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Assessing the Mechanical and Electrical Properties of Concrete Made from Sustainable Materials: A Case Study of Eggshell Powder and Calcium Chloride

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Abstract
The rising demand for sustainable engineering materials has led to the exploration of green concrete production. This research examines the structural and electrical parameters of bio-concrete, produced by integrating eggshell powder (ESP) and calcium chloride ($CaCl_2$) admixtures into cement matrix. Series of concrete units were prepared with varying ESP percentages from 0 to 15%, and $CaCl_2$ addition of 0 to 1%. A concrete mix ratio and water to cement ratio of 1:2:4 and 0.55, respectively, were adapted to create the concrete. The samples' compressive strength, electrical resistivity and electrical conductivity levels were measured at curing day 28 day, using International approved standards. Results attained indicated that the inclusion of $CaCl_2$ and ESP in the concrete, significantly affects its' electrical and mechanical properties. The findings portrayed that the compressive strength for the control group and Treatments 1 to 6 were, 22.24, 24.58, 23.51, 20.77, 23.40, 22.20, and 20.28 MPa, respectively. The resistivity (ρ) values for the T1 to T6 concrete samples were 64.67, 75.00, 77.33, 65.00, 68.33, and 76.33 Ωm, respectively. Similarly, their electrical conductivity (EC) values were 0.016, 0.013, 0.013, 0.015, 0.015, and 0.013 S/m, respectively. This emphasized that the introduction of ESP raises the concrete's density values, as the ESP proportion augmented from 0 to 15%. Similarly, the electrical resistivity of the concrete decreased with an increase in $CaCl_2$ quantity from 0.5% to 1%. This research's findings highlight the possibility of using agricultural waste materials (pulverized eggshell), and chemical admixtures, in enhancing concrete's engineering properties, while promoting environmental friendliness and sustainability.

Keywords: Compressive strength, electrical conductivity, eggshell powder, green concrete, waste management

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1. Introduction

Concretes are special cement matrix - composite materials, with considerable compressive strength, durability, and versatility, which are widely utilized in engineering and construction tasks. Concretes play an essential role in modern engineering applications, as they are designed to meet the specifications of the desired applications; hence resulting as one of the most important engineering materials to date (Gagg, 2014; El-Hallak *et al.,* 2024; Owamah *et al.,* 2024). Portland cement concretes are basically produced from Portland cement, granular materials (aggregates) and water; and the combination of these materials, significantly impacts the engineering properties of the concrete produced. Aggregates consistent about 75% of the total concrete's volume, and contribute significantly to its' weight, strength, and overall performance. Additionally, admixtures are optional constituents in concrete, which are incorporated into the concrete to induce additional effects, predominantly to enhance their workability, durability and engineering properties (Akpokodje *et al.* 2020; Tiegoum Wembe *et al.,* 2023).

Sustainable concretes, which involve the utilization of environmentally-friendly materials in concrete production, are now being designed for electrical properties, in building construction, pavement construction, bridges and dams (Barbhuiya *et al.,* 2024). Green concrete has becomes increasingly important, due to their decarbonisation and environmentally friendliness; which align with the Paris Agreement on climate change mitigations (Johnsson *et al*., 2020).

Conductive concretes (CC) are specially designed cement composites, with appreciable electrical properties, used in electrical applications such as; electromagnetic shielding, de-icing, and electrical earthing. These concrete are produced by integrating electrically conductive materials (additives) into the concrete mix-design; thus enhancing its electrical properties (Han *et al*., 2017; Fulham-Lebrasseur *et al.,* 2020). Conductive concretes are used in the construction of electrically-heated rigid pavements, mostly in regions prone to harsh snow conditions (Sassani *et al.,* 2019). Notably, CCs are employed in electrical power substations and Surveillance systems, to improve the lightning protection capabilities and intrusion detection features of the system (Zhao *et al*., 2021), Admixtures such as carbon black, carbon fillers, metal fillings, calcium chloride, graphite powder, and graphene particulates, are some of the materials used for the CC production; since these materials have the potential of developing electrically conductive linkages within the concrete mass (Zhou *et al.,* 2020; El-Hallak *et al.,* 2024)

Electrically conductive concrete (CC) have been produced by several researchers (Sassani *et al.,* 2018; Xu *et al*., 2018; Li *et al.,* 2020; Radwan and Abdel Raheem, 2023), but comprehensive information on green conductive concrete is still lacking. This study aims at producing and comparing conductive concrete at varying concentrations of eggshell powder (ESP) and calcium chloride. The adaptation of green materials in CC production not only addresses sustainability issues, but also explores their potential to improve the electrical characteristics of concrete.

