CESP concrete with CESP sourced from Ghana and established the optimum replacement level as well. This lack of literature within the context of Ghana has derailed the repurposing, reusing, and recycling of chicken eggshells and other agricultural waste for construction purposes, thereby inhibiting material circularity and agricultural waste valorization.

Hence, the relevance of this current study lies in its assessment of the feasibility of chicken eggshell powder, sourced from poultry and food vendors in Takoradi, Ghana, as a supplementary cementing material in concrete production. By evaluating the practical feasibility of CESP from Takoradi, Ghana, in concrete production, instead of the theoretical potential, empirical evidence is adduced to expand the frontier of existing literature on CESP as an SCM, and the applied relevance and originality of this current study are also enhanced.

This current study is unique in that it provides a geographical and context-specific evaluation of CESP sourced locally from food and poultry vendors in Takoradi, Ghana, as an SCM in Portland composite cement (PCC) concrete, a domain with limited prior empirical investigations. Replacing cement partially in concrete with CESP reduces the carbon footprint of concrete and aids in combating climate change, which aligns with Sustainable Development Goal 13: Climate Action [8]. The specific objectives that guided the study were:

- To assess the performance of fresh concrete with cement partially replaced with chicken eggshell powder, and
- To assess the performance of hardened concrete with cement partially replaced with chicken eggshell powder.

Performance of fresh and hardened concrete has been evaluated in previous studies using a combination of parameters such as slump value, temperature, compressive strength, flexural strength, density, microstructure, and water absorption [1, 2, 6, 7]. In this current study, a combination of slump value, compressive strength, temperature, flexural strength, density, water absorption, and microstructure analysis aided in evaluating the performance of CESP concrete towards ascertaining the feasibility of partially replacing cement with locally sourced chicken eggshell powder in Ghana.

More so, findings of the study offer lessons for countries such as Burkina Faso, Togo, and Côte d'Ivoire, whose construction industry shares close resemblances with Ghana. The study helps in practice as it establishes the optimum partial replacement level essential for construction practitioners in using CESP as an SCM in concrete production.

2. Ascertaining the Feasibility of CESP Use in Concrete in Existing Studies: A Literature Review

Eggshells are abundant in calcium and magnesium carbonate (lime), and their structure is comparable to that of limestone, one of the elements for cement production [5, 9]. In Oman, Al Abri et al. [5] obtained eggshells from Barka Farm, Muscat, which were used for standard concrete production (M25). Mechanical performance evaluations, including compressive and flexural strength tests, were performed on the concrete specimens. An optimum replacement level of 10% was identified, while compressive strength reduced beyond the optimum replacement level. Additionally, higher replacement levels were associated with reduced workability of the concrete mix. The study did not investigate concrete strength beyond 28 days. This weakness was addressed in this current study, as the long-term compressive strength of CESP concrete was investigated at age 63 days.

In a related study in Pakistan by Balouch et al. [10], the researchers partially replaced Ordinary Portland Cement with 5%, 10%,15% and 20% chicken eggshell powder. Performance of the concrete was evaluated using workability (slump and compaction factor), and compressive strength at ages 7, 14, 28, and 63 days. It was observed that workability decreased with a percentage increase in eggshell powder in the concrete mix. In comparison with the respective control concrete specimens, compressive strength was lower at age 7 days, and 14 days of curing recorded a further decline in compressive strength. This was attributed to the view that limestone-cement concrete is not fully hydrated even after 28 days of curing [10]. The fine cement filler particles accelerated the hydration of concrete and subsequently increased the early strength. Alternatively, the coarser particle size of eggshell powder adversely affected the early-age compressive strengths of CESP concrete [10]. None of the CESP concretes showed a superior performance in compressive strength compared with the control mix [10]. The study, among others, concluded that eggshell powder (10% and 15% partial replacement) is best used as a retarder [10]. The study partially replaced OPC with CESP. Therefore, there are no prior studies that partially replaced PCC with CESP. Thus, the need for this current study is to address the weaknesses highlighted.

In a related study by Yerramala [11], ordinary Portland cement was replaced partially with eggshell powder in proportions of 5%, 10%, 15% and 20%. 5% partial replacement level emerged as the optimum proportion of replacing cement partially with eggshell powder, while all other percentages recorded lesser compressive strength values compared to the control mix [11, 12]. After 1, 7, and 28 days of curing, the concrete specimens were assessed. Slump was found to be very low (5mm-12mm) and did not exceed that of the control specimen. Density decreased with increasing CESP levels. This was attributable to the fact that a low-density material (CESP) was used to replace a high-density material (cement) partially. No investigation on concrete was done beyond the 28 days; therefore, the long-term performance of the concrete specimens was not known. Hence, the relevance of this current study lies in addressing the highlighted weaknesses in the existing study. Hama et al. [13] partially replaced cement with eggshell powder in percentages of 0%, 3%, 5%, 8%, 10%, 13% and 15%, with 3% partial replacement being the optimal proportion. However, with additives, compressive strength improved up to 10% partial replacement, beyond which compressive strength decreased. The performance of the concrete was evaluated using the density, flexural strength, and compressive strength. Scanning Electron Microscopy (SEM) was employed in examining the microstructural features of the concrete. The results indicated that mixes containing CESP exhibited a more compacted internal structure compared with the control specimen. Furthermore, the findings revealed that increasing CESP content led to reductions in concrete density, workability, and compressive strength [13].

