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Index-Based Evaluation and Statistical Modelling of Cassava Peel Ash Blended High-Strength Concrete

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ABSTRACT: The rapid growth of the construction sector has increased the need for sustainable materials. High dependence on Ordinary Portland Cement (OPC) contributes significantly to CO_2 emissions. This study evaluates index-based performance and statistical modelling of cassava peel ash (CPA) blended high-strength concrete. Air-dried cassava peels were incinerated at 600°C for 6 hours and sieved to 75 µm. Coarse aggregates were characterized for specific gravity (2.58–2.64), water absorption (0.87%), flakiness (23.75%), elongation (17.5%), and aggregate crushing value (23.75%). Concrete mixes with 0%, 5%, 10%, and 15% CPA were cast and cured in wet sand and water. Compressive and splitting tensile strengths were measured at 3, 7, 14, 28, and 42 days. Performance and durability indices were calculated, and ANOVA and regression analyses were conducted using SPSS. Compressive durability indices ranged from 92.23 ± 10.46 at 3 days to 101.35 ± 9.30 at 17 days, with values of 73.35 ± 49.30 at 21 days and 49.08 ± 56.68 at 28 days. Splitting tensile durability indices ranged from 101.68 ± 33.95 at 3 days to 105.83 ± 8.04 at 21 days and 95.45 ± 7.76 at 28 days. For CPA replacement levels, compressive indices were 99.73 ± 6.06 (0%), 94.71 ± 4.08 (5%), 81.16 ± 31.03 (10%), and 83.18 ± 47.25 (15%), while splitting tensile indices were 76.46 ± 11.32 (0%), 104.70 ± 7.31 (5%), 114.68 ± 18.05 (10%), and 102.30 ± 5.92 (15%). Normality and homogeneity tests confirmed the suitability of data for statistical modelling. CPA incorporation at 5–10% produced optimal durability indices. It is recommended to limit CPA replacement to these levels for sustainable high-strength concrete production.

KEYWORDS: Cassava Peel Ash, compressive strength, tensile strength, performance index, statistical modelling.

1.0 INTRODUCTION

The global construction sector continues to expand due to population growth, rapid industrialisation, and increased infrastructural development demands. Concrete, as the most extensively utilised construction material, plays a central role in this expansion because of its strength, versatility, and cost efficiency (Sandanayake et al., 2020). Nevertheless, its heavy dependence on Ordinary Portland Cement (OPC) raises significant sustainability concerns. Cement manufacturing is energy-intensive and heavily reliant on calcination, contributing approximately 7–8% of global carbon dioxide emissions (Kioko, 2020). These environmental implications have driven a global shift toward low-carbon construction materials and the adoption of supplementary cementitious materials derived from waste streams to reduce OPC consumption (Barbhuiya et al., 2025).

Agricultural waste utilisation has gained prominence as an effective strategy for sustainable construction. In sub-Saharan Africa, agricultural residues are generated in large volumes but remain largely underutilized (Lungaho et al., 2025). Cassava peels, in particular, constitute one of the region's most abundant agricultural wastes due to extensive cassava cultivation and processing. Nigeria, which leads global cassava production, generates millions of tonnes of cassava peel waste annually (Musa et al., 2022). Uncontrolled disposal of these peels contributes to environmental degradation through methane emissions, unpleasant odour, and contamination of nearby water bodies (Rajib and Suborna 2020).

Cassava Peel Ash (CPA) has received increasing attention due to its pozzolanic nature, which is attributed to its reactive silica and alumina contents. Studies have reported improved mechanical and durability properties when CPA is incorporated in concrete at moderate replacement levels (Oruabena and Steyn, 2025); Baba et al., 2023). While many of these studies have focused primarily on direct strength measurements, less emphasis has been placed on analysing derived performance indices. Performance indices such as compressive strength index and tensile strength index offer a more refined assessment of the material's efficiency by comparing its behaviour relative to conventional control mixes. These indices also facilitate comparative evaluations across different curing regimes, replacement percentages, and concrete classes.

The curing environment plays a critical role in the strength evolution of blended concrete systems. Research has shown that high-strength concrete incorporating pozzolanic materials exhibits varied hydration kinetics depending on the moisture availability and temperature of the curing medium (Jindal et al., 2023). A shift from absolute mechanical values to index-based evaluations is therefore essential to characterise the performance sensitivity of CPA-modified concrete to curing conditions. This type of analysis provides useful insights for practical field applications, especially in regions where controlled curing is difficult to maintain.

