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Effects of the Partial Replacement of Cement with Eggshell Ash and Glass Powder on the Flexural Strength of Concrete

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ABSTRACT

In the view of combating against the negative carbon footprint associated with the conventional means of extracting and producing cement, as well the rising cost of cement influenced by the increase in global inflation, there is a need to explore for environmentally friendly, waste materials that can potentially replace cement in concrete production. Hence, this study is embarked on to explore the viability of using eggshell ash and glass powder as substitutes for cement in concrete production, assessing their properties and their influence on the flexural strength of the concrete. The effect on the density of concrete was also assessed. The materials used were coarse and fine aggregates, Dangote OPC 42.5-grade cement, eggshell ash, glass powder, and water obtained from different sources. Conforming to British standards, the experimental process involved sieve size analysis and specific gravity tests on the aggregates, casting of concrete specimens, slump test, and flexural test. Cement was replaced at 5%, 15%, 25% and 35%. Thirty-five 150 x 150 x 600mm concrete beam specimens were cast and cured for three different curing regimes of 14 days, 21 days and 35 days. The test results showed that the workability of concrete is reduced with an increase in the percentage replacement of cement. The specimen with 15% replacement of cement gave the highest flexural strength of 4.65Mpa after 35 days of curing. The density of concrete is reduced with an increase in the percentage replacement of cement. It was concluded that the specimen with 15% replacement of cement is the optimal sample.

1.0 INTRODUCTION

Concrete is a major construction material that underpins modern infrastructure. Concrete primarily comprises cement, water, and aggregates. Cement serves as the pivotal binding agent in its composition. However, conventional concrete production necessitates a substantial volume of cement, leading to notable costs, resource consumption, and environmental drawbacks. This has raised questions about possible substitutes for cement in concrete production.

According to Ho et al. (2013), eggshells consist mainly of calcium carbonate, with smaller amounts of organic materials and trace minerals like magnesium carbonate and calcium phosphate. To harness the pozzolanic properties of eggshells, they are subjected to calcination, which involves heating them at very high temperatures. This heat causes the calcium carbonate in the eggshells to decompose into calcium oxide (commonly known as quicklime) and carbon dioxide gas as shown in equation 1.

$$CaCO_3 \rightarrow CaO + CO_2 \quad (1)$$

The resulting calcium oxide is highly reactive. When it is mixed with water, it undergoes a hydration reaction, transforming into calcium hydroxide. This calcium hydroxide can then engage in pozzolanic reactions, particularly in the presence of silica, which is often found in concrete mixtures. The interaction between calcium hydroxide and silica leads to the formation of calcium silicate hydrates as shown in equation 2. These hydrates are crucial because they enhance the strength and durability of the concrete (Amran et al., 2021).

$$Ca(OH)_2 + SiO_2 \rightarrow CSH \quad (2)$$

Glass contains a high amount of silica, along with other oxides like alumina, calcium oxide, and sodium oxide (Carraher, 2012). This composition makes glass a potential pozzolanic material, meaning it can react with calcium hydroxide in the presence of water to form compounds that enhance the strength and durability of concrete. The process of converting glass into a pozzolanic material begins with the collection and sorting of waste or recycled glass. Once sorted, the glass is thoroughly cleaned and then crushed into smaller pieces known as cullet. Next, the cullet is ground into a fine powder using industrial grinders or mills. The fineness of the glass powder is crucial because finer particles have a larger surface area, which increases their reactivity (Pereira-De-Oliveira et al., 2012). The amorphous structure of glass, resulting from its rapid cooling during manufacturing, is highly reactive when ground into a fine powder, making it an effective pozzolanic material. When glass powder is added to a concrete mix, it reacts with calcium hydroxide, a byproduct of the hydration of Portland cement. The silica in the glass powder reacts with the calcium hydroxide to produce calcium silicate hydrates as shown in equation 3 as stated by Chithra et al., 2016.

$$SiO_2+Ca(OH)_2+H_2O \rightarrow CSH \quad (3)$$

The use of waste eggshells as eggshell ash and waste glass as glass powder as a partial replacement of cement in concrete production has the benefit of minimizing cement usage and contributes to waste recycling. The study into the use of these materials as potential substitutes for cement is not alien and previous studies into this cause have been carried out in the past. Patil and Sangle (2012) studied the test results of waste glass powder particles ranging from size 150µm to 90µm and less than 90µm. He showed that initial strength gain is much less due to the addition of glass powder on the 7th day but it increases on the 28th day. It is found that a 20% addition of glass powder gives higher strength. Also, a glass powder size of less than 90 microns is very effective in the enhancement of strength.