In Malaysia, Ramdzam et al. [2] replaced cement partially with eggshell at percentages of 0%, 5%,10%, and 15%, and revealed that the optimum replacement was at 5%. The concrete performance was evaluated using the slump, density, and compressive strength on days 7 and 28. CESP concrete recorded a lower density, lower compressive strength, and lower slump values compared with the control specimen. The eggshell was sieved using the 90 µm [2]. In a related study in Nigeria, Onu and Egwu [14] partially replaced cement with native eggshell powder at percentages of 5%, 10%,15%, and 20%, with 5% partial replacement being the optimal proportion of replacement, obtaining a compressive strength score of 21.91 N/mm^2. Although 5% was the optimal proportion that gave the highest compressive strength, its value was small compared to that of the control (22.94 N/mm^2). The mix ratio was 1:2:4. Concrete performance was evaluated using the slump and compressive strength at days 7,14, and 28 [14]. Also, the study attributed the low permeability of CESP concrete to the filler effect of CESP in concrete.

Paruthi et al. [7] reviewed existing literature that used CESP as a partial replacement for cement and concluded that workability decreases as CESP content increases. The slump values of CESP concrete specimens were lower than those of the control specimen. In addition, the tensile, flexural, and compressive strengths of the concrete improved progressively up to the optimum replacement percentage, after which further increases in replacement resulted in diminishing performance. It is also informed that increasing CESP content leads to decreasing water absorption for both air-dried CESP and oven-dried CESP. Again, there was a significant weight loss and loss of compressive strength when CESP concrete was exposed to sulphate and chloride solutions.

Thus, from the literature reviewed, CESP has been used to replace Ordinary Portland cement partially. None of the optimum levels of CESP exceeded 5 %, apart from the study in Oman by Al Abri et al. [5], which observed an optimum level of 10% without an additive. The 10% optimum replacement level by Hama et al. (2019) was with an additive. An increase in partially replacing cement with CESP generated a decrease in slump (workability). CESP increased as density and water absorption decreased. What is not known is the use of CESP to partially replace a Portland composite cement and the performance thereof. In Ghana, the predominant cement being manufactured is the Portland limestone cement, a composite cement whose performance when partially replaced with CESP is not known. Also, none of the studies used locally sourced materials from Takoradi, Ghana. Thus, the elemental composition of CESP sourced locally from Takoradi, Ghana, is not known. Hence, the relevance of this current study also lies in partially replacing PLC with CESP and assessing the performance thereof in its fresh and hardened states.

2.1. Theoretical basis of the Study

2.1.1. Loss of Clinker Theory

This theory espouses that partially replacing cement with SCM beyond a certain threshold results in a dilution effect, which leads to loss of cementitious binder, notwithstanding the gains from pozzolanic activity [15]. Hence, the optimum level of partial replacement is essential. This implies that there is an optimal partial replacement level for CESP beyond which loss of clinker sets in, and CESP concrete performance reduces. This theory is relevant for this current study as it establishes the optimal partial replacement level of CESP.

2.1.2. Pozzolanic Reaction Theory

The theory opines that CESP is rich in $CaCO_3$. During hydration, when cement comes into contact with water, calcium hydroxide ($Ca(OH)_2$) is produced, which subsequently reacts to form calcium silicate hydrate (C–S–H) [16, 17]. The development of C–S–H contributes to a reduction in pore volume and enhances the strength of concrete [16, 17]. Among others, the reaction is influenced by the availability of $Ca(OH)_2$, the level of dispersion, and the reaction in a concrete mix. Any replacement level beyond the optimum reduces the total clinker content, thus, the $Ca(OH)_2$ reservoir [17].

2.2. Synthesis of Literature

Based on the theoretical basis and empirical literature reviewed, this current study conceptualizes that partially replacing cement with CESP leads to an increase in performance of concrete (compressive and flexural strength) until optimum performance is attained, beyond which the loss of clinker effect sets in. While CESP concentration in a concrete mix decreases the water absorption, density, and slump of concrete increase.

3. Materials

3.1.1. Portland Composite Cement

CEM II/B-L: Portland limestone cement (PLC), strength class 42.5 R, was used in this study. X-ray fluorescence (XRF) spectrometry was conducted to identify the elemental composition of the cement. The typical elemental composition specified for Portland limestone cement (PLC) comprises silicon (Si), aluminium (Al), calcium (Ca), magnesium (Mg), iron (Fe), sulphur (S), sodium (Na), and potassium (K), in accordance with relevant standards [18-21].

3.1.2. Chicken Eggshell Powder (CESP)

CESP was used as an SCM to replace PLC partially. XRF spectrometry was conducted to determine the elemental composition of the locally sourced CESP. This provided the basis for comparing the elemental composition of CESP with PLC to ascertain its suitability as an SCM.

3.1.3. Water

Potable water, per BS EN 1008:2002, was used for the concrete specimens [22]. It was clean and odourless when smelled.

3.1.4. Fine and Coarse Aggregates

Coarse and fine aggregates for the concretes were BS EN 933-1:2012 and BSI 1377-3:1990 to determine the particle sizes of fine and coarse aggregates for the concrete specimens ([23, 24]).

