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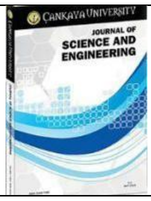

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# Structural Strength Characteristics of Coal Ash Blended Cement Concrete Exposed to Coastal Environment

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**Keywords**

Coal-ash,
Concrete structures,
Seawater,
Strength Characteristics,
Infrastructure.

**Abstract**

The study investigated coal ash, a waste product, in proper blends with cement in concrete for infrastructure projects in the coastal environment. The coal ash was partially replaced in the concrete matrix at the percentage rates of 0, 5, 10, 15, and 20 by weight of cementitious material. Concrete of grade 20 were cast in batches, cured in seawater under two conditions of exposure for 28 days and the mechanical properties of the specimens examined. The results revealed that the strength properties of the cement matrices partially replaced with coal ash improved with curing age. The strengths of coal ash concrete fully exposed to seawater were lower than those partially exposed to seawater. The 10% coal ash concrete had compressive strengths of 24.54 N/mm$^2$ and 22.7 N/mm$^2$ for partial and full exposure in seawater and split tensile values of 3.13 N/mm$^2$ and 1.93 N/mm$^2$ for partial and full exposure in seawater, respectively. The results indicated that coal ash, in partial replacement of cement in concrete, is beneficial for sustainable infrastructural development in coastal environments.

## 1. Introduction

Providing housing for all is vital to the Sustainable Development Goals (SDGs). The rising cost of construction materials, especially cement; and the challenge of combating the freshwater crisis in coastal environment are serious conditions to the actualization of this goal. Studies on behaviour of concrete exposed to severe environments had been conducted by various researchers. Amusan and Olutoge [1] studied the shrinkage properties of concrete exposed to seawater and discovered concrete suffered higher shrinkage effects when exposed to seawater. Another study by the authors on effect of seawater on the compressive strength of concrete. The researchers found that the compressive strength increased for concrete mixed and cured with seawater (SS) than concrete mixed with freshwater and cured with seawater (FS) [2].

Farooq and Yokota [3] studied the residual mechanical properties of plain and steel fiber reinforced concrete damaged by alkali silica reaction (ASR) and chloride ion ingress. The researchers evaluate accelerated degradation tests on three concrete mixes. The findings showed that flexural strength loss was less in prisms exposed to combined alkali and chloride environment. Rathnarajan and Sikora [4] submitted in a review work on seawater-mixed concretes containing natural and sea sand aggregates that mitigation measures including partial substitution of supplementary cementitous materials, inclusion of alternative reinforcements would assist to combat the freshwater crisis in nations suffering severe water stress. There is, therefore, a need to research substitute materials to partially replace cement and other construction materials to provide sustainable infrastructures in coastal environments.

Effective fly ash in concrete was investigated, and the findings revealed that fly ash increases compressive strength and modulus of elasticity up to 15% [5]. Amusan *et al*. [6] examined the properties of empty palm fruit

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bunch ash blended cement in concrete production. The authors submitted that 5% EPFB ash concrete was comparable to conventional concrete.

Similarly, an experimental study on the strength of wood ash in concrete production showed significant improvements in compressive strength [7-9]. Studies on coal fly ash, revealed that the mechanical strength of concrete developed at older curing age. However, at early ages, the strength was low owing to incomplete pozzolanic activity [10-12]. Ankur *et al*. [13] suggested that large dosage of coal fly ash is practicable in self-compacting concrete where early days' strength is not necessary. Hydration, pore diameter, workability, and durability properties were also reported to improve by adding coal fly ash to concrete [14].

Consequently, Saboo *et al*. [15] suggested coal fly ash dosage within the range of 5 to 15% for better output. Bayqra *et al*. [16] found that coal fly ash in large quantity reduces the hydration temperature of roller-compacted concrete (RCC). However, the authors submitted that high content of coal fly ash had adverse effect on the compressive strength of roller-compacted concrete. Sanjuan *et al*. [17] considered fineness a critical parameter affecting fly ash pozzolanicity. Jing *et al.* [18 ] and Ferdosian *et al*. [19] also reported that ultra-fined coal fly ash improves high-performance concrete pastes compared to the conventional.