Mtallib & Rabiu, (2009) investigated the impact of eggshell ash on the setting time of cement. They examined different proportions of eggshell ash, ranging from 0% to 2.5%. Their findings indicated that the presence of eggshell ash led to a reduction in the setting time of cement, suggesting that eggshell ash serves as an effective accelerator. Additionally, the research revealed that as the ash content increased, the setting time decreased, indicating a stronger accelerating effect. Based on the outcomes of this study, it can be inferred that eggshell powder is a viable candidate for replacing cement. Furthermore, not only does it serve as a cement substitute, but it also enhances various properties of concrete.

Wang and Hou (2011) carried out their study of Elevated Temperatures on the Strength Properties of LCD Glass Powder Cement Mortars and concluded that substituting 10% of cement with glass powder would gain a very promising compressive strength of the mortars, particularly when the added glass has a powder fineness ≥ 4500 cm2/g. In real practice, this amount of glass powder substituent could be suggestively used to replace cement.

Narayanaswamyet et al, (2017) conducted an experimental study to investigate the impact of eggshell powder and silica fume on M40-grade concrete. They conducted a comparison between two sets of concrete mixes: one group with eggshell powder replacing cement in percentages ranging from 5% to 15%, and another group with a combination of both eggshell powder and silica fume. In the latter case, the eggshell powder ranged from 5% to 15%, while the silica fume varied between 2.5% and 7.5% by weight of the cement. Their findings ultimately revealed that the strength of concrete with eggshell powder alone was sufficient. The addition of silica fume did not result in a significant difference in strength. Furthermore, it was noted that silica fume is a relatively expensive material when used as a cement replacement.

Mohd et al., (2014) studied the behaviour of eggshell powder as a partial replacement of cement in concrete. In this paper partial amount of cement is replaced by eggshell powder as a 5% increment up to 30% by weight and strength characteristics at the end of 28 days is noted down. The strength that decreased beyond 5% is enhanced by the replacement of some mineral admixtures namely fly ash, micro silica, and sawdust. By this scenario, it is found that 5% of ESP with 10% micro silica, fly ash, and sawdust replacement increases the strength property of concrete.

Previous studies have individually used eggshell powder, glass powder, eggshell ash as well as combining eggshell powder and glass powder in partially replacing cement. The justification for study relies on its uniqueness for using both eggshell ash and glass powder as the main materials for replacing cement

2.0 MATERIALS AND METHODS

MATERIALS

Cement

The cement used in conducting this research was the ordinary Portland cement produced in Nigeria by Dangote Cement Company, grade 42.5. the cement was sourced from a retailer along the FUTO-Obinze road. The cement complied with CEM II of NIS-444 Part 1 (NIS-444,2003).

Fine aggregates

River sand sourced from the banks of Otamiri River was used as fine aggregates. It was clean, sharp, and free from any unwanted materials like clay, loam, dirt, etc. The fine aggregates had a coefficient of uniformity of 2.7. Thus, they were well-graded because this value falls within the range stipulated by BS 812-2:1995. The particle size distribution curve of the fine aggregates is shown in figure 1.

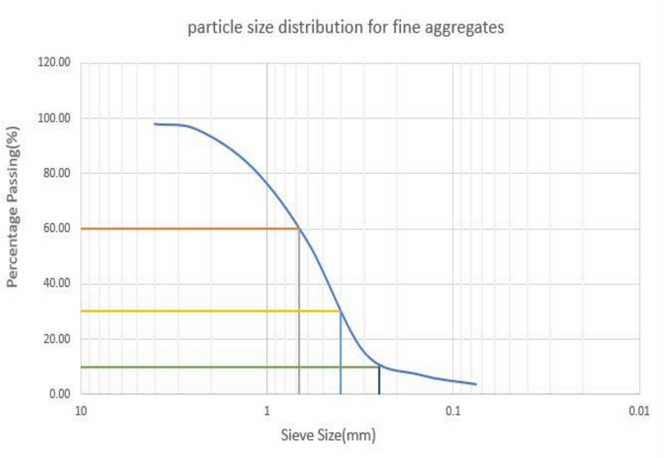

Figure 1: particle size distribution curve for the fine aggregates.