In addition to index-based evaluation, contemporary concrete research increasingly incorporates statistical modelling to enhance analytical depth. Regression modelling is widely used to predict concrete behaviour, identify significant influence parameters, and optimise mix proportions (Motlagh and Naghizadehrokni, 2022). By establishing quantitative relationships between CPA content, curing regime, and performance indices, regression analysis enables predictive evaluation of the blended concrete's behaviour. Such modelling reduces the need for extensive laboratory trials, enhances reliability in mix design, and supports the integration of agricultural waste materials into mainstream concrete practice.

Despite the growing body of research on agricultural waste ashes, there remains a noticeable gap in comprehensive, index-focused evaluation and statistical modelling of CPA-blended high-strength concrete. Existing studies largely concentrate on raw strength data without transforming these results into comparative indices that reflect performance efficiency. Moreover, very few investigations have utilised regression-based models to predict index behaviours across curing ages and replacement levels. Addressing this gap is essential for deepening understanding of CPA's effect on high-strength concrete and strengthening its suitability for structural applications.

2.0 METHODOLOGY

2.1 Sample Collection and Preservation

Cassava peels were collected immediately after processing, air-dried under sunlight for 72 hours, and stored in labeled, moisture-proof polyethylene containers to prevent microbial degradation. Coarse aggregates of 3/8″, 1/2″, and 3/4″ sizes were collected from the quarry, washed, and oven-dried at 105°C for 24 hours using a Memmert UN30 drying oven before testing. All samples were kept in sealed containers to avoid moisture absorption prior to characterization.

2.2 Sample Preparation

The dried cassava peels were incinerated in a Carbolite CWF 1100 muffle furnace (UK) at 600°C for 6 hours to obtain cassava peel ash (CPA). The resulting ash was sieved through a 75 µm ASTM standard sieve to achieve uniform particle size. Coarse aggregates were sieved using a Retsch AS 200 sieve shaker to verify compliance with ASTM C136-14 grading specifications. Cement was blended with CPA at replacement levels of 0% (control), 5%, 10%, and 15% by weight, following a 1:2:4 mix ratio.

2.3 Properties of Aggregates

Specific gravity and water absorption of aggregates were measured according to ASTM C127-20 using a Pycnometer (Pycnolab, Germany). Flakiness and elongation indices were determined using the Vernier caliper method per BS 812-105. Aggregate crushing value (ACV) and aggregate impact value (AIV) tests were conducted using a Controls ADV 2000 compression testing machine (Italy) and standard impact testing apparatus respectively.

2.4 Concrete Preparation and Testing

Concrete cubes (100 mm) and cylinders (150 × 300 mm) were cast for compressive and splitting tensile strength evaluation, respectively. Curing was performed under two regimes: wet sand and water immersion. Compressive strength was measured at 3, 7, 14, 28, and 42 days using the Controls ADV 2000 universal testing machine. Splitting tensile strength tests followed ASTM C496-17.

2.5 Performance and Durability Indices

Compressive and splitting tensile strength data were used to derive performance and durability indices. The Performance Index (PI) was calculated as:

$$\mathrm{PI} = \frac{\text{Mean Strength of Control Mix}}{\text{Mean Strength of CPA Mix}} \qquad (1)$$

Durability Index (DI) was expressed as:

$$\mathrm{DI} = \frac{\text{Compressive Strength at 42 Days}}{\text{Compressive Strength at 7 Days}} \qquad (2)$$

2.6 Statistical Analysis

All experimental data were subjected to statistical evaluation using Design-Expert 13 (Stat-Ease, USA). Analysis of Variance (ANOVA) determined the significance of CPA replacement levels on mechanical performance, while multiple regression models quantified the predictive behavior of derived indices relative to concrete age. Collinearity diagnostics and residual analyses were performed to assess model reliability and identify potential multicollinearity.