2. Materials and Methods

Materials

The Portland limestone cement and calcium chloride ($CaCl_2$) used for the concrete production were of analytical grade. The calcium chloride, of 93% purity, was manufactured by Thermo Scientific Chemicals, America. The eggshells were obtained from a local eatery, dried, crushed, and sifted through a 0.150 mm sieve to produce fine particulates. Moreover,

the fine aggregates were sourced from the bed of the River Niger as river sharp sand; whereas, the coarse aggregates consisted of crushed granite rocks having the size of 19 mm, quarried from rock outcrops of the Precambrian basement complex. Water used for the research was obtained from a borehole, free from dirt and oily materials.

Methods

Experimental design

The experimental design analytically evaluates the mechanical and electrical properties of concrete, manufactured through the incorporation eggshell powder (ESP) and $CaCl_2$ as sustainable admixtures and as partial replacements for cement. The mix design accepted for this present study is presented in Table 1. Notably, a water to cement (w/c) ratio of 0.55 was chosen for the concrete production, irrespective of the mix design.

Table 1: The concrete mix design

Code	Cement (%)	ESP (% Cement Weight)	$CaCl_2$ (% Cement Weight)	Fine Aggregate (%)	Coarse Aggregate (%)
Control	100	0	0	100	100
T1	94.5	5	0.5	100	100
T2	89.5	10	0.5	100	100
T3	84.5	15	0.5	100	100
T4	94%	5	1.0	100	100
T5	89	10	1.0	100	100
T6	84	15	1.0	100	100

Concrete production

An NIS approved concrete mix ratio - 1:2:4, was used for producing the concrete, and the concrete samples were molded in standard cube shapes measuring 0.15 m by 0.15 m. Additionally, a mechanical mixing approach was employed to achieve a homogeneous blend of the concrete constituents. Thereafter, curing of the concrete cubes produced was done by using the total immersion method for 28 days.

Laboratory analysis

Density

The concrete's cubes density was determined in accordance with ASTM C642 guidelines, and as related in explanations by Eboibi *et al.* (2022).The density of each tested concrete cube was calculated through the expression given in Equation 1.

$$Density = \frac{Mass}{Volume} \quad (1)$$

Compressive strength

The compressive strength of the concrete was determined at day 28, in harmony with ASTM C39 approved procedures, as explained by Eboibi *et al.* (2022). Each cube's strength was calculated using the expression given in Equation 2.

$$Compressive\ strength = \frac{Force}{net\ surface\ area} \quad (2)$$

Electrical resistivity and conductivity

The CC electrical resistivity (ρ) was measured in accordance with ASTM C1760 strategies, employing the four-probe technique to assess the concrete's conductivity.Additionally, the

electrical conductivity (EC) of the concrete was calculated through Equation 3. The EC unit is Siemens per meter (S/m), while ρ unit is Ohm meters (Ωm).

$$EC = \frac{1}{\rho} \quad 3$$

:

Statistical analysis

The Analysis of Variance (ANOVA) was used to evaluate the impact of the admixtures on the mechanical and electrical properties of the concrete. Subsequently, the means were separated using the Duncan's Multiple Range Test (DMRT), at a significance level of 5% ($p \leq 0.05$).

3. Results and Discussion

Mechanical properties

Density

The results presented in Figure 1 shows that eggshell powder and calcium chloride have significant effect on the concrete density. It was observed that the density of the control group, and Treatments 1 to 6 experimental units was 2446.33, 2310.67, 2267.33, 2039.33, 2240.00, 2114.33 and 1931.00 kg/m^3, respectively. This shows that the admixtures significantly reduced the concrete's unit density. Ebiobi *et al.* (2022), stated that using lightweight bio-materials as a supplementary alternative for convectional concrete materials, or as an admixture in concrete production, typically results in lightweight concrete. The results however indicated that low percentages of ESP (≤10%) did not significantly affect concrete's density; whereas, excessive ESP quantity (>10%), had a notable effect on its density.

