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Use of native-chicken eggshell powder as a partial replacement for cement in concrete development

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ABSTRACT

This study aimed to determine the suitability of native egg shell powder, prepared in a simple and economic manner, as a partial replacement for cement in concrete production. The variations in properties of concrete when native eggshell powder was used to partially replace cement as binder material was determined and compared with the values obtained when cement only was used as the binder. 16 samples of eggshell powder concrete (EPC) developed with a partial replacement of cement with 5%, 10%, 15% and 20% native eggshell powder were produced while 4 control cubes of plain cement concrete (PCC) were also produced. Sieve analysis were carried out to determine the properties of the materials used, while slump and compressive strength tests were done to determine the early and the hardened properties of the concrete produced. The results show that the concrete slump, which is a measure of workability, decreased from 48mm for plain concrete to 44, 39, 33 and 31mm representing 8.3%, 18.7%, 31.2% and 35.4% reductions in slump values for 5%, 10%, 15% and 20% dosages of native eggshell powder in the mixes respectively. Compressive strength also reduced slightly with increase in dosage of native eggshell powder. Values of compressive strength observed after 28days of curing were 22.94N/mm^2 for plain concrete, 21.91, 20.71, 17.11 and 12.24N/mm^2 for 5%, 10%, 15% and 20% native eggshell dosages respectively; accordingly indicating 4.6%, 9.2%, 25.4% and 46.6% strength reductions for 5%, 10%, 15% and 20% cement replacements with native eggshell powder. It was observed that at 5% and 10% eggshell powder content, the reductions in strength were within tolerable values. Hence eggshell powder obtained from the eggshell of locally sourced native domestic chickens in a simple and economic manner were effective when used as a partial replacement for cement in concrete production. However, such replacement of cement with native eggshell powder should not exceed 10%. This is because after the 10% replacement the loss in structural strength was observed as becoming substantial.

1. Introduction

Concrete, a mixture of binding material, fine aggregate, coarse aggregate and water is unarguably the most universal material used in construction works. It is used extensively in African countries including Nigeria. The over reliance on cement for concrete works has over the years resulted in an unprecedented high and excruciating cost of the material, thus rendering the efforts of successive Governments to make housing cheap and affordable for all, a failure. Furthermore, the manufacture of several tons of cement by local companies has been a potential source of threat to environmental and health safety as considerable quantities of various forms of carbon (IV) oxide, a silent killer, is continually released to the atmosphere as bye-product. Towards arresting this ugly trend and thus converting wastes to wealth, curious attempts have been made to utilize either mineral admixture or ash derivatives of solid agricultural wastes, as partial substitutes for cement in concrete production. Documented evidence abounds indicating that these efforts have been substantially fruitful both economically and in terms of environmental safety, without compromising properties of structural concrete such as strength, workability and durability. Vasudevan and Wei showed that eggshell concrete greatly

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improved the compressive and flexural strength of concrete. Similarly [1], reported that mixing eggshell powder as a partial substitution of cement in traditional concrete led to higher compressive strength in the mixture than the reference mixture.

Egg shell is an important component of solid agricultural wastes, indiscriminately deposited in both urban and rural communities in Nigeria. They are mostly generated in large quantities by chick hatcheries, bakeries and fast-food vendors and eateries, etc as 'throw-away' waste material. They are also generated as a waste product from the rearing of native domestic chickens. Eggshells constitute high nuisance value to the environment because of their indiscriminate deposition. Therefore, in our ever-increasing efforts to convert waste into wealth, the idea of investigating the possibility of replacing cement with eggshell powder, at least, partially is worth embracing [10]. Various researches carried out in recent times have mostly used eggshell ash obtained from oven-heating and grinding of poultry-farmed eggshells. This study aimed to determine the suitability of egg shell powder made from locally sourced eggshell of native domestic chickens as partial replacement for cement in concrete production. Furthermore, it was aimed to use simple, economic method of eggshell powder preparation that required less energy demand. Hence this work was carried out to determine whether the powder obtained in a simple and economic manner from the shells of these native chickens, as different from the ash obtained from the eggs of poultry-farmed chickens, would be effective as a partial replacement for cement in concrete development.

