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Mechanical Properties Enhancement of Concrete Sand Bulking using Egg Shell Ash Particulates

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Abstract
The research work investigated the Pozzolanic and filling effects of the egg shell ash particulate on concrete sand bulking. The materials used are eggshell ash particulate, Otamili river sand, water and wooden mold. The sand bulking, workability, compressive and tensile strengths were tested with varying compositions of the egg shell ash (0%, 1%, 2% and up to 10%) in the mix. The regression statistical model was used to analyze the data. Results obtained showed that percentage sand bulking, compressive and tensile strengths were rising at 60 %, 45% and 41% respectively with the egg shell ash concentration due to the increased binding effect of the ash on the mix compositions while the workability decreased slightly owing to the increase in the water repellent property of the concrete mix with rise in eggshell ash concentration. These results are in consonance with the result of the statistical linear regression model obtained. This indicates the positive use of agricultural wastes to tackle sand bulking and to produce sound and eco-friendly concretes, thus paving the way for a sustainable material development, shunning dependence on synthetic alternatives and above all maximizing industrial profit through the reduction of material input cost

Keywords: Eggshell ash, sand bulking, tensile and compressive strengths, biogenic waste, workability,

1. Introduction

Sand bulking is the increase in volume of sand of fine aggregate upon coming in contact with moisture. This is due to the establishment of a moist film between the sand particles that create surface tension forces which pulls the particles apart, causing rise in volume (Okoro 2022). The extent of concrete sand bulking is strongly dependent on the amount of moisture present and the fines of the sand particles. Obviously, fine sand particles bulk more than the coarse once (Rajput, 2006). Bulking leads to a state of disparity in sand volumes during concrete production which paves the way for such negative development in concretes such as inaccurate mix proportion, reduction in mechanical strengths, durability and general viability of the concrete (Imamudeen et al. 2024, Iyebeye et al. 2024). Some synthetic materials are usually employed in the form of fillers, pozzolanas or plasticizers to solve the problem of bulking and its effect in concretes structure. But these materials have their various associated environmental threats (Ababa, 2001, Nwoye et al. 2023, Onyia et al. 2023).

Therefore, proper consideration of sand bulking helps in ensure accurate proportioning of construction materials. It also improves the strength and durability of the concrete produced (Agarwal, 2005, Anyafulu et al. 2024). Engineers, builder and construction workers must therefore strive to understand the concept of sand bulking and apply necessary corrections during batching. Also, the understanding and testing for bulking of sand during concrete production, will help to maintain adequate material ratios and produce high quality structures (Shrivastava 2009, Ezeobi et al. 2024). Biogenic waste such as eggshell ash has already been studied by some scholars on the bases of its pozzolanic and filling effect on properties of concretes, though, its impacts on sand bulking has remained uninvestigated over the years (Ekwedigwe et al. 2023).

The primary component of egg shells is high calcium carbonate, which burns at high temperatures to liberate gaseous carbon (IV oxide) and lime into the atmosphere. Because of these special qualities, egg shell ash behaves similarly to regular lime, an important chemical substance that typically combines with water and other material compounds (Ababio, 2001). Because of its high calcium content, biogenic waste can be used to improve soil quality and partially substitute cement in concrete (Nwambu et al. 2017, Okelekwe et al. 2024). However, despite the growing research on the use of egg shell ash in construction works and several other areas of human endeavor, limited attention has been paid regarding its influence on sand bulking which is a crucial factor in concrete mix proportioning (Milewski and Kats, 1987, (Morgan, 2006, Parmer, 2007). Consequently, this study is targeted to bridge this gap in knowledge by examining how egg shell ash affects sand bulking as well as the resultant effect on the properties of the concretes produced. The findings in this research work will contribute to a better understanding of the roles of egg shell ash in concrete mix design and improve its practical use in construction process and beyond

