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Valorization and Utilization of Nano-CaO from Eggshell Waste in Concrete Composites for Sustainable Structures

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Abstract
Sequel to sustainability and the rise in the cost of building materials, the search for affordable and cheap building materials has been on the increase, especially in developing countries. Consequently, this research investigates chemical, strength and workability properties of Bamboo Leaf Ash **(**BLA) and Egg Shell Powder (ESP) concretes. Bamboo leaves and Eggshells (ESs) were processed to obtain BLA and Nano - CaO. The X-ray fluorescence (XRF) technique was used to analyze the chemical compositions of BLA and ESP. The cement (Ordinary Portland cement) was replaced at 15% in weight for the ratios (40:60, 45:55, 50:50 and 55:45) of BLA: ESP respectively. The cubes were crushed to get the various compressive strength of the concrete at different curing days. XRF analysis shows that BLA is formed by silica in concentration level of about 68% and ESP has a high concentration of CaO (89.2%), which contributes to strength development of concrete. At 28day curing, the 40:60 replacement gave optimal strength of 25.90 MPa slightly above the 0% replacement of 25.59 MPa. Samples with 55:45 ratios produced highest slump at 60mm. Based on the findings, it is concluded that ternary blend of these composite materials can achieve enhanced concrete properties for sustainable constructions.
Keywords: Sustainable concrete, waste management, supplementary cementitious material, recycled materials.

1. Introduction
The idea of environmentally friendly construction has motivated researchers to take more action to protect the environment. The increased pace of cement production results in significant annual waste generation, enormous capital cost requirements, high energy and carbon emission costs, and substantial traditional raw material consumption (Ibeabuchi et al., 2022; Kolawole et al., 2021). In response to the environmental problem, the use of waste products as alternative building materials has gained attention in the majority of developing countries (Ghavami, 2005; Ibeabuchi et al., 2022b; Wahyuni et al., 2014). Recent research has focused on using pozzolans made from agricultural solid waste to make blended mortars and concrete. Reusing agricultural and industrial waste as building materials can improve the construction sector's sustainability. In fact, adding agricultural solid waste combustion ashes to concrete is a common technique at the moment due to the ashes' chemical reactivity with the mixture produced during the cement hydration reaction. Some of these agricultural byproducts are being tested for mortar and concrete manufacturing, including rice husk ash, sawdust, cork granules and sugarcane bagasse ash (Villar-Cociña et al., 2011).

The fastest growing as well as highest-yielding natural resource and building material now available to humans is bamboo. Significant amounts of bamboo are processed in several nations, producing large amounts of solid waste (Thomas et al., 2021). The ecofriendly bamboo fibres, derived from new bamboo-chips or clippings has successfully been applied for the reinforcement of cementitious materials. However, using bamboo results in various waste products that are not used as fibers, including the bamboo leaf. Approximately, 35-40percent by weight of cultivated bamboo is typically burned in open landfills (Villar-Cociña et al., 2011). As a result, various research in the past have looked into bamboo leaf ash (BLA) as an additional cementitious material.

In recent decades, pollution levels in the environment have increased quickly, and the building industry is a key contributor to the increase. Agricultural wastes known as eggshells (ESs) are collected from bakeries, chick hatcheries, and fast-food establishments. When left in landfills for extended periods of time without proper treatment, these wastes cause significant damage to the surrounding environment and cause certain allergies (Mohamad et al., 2016). The application of ESP for construction works may reduce environmental pollution because improper disposal of ES creates an unsolvable problem and causes irritation due to its disagreeable odor. According to Bashir and Manusamy (2014), ES a bio-waste, is one of the worst environmental hazards contributor. However, the right application of this waste can benefit the environment. In addition to construction material, ES has been investigated as a potential heavy metal adsorbent to reduce environmental pollution, as well as a potential adsorbent for heavy metals from wastewater as well as non-oxide materials (Bhaumik et al., 2012; Park et al., 2007).