2. Materials and Methods

2.1 Materials

Cement

The Portland cement used in this research is a lime-based cement. It is the most common type of cement in general use around the world as a basic ingredient of concrete. They were obtained from accredited dealers in Port Harcourt city, Nigeria

Fine Aggregates

The fine aggregates used for this research was a locally sourced natural river sand. Sieve analysis was carried out to determine the zone of the sand and its particle size distribution

Coarse Aggregates

The coarse aggregate used for this experimental study was gravel, locally sourced from a nearby retailer.

Water

Water used was potable tap water free from impurities, odour, colour and taste. The quality of water conformed to the specifications provided in BS EN 1008.

Eggshell Powder

The eggshell wastes were obtained from local breeders of native chickens in Ovogo, Emohua Local Government Area, Rivers State. The eggshell wastes were cleaned with tap water and dried under the sun for several days. The eggshells were crushed and ground to powder. Eggshell powder has been found to have similar composition with cement but in varying percentages as shown in Table 1 [10].

Table 1. Chemical properties of eggshell powder

Composition	Cement	Eggshell Powder
CaO	60.10%	62.35%
SiO_2	21.80%	0.61%
AL_2O_3	6.66%	0.07
Fe_2O_3	4.10%	0.63
MgO	0.50%	0.36
SO_3	2.50%	1.32%
K_2O	0.25%	0.22

2.2 Methods

Mix Design

A concrete mix design of 1:2:4 representing the ratio of binder, fine aggregates and coarse aggregates was employed.

Batching

Batching by weight was used to determine the amount of binder, eggshell, fine and coarse aggregate used for the research.

Sieve Analysis

Sieve analysis was conducted in accordance with BS EN 933 for both fine and coarse aggregates. A sample of 2kg of fine aggregate was poured into BS sieves with aperture sizes of 5mm, 2.36mm, 1.18mm, 600µm, 300µm, 150µm and pan arranged in that order.

Similar procedure was carried out for coarse aggregates using different sieve sizes and 3kg sample. The sieves had aperture sizes of 40mm, 20mm, 5mm, 2.36mm and pan arranged in that order.

Mixing, Casting and Curing

The materials used were batched by weight, and manual mixing was done based on nominal mix ratio of 1:2:4 and water-cement ratio of 0.5. Four (4) samples each of concrete developed with each percentage partial replacement of eggshell powder, 5%, 10%, 15% and 20%, were produced, totaling 16 samples, while 4 control cubes were produced to serve as benchmark for comparison with the replacement values. The size of cube moulds used for this study conformed with BS EN 12390, that is, 150mm×150mm×150mm. Twenty-four hours after casting, the concrete specimen was removed from the moulds, marked and then cured by complete immersion in normal water for the required period of hydration of 7, 14 and 28days.

Workability

Workability is a measure of the amount of useful internal work necessary to be done on a concrete mix to produce full compaction. A standard measure of workability is the slump test [10][8]. The workability of the fresh concrete was determined by the Slump test in accordance with BS 1377. The test was carried out for each of the 20 samples of concrete produced using both plain concrete and eggshell powder concrete.

Compressive Strength Test

Concrete cubes of dimension 150mm x150mm x 150mm were used for compressive strength test. All concrete cubes were cured in a tank filled with water. The compressive strength test was conducted according to BS 1881: Part 116 using the compressive strength test machine. This single test judges whether concreting has been done properly or not. Compressive strength is the ability of material or structure to carry the loads on its surface without any crack or deflection. The test was undertaken at the end of the nominal period of 7, 14 and 28 days of curing the cubes. The concrete specimens (cubes) were removed from the curing tank and placed outside to surface dry before they were tested using the automatic compression machine.