3.0 RESULTS AND DISCUSSION

3.1 Properties of Coarse Aggregate

The physical properties of the ½″ coarse aggregate demonstrate a generally satisfactory quality profile suitable for structural concrete. The specific gravity values ranged from 2.58 to 2.64, yielding an average of 2.61, which indicates a dense aggregate with minimal internal voids. This level of density agrees with earlier observations that quality natural aggregates typically exhibit specific gravity values above 2.5, reflecting good mechanical stability (Hettiarachchi and Mampearachchi, 2025). Additionally, the water absorption averaged 0.87%, remaining well below the commonly accepted limit of 2%, thereby confirming low porosity and enhanced resistance to moisture-related deterioration.

Mechanical shape characteristics further support the suitability of the aggregate. The elongation index averaged 17.5%, while the flakiness index stood at 23.75%, both within acceptable thresholds for concrete production. These values suggest that particle geometry is unlikely to impair compaction efficiency or aggregate interlock. Moreover, the distribution of samples shows no extreme deviations, indicating uniformity in aggregate processing. Similar findings were reported by de Andrade et al. (2020), who observed that aggregates with moderate shape indices promote improved packing density and contribute to better mechanical performance in hardened concrete.

Strength-related properties, particularly the Aggregate Crushing Value (ACV), provide additional assurance of performance. The ACV averaged 23.75%, demonstrating adequate resistance to crushing loads and meeting the requirements for structural-grade coarse aggregates. This is consistent with reports that aggregates with ACV values below 30% generally enhance load-bearing capacity in concrete (Atigah et al., 2025). Consequently, the combined assessment of density, absorption, particle shape, and crushing resistance confirms that the ½″ coarse aggregate satisfies standardized durability and strength expectations for high-quality concrete applications.

Table 1: Physical Properties of Coarse Aggregates

Property	Sample 1	Sample 2	Sample 3	Sample 4	Average	Remarks
Specific Gravity	2.62	2.64	2.61	2.58	2.61	Satisfactory
Water Absorption (%)	1.22	1.04	0.55	0.66	0.87	Satisfactory
Elongation Index (%)	13	16	17	24	17.5	Satisfactory
Flakiness Index (%)	20	25	23	27	23.75	Satisfactory
Aggregate Crushing Value (ACV) (%)	23	28	24	20	23.75	Satisfactory

3.2 Performance and Durability Indices

3.2.1 Index Performance of Compressive Strength

The durability index values reveal distinct performance patterns across the curing ages. At the early age of 3 days, all mixes exceeded the minimum performance threshold, with the 15% CPA blend showing the highest index, indicating accelerated early-age strength development. This enhanced response aligns with studies reporting that moderate ash incorporation can promote early pozzolanic reactions due to finer particle effects (Benkeser and Kurtis 2020). However, the 10% CPA sample exhibited a comparatively lower index at this stage, suggesting delayed strength gain relative to the other blends, although still well above the BS EN 12390-3 requirement.

Strength behaviour between 7 and 14 days shows a more balanced trend, as all mixes maintained values that surpassed or closely approached the reference standard. The 15% CPA sample consistently recorded higher indices, demonstrating improved medium-age strength evolution. Furthermore, the control and 10% CPA mixes displayed stable progression, while the 5% CPA blend showed marginally reduced performance at 7 days before improving at 14 days. These outcomes correspond with findings where the optimum ash replacement does not always occur at the lowest percentages but at levels that enhance binder reactivity (Mohamed, 2023).

Moreover, at later curing ages, the durability index patterns became more differentiated. The control, 5% CPA, and 15% CPA mixes sustained desirable strength retention between 17 and 42 days, although the 10% CPA sample experienced a gradual decline, signifying reduced long-term resistance. Additionally, the 15% CPA blend maintained superior durability at these ages, except for the 21st and 28th days where missing values indicate non-assessed performance. Comparable trends have been observed in previous research, where higher ash content improved long-term pozzolanic activity and enhanced durability metrics (Becerra-Duitama and Rojas-Avellaneda, 2022).