3.2. Experimental Procedure

Chicken eggshells, an agricultural waste, were cleaned and air-dried under the sun for 6 hours to remove moisture. The sample was pulverised into smaller particles with the help of a blender, and then sieved using a 75µm sieve (see [6]). A mix design was developed to guide the concrete production (see Table 1). Firstly, the control concrete, which had 0% CESP, was prepared targeting a compressive strength of 20 N/mm2 after curing for 28 days. Water-to-cement ratio was 0.58. PLC was replaced partially with CESP in proportions of 5%, 10%, 15% and 20%.

The concrete mixes were labelled as CESP 0, CESP 5, CESP 10, CESP 15, and CESP 20, when CESP partially replaced cement (PLC) in proportions of 0%, 5%,10%,15%, and 20%, respectively. After 7 days, 28 days, and 63 days of curing, three concrete specimens each were tested for compressive strength following BS EN 12390-3:2019 [25], density of concrete following BS EN 12390 -7 (2009) [26], water absorption per BS EN 1881-122: 2011[27], and flexural strength following BS EN 12390-5: 2019 [28]. Concrete was mixed and cured following BS EN 12390-2: 2000 [29].

3.3. Determining the Properties of Materials for Concrete Production

3.3.1. Grading Test for Coarse Aggregate

The grading test for coarse aggregates for the concrete mix is guided by ASTM C33/C33M-24 [30] and BS EN 933-1:2012 [24]. [24] Moreover, [30] among others specify the sieving method for determining aggregate size [24, 30]. The sieves used were: 22 mm, 20 mm, 19 mm, 14 mm, 12.5 mm,10 mm, 4.75 mm, and 2.36 mm.

3.3.2. Grading Test for Fine Aggregate (Sand) for Concrete

Grading test was done in accordance with BS EN 933-1:2012 [24]; and classified following BS 882:1992 [31], and BS EN 12620:2013 [32]. The specific sieves used for the test were: 5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3mm, 0.15 mm, and 0.075 mm.

3.3.3. Energy Dispersive X-ray Spectroscopy (EDS) and Scanning Electron Microscope (SEM) for Concrete Specimens

Energy Dispersive X-ray Spectroscopy (EDS), also known as EDAX or EDX, was integrated with the Scanning Electron Microscope (SEM) test to provide both elemental composition and morphological information of the concrete specimens [33, 34]. Firstly, the specimens were imaged using SEM to locate regions of interest such as unreacted particles, hydration products, and/or voids. It provided information about the texture, microstructure, cracks, and bonding characteristics within a concrete specimen [16].

Table 1. Mix design for C20 concrete with cement partially replaced with a CESP

Mix ID	CESP (Kg)	Cement (Kg)	Sand (Kg)	Crushed rock (Kg)	Water-cement ratio (0.58)(Kg)
(CESP 0)	0	1.52	2.27	4.55	0.84
(CESP 5)	0.08	1.44	2.27	4.55	0.84
(CESP 10)	0.15	1.37	2.27	4.55	0.84
(CESP15)	0.23	1.29	2.27	4.55	0.84
(CESP 20)	0.30	1.22	2.27	4.55	0.84

4. Results and Discussions

4.1. Fine and Coarse Aggregates

From Figure 1, with 56.86% passing through the 0.6 mm sieve (see Figure 1), the fine aggregate falls within zone II: Medium sand, reference to BS 882:1992 and BS EN 12620: 2013 [31, 32]. Thus, suitable for the production of general concrete. From Figure 2, the coarse aggregate was well graded with an upper limit not exceeding 20 mm and a lower limit not exceeding 4.75 mm. The aggregate met the grading limits for 20 mm coarse aggregate for coarse concrete, in reference to BS 882:1992 and BS EN 12620:2013 [31, 32], indicating a well-graded coarse aggregate for a concrete mix.

