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Evaluation of the impact of waste egg shell powder on the workability and stability characteristics of cement mortar

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Abstract

The disposal of eggshell waste poses significant environmental challenges. Concurrently, the high carbon footprint of cement production drives the search for sustainable alternative materials. This study investigates the feasibility of using incinerated eggshell powder (WEP) as a partial replacement for cement by examining its effect on key physical properties: fineness consistency, setting time, and soundness. Cement was replaced with WEP at ratios of 0%, 2.5%, 5.0%, 7.5%, and 10.0% by weight. The fineness test result of cement and WEP showed 3.5% and WEP 3.7% respectively which is within the recommended limit. The resulting blends were tested for standard consistency (water demand), setting time, and soundness. The results revealed a consistent trend with increasing WEP content. Water demand for standard consistency decreased from 34.4% to 30.1%, indicating improved workability. However, the initial setting time was significantly prolonged from 12.4 minutes to 20.6 minutes. The soundness increase from 1,65mm to 5.40mm as WEP increased from 0 to 10%. From the findings, Waste Eggshell Powder can be considered a sustainable option for partially replacing cement.

Keywords: Waste Eggshell; Cement; Soundness; Setting time; Consistency

1. Introduction

Waste is an unusable or unwanted material or substance that is being discarded by the owner after use. Waste can either be solid or liquid (Encarta dictionaries 2009). When the management of solid waste is poor in terms of collection and disposal, it lead to pollution of both surface and ground water as leachate occur in the solid waste and the environment at large is being polluted. This is due to the unauthorized dumping of solid waste at dumping site (Dhanalakshmi et al. 2015).

The census result of Nigeria population in 2017 is 190.9 million with this population, proper solid waste disposal and treatment is essential in order to free the environment and the society of pollution which could be as a result of solid waste.

In other to reduce solid waste accumulation in the environment, Researchers have being carrying out investigations to see how solid waste can be applied in areas where it will be beneficial to the society, and progress has being made so far.

Cement happens to be the major component when it comes to the production of concrete and mortar. For a cement to be manufactured, a lot of energy is being required, which demands great amount of natural resources and if allowed to continue no virgin material for cement production will be left for future generation. And in order to get rid of solid waste economically in the environment and to seek local substitute for construction material, egg shell ash was mixed in ordinary Portland cement in this study to determine if cement will loss it properties or not.

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Eggshell is an Agricultural waste from chick hatcheries, bakeries, fast food restaurant etc, which litter the environment due to poor handling and result to environmental problem, such as pollution. Hence, proper disposal is required.

Scientifically, researchers have been able to confirm that eggshell is composed of calcium compounds that are similar to that of cement, and in the ever increasing effort to see how waste can be converted to wealth, and foreseeing the benefits eggshell will bring, the idea became necessary to embrace (Karthick et al 2014).

Eggshell contributes to the construction industry, this is because literature has shown that eggshell ash contains calcium, protein, and lime. Hence, transforming eggshell into a useful product would definitely add to construction industry, where eggshell ash would be mixed in cement that will be used to produce concrete or cement mortar. Therefore, eggshell ash is being investigated as an alternative material to reduce the quantity of cement needed in the production of concrete or cement mortar, thereby reducing the cost over head. Hence, eggshell is a new raw material for construction industry used as an additive in concrete (Karthick et al 2014).

2. Materials and methods

2.1. Materials

In order to produce calcined eggshell powder, eggshells were collected from fast food restaurant, local market, poultry and eggshell generated from house hold in Bori town in Rivers State, Nigeria. After these eggshells were collected, it was then hand washed and exposed to strong heat. It was then ground to powdered form and sieved using a standard sieve size 90 µm in order to obtain a fine powder. Ordinary Portland cement manufactured by Dangote Cement Company was used and was purchased from a building material store in Bori Town.