Composite materials are created from parts that result in an enhanced material with physical or chemical properties that are very different from those of the separate parts (Esonye et al., 2022). Due to this, waste products like eggshells and bamboo leaves have a lot of potential for use as building materials. The characteristics of materials formed by this combination are those influenced by the pozzolanic behaviour of the mixture of high silica content from BLA and high CaO from ESP. Studies show that BLA has a lot of silica (SiO_2 of around 72-81%) and very little calcium oxide (CaO of around 2-5%) (Kolawole et al., 2021; Odeyemi et al., 2022). In another research, Hamada et al. (2020) ESP had a high CaO concentration of around 32.5 - 99.8% and a low silica of around 0.05 - 1.22%**.** A review of the literature shows that supplementary cementitious materials (SCMs) with high silica content, as well as CaO, produce binders with higher strength and improved overall properties. Therefore, combining these SCMs could create synergetic effects due to their composition and increase the percentage replacement value which will consequently impact positively on the environment is the motivation for this study. The study attempts to combine the highlighted advantages in order to achieve a sustainable binder with good strength and durability, which is scares in the literature.

1.1. Properties of ESP filler

It is reported that ESP has a lower specific gravity than cement. ESP has a 2.33 specific gravity, according to Mishra and Pathak (2017) investigations. However, according to different reports, the specific gravity varies between 0.85 and 2.66 (Hamada et al., 2020), and between 3.15 and 3.18 for cement, depending on the source, production process, and degree of fineness (Pakbaz & Alipour, 2012; Rao, 2003). The bulk density results range from 700 to 2088 kg/m^3, while those for cement are between 1000 and 1300 kg/m^3. The approach for assessing concrete's workability is the slump value. It gauges the consistency and fluidity of concrete. For concrete incorporating ESP as a partial cement replacement, the slump value was significantly low, ranging from 5 mm to 12 mm (Hamada et al., 2020). It is reported that increasing ESP in a mix will lead to decrease in workability and the slump value ranged from 50 mm to 100 mm for all concrete compositions with ESP. High CaO content of about 32.5 – 99.8% and low silica of about 0.05 – 1.22% (Hamada et al., 2020). The CaO and SiO_2 enhances strength properties of concrete among others. Hence, ESP can have significant influence when blended with pozzolans with high silica content for sustainable construction.

1.2. BLA – ESP Concrete

Yerramala (2014) studied concrete with ESP with 5% to 15% cement substitutions. The findings demonstrate that ESP can be used to partially replace cement in the production of sustainable concrete. Additionally, the findings show that ESP concrete with 5% ESP has greater compressive strength than the control sample. Some studies, however, found a reduction in strength when cement is replaced with higher percentage of ESP that are greater than 10%. Raji and Samuel (2015) demonstrated that the optimal replacement ratio for eggshell powder is 10%. Both the replacement and control samples achieved the same strength at this ratio. He concluded that increasing the replacement ratio to 20percent could cause bleeding, micro-cracks, and segregation problems. According to a recent review Murthi et al. (2022), approximately 8-10% cement replacement is possible without compromising mechanical strength and structural performance, and it increases the hydration process during the early periods.

The use of bamboo leaf ash (BLA) as an additional cementitious ingredient has been studied by researchers separately (Dwivedi et al., 2006; Villar-Cociña et al., 2011). According to these experiments, BLA can successfully replace Portland cement (PC) by 5% to 20%. Despite having a high silica concentration (SiO_2 of roughly 76 to 81%), it also has a low alumina percentage and a low CaO content. This has led to ternary blend of this pozzolan with other fillers for improved performance. In order to create sustainable concrete, Kolawole et al. (2021) explored the blending of cement binders using bamboo leaf ash and ground clay brick (GCB) waste. They found that GCB had an alumina content of approximately 16–21% compared to BLA (1–4%). The findings demonstrate that although while GCB outperforms the BLA, they can both be mixed at a rate of 10% each to produce adequate strength and chemical resistance.