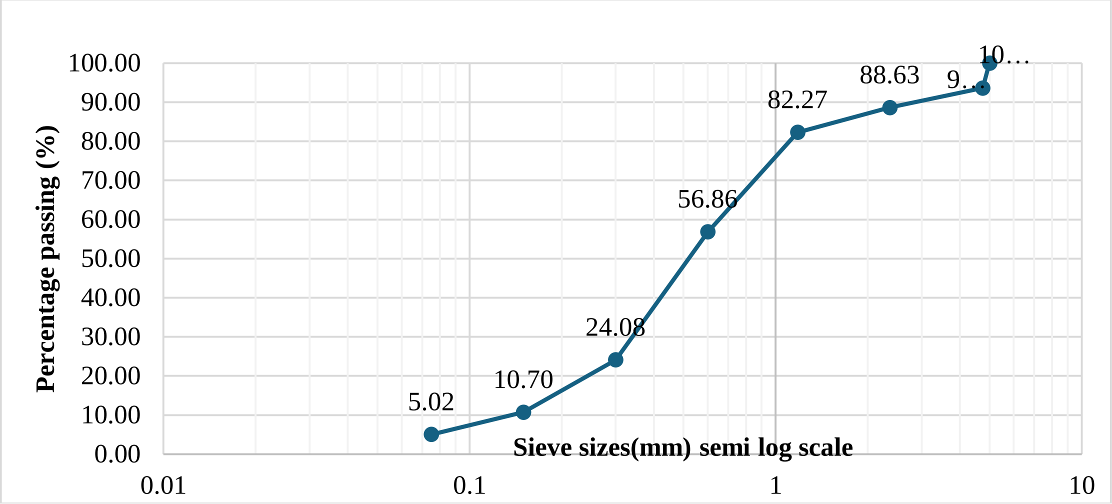

Fig. 1 Gradation curve for fine aggregate

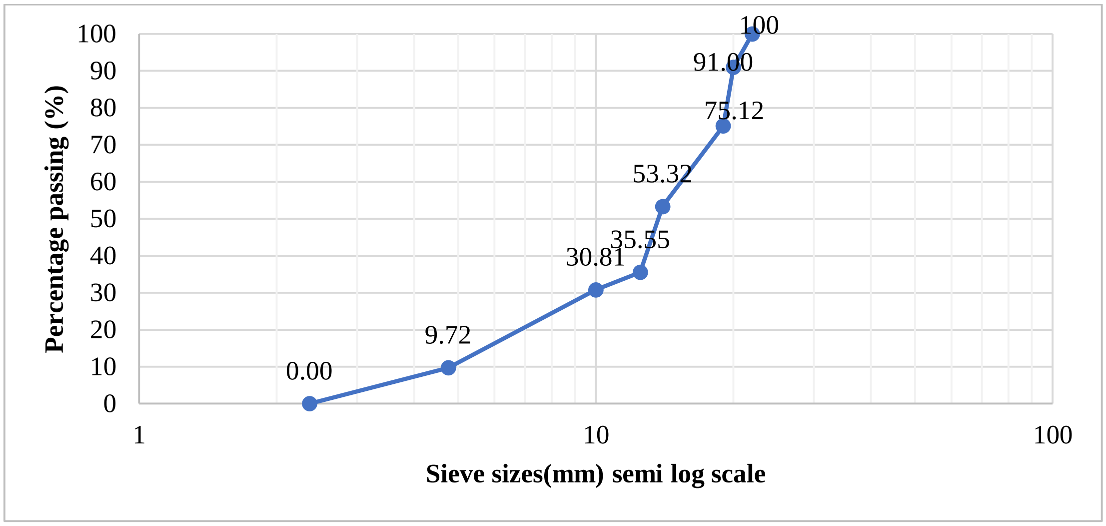

Fig. 2 Gradation curve for coarse aggregates

Table 2. Properties of CESP and PLC

Material	Ca	Al	Fe	Si	S	Mg
Cement (ppm)	441500	41800	34650	141500	18650	27750
CESP (ppm)	421000	1010	107.5	1100	4550	7665

4.2. Elemental Composition of CESP

From Table 2, the elemental composition of CESP was comparable to that of the PLC cement, but in varying parts per million (ppm), affirming the potential of CESP as a supplementary cementing material. The richness of CESP in Ca (421000 ppm) affirms the findings of previous studies that CESP is rich in Ca, the primary element in limestone [2, 5, 9, 14]. In affirmation, a comparative analysis by Yerramala [11] found the chemical composition of CESP to be just like limestone.

Objective one: To assess the performance of fresh concrete with cement partially replaced with chicken eggshell powder.

4.3. Workability and Temperature

From Figure 3, the slump value decreased with a percentage rise in CESP, an indication of a decrease in workability as the CESP increased in the concrete mix. This affirms the position of Paruthi et al. [7] that workability decreases with an increase in partial replacement. Also, none of the slump values exceeded that of the control specimen. This supports the findings of Ramdzam et al. [2] in Malaysia, when the researchers observed that CESP slump values were lower than the control and concluded that the presence of CESP in a concrete lowers the slump value. With reference to BS EN 206-1:2000, true slump was ideal for a concrete mix, and it ranged from (10mm to 220mm), specifically S1: 10-40 mm slump was suitable for low-workability applications [35].

Thus, with a slump of 16 mm to 40 mm recorded in this study, for both the control concrete and the CESP concrete, the concrete specimens could be classified as S1 slump and ideal for low workability applications. The temperature for freshly mixed normal concrete should typically range between 10 °C and 32 °C, with 20 °C–27 °C being considered the optimal range for normal concrete [36]. Thus, from Figure 4, the temperature of freshly mixed concrete ranged from 26 °C to 21 °C. The trend suggested a decreasing temperature of fresh concrete as the percentage of CESP concentration increased from 0% to 20%. Mehta and Monteiro [16] and Neville and Brooks [37] opined that as the level of partial replacement increased, it reduced the heat generated during hydration, thereby lowering the temperature of the fresh mixed concrete [16, 37].