Nevertheless, for the best ash performance in cement blended concrete, mix design, curing conditions and chemical composition of coal ash are strong determinants. The Coal Ash (CA) considered in this study as supplementary cementitious material is ash from fossilized wood. The ash is a waste considered less expensive and affordable. Data from previous research indicated that Nigerians depended heavily on local energy sources like firewood and charcoal for daily energy needs [20]. It was reported that about 70 percent of families in rural areas used firewood as cooking energy in Nigeria, and more than 2.9 billion people globally relied on firewood and coal [21].

Therefore, this paper examined the structural strength properties of coal ash blended cement concrete exposed to coastal environments for optimal infrastructural development sustainability. Thus, the compressive strength and split tensile strength of coal ash concrete were investigated to determine the effect of seawater on structures built in coastal environments using coal ash blended cement for express adoption to attain sustainable development goals.

## 2. Materials and Methods

### 2.1. Materials

The materials employed in the investigation included water, seawater, coal ash, fine and coarse aggregate, and cement. Materials were subjected to preliminary testing in order to analyse their properties. The cement utilized was ordinary Portland cement. It complied with BS12's requirements [22]. Sharp sand was the fine aggregate used in this project. It contained no silt, contaminants, or organic stuff. Granite was utilized as the coarse aggregate. 12.5 mm was the size employed in the study. Both the fine and coarse aggregates met BS882 [23] requirements.

The powdered, amorphous solid coal ash was obtained locally from bakery. The coal ash was stored in waterproof sacks after passing through a BS sieve measuring 0.063 mm. Figure 1 shows a representative sample of the coal ash sample. Oil-free, clean potable water was used to mix the concrete, and seawater was used to simulate exposure to coastal environments during the curing process.

**Figure 1.** Coal ash sample.

## 2.2. Methods

### 2.2.1. Mix Proportion and Casting of Concrete Specimens

Coal ash was added to cement at a rate of 0–20% by weight to partially replace cement. A 1:2:4 concrete mix ratio containing 0.5 water-to-cement was employed. The process of mixing involved rotation of aggregates, cement, coal ash, and water. Five mixtures with partial replacements of cement and coal ash (0%, 5%, 10%, 15%, and 20%) were made. This ascertained the ratio that would yield the most advantageous outcome. For the other samples, the 0% substitution functioned as the control. Table I displayed the mix proportions. Concrete cubes and cylinders were cast using steel molds 150 mm by 150 mm by 150 mm and 150 mm by 300 mm, respectively. Polyurethane membranes were placed on the specimens. After 24 hours, the specimens were demolded and allowed to cure by partial and total immersion of the specimens in seawater at room temperature until the test ages. The partial and total immersion in seawater is shown in Figure 2.

**Table 1.** Mixture proportions

| Mix Designation | *Cement ($kg/m^3$)* | *Coal ash ($kg/m^3$)* | Fine aggregate *($kg/m^3$)* | *Coarse* aggregate *($kg/m^3$)* | *Water ($kg/m^3$)* |
|---|---|---|---|---|---|
| 0% CA | 385.0 | 0.0 | 770 | 1540 | 192.5 |
| 5% CA | 365.7 | 19.3 | 770 | 1540 | 192.5 |
| 10% CA | 346.5 | 38.5 | 770 | 1540 | 192.5 |
| 15% CA | 327.5 | 57.8 | 770 | 1540 | 192.5 |
| 20% CA | 308.0 | 77.0 | 770 | 1540 | 192.5 |

**(a)** **(b)**

**Figure 2.** Coal ash blended cement concrete (a) partially and (b) fully immersed in seawater.

#### 2.2.2. Compressive Strength Test

150 mm × 150 mm × 150 mm cube moulds were used to cast the specimens for the compression test. In the lab, the specimens were allowed to cure in the moulds for a full day. Subsequently, the samples were demolded and positioned in partially filled curing tanks with seawater until the curing process took place. Specimens underwent testing beneath the compressive testing machine's bearing surface following their curing period. The specimens underwent a process of draining excess seawater from their surface, weighing, and placing them within the machine. The load was progressively raised until the specimens failed. At failure, the maximum load was recorded. For every category, three specimens underwent testing, and the average compressive strength determined following BS 1881 [24].

#### 2.2.3. Split Tensile Strength Test

As previously mentioned, 150 mm in diameter and 300 mm in height cylinders were cast and cured in two different exposures. A cylindrical specimen was positioned horizontally between the loading surface of a compression testing apparatus, and the load was applied along the vertical diameter of the specimen until the cylinder failed. Three cylinders per category were tested, and the average tensile strength values were determined using BS 1881 [25] and ASTM C496 [26].