2.0 Materials and methods

The egg-shell as shown in Fig. 1a, was gathered from Ugo best kitchen in Owerri metropolis, a special kitchen for the preparation of noodles for local consumers. The sand was collected from Otamiri River in Imo State as shown in Figure 1b. Beaker, 1000cm^3 capacity cylinder, nose mask, hand glove and water were gotten from the Pac College Laboratory in Egbeada Housing Estate Owerri, Imo State. The mold was made at the Igwe furniture workshop in Owerri Imo State with dimensions of 130mmx110mmx90mm as shown in Figure 2a. The work began by using of cotton wool to remove contaminants from the eggshell. Such contaminants like oils, and organic matter that may interface with the intended result were removed. Subsequently, the eggshells were put in enclosed container and heated to a high temperature to obtain the eggshell ash in its fine particulate state. Afterwards, chemical analysis of the eggshell ash was carried out using X-ray diffraction Fluorescence instrument and the result were presented in Table 1. Likewise, chemical analysis of the Otamili River sand was conducted and the result presented in Table 2.

Table 1: The chemical compositions of the egg shell ash.

Chemical compositions of the egg shell ash								
Constituents %	CaO	P_2O_5	SO_3	SiO_2	SrO	Al_2O_3	CuO	Total
Composition	94.672	2.198	1.165	0.342	0.102	-	-	100

Table 2: The chemical composition of the river sand.

Chemical composition of the river sand												
Constituents	Al_2O_3	Si	K	Ca	Ti	Fe	V	Cr	Mn	Co	Ni	Zn	Total
% Composition	16.05	45.31	11.11	9.01	8.02	10.03	0.11	0.02	0.20	0.11	0.02	0.02	100

Figure 1: photograph of the eggshells (a) and Otamili sand (b) before sorting stage.

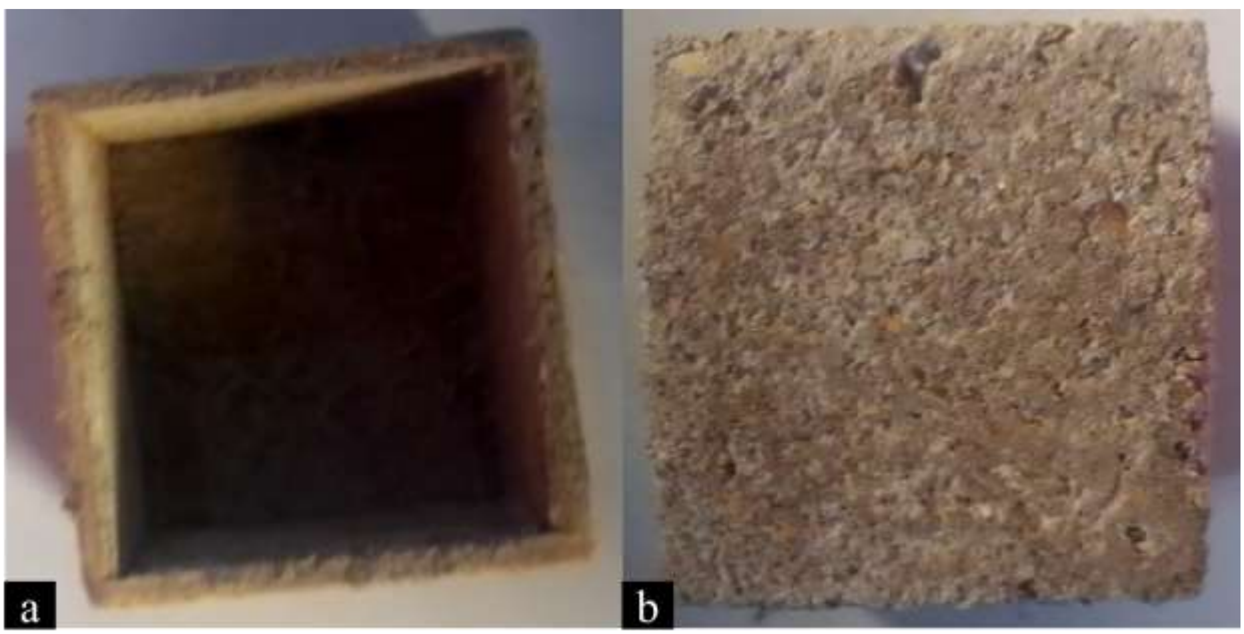

Figure 2: The Wooden mold of dimension 130mmx110mmx90mm (a) and concrete produced with some quantities of eggshell ash (b).