Consequently, blending of BLA and ESP will enhance properties of the composite mix. This work tends to study the combine effect of ESP and BLA on physical, chemical, workability and strength properties of concrete. The influence of ESP in ternary concrete with cement replacement up to 15% is well investigated. From precious research ESP or BLA have been employed for concrete production as pozzolan or additive, also these materials have been combined with other materials for improved properties, however, there is dearth of literature on the potentials of BLA-ESP mortar/concrete production.

2. Materials and Methods

2.1. Cementitious Materials

Bamboo leaves are gathered from a bamboo farm in the southern Nigerian state of Ebonyi, in the town of Ikwo. The bamboo leaves were collected, sun-dried for 24 hours to remove moisture, and then burned for two hours in a laboratory electric furnace at 600°C. This process is in accordance with Villar-Cociña et al. (2011). Ordinary Portland Cement (OPC) was purchased at the Ikwo local market. For this investigation, aggregates as well as used were sourced within Abakaliki. The eggshell waste is collected from Abakaliki's poultry farms, bakeries, and restaurants.

The Nano - CaO in ESP is obtained from the calcination process as shown in the formula of Eqn. 1

$$CaCO_3 \xrightarrow{900\ ^\circ C \text{ for } 2\ h} CaO + CO_2 \quad (1)$$

After gathering the ESs, the cleaning procedure is performed, and the ESP is then dried in an electrical oven at 120 °C for 24 hours. Before being calcined at 900 °C for two hours to thoroughly burn away the residual organic elements and transform the majority of CaCO3 into CaO, the surfaces of the collected ES wastes were cleaned with water to remove dust and other organic contaminants. When heated to about 900 degrees Celsius, CaCO3 totally decomposes into Nano-CaO, which could be useful if combined with pozzolanic materials. Chemical compositions for the OPC, BLA and ESP are shown in Table 2.

2.2. Aggregates

Aggregates made of river sand (fine) and crushed stone (coarse) with 19 mm as the maximum size of the coarse particle were used. The aggregate tests were conducted in accordance with standard procedures. Table 1 illustrates the characteristics of both sand and crushed stone. Fig. 1 displays the results of analyzing the particle size distribution of crutched stone and sand.

Table 1: Physical and mechanical properties of fine and coarse aggregates.

Properties	Sand	Crushed stone
Specific gravity	2.65	2.74
Fineness modulus	2.53	5.96
Unit weight (kg/m 3)	1.66	1.69
Water absorption (%)	0.71	0.20
Elongation index (%)	1.44	2.98
Crushing value (%)	-	10.8
Impact value (%)	0.16	10.2
Los Angles abrasion loss (%)	-	12.1

2.3. Test Procedure

In the mix design, M25 concrete grade was taken into account. Using a different BLA: ESP mix ratio, egg shell powder and bamboo leaf ash are used to substitute cement at 15%. Experimental studies on compressive strength and the slump test were conducted for cement replacement rates of 15% and 0%. When the mixes were still fresh, the workability qualities were measured. The slump test was conducted in accordance with standard procedure to determine the consistency of the concrete. The slump results are given in Fig. 2. The combination of four different mixture of BLA and ESP i.e : 40:60, 45:55, 50:50 and 55: 45 were utilised for 15% replace cement by weight. The compressive strength of the 150 150 150 mm cubes was evaluated at 7, 14, 21, and 28 days. Fig. 3 shows the result of the compressive test

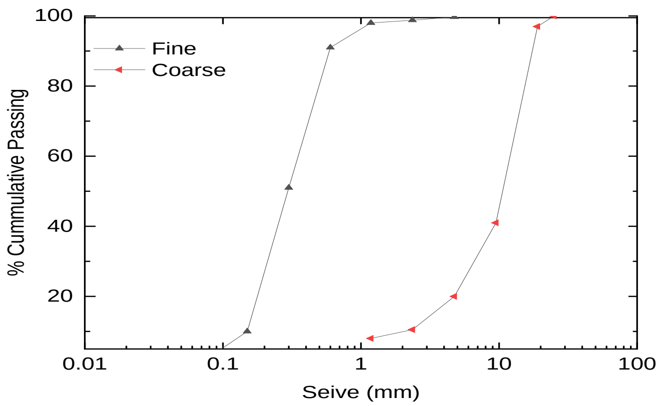

Figure 1: Particle size distribution of the aggregates.