Table 2: Durability Index for Compressive Strength

Age (days)	Control (%)	5% CPA (%)	10% CPA (%)	15% CPA (%)	BS EN 12390-3 (%)
3	89.3	94.3	80.1	105.2	40
7	102.6	86.1	98.8	105.1	65
10	106.9	91.2	97.8	103.6	–
14	99.5	94.2	97.5	106	90
17	102.2	98.8	91	113.4	–
21	105.5	97.8	90.1	0	–
28	99.6	96.7	0	0	100
35	90.6	98.7	87.4	105.2	–
42	101.4	94.6	87.7	110.1	–

3.2.2 Index Performance of Splitting Tensile Strength

The durability index results for splitting tensile strength presented in Table 5 provide a comprehensive assessment of the long-term tensile performance and stability of concrete mixes containing varying levels of cassava burnt ash (CPA). To begin with, the control mix shows relatively moderate durability indices, ranging from 58.3% at 3 days to 87.9% at 21 days, before slightly declining to 73.8% at 28 days. Although these values exceed the minimum requirements specified by BS EN 12390-6 for M30 concrete at early ages, the slight decrease at later ages may reflect minor microstructural adjustments or drying shrinkage effects inherent in conventional concrete. Similar trends were observed by Yu et al. (2021), who highlighted that tensile durability indices in standard concrete can fluctuate due to differential stress redistribution within the matrix during early and intermediate curing periods.

In contrast, the 5% CPA mixes display consistently higher durability indices throughout the curing period, reaching 111.7% at 3 days and 110.6% at 28 days. This pattern suggests that low-level ash replacement positively contributes to tensile durability, likely through secondary pozzolanic reactions that refine pore structure and strengthen the interfacial transition zone between the paste and aggregates. This observation is in agreement with Madhavan et al. (2025), who reported that moderate inclusion of agro-waste ash enhances both microstructural densification and tensile performance over time. The sustained high indices indicate that the 5% CPA mixes possess excellent resistance to tensile cracking and maintain structural integrity under service loads.

For the 10% CPA mixes, the durability indices exhibit pronounced fluctuations, with early-age values as high as 139.8% at 3 days and 126.6% at 21 days, before stabilizing at 100% by 28 days. These elevated initial values may suggest a rapid early pozzolanic contribution, yet the decline at later ages indicates potential microstructural instability or delayed hydration effects that limit long-term tensile performance. At 15% CPA replacement, durability indices remain relatively high at early ages, with values such as 96.9% at 3 days and 100% at 7 days, yet slightly decrease at later ages to 97.4% at 28 days. While these indices suggest acceptable initial tensile performance, the overall stability is less predictable compared to the 5% CPA mixes. This behavior indicates that excessive ash substitution can create irregular bonding within the matrix, reducing the reliability of long-term tensile resistance. Similar patterns were observed by Pachideh et al. (2020), who highlighted that high ash replacement levels, despite initial pozzolanic activity, can result in uneven matrix development and lower durability under tensile stresses.

Table 3: Durability Index for Splitting Tensile Strength (N/mm^2)

Age (days)	Control (%)	5% CPA (%)	10% CPA (%)	15% CPA (%)	BS EN 12390-6 (%)
3	58.3	111.7	139.8	96.9	40
7	80.5	93.9	97.8	100	65
14	81.8	106	109.2	109.7	90
21	87.9	101.3	126.6	107.5	–
28	73.8	110.6	100	97.4	100

3.3 Statistical Analysis

The durability index summary presented in Table 4 highlights the temporal variation in compressive and splitting tensile strengths of the concrete samples. Compressive durability exhibited a progressive increase from 92.23 at 3 days to a peak of 101.35 at 17 days, indicating early-age strength development. However, notable reductions were observed at 21 and 28 days, likely due to sample heterogeneity or microstructural anomalies, before stabilizing towards later ages. The splitting tensile durability index displayed higher variability at early ages, particularly at 3 days, but stabilized by 7 to 14 days, suggesting that tensile properties are more sensitive to curing conditions and material dispersion (Skyrianou, et al., 2025). The observed trends imply that compressive strength evolution may not directly correspond with tensile performance at all ages, reinforcing the importance of dual assessment for durability characterization. Overall, the data suggest consistent performance beyond 35 days, indicating the material's potential for long-term structural applications.

Table 4: Durability Index Summary (Compressive and Splitting Tensile Strengths).