2.2. Methods

The different laboratory experiment were conducted in other to investigate the effect of eggshell on physical properties of cement. Sample collection and preparation, testing and analysis were carried out in accordance with the relevant international standards and specifications. Specimens were prepared in accordance with BSI (1978) – Methods of Testing for cement Waste egg shell 9WEP) modified cement specimens were prepared for 2.5 %, 5.0 %, 7.5 % and 10.0%, 25%, and 30% by weight of cement. While the unmodified sample with 0% WEP was used as the control specimen.

The fineness test was carried out in accordance with BSI (1978) by sieving the cement and calcined WEP through a standard sieve size of 90µm. The proportion that was able to pass through the sieve, and the size which is larger than the sieve size, and as such has retained in the sieve is then determined.

Consistency test was done in accordance with BSI (1978), 400g of cement sample was weighed and spread out on a steel plate for about 30 minutes to cool to the temperature of the mixing room

(27 ± 50°C). 30% water content of the mass of dry cement was added as a start. The mixture was mixed for 4 ± 0.25 minutes by using a trowel to give a paste and was immediately transferred into the mould. The top of the mould was smoothened off as quickly as possible with the aid of the trowel. The mould and paste were placed under the plunger in the vicat apparatus and the plunger lowered gently to contact the surface of the paste. This material was released quickly and allowed to sink into the paste. The scale reading of the vicat apparatus was noted after 1 minute and recorded. If the plunger penetrates to a point 5 mm above the bottom of the mould, the water-cement ratio is taken as the consistency, if not, a new water-cement ratio is taken and the procedure repeated. The detailed results are shown in Table 1 and a graph of Consistency against WEP content is shown in Figure 1.

Initial and Final Setting Time Test was carried out in accordance with BSI (1978), a sample of cement paste of standard consistency was prepared and the time of first mixing the water with cement was noted down. A slight excess of paste was immediately transferred into the mould in one layer by using hand trowel. The top of the mould was smoothened and levelled. The mould was placed under the initial set needle of cross-sectional area of 1mm and the needle was covered gently onto the surface of the paste and was quickly released by allowing it to sink to the bottom. These tasks were repeated several times at regular intervals of 10 minutes in different positions of mould until the paste has stiffened sufficiently for the needle not to penetrate deeper than 5mm above the bottom of the mould. The time interval between the addition of water and the initial setting time was recorded. Finally, the needle was replaced with a 1mm square needle fitted with a metal annular attachment and this probe was allowed to come gently with contact with the surface of the cement paste at an interval of 15 minutes. The final set was reached when the needle makes an impression on the surface but annular cutting edges fail to do so. The detailed results are shown in Table 1 and a graph of initial and final setting time against WEP content is shown in Figure 2.

Soundness Test (Expansion was carried out in accordance with BSI (1978). The cement paste was prepared as of a standard consistency and filled in to the Le Chatelier mould . The split end of the mould was gently closed by tying it with a piece of cotton as the operation was being carried out. The surface of the paste was well smoothened and levelled with the blade of a gauging trowel and was covered with another piece of glass and was immediately immersed in clean water. A 50g weight was placed on top of the plate for compaction. After 24 hours, the mould was removed from the water and the distance between the pointers measured by using a meter rule. The mould was re-immersed in water again and was brought to boiling point within 30 minutes and afterwards allowed to boil for one hour. This material was then kept in the water and allowed to cool. The distance between the pointers was again measured. The difference between the two measurements represents the value for soundness. The detailed results are shown in Table 1 and a graph of Soundness against WEP content is shown in Figure 3.

3. Result and discussion

Hydration rate of cement is depending greatly on the fineness of cement, hence likewise the strength gained by cement after setting. The fineness test of cement is employed to determine the grinded extent of cement and WEP and the surface area of the cement particle size per unit mass is also measured. From the result of the test cement has a fines of 3.5% and WEP 3.7%. Both result fall within the recommended value less than 10 %

Table 1 Physical Properties Cement modified with varying percentage of WEP

Percentage of WEP	**Physical Properties Cement**		
	Consistency (%)	Setting Time (min)	Soundness (mm)
0	34.4	12.4	1.65
2.5	33.7	13.1	2. 13
5.0	33.2	14.4	3.51
7.5	31.0	16.6	4.22
10.0	30.1	20.6	5.40