3. Results and Discussion

Sieve Analysis

From Figure 1, Cu = 2.81 and Cc is less than 1 for fine aggregates. Hence Cu<1<6, showing the sand is uniformly/poorly graded. For the coarse aggregates, the Cu is 1.76 and Cc is 1.23, showing that it is uniformly graded and the coarse aggregate is a coarse gravel. For granite to be classified as well graded: $C_u > 4$ and $1 < C_c < 3$, in accordance with unified soil classification system [11]

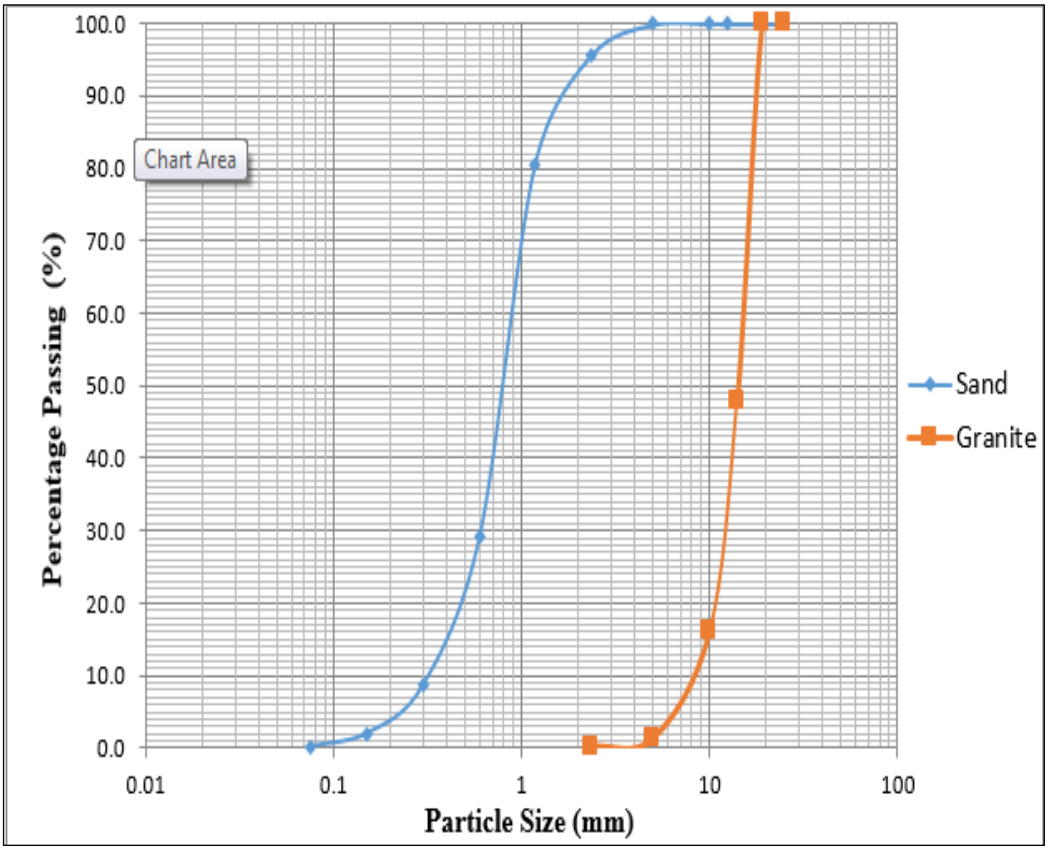


Figure 1: Sieve Analysis Results for fine and coarse aggregates.

Workability

Table 3 and Figure 2 indicate that the concrete slump decreased as the percentage dosage of eggshell powder increased in the mixes. The plain concrete yielded the maximum slump value of 48. The slump value reduced to 44, 39, 33 and 31 representing 8.3%, 18.7%, 31.2% and 35.4% reductions in slump values for 5%, 10%, 15% and 20% eggshell replacements respectively. This result indicates that using eggshell powder as partial replacement for cement will require more water in the concrete mix in order to obtain a required workability of the concrete or more mechanical effort or admixtures will be required.