## 3. Results and Discussion

### 3.1. Results of Chemical Analysis of Coal Ash and Seawater

**Table 2.** Chemical properties of coal ash.

| Constituent | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $K_2O$ | $Na_2O$ | $SO_3$ | LOI |
|---|---|---|---|---|---|---|---|---|---|
| **Composition (%)** | 37.6 | 18.4 | 10.3 | 7.6 | 1.3 | 2.9 | 0.4 | 1.7 | 13.0 |

**Table 3.** Chemical properties of seawater.

| Constituent | $Cl^-$ | $SO^{2-}_4$ | $Mg^{2+}$ | $Ca^{2+}$ | $K^+$ | $PO^{3-}_4$ | $Fe^+$ | S | $P^H$ | TDS |
|---|---|---|---|---|---|---|---|---|---|---|
| **Composition (mg/l)** | 6150.0 | 1550.3 | 1640.0 | 220.1 | 550 | 2.00 | 0.15 | 34.2 | 8.1 | 30000 |

Tables 2 and 3 showed the chemical constituents of coal ash and seawater, respectively. In Table 2, the total of the three primary chemical constituents, silicon dioxide, aluminium oxide, and iron oxide equivalent to 66.38%. Table 3 indicated that the seawater has the Chloride, Sulphate, and Magnesium as the most dominating abundant ions in seawater. This agrees with previous research [2]. The oxide class percentage compositions in Table 2 fell within the limit, but the summation of the three oxides was less than the 70% minimum requirement for pozzolana. This is in accordance with ASTM C618 [27].

### 3.2. Results of Particle Size Distribution

The particle size of coal ash used passed through a BS sieve 0.063 mm in size. The fineness was comparable to cement. From the particle size distribution results, the fine and coarse aggregates can be classified as well-graded sand; each had a coefficient of curvature greater than one. Figure 3 represents the sieve analysis results of the aggregates and coal ash used.

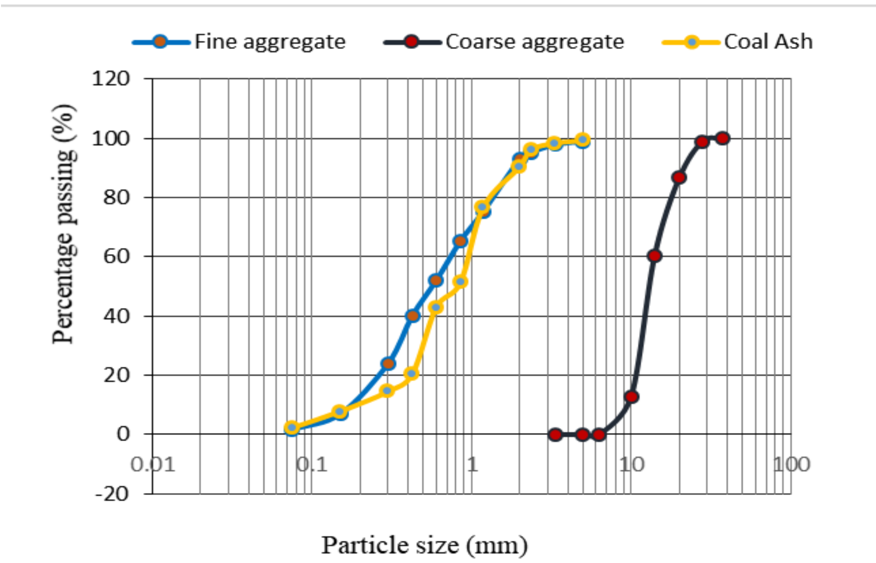


**Figure 3.** Particle size distribution of coal ash and aggregates.

### 3.3. Results of Concrete Fresh Properties

The results revealed an increase in slump as coal ash dosage increases. The workability of the concrete was moderate, and the compacting factor results were comparable to the control. The increase in slump values showed lesser water demand for coal ash cement blended concrete.

**Table 3.** Concrete fresh properties.

| **Designation** | ***0% CA*** | ***5% CA*** | ***10% CA*** | ***15% CA*** | ***20% CA*** |
|---|---|---|---|---|---|
| Slump (mm) | 55 | 61 | 65 | 67 | 70 |
| Compacting factor | 0.70 | 0.71 | 0.73 | 0.70 | 0.69 |

### 3.4. Results of Compressive Strength

The compressive strength results in Figures 4 and 5 were observed to be significantly influenced by curing days for both exposure conditions. Hence, the mass concrete's hydration process was constant and consistent. The results agree with the previous studies that coal ash addition improves compressive strength of the concrete at early ages and performs better at older ages [11, 14].