2.1.1 Experimental Testing

The sand bulking test procedure

The sand bulking experiment was performed in a 1000cm^3 capacity measuring cylinder at PAC college laboratory Egbeada in Imo State. The moist River sand samples with 0%, 1% and up to 10% concentrations of the eggshell ash were tested to determine the percentage sand bulking in each case.

The percentage sand bulking was calculated using the formula

$$\frac{H_2 - H_1}{H_2} \times \frac{100}{1}$$

Where H1 = initial or bulked sand volume in cm^3
H_2 = Finial or saturated sand volume in cm^3

Tensile strength Test procedure

The tensile strength test was carried out on a universal testing machine according to ASTEMC496/C496m-17 standard at the Imo State Polytechnic Engineering workshop. The concrete samples were 130mm x 110mm x 90mm in dimensions and they were all subjected to tensile forces in the longitudinal direction till rupture occurred. The tensile strengths values obtained in each case were recorded in mega pascal (MPa).

Compressive Strength Test Procedure

The compressive strength test was carried out on a compressive testing machine according to ASTM C639 /C396m standard at the Imo State Polytechnic Engineering workshop. The concrete samples were 130mm x 110mm x 90mm in dimensions and they were all subjected to compressive forces in the longitudinal direction till rupture occurred. The compressive strengths values obtained in each case were recorded in mega pascal (MPa).

Workability Test Procedure

The molten concrete mix of varying eggshell ash compositions (0%, 1%, 2% up to 10%) were tested for workability in a slump cone with three (3) layers according to ASTMC143/C143m standard. Each layer having a height of about 1/3 of the total height of the cone. The slump value which measures the workability of the concrete were obtained and recorded in each case in millimeters (MM).

3.0 Result and Discussion

Figure 3.0 shows the variation of concrete sand bulking with egg shell ash concentrations. The control sand mix has the highest percentage sand bulking of 10%. Adding eggshell ash inclusions of (1% - 10%) greatly decreased the percentage sand bulking from 9% to 0%. The pozzolanic and filling effects of the ash on the sand mix is responsible for this palpable decrease as pores between the sand particles are closed up thereby arresting bulking. Indeed, when the concentration of eggshell ash rises in the mix, more quantities of the lime content will be available to react with the silica content of the sand to for calcium silicate hydrate gel that binds the particles of sand together thereby arresting bulking. This gel establishes a cohesive force of attraction between the sand particles whose effect is pronounced as the concentration of the eggshell ash rises in the mix. The pozzolanic effect of eggshell ash in mix rises as its concentration increases. The eggshell ash exhibits filling effect on the sand paticles as it capable of occupying the pores between sand particles thereby closing up the voids and arresting bulking as a consequence. This deduction is in conformity with research results obtained by okonkwo et al (2017) in similar area.