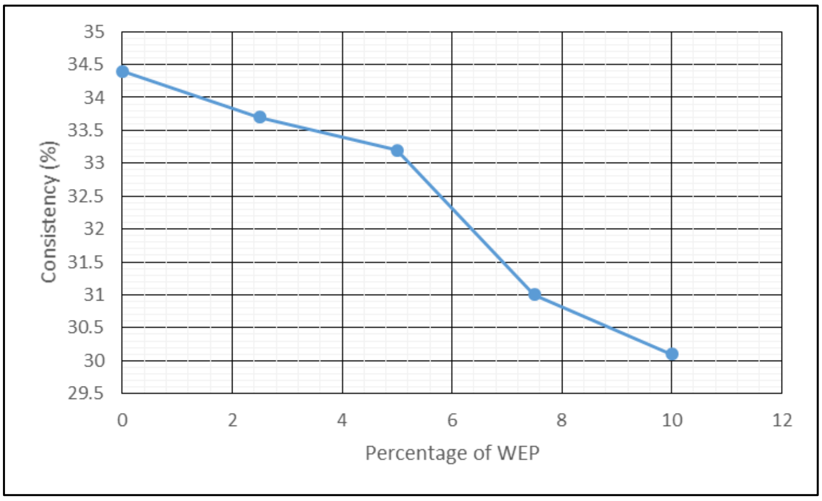

Figure 1 Effect of Percentage WEP content on Cement Consistency

The consistency test is designed to check the quantity of water required to produce a cement paste of uniformity. Hydrations starts the moment water is added to cement. When excess amount of water is added to cement, the strength of cement is reduced when it finally hardened. Also, when less quantity of water is added to cement during mixing, improper hydration occur which results to strength loss of cement when it hardened. The consistency test of cement was carried out to determine the required quantity of water which can produce a standard consistency. From the test, it is observed generally, that the increase in the eggshell powder resulted to a decrease in the consistency. It is observed that at 0% of eggshell powder, the consistency is 34.4%, as the WEP increases from 2.5% to 10%, the consistency increases from 33.7% to 30.1%. This indicates a lower water demand for the cement paste to achieve a standard consistency. This is likely due to the low water absorption of the in WEP and its particle characteristics. Studies has shown that heat treatment of eggshells effectively removes organic content and calcination can seal the pores of the eggshell particles, reducing their ability to absorb water (Chong, et al 2025 and Wang et al 2025). A lower water demand can be beneficial for achieving higher strength and durability, provided the mix remains workable.