The CA concrete partially immersed in seawater had compressive strength values of 22.41 N/mm$^2$, 24.54 N/mm$^2$, 18.50 N/mm$^2$ and 17.70 N/mm$^2$ for 5%, 10%, 15% and 20% CA dosage, respectively. However, the CA concrete fully immersed in seawater had compressive strength values of 20.04 N/mm$^2$, 22.70 N/mm$^2$, 17.80 N/mm$^2$ and 17.34 N/mm$^2$ for 5%, 10%, 15% and 20% CA dosage, respectively. The compressive strength values of CA concrete fully immersed in seawater were lower than those of CA concrete with partial exposure to seawater. The findings agree with previous work on seawater exposures [28].

CA concrete with the two exposure conditions had compressive strength higher than the control concrete samples with compressive values of 19.69 N/mm$^2$. This implies that the CA concrete had more elastic behavior than the control samples. The 10% CA concrete had the highest 28 days compressive strength, followed by 5% CA for partial exposure to seawater. The compressive strength of CA concrete decreases with the level of exposure to seawater. The work agrees with previous studies [13, 17, 28].

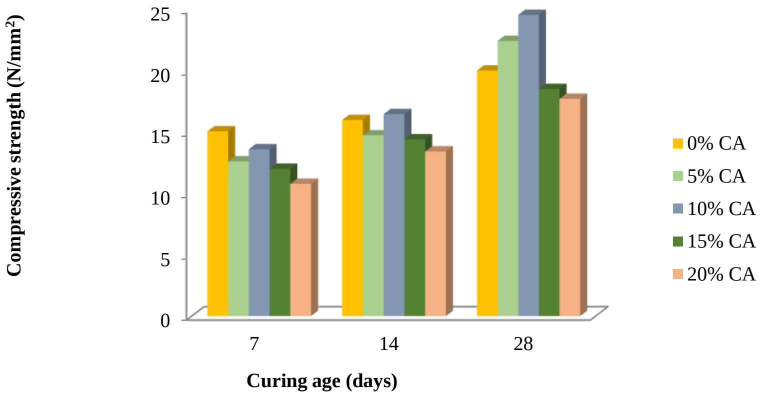


**Figure 4.** Compressive strength of coal ash blended cement concrete partially immersed in seawater.

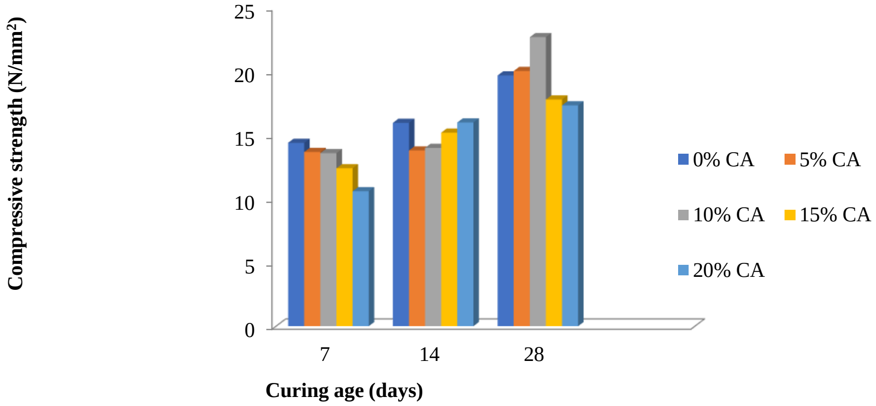


**Figure 5.** Compressive strength of coal ash blended cement concrete fully immersed in seawater.

### 3.5. Results of Split Tensile Strength

The split tensile strength results in Figures 6 and 7 revealed that the coal ash concrete improved with the increasing curing age. CA concrete had split tensile strength values of 2.72 N/mm$^2$, 3.13 N/mm$^2$, 2.60 N/mm$^2$ and 2.23 N/mm$^2$ for 5%, 10%, 15% and 20% CA dosage, respectively, when partially immersed in seawater. While the CA concrete had split tensile strength values of 1.82 N/mm$^2$, 1.93 N/mm$^2$, 1.64 N/mm$^2$ and 1.61 N/mm$^2$ for specified CA dosage, when fully immersed in seawater compared to control with split tensile values of 1.71 N/mm$^2$. Significant increase in split tensile strength was noticed in 5% and 10% CA concrete, whereas a reduction occurred for coal ash addition beyond this dosage. This agrees with previous studies [10, 14, 15].