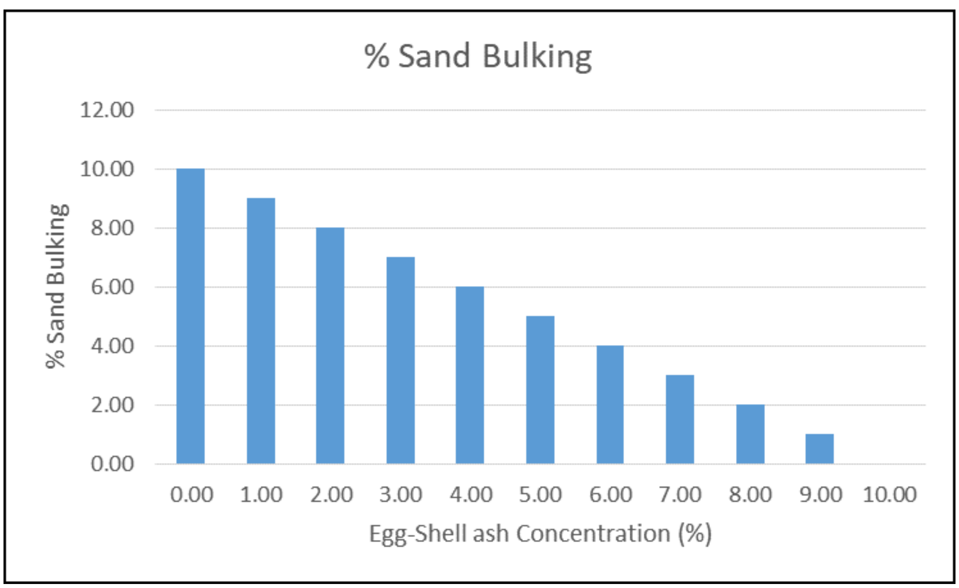

Figure 3.0: The variation of egg shell ash with concrete sand bulking

Figures 4.0 and 5.0 show the variation of the concrete's compressive and tensile strengths with eggshell ash concentration. The control concretes have the lowest strength values in terms of compression and tension. However, the values got a gradual rise as the eggshell ash concentration in the concrete mix rises from 1% to 10%. The addition of eggshell ash in the concrete mix increased the compressive and tensile strength from 3.86mpa to 42.71mpa and 0.48mpa to 5.30mpa respectively. These increases are as result of the fact that the ash concentration rise, bringing more calcium oxide(lime) into the mix that favors the formation of silicate gel which is responsible for the creation of strong cohesive force of attraction between the concrete particles, hence increases the compressive and tensile strength of the concrete. The fine particles of the eggshell ash fill the voids between concrete particles that increases the density and strength of the resultant concrete in tension and compression. This result agrees with findings of Ayodele et al. (2019) and Shakiru (2024) in same area of study.

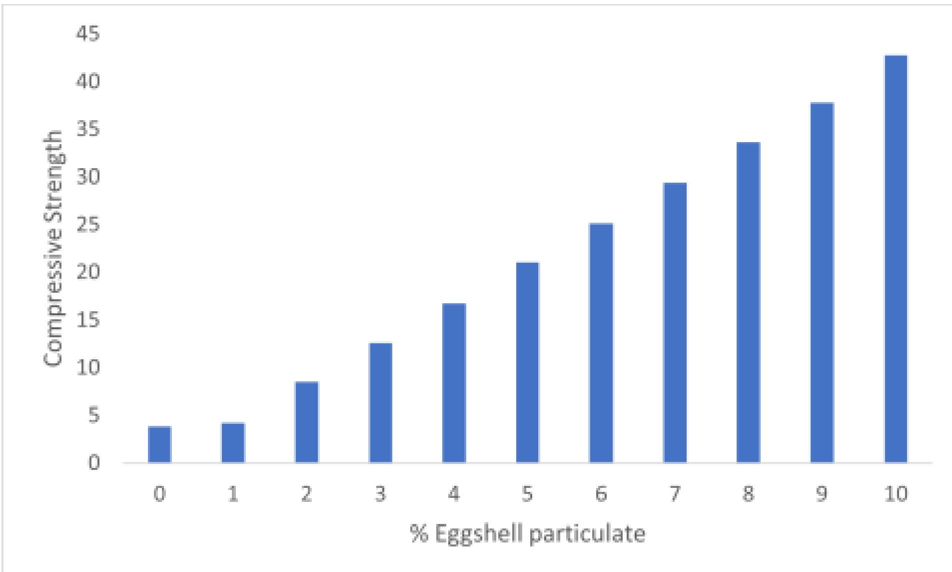

Figure 4.0: The variation of egg shell ash concentration with concrete compressive strength