Density is vital property of concrete that largely influences its utilization, workability, and its overall performance. According to Nigeria Industrial Standard, normal concrete required in general for residential buildings should have density that lies between 2,200 and 2,500 kg/m^3; while lightweight concrete (≥2,000 kg/m^3), can be used for high-rise buildings construction (Oriola, 2921).

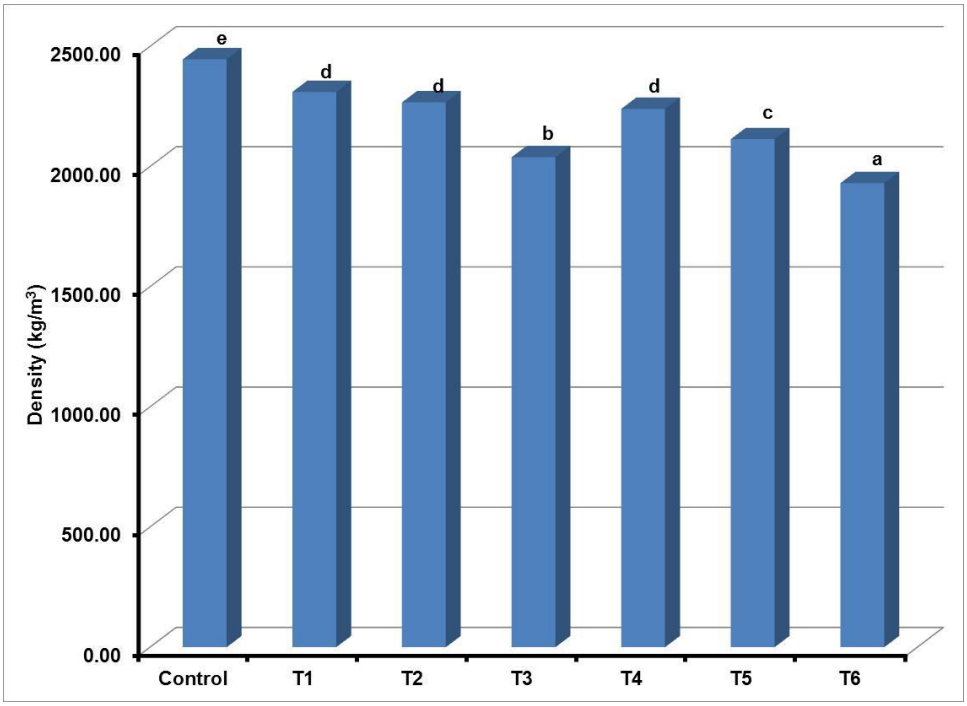


Figure 1: The cube's density

Compressive strength

Table 2 presents the concrete's mechanical strength, made from the different mix design. Statistically, it was observed that both the ESP and $CaCl_2$ quantity has significant effects on the concrete's compressive strength ($p \leq 0.05$). The outcomes portrayed that the compressive strength of the control group and Treatments 1 to 6 were 22.24, 24.58, 23.51, 20.77, 23.40, 22.20, and 20.28 MPa, respectively. This is indicatives that lower ESP (< 10%) and CaCl (<1%) quantities cause substantial increment in the concrete's compressive strength. ESP is a potential pozzolan, which have the ability of enhancing concrete compressive strength, by improving the hydration rates, development of calcium silicate hydrate (C-S-H), and densification of the cement matrix. However, excessive ESP quantity tends to cause a decline in the concrete's compressive strength, as it results in weak bonding between the matrix's paste and aggregates, alongside extreme weakening of the overall cementitious material (Owamah *et al.*, 2024).