Table3: Slump test results

S/N	ESP %	Slump(mm)	% Decrease
1	0	48	0
2	5	44	8.3
3	10	39	18.7
4	15	33	31.2
5	20	31	35.4

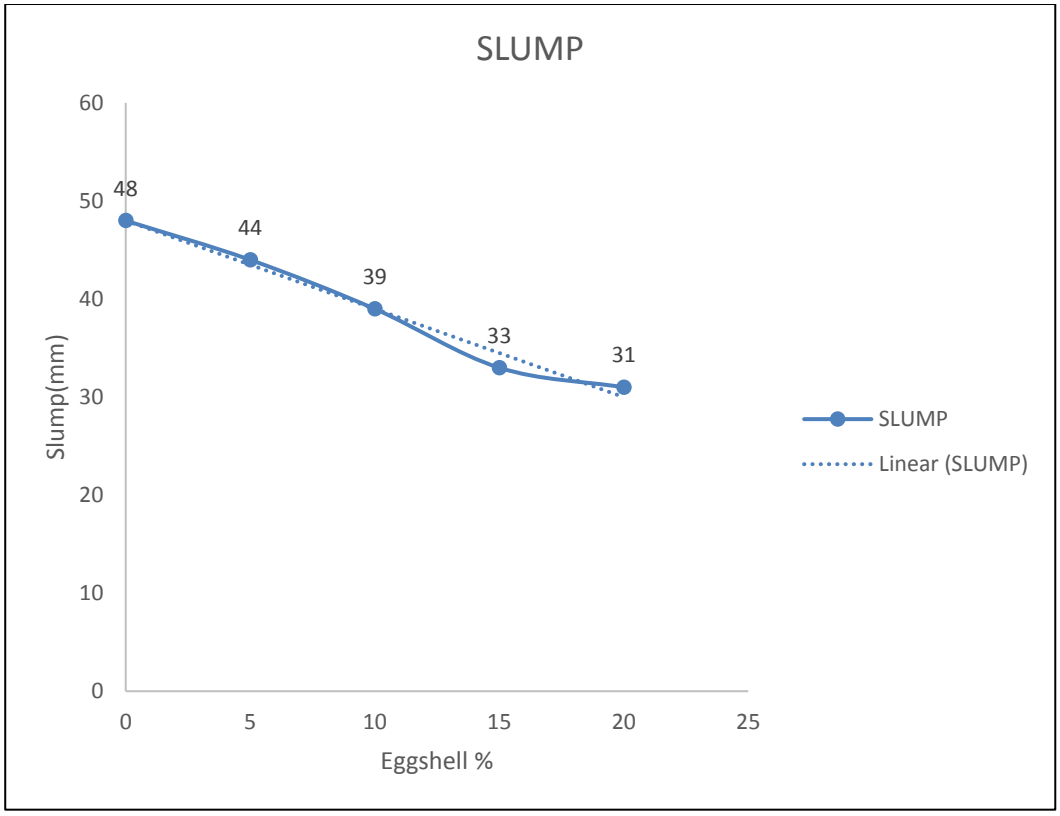


Figure 2: Slump test results

Compressive strength tests

Figures 3, 4 and 5 show the rate of increase from the 7-day strength to the 28-day strength of plain concrete as well as the eggshell powder concrete. Although concrete of both types generally increased in strength as curing progressed, the strength of concrete containing eggshell powder was mildly reduced when compared with that of plain concrete. As shown in Figure 3, the 7-day strength of the plain concrete was 20.47 N/mm^2, while that of concrete with 5%, 10%, 15% and 20% partial replacement of cement with eggshell powder were 16.38, 13.22, 12.46 and 11.02 N/mm^2 respectively. A similar trend was seen after the 14-day period of concrete curing. Figure 4 shows that the 14-day strength of plain concrete was 21.69 N/mm^2, while those of the concrete with 5%, 10%, 15% and 20% partial replacement of cement with eggshell powder were 17.67, 13.57, 12.87 and 11.36 N/mm^2 respectively. After 28days of curing the compressive strengths were 22.94N/mm^2 for plain concrete, 21.91, 20.71, 17.11 and 12.24N/mm^2 for 5%, 10%, 15% and 20% native eggshell dosages respectively. These indicated 4.6%, 9.2%, 25.4% and 46.6% comparative strength reductions for 5%, 10%, 15% and 20% cement replacements with native eggshell powder. It can be deduced that such replacement of cement with native eggshell powder should not exceed 10%. This is because after the 10% replacement the loss in strength can be seen as becoming substantial.