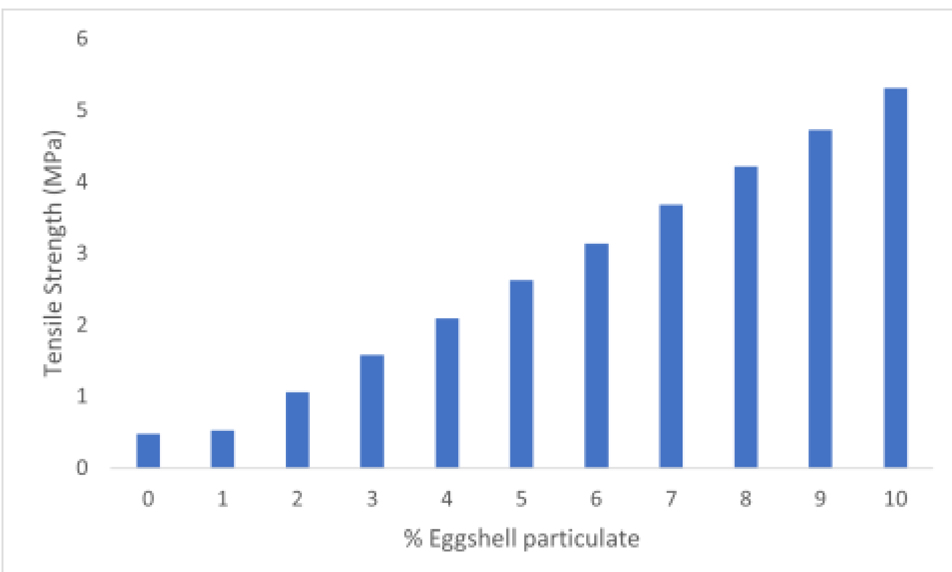

Figure 5.0: The variation of egg shell ash concentration with concrete tensile strength

The difference in concrete workability with egg shell ash concentration is depicted in Figure 6.0. The workability of the concrete decreases as the quantity of egg shell ash in the mixture rises because the concrete's water-repellent qualities increase. Additionally, the stiffness of the concrete gradually increases with concentration due to the strong water-repellent properties of eggshell ash, which make it difficult to cover cavities on solid surfaces. Concrete's water-resistant qualities increase with the amount of ash in the mixture; thus, workability declines. Furthermore, as the ash concentration increases, more eggshell ash particles will be available to provide a larger surface area of contact with one another. This results in high frictional resistance between the particles, making it difficult for them to pass one another easily, which lowers workability. This outcome supports the findings of researchers in related fields, including Muhammad T.Y. et al. (2022), and Olubajo (2020).

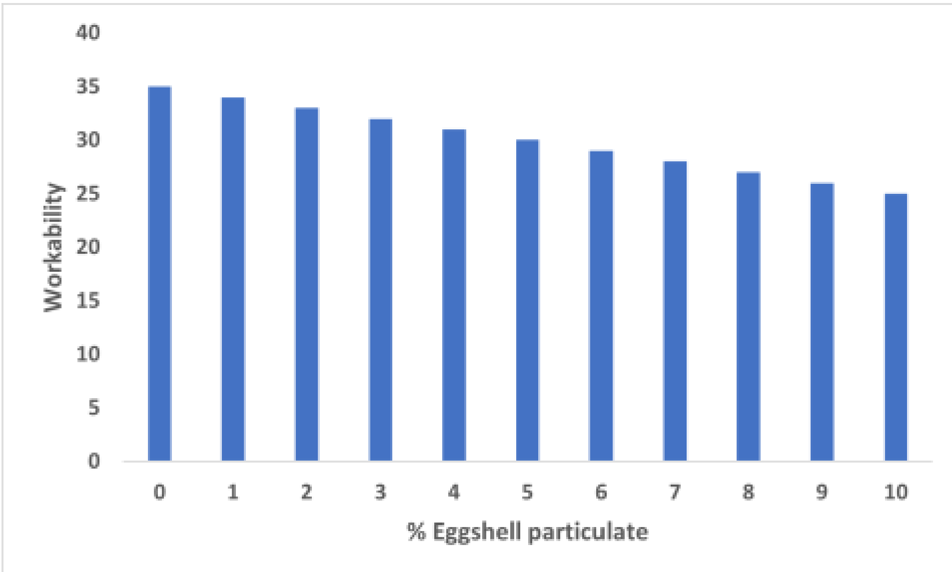

Figure 6.0: The variation of egg shell ash concentration with concrete workability.