This study's findings are similar to the previous observations reported by Teara and ShuIng (2020), though Teara and ShuIng (2020) recorded that a 40% increment of ESP instigated 33% increment in the concrete compressive strength. The compressive results documented in this present work, were less than those observed by Tan *et al*. (2018), where the compressive strength inclined from 24 to 30 MPa, as the ESP volume in the concrete increased from 0 to 80 kg/m^3. Similarly, Bruce*et al.* (2021) documented that $CaCl_2$ caused significant appreciation in bio-concrete compressive strength after 28 curing days. Likewise, MdShoriful (2022) stated that the introduction of $CaCl_2$in cement composites, help to enhance mechanical strength development, regardless of the curing approach used during the manufacturing process.

The variations in the concrete's compressive strength recorded by various authors, as compared to those of this research's findings, could be caused by several factors, which include: mix ratios adopted, material quality variability, environmental conditions, and curing methods employed (Ebiobi *et al*., 2022; Owamah et *al*., 2024). Interestingly, despite these

basic limitations, this study's outcomes revealed that hybridization of ESP and $CaCl_2$, can yield concrete with significant strength development to withstand imposed compressive loads. Furthermore, its consistency can be improved upon by careful material selection procedures.

Table 2: The concrete's compressive strength

	Mean	**Std. Deviation**	**Minimum**	**Maximum**
Control	22.24^{bc}	0.62	21.59	22.83
T1	24.58^{d}	0.96	23.51	25.35
T2	23.51^{cd}	0.81	22.58	24.04
T3	20.77^{ab}	0.58	20.16	21.32
T4	23.40^{cd}	0.64	22.74	24.01
T5	22.20^{bc}	1.06	20.98	22.91
T6	20.28^{a}	1.19	18.94	21.22

Electrical properties

The results of the electrical resistivity and electrical conductivity are presented in Table 3. It was noted that both ESP and $CaCl_2$ have significant influence on the ρ and EC of the concrete produced. It is interestingly to observe that the ρ values for the T1 to T6 concrete samples were 64.67, 75.00, 77.33, 63.00, 68.33, and 76.33 Ωm, respectively; likewise, their EC values were 0.016, 0.013, 0.013, 0.015, 0.015 and 0.013 S/m, respectively. This highlighted that the ESP created an increment in the concrete'sρ values, when ESP quantity increased from 0 to 15%; similarly, the $CaCl_2$ caused a reduction in the concrete's electrical resistivity, as the $CaCl_2$ quantity increased from 0.5 to 1%. These findings could be linked to the increase ionic conductivity within the concrete's matrix, which is initiated the free chloride ions emanating from the presence of calcium chloride (Saeed *et al*., 2023).

This study's results further depicted that eggshell powder has potential insulating power; hence, enhancing the electrical resistivity in concrete. Eggshell powder consists of non-conductive very-fine particles, which create micro insulation linkage within the concrete's matrix; thus, potentially improving the concrete's insulating properties and electrical resistivity (Dong *et al.*, 2021). Remarkably, the outcomes of this research corresponded with the findings presented by Yehia and Tuan (1999), for CC produced through the amalgamation of carbon filler to the concrete. In contrast, the ρ results obtained in this research were lower than the findings documented by Gomis *et al*. (2015), in their investigations into CC manufactured with graphite powder. Findings of this current study revealed that conductive concrete of appreciate electrical properties can be produced through the integration of $CaCl_2$ into the concrete matrix. Variations in the concrete's EC and ρ values observed between this study's outcomes, and reports of other researchers, could be attributed to the type of admixtures used, the concrete mix design, production techniques adopted, and the engineering properties of the ESP.

Table 3: The CC electrical properties

	Electrical resistivity (Ωm)	**Electrical conductivity (S/m)**
Control	82.00^{c}±4.36	0.012^{a}±0.001
T1	64.67^{a}±3.21	0.016^{b}±0.001
T2	75.00^{b}±3.00	0.013^{a}±0.001
T3	77.33^{bc}±1.53	0.013^{a}±0.000
T4	63.00^{a}±4.58	0.015^{b}±0.001
T5	68.33^{a}±1.53	0.015^{b}±0.000
T6	76.33^{bc}±3.79	0.013^{a}±0.001