Age (days)	Compressive Durability Index (Mean ± SD)	Range (Compressive)	Splitting Tensile Durability Index (Mean ± SD)	Range (Tensile)
3	92.23 ± 10.46	80.1 – 105.2	101.68 ± 33.95	58.3 – 139.8
7	98.15 ± 8.44	86.1 – 105.1	93.05 ± 8.74	80.5 – 100.0
10	99.88 ± 6.90	91.2 – 106.9	—	—
14	99.30 ± 4.97	94.2 – 106.0	101.68 ± 6.68	81.8 – 109.7
17	101.35 ± 9.30	91.0 – 113.4	—	—
21	73.35 ± 49.30	0.0 – 105.5	105.83 ± 8.04	87.9 – 126.6
28	49.08 ± 56.68	0.0 – 99.6	95.45 ± 7.76	73.8 – 110.6
35	95.48 ± 8.04	87.4 – 105.2	—	—
42	98.45 ± 9.57	87.7 – 110.1	—	—

Table 5 illustrates the influence of cassava peel ash (CPA) replacement on durability indices. Compressive durability decreased with increasing CPA content, with the control sample showing the highest mean value of 99.73, while the 10% CPA mix dropped to 81.16, demonstrating the dilution effect of partial cement replacement on early mechanical performance. Conversely, splitting tensile durability increased with CPA incorporation, reaching a peak of 114.68 for the 10% replacement, which may be attributed to the pozzolanic reaction of CPA contributing to microstructural densification. The observed range of values for both strength parameters highlights variability in response, emphasizing the need for optimal replacement levels to achieve balanced compressive and tensile performance. Furthermore, the data emphasize that moderate CPA incorporation can enhance tensile resilience without significantly compromising compressive durability, corroborating prior studies that advocate low-to-moderate pozzolanic replacements for sustainable concrete production.

Table 5: Durability Index Summary by CPA Replacement Level for Compressive and Splitting Tensile Strength

CPA Level	Compressive Durability Index (Mean ± SD)	Range (Compressive)	Splitting Tensile Durability Index (Mean ± SD)	Range (Tensile)
Control (0%)	99.73 ± 6.06	89.3 – 106.9	76.46 ± 11.32	58.3 – 87.9
5% CPA	94.71 ± 4.08	86.1 – 98.8	104.70 ± 7.31	93.9 – 111.7
10% CPA	81.16 ± 31.03	0.0 – 98.8	114.68 ± 18.05	97.8 – 139.8
15% CPA	83.18 ± 47.25	0.0 – 113.4	102.30 ± 5.92	96.9 – 109.7

Normality assessment of the durability indices across curing ages is presented in Table 6 using Kolmogorov–Smirnov and Shapiro–Wilk tests. Most compressive and tensile indices exhibited p-values above the 0.05 threshold, indicating approximate normality, although deviations occurred at 21 and 28 days for compressive durability, suggesting skewness or outliers in those samples. Similar patterns were noted for tensile indices, with stable normality at most ages, reinforcing that statistical analyses assuming normal distributions are generally valid for this dataset. These results are critical for subsequent parametric evaluations, ensuring reliability in regression modeling or correlation analyses. The observed deviations at intermediate curing ages could be linked to variations in CPA dispersion or hydration heterogeneity, which have been previously reported as common sources of non-normality in blended cementitious systems (Webb, 2025).

Table 7 presents a comparative normality evaluation for durability indices by CPA replacement level. Compressive strength at 10% and 15% CPA showed significant deviations from normality, whereas 5% and control mixes largely conformed, as indicated by Shapiro–Wilk statistics. In contrast, tensile strengths across all CPA levels demonstrated acceptable normality, highlighting differential responses between mechanical parameters under varying replacement levels (Adamu, et al., 2022). These findings suggest that higher CPA dosages may introduce heterogeneity in compressive strength distributions, potentially due to incomplete pozzolanic reaction or variable particle dispersion. Consequently, statistical interpretations for higher replacement levels should consider non-parametric approaches or data transformation. The consistency of tensile strength normality implies reliable assessment of structural ductility under moderate CPA incorporation, supporting prior research emphasizing the importance of evaluating both compressive and tensile properties in pozzolanic concrete mixtures (Ofwa, 2022).

Table 6: Normality Test Results (Kolmogorov–Smirnov and Shapiro–Wilk) for Durability Indices Across Curing Ages

Age (days)	Compressive Index (K–S Sig.)	Compressive Index (S–W Sig.)	Tensile Index (K–S Sig.)	Tensile Index (S–W Sig.)
3	0.996	0.986	0.194	0.989
7	0.877	0.326	0.289	0.862
10	0.968	0.827	—	
14	0.961	0.784	0.377	0.726
17	0.981	0.910	—	
21	0.747	0.036	0.209	0.983
28	0.742	0.032	0.300	0.916
35	0.951	0.722	—	—
42	0.994	0.976	—	—

The homogeneity of variance analysis using Levene's test in Table 8 indicates significant differences in compressive strength when based on mean and trimmed mean, but no significant differences were detected when using median-based approaches, suggesting the presence of outliers or skewed data in some CPA mixes.