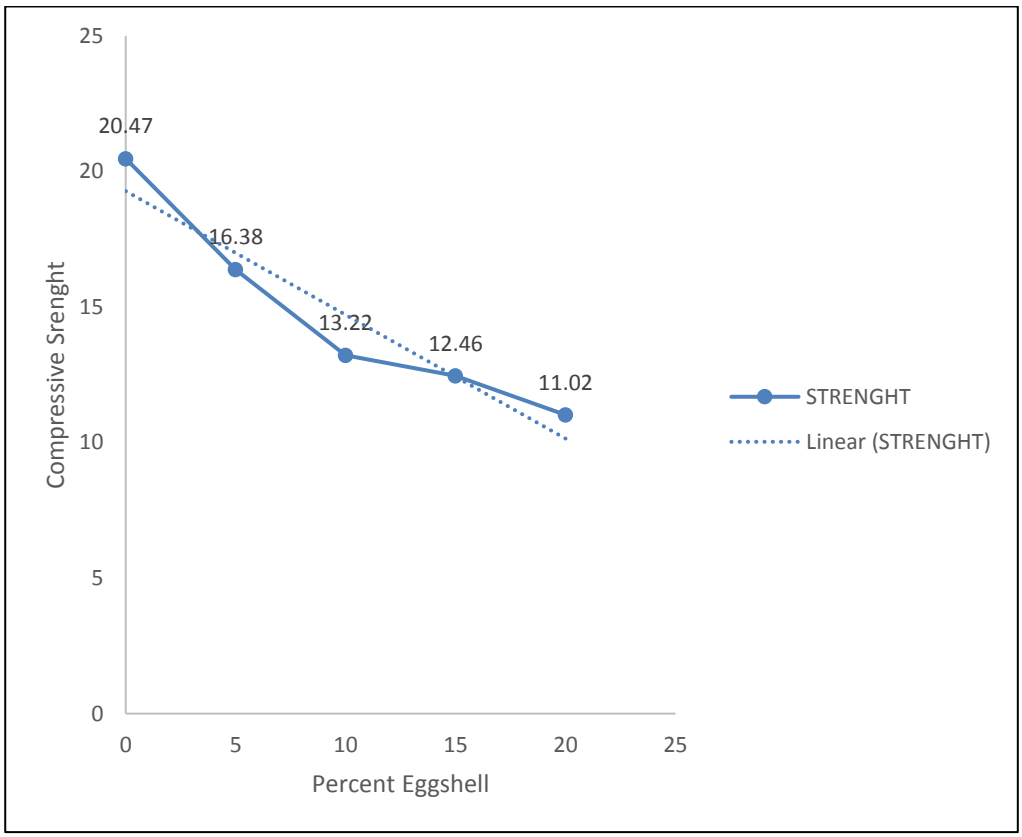


Fig 3: Compressive strength test results after 7 days

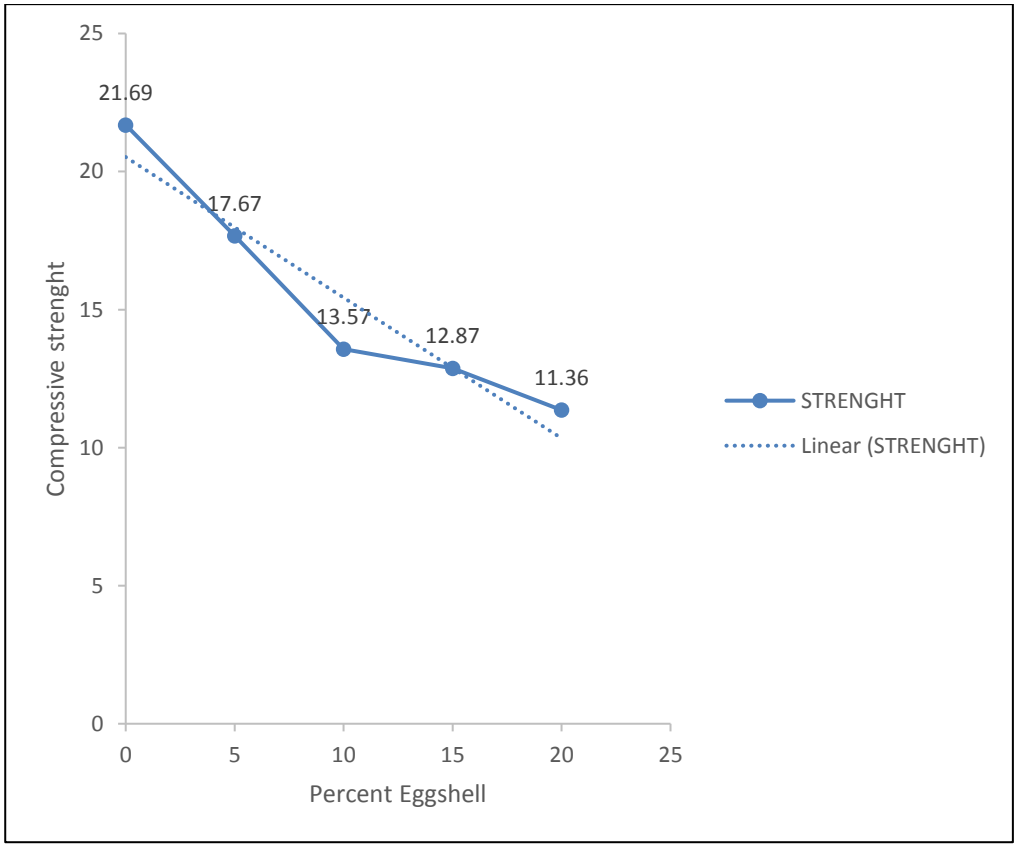


Fig 4: Compressive strength test results after 14 days

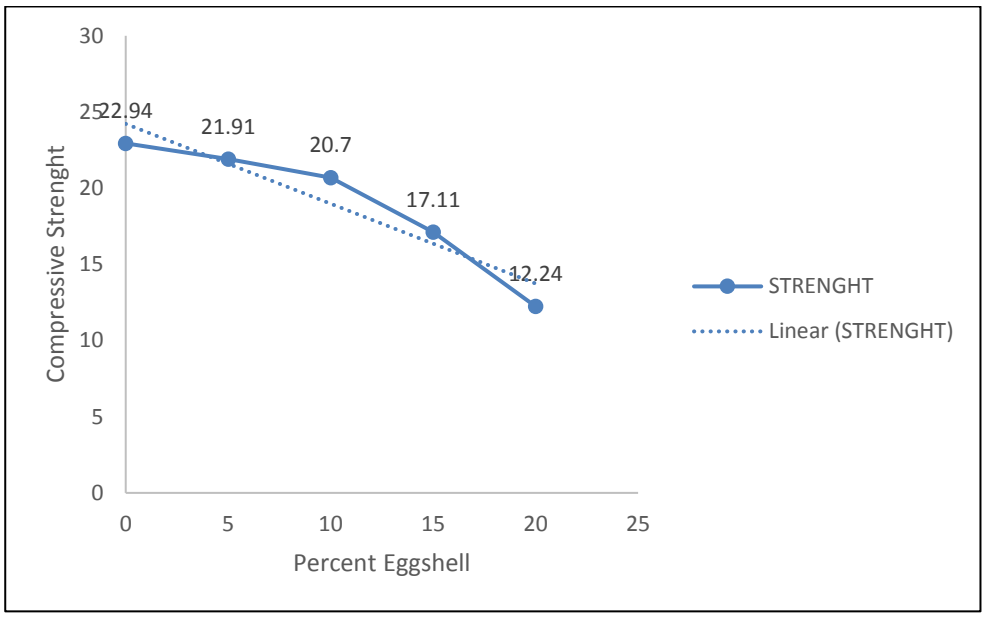


Fig 5: Compressive strength test results after 28 days

This work was carried out to determine whether the powder obtained in a simple and economic manner from the shells of native chicken eggs, as different from the ash obtained from the eggs of poultry-farmed chickens, would be effective as a partial replacement for cement as binder material in concrete development. It was found that partial replacement of cement with native eggshell powder resulted in decreases in the concrete slump compared with that of plain concrete. Concrete slump, which is a measure of workability, decreased from 48mm for plain concrete to 44, 39, 33 and 31mm representing 8.3%, 18.7%, 31.2% and 35.4% reductions respectively in slump values for 5%, 10%, 15% and 20% replacements of cement with native eggshell powder in the mixes. These reductions in concrete slump and hence workability agrees with the report of Desfouli, [8] and [7] that workability of eggshell concrete (ESC) is lower compared to normal Portland cement concrete. Chong et al [8] attributed this to the high-water absorption of eggshell powder at the early stage of casting, opining that Eggshell absorbs the water required to achieve a high workability. Mild reductions