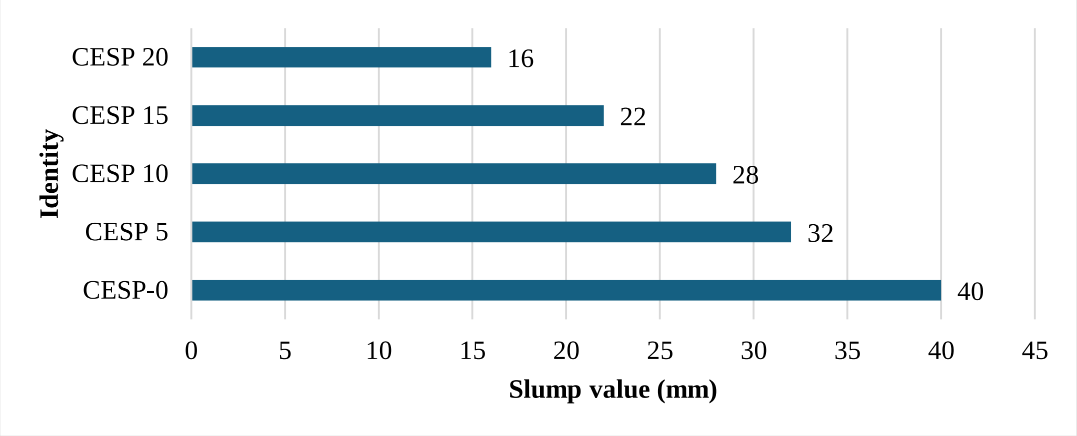

Fig. 3 Slump performance of concretes with CESP partially replacing cement

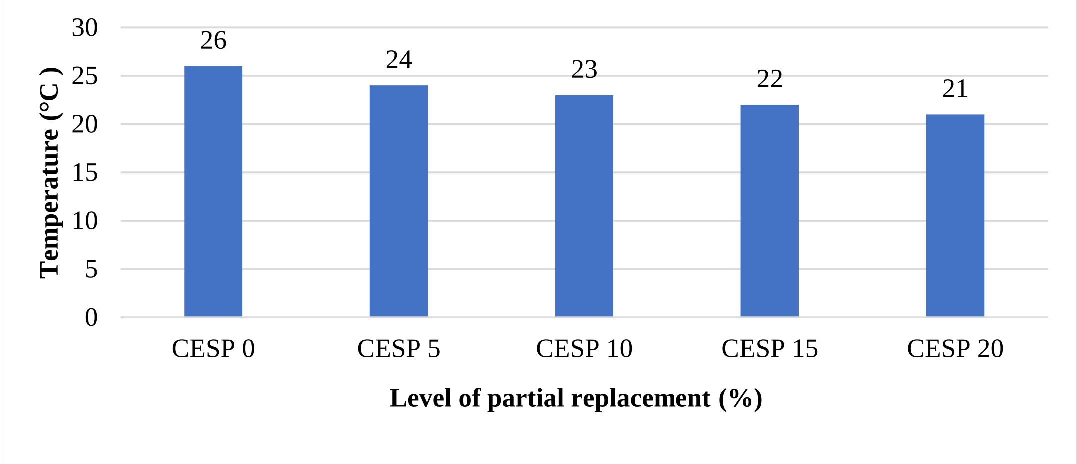

Fig. 4 Temperature of concrete with CESP partially replacing cement

Objective two: To assess the performance of hardened concrete with cement partially replaced with chicken eggshell powder.

4.4. Compressive Strength

The compressive strength targeted after curing for 28 days was 20 N/mm². From Table 3, there was an increase in compressive strength of CESP concretes from ages 7 days, through 28 days, to 63 days—an indication of continuous hydration and pozzolanic reaction in the CESP concrete specimens [7]. Also, for all the days (7, 28, and 63), compressive strength improved progressively up to 10% partial replacement, beyond which any additional increase in CESP concentration resulted in loss of clinker effect [15]. The 10% optimum replacement level for 28 days was an improvement on the 5 % recorded by Yerramala [11] and Ramdzam et al. [2] in Malaysia, 3 % by Hama et al. [13], while affirming the 10% by Al Abri et al. [5] in a related study in Oman. Furthermore, contrary to the study by Ramdzam et al. [2] in Malaysia, where the researchers observed that compressive strength of CESP at varying levels of partial replacement never exceeded the control specimens, this current study found compressive strength at 5% and 10% partial replacement levels exceeding that of the control at 7 days, 28 days, and 63 days. Even after 63 days of curing, the compressive strength of (CESP 15) also exceeded that of the control specimens. Also, the early strength of concrete specimens at 7 days showed that at partial replacement levels of 5% and 10%, CESP concrete outperforms that of the control specimens. Thus, contrasts the position of Balouch et al. [10] that in CESP concrete, the 7-day compressive strength is lower than that of the control concrete and that CESP should be used as a retarder.

Table 3. Compressive strength performance of concretes with cement partially replaced with CESP

Percentage of partial replacement (%)	7 days (N/mm^2)	28 days (N/mm^2)	63 days (N/mm^2)
(CESP 0)	12.20	21.35	23.20
(CESP 5)	12.50	21.75	23.90
(CESP 10)	13.49	22.88	23.95
(CESP 15)	12.10	19.82	20.45
(CESP 20)	11.33	17.74	19.20

Furthermore, in this study, a regression model was developed to practically guide construction practitioners for the ease of applying the concrete mix for optimum results, as presented in Table 4. From Table 4, R^2 values ranged between 0 and 1. According to Kutner et al. [38] and Montgomery et al. [39], an R^2 value below 0.2 signifies a very weak relationship, 0.2-0.4 signifies a weak to moderate relationship, 0.4-0.6 signifies a moderate relationship, 0.6-0.8 represents a strong relationship, and values above 0.8 signify a very strong relationship between the variables [38, 39]. The R^2 values for the 7-day compressive strength model, 28-day compressive strength model, and 63-day compressive strength model were 0.95, 0.96, and 0.94, respectively (see Table 4). Indicating a very strong relationship. From Table 4, (Y) is the compressive strength, and the models confirmed that the optimum level of partial replacement was 10%.