4. Conclusion

This research was aimed to assess the mechanical and electrical properties of conductivity concretes, produced by integrating eggshell powder (ESP) and calcium chloride ($CaCl_2$) as sustainable additives materials. Concrete produced by addition of different proportions of ESP and $CaCl_2$, had their electrical and mechanical properties evaluated, in accordance with International standards at curing day 28. The results revealed that both ESP and $CaCl_2$ had significant influence on density, compressive strength, electrical resistivity and electrical conductivity of the concrete cubes. It was noted that the density of the concrete produced declined unevenly, as the ratio of the admixtures introduced into the concrete mass increases; while the lower proportion of ESP ($\leq$10) instigated notable boost in the concrete's compressive strength. Similarly, the results indicated that the ESP led to an increase in the concrete's ρ values, whereas the $CaCl_2$ caused substantial decline in the concrete's electrical resistivity. The findings of this study had depicted that agricultural materials, can serve as sustainable resources in the concrete industry, for producing conductive composites with commendable electrical as well as mechanical properties. Based on the observations documented in this research, it is recommended that additional investigations should be carried out to examine the durability, and environmental effects of these green conductive concretes.

References

Akpokodje, O.I., Agbi, G.G, & Uguru, H. (2020). Evaluation of Cassava Effluent as Organic Admixture in Concrete Production for Farm Structures.*Turkish Journal of Agricultural Engineering Research (TURKAGER*), 1(2), 271-282. https://doi.org/10.46592/turkager.2020.v01i02.005

Barbhuiya, S., Kanavaris, F., Das, B. B., & Idrees, M. (2024). Decarbonising cement and concrete production: Strategies, challenges and pathways for sustainable development. Journal of Building Engineering, 86, 108861.https://doi.org/10.1016/j.jobe.2024.108861

Bruce, R.T.V., Sanele, R.M. & Shongwe, M.I. (2021).The Effect of Calcium Chloride Admixture on the Compressive Strength of Concrete Blocks. Journal of Agricultural Science and Engineering, 7(2), 30-35

Eboibi, O., Akpokodje, O. I., & Uguru, H. (2022). Evaluation of organic enhancer on the mechanical properties of periwinkle shells concrete. Journal of Engineering Innovations and Applications, 1(1), 13–22. https://doi.org/10.31248/jeia2022.020

El-Hallak, M., El-Mir, A., Najm, O., El-Hassan, H., & El-Dieb, A. (2024). Optimization of CF-GP Blended Electrically Conductive Concrete. Proceedings of the 9th International Conference on Civil, Structural and Transportation Engineering (ICCSTE 2024).https://doi.org/10.11159/iccste24.195

Dong, W., Huang, Y., Lehane, B., Aslani, F., & Ma, G. (2021). Mechanical and electrical properties of concrete incorporating an iron-particle contained nano-graphite by-product. Construction and Building Materials, 270, 121377.https://doi.org/10.1016/j.conbuildmat.2020.121377

Fulham-Lebrasseur, R., Sorelli, L., & Conciatori, D. (2020).Development of electrically conductive concrete and mortars with hybrid conductive inclusions.Construction and Building Materials, 237, 117470. https://doi.org/10.1016/j.conbuildmat.2019.117470

Gagg, C. R. (2014). Cement and concrete as an engineering material: An historic appraisal and case study analysis. Engineering Failure Analysis, 40, 114–140.https://doi.org/10.1016/j.engfailanal.2014.02.004

Han, B., Zhang, L., & Ou, J. (2017).Electrically Conductive Concrete. Smart and Multifunctional Concrete Toward Sustainable Infrastructures, 247–259. https://doi.org/10.1007/978-981-10-4349-9_13

Johnsson, F., Karlsson, I., Rootzén, J., Ahlbäck, A., & Gustavsson, M. (2020). The framing of a sustainable development goals assessment in decarbonizing the construction industry – Avoiding "Greenwashing."Renewable and Sustainable Energy Reviews, 131, 110029.https://doi.org/10.1016/j.rser.2020.110029

Li, J., Qin, Q., Sun, J., Ma, Y., & Li, Q. (2020). Mechanical and conductive performance of electrically conductive cementitious composite using graphite, steel slag, and GGBS. Structural Concrete, 23(1), 533–547. Portico.https://doi.org/10.1002/suco.202000617