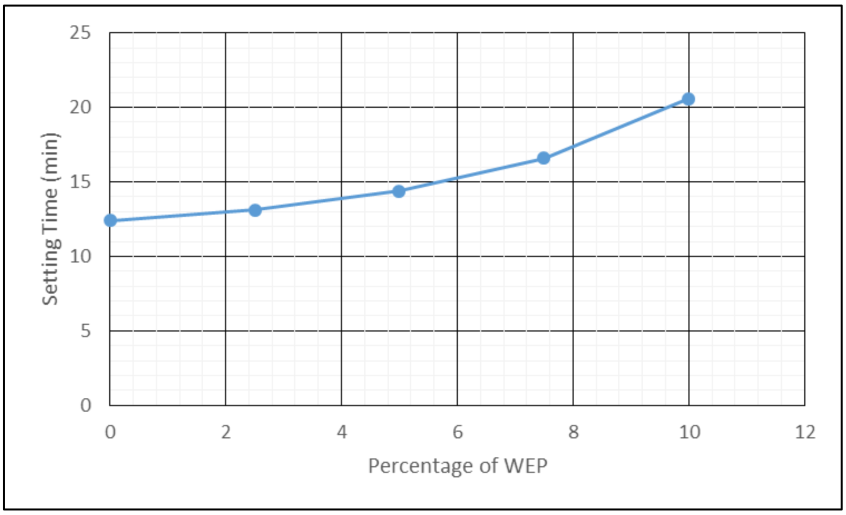

Figure 2 Effect of Percentage WEP content on setting time of Cement

This test is carried out to understand the time it will take cement for initial setting i.e. the time taken between mixing the concrete and transporting the concrete to site and placing of the concrete at the required position in the site. It is observed generally, that the introduction of cement with eggshell powder, reduced both the initial and final setting time of cement as compared to the control mix. It is observed generally, that the increase in the eggshell powder resulted in increase in the setting time. It is observed that at 0% of eggshell powder, the setting time was 12.4 min, as the WEP increases from 2.5% to 10%, the setting time increases from 13.1 min to 20.6 min. The research by Wang et al. (2025) on thermally activated eggshell powder, they found that while calcination removes organic matter, it can also lead to the formation of calcium oxide (CaO). The hydration of this free lime is a slower process that can initially disrupt the rapid hydration of tricalcium silicate (C_3S). This slower initial reaction would delay the overall setting time (Pliya and Cree, 2015).

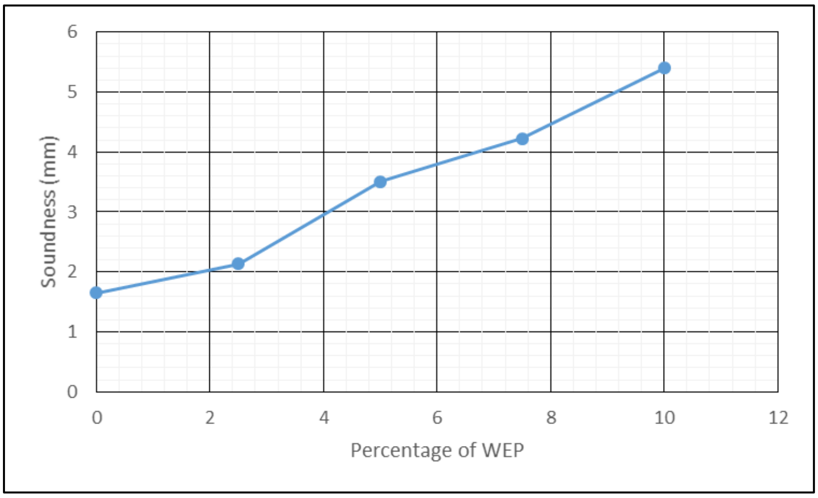

Figure 3 Effect of Percentage WEP content on soundness of Cement

In Table 1, at 0% WEP content, the soundness is 1,65mm, at 5% WEP, it is 3.13mm and at 10% WEP content it increased to 5.40mm. This indicates that as the WEP content increases, the soundness also increases see figure 3. WEP Subjected to heat can convert some of the calcium carbonate ($CaCO_3$) in eggshells into calcium oxide (CaO) Wang et al. (2025) . When this CaO is present in the cement paste, it hydrates slowly to form calcium hydroxide, $Ca(OH)_2$. This reaction is expansive. It is observed generally, that no expansion occurred after the specimen was immersed in water and brought to boiling point for the all the concentration of WEP investigated. Hence, since the volume of WEP modified cement it is expected that the volume of a cement of good quality must not expand but still retained its volume upon setting.

4. Conclusion

In conclusion, the fineness test carried out on cement and WEP shows 3.5% and 3.7% which are less than the standard value as specified in the code. It is observed generally, that the increase in the eggshell powder resulted to a decrease in the consistency. It is observed, that the increase in the eggshell powder resulted in increase in the setting time and soundness of cement. From the findings, Waste Eggshell Powder can be considered a sustainable option for partially replacing cement. To harness the benefits of WEP more effectively, higher temperature for incineration should be explored. These processes could mitigate the negative impacts on workability, setting time, and soundness by removing all organic matter and increasing chemical reactivity.

Compliance with ethical standards

Disclosure of conflict of interest

The author Achemie Lewis Oba declares no conflict of interest.

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