Table 4. Models explaining compressive strength performance of CESP concretes

Model	Equation	R^2 (goodness of fit)	Remarks
For 7-Day Strength (Y_7)	$Y_7 = [-0.0143x^2 + 0.187x + 12.2]$	0.95	An indication that 95 % of the change in compressive strength at age 7 days can be predicted from the proportions of CESP, a very strong model fit.
For 28-Day Strength (Y_{28})	$Y_{28} = [-0.0267x^2 + 0.32x + 21.35]$	0.96	An indication that 96 % of the change in compressive strength at age 28 days can be predicted from the proportions of CESP, a very strong model fit.
For 63-Day Strength (Y_{63})	$Y_{63} = [-0.0208x^2 + 0.25x + 23.90]$	0.94	An indication that 94 % of the change in compressive strength at age 63 days can be predicted from the proportions of CESP, a very strong model fit.

4.5. Flexural Strength, Density, and Water Absorption of Hardened Concrete.

According to Paruthi et al. [7], as CESP content in concrete increases, flexural strength also increases until an optimum level of partial replacement is reached, beyond which any further increase in CESP content leads to a decrease in flexural strength. This position was supported by the findings of this current study. From Table 5, flexural strength increased from day 7 to day 63, an indication of continuous hydration and pozzolanic reactivity within the concrete specimens. The optimum level of partial replacement was 10%. Also, the density of hardened concrete was determined guided by BS EN 12390 -7: 2009 [26].

From Table 6, the density of concrete increased with curing age (7, 28, and 63 days). Also, for ages 7 days, 28 days, and 63 days, density was found to decrease as the percentage of CESP partially replacing cement in a concrete mix increased.

This finding in Ghana supports the view of Ramdzam et al. [2], Paruthi et al. [7], and Hama et al. [13] that increasing the content of CESP as a partial replacement for cement leads to a decrease in the density of concrete. Again, none of the densities of CESP concrete exceeded that of the control for all the days of curing.

A phenomenon Hama et al. [13] attributed to the notion that CESP is less dense than cement, as a result, using a less dense material to replace a highly dense material in concrete will result in a less dense concrete. Furthermore, in accordance with the BS EN 206-1:2000 [35], the CESP concrete could be classified as a normal-weight concrete since the average oven-dry density values were more than 2000 kg/m^3 but did not exceed 2600 kg/m^3.

From Table 7, for (CESP 0), (CESP 5), (CESP 10), (CESP 15), and (CESP 20) concrete mixes, water absorption of concrete decreased with increasing curing age. It also decreased with increasing CESP concentration in a concrete.

This observation supports the opinion by Paruthi et al. [7] that increasing CESP content leads to decreasing water absorption for both air-dried CESP and oven-dried CESP. This is because C-S-H gel in concrete mix increases with an increase in curing time, while total voids decrease [1].

Table 5. Flexural strength performance of concrete with age

Percentage of partial replacement (%)	**7 days (N/mm^2)**	**28 days (N/mm^2)**	**63 days (N/mm^2)**
(CESP 0)	1.28	2.3	2.47
(CESP 5)	1.34	2.5	2.55
(CESP 10)	1.89	2.7	2.61
(CESP 15)	1.20	2.2	2.4
(CESP 20)	1.10	1.8	1.97

Table 6. Density of CESP concrete

Percentage of partial replacement	**7 days (kg/m^3)**	**28 days (kg/m^3)**	**63 days (kg/m^3)**
(CESP 0)	2370	2409	2411
(CESP 5)	2364	2404	2407
(CESP 10)	2338	2392	2394
(CESP 15)	2335	2385	2389
(CESP 20)	2332	2384	2387

Table 7. Water absorption of CESP concrete

Percentage of partial replacement	**28 days (%)**	**63 days (%)**
(CESP 0)	0.91	0.87
(CESP 5)	0.78	0.69
(CESP 10)	0.53	0.43
(CESP 15)	0.39	0.28
(CESP 20)	0.30	0.22

4.6. Microstructure of Concrete

Energy-dispersive X-ray Spectroscopy (EDS) and Scanning Electron Microscopy (SEM) were employed in analysing the microstructure of concrete specimens. The focus was on the 0% and 10% optimum partial replacement specimens.

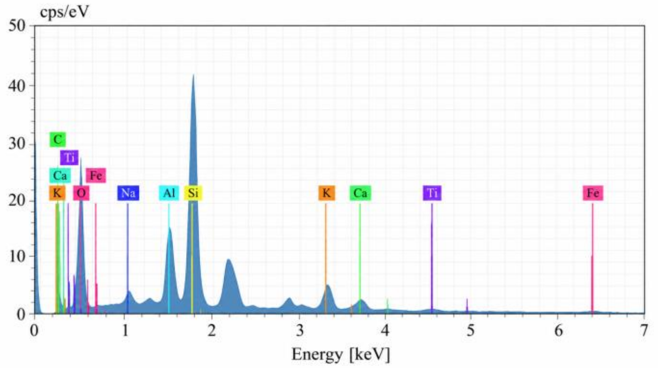

Fig. 5 EDS elemental analysis of concrete with 0% CESP as a partial replacement of cement

From Figure 5, the EDS elemental analysis established that the control concrete specimen with 0% CESP partially replacing cement comprised a typical cement–aggregate system, with cement hydration products (Si, Ca, Al, O, Fe) and aggregate phases (O, Si, Mg, Al) clearly identifiable. The dominant elements appeared to be Ca and Fe. Calcium is associated with calcium silicate hydrates (C-S-H) and calcium hydroxide formation in concrete during hydration [1].