Coarse aggregates

The coarse aggregates were sourced from local retailers and were free from dirt. Crushed granite maximum nominal size of 25mm and a specific gravity of 2.72 was used as coarse aggregates in accordance with BS 812-2:1995.

Eggshell ash

The eggshells were sourced from bakeries and restaurants around Eziobodo and Umuchima. The eggshells were converted to ash by burning and subsequently grinding. The ground particles were sieved through a 30µm sieve according to BS EN 933-1: 2012.

Water

The water used for both casting and curing was tap water from the borehole used by SUNIC Fast Foods within the university close to the workshop. The water is fit for human consumption in accordance with (BS EN1008, 2002).

glass powder

The glasses used for this study were obtained from the debris of discarded window louver blades from the university hostels. The glasses were washed, and a high-precision miller was used to crush the glass to powdered particles fine enough to pass through a 30µm sieve in accordance with BS EN 933-1: 2012.

METHODS

Sieve analysis test

The sieve analysis test was used to get the particle size distribution curve of the fine and coarse aggregates. The test was done following BS 1372:1990.

Specific gravity test

The pycnometer test was used. Two pycnometers with weights of 753 grams and 137 grams were used to determine the specific gravity of the fine aggregates and coarse aggregates respectively. The test was conducted following the recommendations of BS 812-2:1995.

Mix proportion

A concrete mix ratio of 1:2:4 and a water-cement ratio of 0.6 were selected for experimental purposes. With this mix ratio, cement was partially substituted with different proportions of equal weight of eggshell ash and glass powder. The total substitution percentages were 0%, 5%, 15%, 25% and 35% by weight of the cement. The proportion of concrete constituents for each sample is shown in Table 1.

Table 1:proportion of concrete constituents for each concrete sample

Percentage replacement	Cement (kg)	Fine aggregates(kg)	Coarse aggregates(kg)	Eggshell ash(kg)	Glass powder(kg)	Water (kg)
0%	9.3	18.5	37	0	0	5.58
5%	8.835	18.5	37	0.24	0.24	5.58
15%	7.9	18.5	37	0.7	0.7	5.58

25%	6.98	18.5	37	1.2	1.2	5.58
35%	6.05	18.5	37	1.63	1.63	5.58

Slump test

The apparatus used for the slump test were the slump cone, the tamping rod, and the measuring ruler. Slump test was carried out on fresh concrete with 0%, 5%, 15%, 25%, and 35% replacement with an equal weight of eggshell ash and glass powder. The test was done in accordance with (BS1881-102, 1993).

Flexural test

Flexural strength tests were conducted on concrete beams specimens with dimensions of 150 x 150 x 600 millimetres. A total of 45 beam specimens were prepared, and their weights were measured to determine their density. The flexural strength tests were performed at 14, 28, and 35 days of curing following the guidelines of BS EN 12390-3:2009.

3.0 DISCUSSION OF RESULTS

Effects of eggshell ash and glass powder on the workability of concrete

Table 2 presents the result of the slump test on the different concrete samples. Figure 2 graphically shows how the slump value changes when the cement in concrete is replaced with different percentages of an equal weight of eggshell ash and glass powder. As the percentage replacement increases, the slump value decreases, indicating a reduction in concrete workability and consequently an increased water content. This is likely due to the high specific surface area of the ash and glass powder, as noted by Ukpata, J. O. (2017) and Choi, H. (2019).