Statistical Analysis of the mechanical properties

The data set from the research result follows a quantitatively continuous pattern and linearity both in the descending and ascending fashion. Again, there exists a variable Eggshell concentration (x) upon which other variables such as % sand bulking, tensile strength and compressive strengths as well as workability of the concrete – the dependent variables (y) depend. There is no curvature in the sets of data obtained. All these and many more reasons make linear regressions model appropriate for the analysis of these datasets. Here the person's coefficient of correlation a type of linear regression model was used to determine the relationships between the dependent variables and the independent one as well as the extent of their relationship. The graphs below show the illustration of the relationship between of the eggshell ash concentration (X) and the corresponding percentage of sand bulking(y).

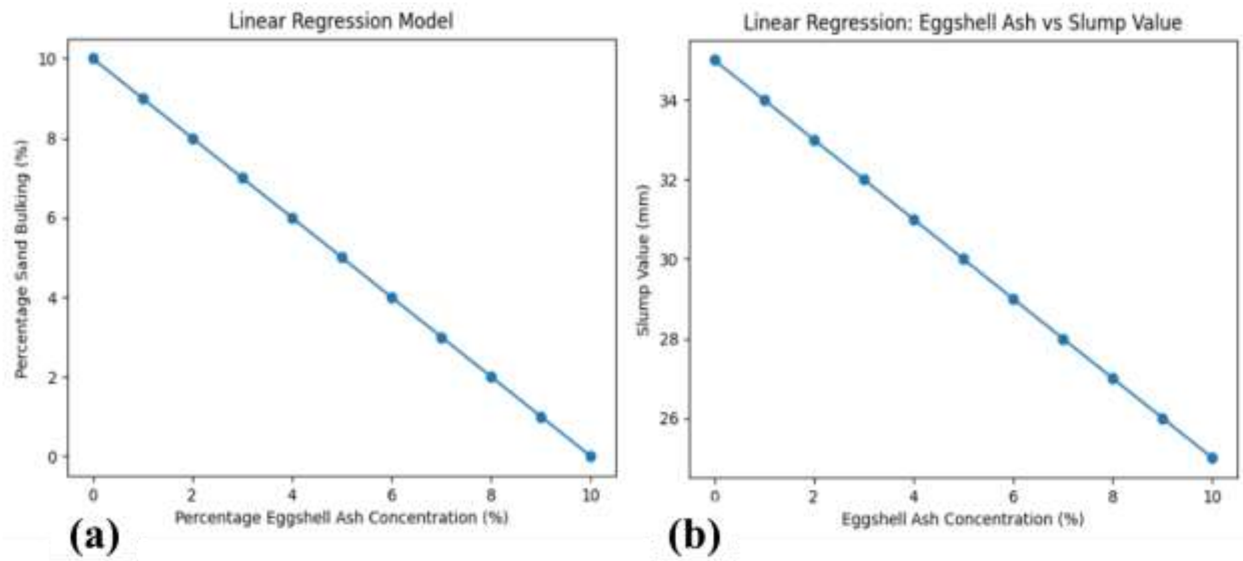

Figure 7.0: The regression graph oh percentage sand bulking (a) and workability (b) versus eggshell ash concentration.

It is clear that the regression line slopes downward from left to right which indicated a negative linear relationship between egg shell ash concentration and sand bulking. Once more, the regression line shows perfect linearity and correlation between the variables because the data points are right on it. Therefore, as Figure 7.0 (a) illustrates, there is a clear perfect statistical significance between the two variables. Similarly, the line in Figure 7.0(b) slopes downward, suggesting that the concrete becomes less workable as the volume of eggshell ash in the mix increases. Strong correlation and statistical significance between the variables are indicated by the points that are near and on the line.