were observed in the compressive strength of concrete made with native eggshell powder content when compared with that of plain concrete. Compressive strength test results for the 7-day, 14-day and 28-day cured concrete followed the same trend. Results of the final test at the 28th day showed 4.6%, 9.2%, 25.4% and 46.6% strength reductions for 5%, 10%, 15% and 20% cement replacements with native eggshell powder. It was observed that beyond 10% replacement of cement with eggshell, the percentage reduction in strength was becoming substantial. Hence, replacement of cement with eggshell powder may be limited to a maximum value of 10% within which reduction in compressive strength is mild and tolerable

The results obtained were however, contrary to the reports of Desfouli [8], Amanah and Khalil [1], and Vasudevan and Wei [12]. The authors reported increase in the compressive strength of concrete as the percentage of eggshell increased up to a maximum of 10 to 15%. Desfouli [8] further reported that compressive strength of concrete increased by adding eggshell up to 10%, but by adding eggshell of 20%, a decrease in compressive strength of concrete compared to the control sample was observed. This corroborates the significant reduction in compressive strength of concrete when 20% native eggshell powder replacement of cement was used. The difference in results may be due to the method of preparation of the eggshell powder. While the other researchers used oven-dried eggshell ash to prepare the powder used in the concrete, the present work used simply sun-dried and grinded eggshell.

4. Conclusions

Native Eggshell powder is effective as partial replacement for cement in concrete development. The ranges considered were from 5% - 20%. The core conclusions from this study are as follows:

1. Increasing of the percentage of eggshell powder decreases the workability of concrete mix
2. Compressive strength of concrete containing eggshell powder was reduced compared with that of plain concrete. The reduction was tolerable within 5-10% eggshell content.
3. After 28days of curing, concrete produced with 5% native eggshell powder cement replacement had a decrease of 4.5% in the compressive strength compared with plain cement concrete. The decrease in compressive strength resulting from the other percentage replacements were 9.2%, 25.4% and 46.6% for 10%, 15% and 20% eggshell powder respectively.
4. Decrease in compressive strength disagreed with the reports of several other authors consulted.
5. This disagreement may be due to the difference in method of preparation of the eggshell powder

6. Hence eggshell powder obtained from the eggshell of locally sourced native domestic chickens are effective when used as partial replacement for cement in concrete production but content must be limited to a value of not more than 10% replacement.

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