3. Results and Discussion

3.1 Chemical composition and workability property of BLA-ESP concrete

Using the X-ray fluorescence (XRF) method, the chemical compositions of the binder components were identified. Table 2 lists the primary components of bamboo ash, presented as oxides. Silica (SiO_2) with concentration of 68.2 is the major component in BLA, following by K_2O, CaO, MgO and Al_2O_3 in concentrations of 8.46, 4.13, 3.16 and 2.58 respectively. Fe_2O_3, P_2O_5, and MnO are examples of oxides with concentrations that are slightly above 1%, whereas SO_3 and TiO_2 are examples of oxides with contents that are below 1%. The weight loss of dry ash was used to calculate the loss on ignition (LOI). This outcome is consistent with that of Villar-Cociña et al. (2011). For the ESP, the main component is CaO with concentration of 89.2%. Oxides of SiO_2, K_2O, Al_2O_3, SO_3, P_2O_5, are below 1%, while other oxides are infinitesimal. Again this result is an agreement with Hamada et al. (2020). The BLA used in this study is a pozzolan with oxides of $SiO_2 + Al_2O_3 + Fe_2O_3$ above 70%. However, in ESP, these oxides are less than 70% which implies that ESP is not a pozzolan but can complement a pozzolan. Consequently, the CaO concentration can significant contribution to strength properties.

Table 2: Chemical composition of OPC, BLA and ESP

Oxides (%)	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	Cr_2O_3	K_2O	SO_3	P_2O_5	MnO	TiO_2	LOI
OPC	16.8	60.4	4.34	2.43	1.43	0.01	0.16	1.63	0.21	0.04	0.24	8.94
BLA	68.2	4.13	2.58	1.46	3.16	0.00	8.46	0.57	1.52	1.18	0.15	4.8
ESP	0.63	89.2	0.49	0.08	0.00	0.00	0.15	0.46	0.45	0.00	0.00	45.1

Table 3 provides an evaluation of the workability of freshly mixed concrete using various BLA and ESP ratios. It is observed that increases in the ratio of BLA:ESP contents resulted in an increase in workability. The slump value for 00:00, 40:60, 45:55, 50:50, 55:45 mixtures were 50 mm, 54 mm, and 55 mm, 54 mm, and 60 mm respectively. A 50 mm slump was maintained by the control mix (00:00) used in the experiment. The workability, however, was found to decline as the ESP in the relative proportion grew. The highest slump value was recorded at BLA:ESP ratio of 55:45. These agreed with Allie and Anand (2018) research, which found that adding eggshell to Portland cement concrete lowered its workability. In a different investigation, RHA and FA were substituted for cement in different proportions, along with ESP, by Sivakumar and Mahendran (2014) cited in (Hamada et al., 2020). They came to the conclusion that as the ESP proportion in concrete mixtures increases, the slump value decreases.

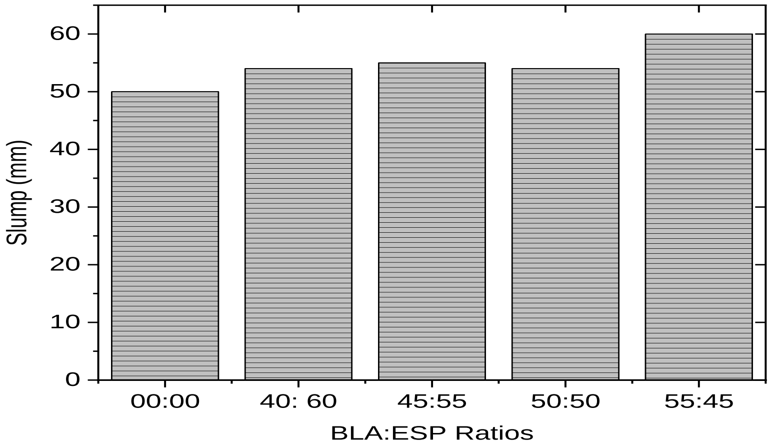

Figure 2. Workability of the concrete mixes.