Table 7: Comparative Normality Test Results for Compressive and Splitting Tensile Strengths Using Kolmogorov–Smirnov and Shapiro–Wilk Tests.

CPA Level	Compressive Strength – Kolmogorov–Smirnov (Statistic / df / Sig.)	Compressive Strength – Shapiro–Wilk (Statistic / df / Sig.)	Tensile Strength – Kolmogorov–Smirnov (Statistic / df / Sig.)	Tensile Strength – Shapiro–Wilk (Statistic / df / Sig.)
10%	0.375 / 9 / 0.001	0.569 / 9 / 0.000	0.219 / 5 / .200*	0.904 / 5 / 0.434
15%	0.445 / 9 / 0.000	0.593 / 9 / 0.000	0.251 / 5 / .200*	0.854 / 5 / 0.208
5%	0.228 / 9 / 0.196	0.885 / 9 / 0.176	0.190 / 5 / .200*	0.927 / 5 / 0.576
Control	0.262 / 9 / 0.074	0.877 / 9 / 0.144	0.239 / 5 / .200*	0.911 / 5 / 0.471

Note:

a. Kolmogorov–Smirnov test uses Lilliefors Significance Correction.

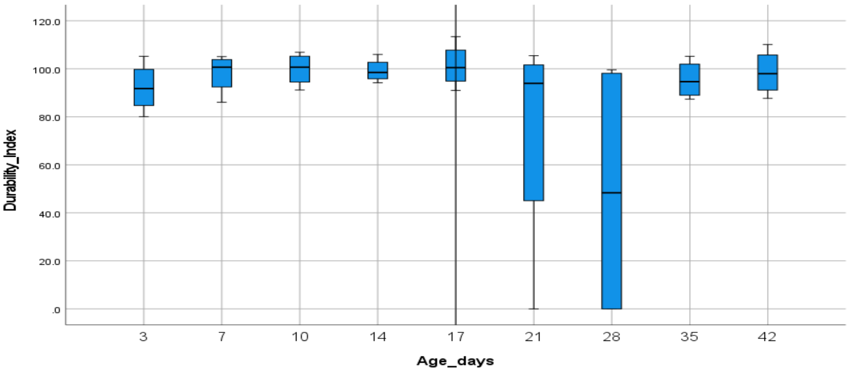
. Values marked ".200" represent the lower bound of the true significance.

Splitting tensile strength showed similar trends with marginal significance based on mean values, but homogeneity was confirmed under median adjustments. This demonstrates that variance assumptions for parametric testing are sensitive to the method of central tendency considered. The results emphasize the need for careful statistical treatment when analyzing CPA-blended concretes, particularly for compressive strength at higher replacement levels. Additionally, the findings corroborate studies reporting increased variability in mechanical properties with higher pozzolanic content, reinforcing the relevance of robust variance evaluation to ensure accurate interpretation of concrete performance (Mohammed et al., 2024).

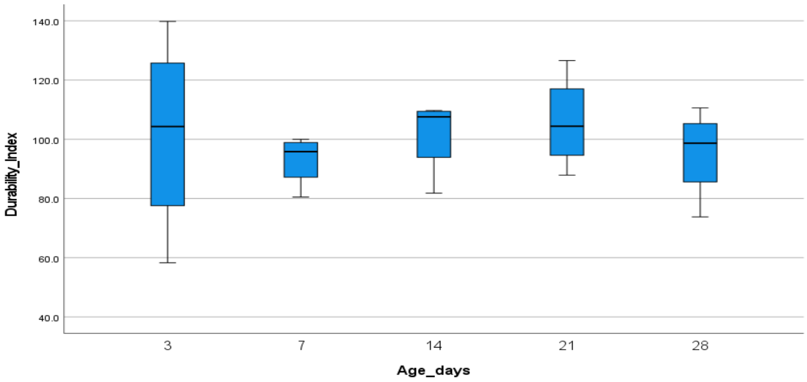
Table 8: Comparative Levene's Test Results for Homogeneity of Variance for Compressive and Splitting Tensile Strengths.