Similarly, from Figure 6, the EDS elemental analysis of the concrete specimen, revealed the presence of iron (Fe), carbon (C), oxygen (O), sodium (Na), calcium (Ca), magnesium (Mg), silicon (Si), and aluminium (Al), at varying concentration levels in the concrete specimens with 10% CESP partially replacing cement.

The dominant elements appeared to be iron and calcium, as indicated by their prominent peaks at different energy levels. Calcium and iron are among the prominent elements in cement, in reference to BS EN 197-1:2000 [20]. The EDS spectrum indicated that the concrete specimen was composed of elements with characteristics of cement (Ca, O, Si, Al, Fe) and aggregates (Si, O, Al, Mg) [40].

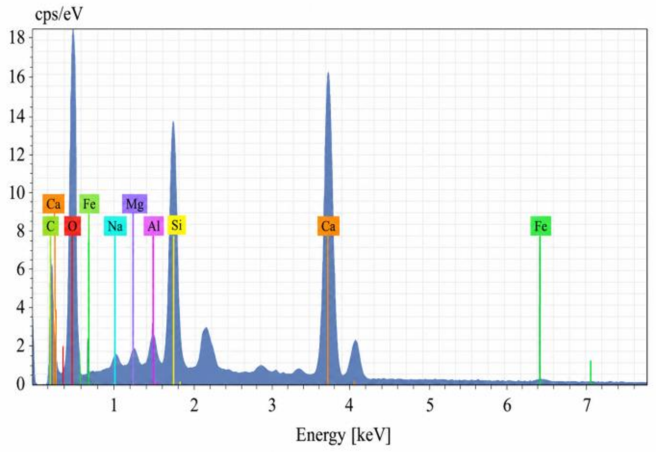

Fig. 6 An EDS elemental analysis of concrete with 10% CESP as a partial replacement of cement

From Table 8, the EDS revealed the presence of carbon (9.56%), oxygen (45.90%), sodium (1.10%), aluminium (6.10%), silicon (23.18%), potassium (7.04), calcium (4.18%), titanium (1.03%), iron (1.95%) in the control concrete (CESP 0); and carbon (11.67%), oxygen (50.79%), aluminium (1.22%), silicon (13.05%), calcium (20.56%), iron (1.46%) and magnesium (0.59%) in the (CESP10). This revealed the close resemblance in the elemental composition of the CESP with cement.

Reference to BS EN [19] and BS EN 197-1:2000 [20], the presence of elements like silicon (Si), aluminum (Al), iron (Fe), and magnesium (Mg) makes the CESP a supplementary cementing material. These elements are present in cement. The elements aid in concrete performances such as durability, sustainability, strength, hydration reaction, and setting time [1, 37].

Table 8. EDS elemental analysis of the concrete with cement partially replaced with 0% and 10% CESP

Element	(CESP 0) Mass Norm. [%]	(CESP 10) Mass Norm. [%]
Carbon	9.56	11.67
Oxygen	45.90	50.79
Sodium	1.04	0.65
Aluminum	6.10	1.22
Silicon	23.18	13.05
Potassium	7.04	-
Calcium	4.18	20.56
Titanium	1.03	-
Iron	1.95	1.47
Magnesium	-	0.59
Sum	100.0	100

Figure 7 presents an image of the microstructure of a concrete specimen with 0% CESP partially replacing cement. The SEM image exposed inconsistencies in the interaction between the phases of the materials. The larger distinct particles revealed the shape and integration of aggregates with their surrounding paste, thus affecting the bonding of aggregates and cement at the interzonal transition zone. The dark and irregular spots revealed the presence of pores or voids in the concrete specimen. The voids and the microcracks revealed the needle-like crystals of ettringite. Also, the concrete specimen was embedded with calcium hydroxide (CH) (portlandites), and C-S-H gel, which are the main binding phases responsible for concrete's strength, and some unreacted particles.

The presence of unreacted particles of cement revealed in the SEM suggests the potential for hydraulic and pozzolanic reaction to continue in the concrete mix. Figure 8 revealed the microstructure and morphology of the CESP concrete with 10% CESP partial replacement. It showed a heterogeneous mixture of particles with varying sizes and shapes, indicating the presence of different components within the concrete matrix: cement, aggregates, and CESP. The texture revealed a blend of coarse and fine aggregates. The presence of calcium silicate hydrate (C-S-H) gel and portlandites, which are formed during cement hydration and pozzolanic reactions of CESP, is an indication of a binding matrix and filling pores.

The dark spots were indicative of areas of pores and voids within the concrete specimen. According to Paruthi et al. [7], this influences the permeability and density of concrete. The image revealed the integration of CESP within the concrete matrix and its contribution to the overall integrity of the microstructure and strength performance of the concrete.