MdShoriful, I. (2022). Influence of calcium chloride on the compressive strength of concrete produced from three types of cement (OPC, PPC & SRC). International Research Journal of Modernization in Engineering Technology and Science.https://doi.org/10.56726/irjmets27106

Owamah, H. I., Uguru, H., Umukoro, L. O., Akpokodje, O. I., Helal, M., Sami, R., Alshehry, G., Algarni, E., Abdelhai, N., Abushal, S. A., & Aljuraide, N. I. (2024). Mechanical and Physiochemical Characteristics of Sandcrete Blocks Produced with Sustainable Biomaterials. Science of Advanced Materials, 16(4), 518–531. https://doi.org/10.1166/sam.2024.4656

Oriola, K. O. (2021). Assessment of Workability and Compressive Strength of Rice Husk Ash-Blended Palm Kernel Shell Concrete.LAUTECH Journal of Civil and Environmental Studies, 7(1).Internet Archive.https://doi.org/10.36108/laujoces/1202.70.0101

Radwan, I., & Abdel Raheem, M. (2023). Initial Investigation of Using Waste Rubber Tires as a Sustainable Material for the Development of Electrically Conductive Rigid Pavements. Airfield and Highway Pavements 2023, 275–284. https://doi.org/10.1061/9780784484913.025

Sassani, A., Ceylan, H., Kim, S., Arabzadeh, A., Taylor, P. C., & Gopalakrishnan, K. (2018). Development of Carbon Fiber-modified Electrically Conductive Concrete for Implementation in Des Moines International Airport. Case Studies in Construction Materials, 8, 277–291. https://doi.org/10.1016/j.cscm.2018.02.003

Sassani, A., Arabzadeh, A., Ceylan, H., Kim, S., Gopalakrishnan, K., Taylor, P. C., & Nahvi, A. (2019).Polyurethane-carbon microfiber composite coating for electrical heating of concrete pavement surfaces. Heliyon, 5(8), e02359.https://doi.org/10.1016/j.heliyon.2019.e02359

Saeed, H. (2023). A REVIEW STUDY OF THE USE OF CALCIUM CHLORIDE IN CONCRETE. Journal of Engineering and Sustainable Development, 27(3), 339–349. https://doi.org/10.31272/jeasd.27.3.4

Tan, Y. Y., Doh, S. I., & Chin, S. C. (2018).Eggshell as a partial cement replacement in concrete development. Magazine of Concrete Research, 70(13), 662–670. https://doi.org/10.1680/jmacr.17.00003

Teara, A., &ShuIng, D. (2020).Mechanical properties of high strength concrete that replace cement partly by using fly ash and eggshell powder.Physics and Chemistry of the Earth, Parts A/B/C, 120, 102942.https://doi.org/10.1016/j.pce.2020.102942

TiegoumWembe, J., MambouNgueyep, L. L., Elat Assoua Moukete, E., Eslami, J., Pliya, P., Ndjaka, J.M. B., & Noumowe, A. (2023). Physical, mechanical properties and microstructure of concretes made with natural and crushed aggregates: Application in building construction. *Cleaner Materials*, 7, 100173. https://doi.org/10.1016/j.clema.2023.100173

Yehia, S., & Tuan, C. Y. (1999).Conductive Concrete Overlay for Bridge Deck Deicing.ACI Materials Journal, 96(3).https://doi.org/10.14359/637

Xu, H., Wang, D., Tan, Y., Zhou, J., & Oeser, M. (2018).Investigation of design alternatives for hydronic snow melting pavement systems in China. Journal of Cleaner Production, 170, 1413–1422. https://doi.org/10.1016/j.jclepro.2017.09.262

Zhou, Z., Xie, N., Cheng, X., Feng, L., Hou, P., Huang, S., & Zhou, Z. (2020). Electrical properties of low dosage carbon nanofiber/cement composite: Percolation behavior and polarization effect. Cement and Concrete Composites, 109, 103539.https://doi.org/10.1016/j.cemconcomp.2020.103539

Zhao, C.L. (2021). The concrete application of lightning protection technology of electrical automation system in water conservancy and hydropower project. Journal of Physics: Conference Series, 1904(1), 012015. https://doi.org/10.1088/1742-6596/1904/1/012015