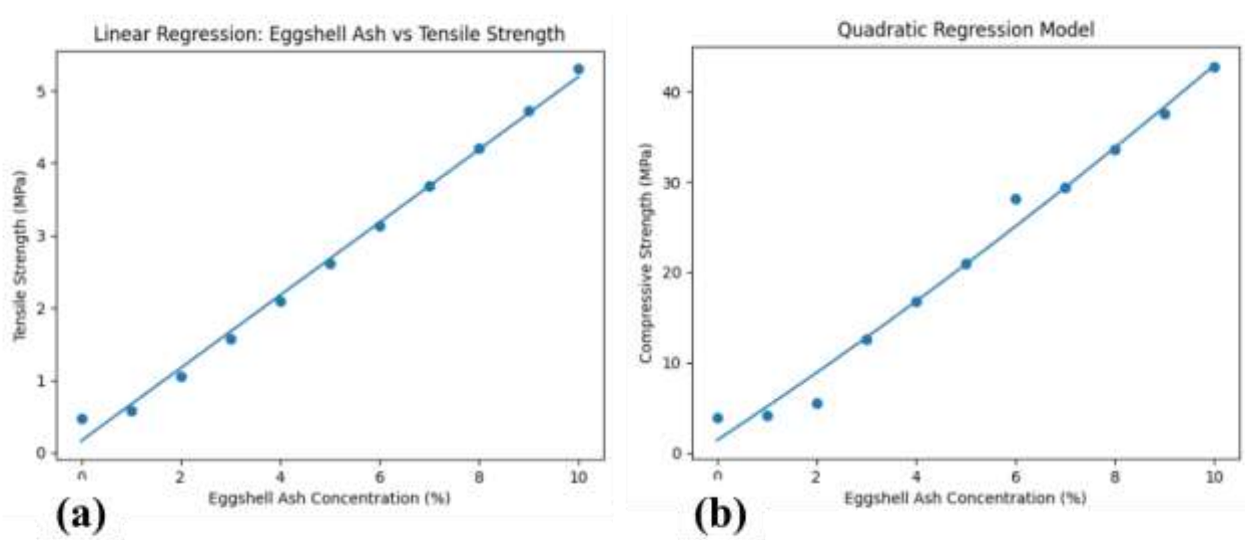

Figure 8.0: The regression graph of concrete tensile strength (a) and compressive strength (b) versus eggshell ash concentration.

Figure 8.0's regression graph depict that the regression line slopes upward, indicating that adding more eggshell to the mix increases the concrete's tensile strength. As seen in Figure 8.0(a), some points are precisely on the line, while the others around it exhibit a significant correlation and a state of statistical significance between them. Additionally, the regression graph in Figure 8.0(b) climbs upward, indicating that the compressive strength increases in tandem with the rise in eggshell ash in the concrete mix. The graph's points show a strong correlation and statistical significance between the variables; some are on the regression line, while others are extremely near to it. This statistical analysis agrees with the results of the experimental research.

4.0. Conclusion

The work investigated the mechanical properties enhancement of concrete sand bulking using egg shell ash particulate. In the course of varying the compositions of the ash in the concrete mix, it was discovered that the compressive and tensile strengths of the concrete rose to their highest values of 42.71mpa and 5.30mpa respectively. The obtained results show that egg shell ash has a significant positive effect on the mechanical compressive and tensile strengths of concretes. However, the workability witnessed slight decreases from 35mm to 25mm. All the same, eggshell can be used in the manufacture of concretes and other materials of construction especially in the areas where high concrete strength and water resistance of the concrete are essential requirements. Finally, the effect of eggshell ash on concrete sand bulking offers a very hopeful avenue for sustainable development combining waste management with improved construction practices. Further research such as engineers and scientists can be built upon the of this work, unlocking more new opportunities for eggshell ash utilization and contributing to a more sustainable future

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