Parameter	Levene's Test (Compressive Strength) – Statistic / df1 / df2 / Sig.	Levene's Test (Splitting Tensile Strength) – Statistic / df1 / df2 / Sig.
Based on Mean	6.892 / 3 / 32 / 0.001	3.648 / 3 / 16 / 0.035
Based on Median	1.318 / 3 / 32 / 0.286	1.419 / 3 / 16 / 0.274
Median with Adjusted df	1.318 / 3 / 13.721 / 0.309	1.419 / 3 / 10.008 / 0.294
Based on Trimmed Mean	5.247 / 3 / 32 / 0.005	3.406 / 3 / 16 / 0.043

The boxplot derived from the durability index data as shown in Figure 1 and 2 effectively visualizes the distribution and variability of compressive and splitting tensile strengths across curing ages and CPA replacement levels. It shows that compressive durability generally increases with age up to 17 days, followed by fluctuations at 21 and 28 days, reflecting the broader ranges and outliers observed in the raw data. In contrast, splitting tensile durability exhibits higher variability at early ages, particularly at 3 days, but stabilizes in later ages, indicating more consistent tensile performance over time. The interquartile ranges and whisker lengths highlight that moderate CPA replacements (5–10%) contribute to tensile strength improvements without causing excessive spread in the data, whereas higher CPA levels introduce greater dispersion in compressive strength.

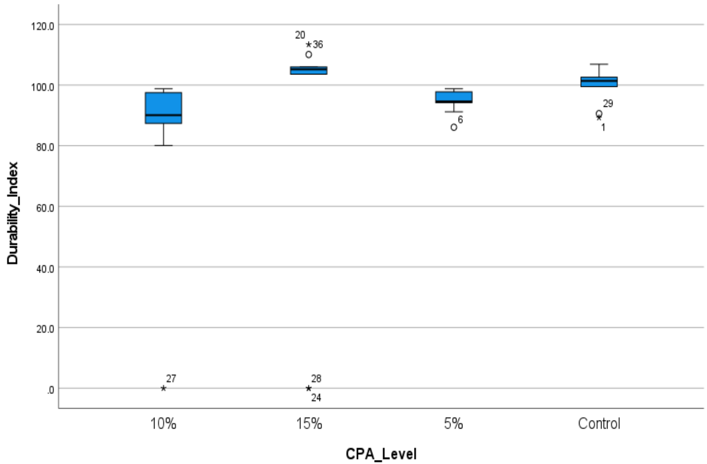


(a)

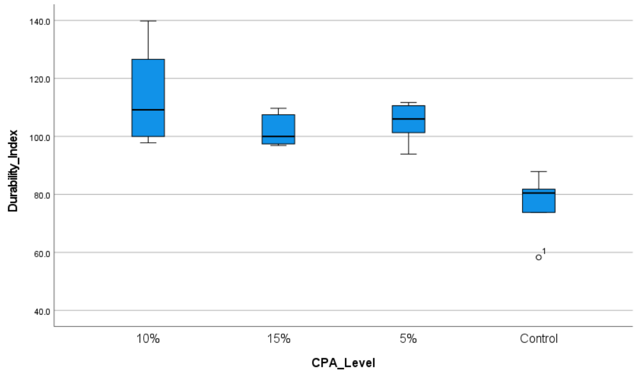


(b)

Figure 1: Box-plot distribution of compressive (a) and splitting tensile strengths (b) across curing ages, and durability index.



(a)



(b)

Figure 2: Box-plot distribution of compressive and splitting tensile strengths across CPA replacement levels, and durability index.

4.0 CONCLUSIONS

The findings indicate that the ½-inch coarse aggregate possesses adequate physical and mechanical characteristics for structural concrete, evidenced by an average specific gravity of 2.61, low water absorption of 0.87%, and acceptable elongation and flakiness indices. Durability assessment showed that compressive strength increased progressively, reaching a maximum value of 101.35 at 17 days, followed by minor variations, while splitting tensile strength exhibited early fluctuations before stabilizing. Additionally, coarse palm ash (CPA) replacement influenced performance differently, as higher replacements reduced compressive durability, whereas tensile durability improved, peaking at 114.68 at 10% CPA. Statistical analyses confirmed acceptable data distribution, although higher CPA contents increased variability. Consequently, CPA replacement levels of 5–10% are recommended to enhance tensile performance while preserving compressive durability.

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