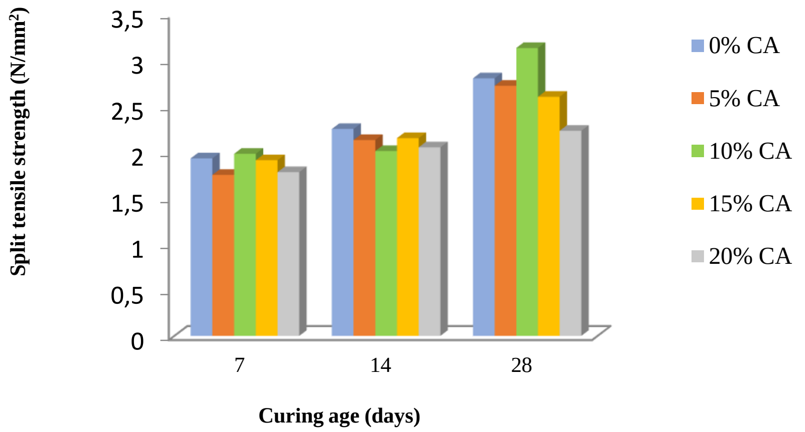


**Figure 6.** Split tensile strength of coal ash blended cement concrete partially immersed in seawater.

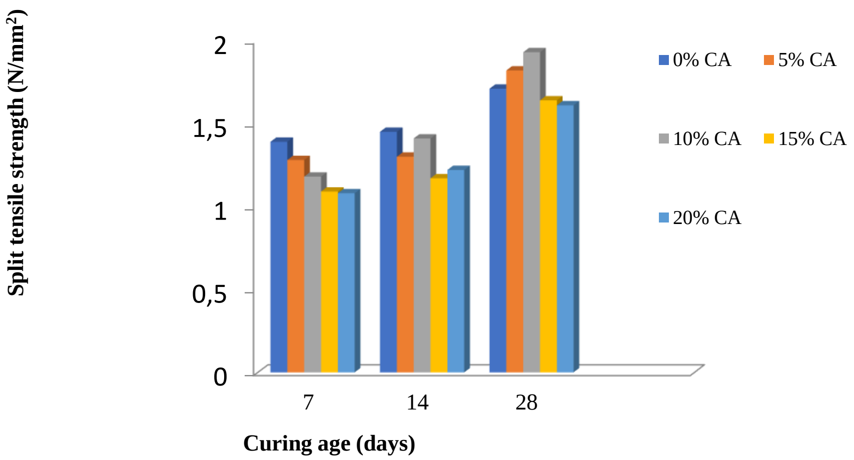


**Figure 7.** Split tensile strength of coal ash blended cement concrete fully immersed in seawater.

## 4. Conclusions

The study examined the strength characteristics of coal ash blended cement concrete exposed to the coastal environment. This was done to ascertain the potential usage of coal ash in partial cement replacement and its behavior for utilization in the coastal environment. Therefore, from the study, the coal ash had a chemical composition comparable to pozzolana, which positions coal ash usage as an alternative cementitious material to replace cement partially. The coal ash conformed to the minimum standard in BS12 [22]. The coal ash blended cement concrete had good workability behaviour, and the slump and compacting factor followed standards in BS1881 [29, 30].

In addition, the strength characteristics of the coal ash concrete matrices improved with curing age. The compressive and split tensile strengths of coal ash concrete immersed fully in seawater were lower compared to the coal ash concrete partially immersed in seawater. However, the performance of CA concrete within the dosage range of 5 to 10 percent had better strength characteristics than the control concrete. In all, the 10% coal ash concrete had the highest compressive and split tensile strengths within the class of CA concrete.

In conclusion, the use of coal ash in partial replacement cement is beneficial; environmental pollution caused through the disposal of coal ash would be drastically reduced, and its usage would reduce greenhouse gas $CO_2$ emission, leading to a free and healthy atmosphere, as well as advance sustainable infrastructural development of concrete structures in the coastal environments.

## Declaration of Competing Interest

No conflict of interest was declared by the authors.

## Authorship Contribution Statement

**Grace Modupeola Amusan:** Writing, Reviewing, Data Preparation, Editing

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