Table 2: slump test result for different concrete samples

SLUMP TEST RESULT		
S/N	percentage replacement (%)	Slump result(mm)
1	0%	82.4
2	5%	73.5
3	15%	69.2
4	25%	66.7
5	35%	62.4

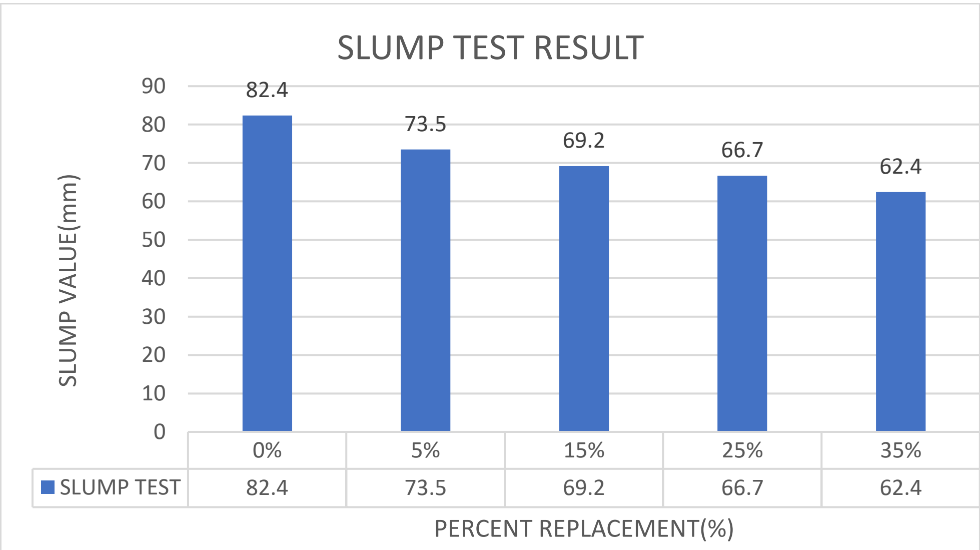

Figure 2: graphical representation of the slump test result for different concrete samples.

Effects of eggshell ash and glass powder on the flexural strength of concrete

The flexural strength gives the behaviour of concrete under bending load. Table 3 presents the result for the flexural strength of concrete for different percentage replacements of cement with eggshell ash and glass powder at 14, 28, and 35 days of curing. Figure 3 gives a graphical presentation of the results in Table 3. From Figure 3, it is seen that the flexural strength initially rises up to a 15% replacement level, then declines to flexural strength below the control sample (0% replacement) as eggshell ash and glass powder content increases at 25% and 35% replacement. The maximum flexural strength of 4.65Mpa is achieved at 15% replacement, exceeding the control by 10.5%.

Table 3: results for the flexural strength of different concrete samples at different curing durations.

curing duration	flexural strength (Mpa)				
	0%	5%	15%	25%	35%
14 days curing	3.82	4.02	4.26	3.63	3.30
28 days curing	4.04	4.27	4.59	4.08	3.62
35 days curing	4.21	4.41	4.65	4.13	3.91