The presence of unreacted particles of CESP revealed in the SEM suggests the potential for pozzolanic reaction to continue in the concrete mix.

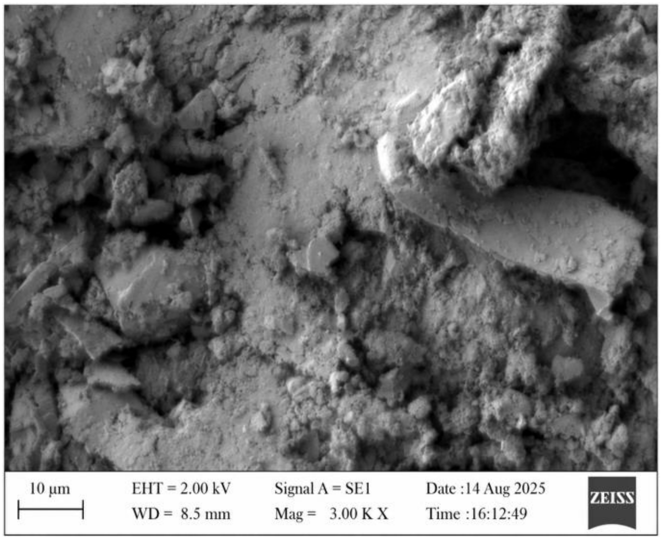

Fig. 7 SEM analysis of the microstructure of a concrete specimen with 0% CESP partial replacement

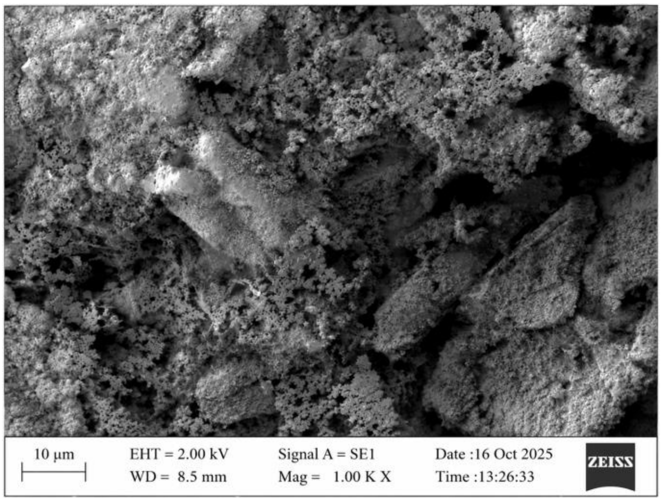

Fig. 8 SEM analysis of the microstructure of a concrete specimen with 10% CESP partial replacement

5. Conclusion

This study assessed the feasibility of chicken eggshell powder, sourced from poultry and food vendors in Takoradi, Ghana, as a supplementary cementing material in concrete production. The study found that CESP from poultry and food vendors in Takoradi, Ghana, is a feasible SCM. In relation to the performance of the CESP concrete specimens, it was observed that the workability of CESP concrete decreased as the CESP content in concrete increased. Compressive strength and flexural strength progressively improved up to 10% as CESP concentration increased, then declined beyond 10% partial replacement level when CESP was further added, making 10% CESP replacement level the optimum, beyond which the dilution effect of concrete sets in. CESP concretes fell within the range of normal concrete, likewise the control concrete. The density of CESP concrete decreased with an increase in CESP partial replacement level as well as an increase in the age of concrete. Also, the water absorption of CESP concrete decreased with increasing concentration of CESP in the concrete mix. The EDS elemental analysis affirmed the XRF findings of the presence of elements such as Fe, Mg, Ca, and Si in CESP concrete and CESP, essential elements for the formation of calcium silicate hydrate gel and portlandites. The SEM images of concrete specimens revealed the presence of calcium silicate hydrate (C-S-H) gel and portlandites in concrete specimens, an indication of continuous hydration reactivity and pozzolanic reactivity in the concrete specimens. Also, many unreacted particles of CESP and cement were revealed in the SEM, suggesting the potential for pozzolanic reaction to continue in the concrete mix. The study found alternative uses for chicken eggshells, otherwise an agricultural waste material polluting the environment, in concrete production. Empirically, the elemental composition of CESP locally sourced from Takoradi in Ghana has been established, and the characterization of CESP concrete with CESP sourced locally in Takoradi, Ghana. The outcome of the study addresses the lack of literature on the elemental composition of chicken eggshell powder, sourced locally from Takoradi, Ghana, as a supplementary cementing material. It also addresses the lack of literature on the characterization of CESP concrete with chicken eggshell powder sourced locally from Takoradi in Ghana. It further promotes waste valorization of eggshells generated by food and poultry vendors in Takoradi, Ghana, as it finds an alternative use for eggshell waste in concrete production. Replacing cement partially in concrete with CESP has the potential of reducing the carbon footprint of concrete and aids in combating climate change. This aligns with Sustainable Development Goal 13: Climate Action [8]. The findings of the study inform policymakers and the government on sustainable construction material policies in Ghana and eggshell waste management strategies at the metropolitan, municipal, and district levels. Practically, it has developed a regression equation that will aid construction practitioners in determining the optimal level of partially replacing cement with CESP in concrete mix regarding compressive strength. Moreover, this study provides the basis for future studies on sourcing SCMs locally for the intended purpose.

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