3.2 Strength Properties

The use of ESP or BLA for the formation of concrete has been the subject of investigation. The best BLA substitute for cement in the manufacturing of concrete was reported to be up to 20%, whilst the optimal ESP substitution was reported to be between 8 and 10%. As a result, the BLA and ESP combination with 15% cement substitution produced good strength. For a 15% replacement of the cement composition, adding BLA: ESP ratios results in a 28-day increase in compressive strength. The compressive strength of concrete mixes for cure times of 7, 14, and 28 days is shown in Fig. 3. At 28day concrete's compressive strength under control (zero replacement) is 25.59 MPa, while strength value for the 40:60 replacements was 25.90 MPa, however, the strength value for the 45:55 replacements was 24.13 MPa. Pozzolan's reaction with CaO and C-S-H gel improves the compressive strength and hardening of concrete mixtures (Amin et al., 2022). Because of the binding effect, it is the component that provides strength. As a result, the 40:60 ratio yielded the best compressive strength value (25.59 MPa).

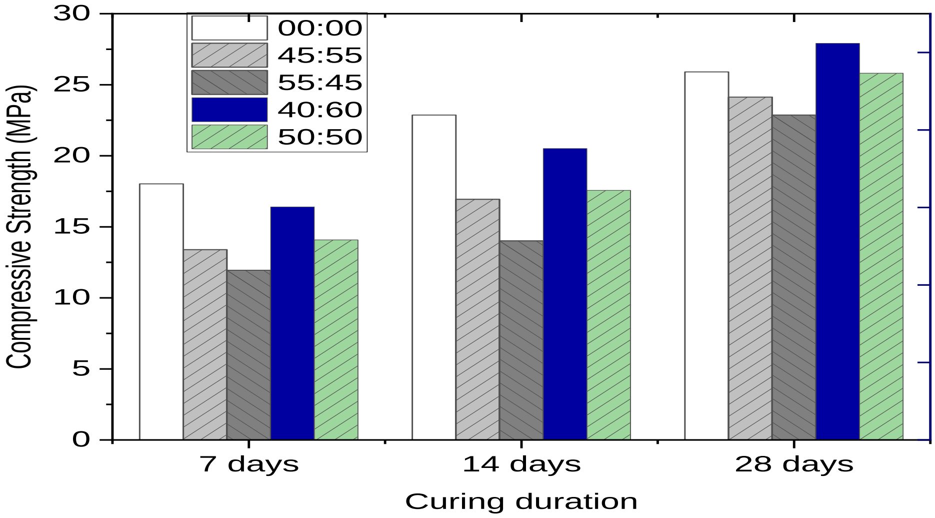

Figure 3: Compressive strength properties

4. Conclusions

The following conclusions can be drawn from the findings of this paper:

i. According to XRF analysis, bamboo ash (BLA) is mostly composed of silica, which is present in quantities of about 68.2%, but calcium oxide (CaO), which is present in concentrations of around 82%, is abundant in ESP. Workability declines as ESP composition increases, reaching its greatest value (60 mm) at a 55:45 ratio.

ii. The use of a ternary blend of BLA and ESP as a potential composite material to replace some of the cement in concrete mixes and reduces environmental waste is very promising.

iii. The findings suggest the possibility for ESP to be used in combination with other pozzolanic materials such as rice husk ash, calcined clay, calcined shales etc. to enhance concrete characteristics and lower cement consumption, hence reducing environmental pollution.

iv. Research on heat of hydration as well as kinetics on the pozzolanic activity of these agricultural wastes is one of the unresolved areas. Optimization approaches still has to be evaluated.

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