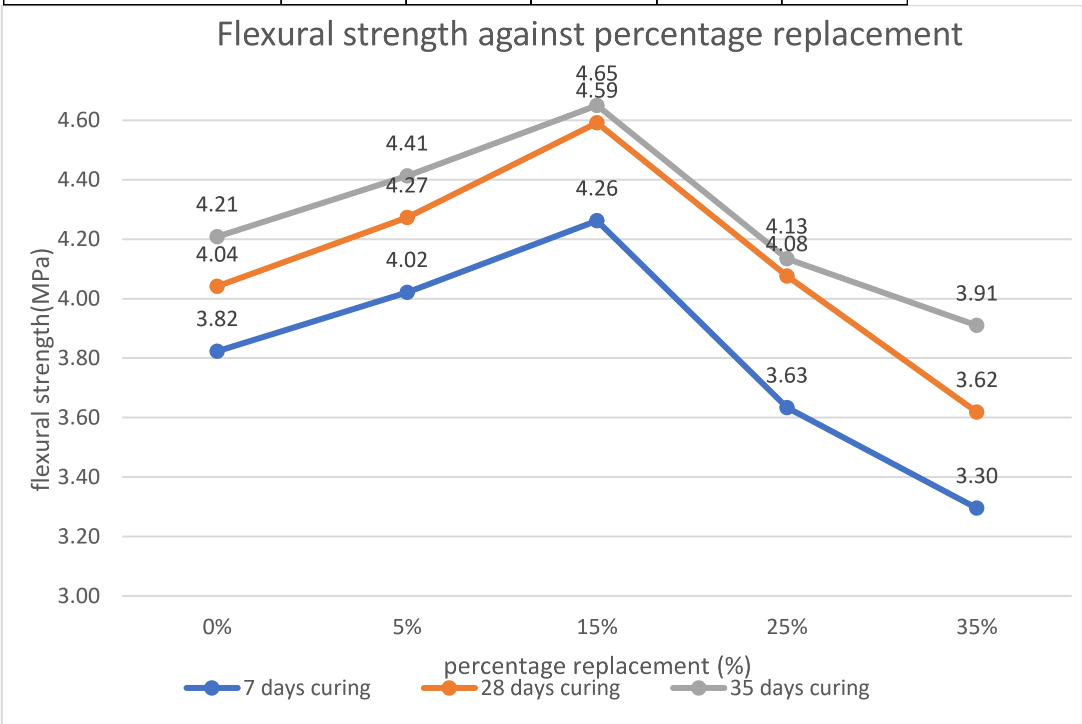

Figure 3: graphical representation of the results of the flexural strength

Effects of Eggshell Ash and glass powder on the density of Concrete

Table 4 presents the results and Figure 4 graphically shows the effect of the partial replacement of cement with eggshell ash and glass powder on the density of concrete for different curing durations. Figure 4 shows that the concrete mix with no replacements (control mix) has the highest density, and as the proportion of eggshell ash and glass powder increases, the density of the concrete generally decreases. The results show that the concrete densities fall within the normal-weight concrete range, as specified in BS EN 206-1:2013, which requires a minimum density of 2000 kg/m3 and a maximum density of 2600 kg/m3.

Table 4: results for the density of different concrete samples at different curing durations.

Curing duration	density of concrete samples (MPa)				
	0%	5%	15%	25%	35%
14 days curing	2580.741	2507.16	2512.593	2444.938	2399.506
28 days curing	2556.049	2371.111	2480.741	2394.815	2321.728

35 days curing	2508.642	2459.753	2406.42	2374.321	2347.16

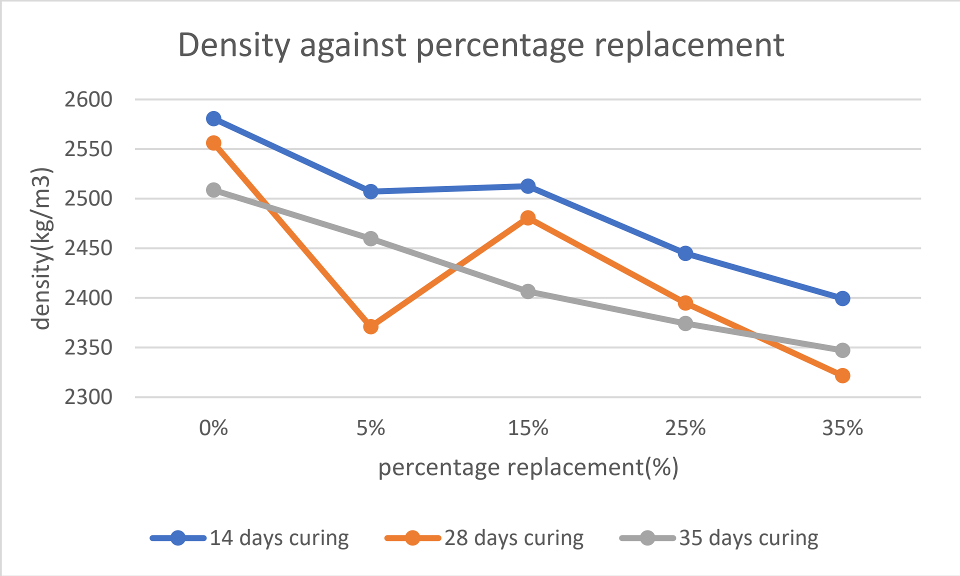

Figure 4: graphical representation of the results of the density of concrete

4.0 CONCLUSION

Based on the test results and discussions, the following conclusions can be drawn:

The replacement of cement with eggshell ash and glass powder has an effect on concrete workability. It decreases the slump thereby making the concrete less workable.

The flexural strength of concrete increased at 5% replacement and reached the maximum flexural strength at 15% replacement, after which there is a decrease in the flexural strength with increase in percentage replacement. Therefore, 15% replacement gives the optimum flexural strength and can be used in concrete production.

The density of concrete reduces with increase in percentage replacement. Therefore, eggshell ash and glass powder has the potential of being used in the production of comparatively lighter weight concrete.

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