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ASSESSMENT OF COMPRESSIVE STRENGTH PERFORMANCE OF CORN COB ASH BLENDED CONCRETE: A REVIEW

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ABSTRACT

The construction industry continuously seeks innovative materials to enhance sustainability and performance. Successful adoption, however, hinges on reliable performance data. Corncob ash (CCA) has been proposed to partially replace ordinary Portland cement (OPC) in concrete, yet varying results in compressive strength (CS) hinder widespread use. This systematic review analyzed experimental articles from 2010-2023, evaluating CS of OPC and CCA blended concrete at a 28-day curing period. It examined the relationship between compressive strength and CCA replacement percentage. Out of 23 studies (9.74% of the total), 60.9% reported lower CS in CCA blended concrete (6%-35.8% reduction). However, 17.4% demonstrated increased CS (3.6%-18.4% rise) with higher CCA replacement. Linear regression analysis yielded $p<0.05$, indicating significant potential for CCA to enhance concrete compressive strength. Conclusively, an optimum 6.86% CCA substitution in concrete without optimization maintains structural integrity and promotes sustainable practices in the industry.

Keywords

Corncob Ash, Concrete, Compressive strength, Ordinary Portland Cement, Replacement

INTRODUCTION

Housing, crucial for human well-being, faces severe challenges in over 50% of urban populations in the developing world, posing life and health threats (WCR, 2022).

Without concerted efforts, this situation is predicted to worsen, with an increasingly urgent need for safe housing (Okosun et al., 2023). Concrete, a major housing component, constitutes over 40% of global human-generated solid material, highlighting its widespread use (Gag, 2014). Historically, cementing materials trace back to ancient civilizations, evolving into modern cement and concrete technology. Global cement production is estimated to reach 18 billion tons annually by 2050 (IEA, 2014). While concrete is considered eco-friendly, its high-volume usage contributes seriously to CO_2 emissions, raising environmental concerns (Adesina, 2020). CO_2 emissions from cement production processes and related activities contribute 8% to global emissions, with alarming projections indicating a 12-23% increase by 2050 (IEA 2018). Despite its finite lifespan, concrete demolition generates substantial waste, impacting the environment and municipal waste management systems. The production of a metric ton of concrete releases around 580 kg of CO_2, prompting interest in alternative clinkers with reduced chemical CO_2 emissions (Schmidt et al., 2021).

The production of concrete, particularly Portland cement and aggregates, is remarkably energy-intensive, with the cement sub-sector alone accounting for 12-15% of total industrial energy consumption (Madlool et al., 2011). OPC, vital in concrete mixtures, exhibits the highest embodied energy among materials, posing a significant sustainability challenge (Hammond and Jones, 2008). This energy-intensive process contributes to strain on material deposits, alteration of natural resources, and environmental deformation, with one ton of Portland cement consuming twice the amount of raw materials (Malhotra, 2010). The concrete industry, a major consumer of freshwater resources, faces concerns regarding resource sustainability and environmental impact (Asadollahfardi et al., 2016). Global concrete production has surged to an alarming 30 billion tonnes annually, with projections suggesting 90 billion tonnes consumed by 2050, doubling CO_2 emissions and exacerbating ecological challenges (Anon, 2021). Market prices of conventional concrete components, like cement and aggregate, are rising due to substantial costs associated with manufacturing, processing, and delivery (Nwalusi et al., 2022). To address these challenges, building professionals explore alternative materials and techniques prioritizing environmental, social, and economic sustainability. Innovations include bio-concrete, utilizing bacteria for self-healing, and eco-friendly binding materials from recycled paper, industrial waste, and biomass. Selecting materials with low environmental impact can reduce CO_2 emissions by up to 30% (González and Navarro, 2006). The industry's shift towards environmentally friendly construction materials responds to global concerns like ozone layer depletion and climate change caused by GHG emissions. Incorporating waste materials in concrete production, coupled with optimized construction processes and greener manufacturing, holds significant promise for reducing reliance on traditional cementitious materials and addressing waste management concerns (Adesina, 2020).

The Industrial Revolution ushered in the incorporation of by-products into the building and construction industry, showing promise despite limited availability and challenges in embracing sustainability's three pillars (Shafigh et al., 2014). Currently, there is a burgeoning interest in sustainability, focusing on biomass from agricultural and aquacultural waste in building materials. plant research concretes, involving bio-

aggregates in matrices with pozzolanic, lime-based, or cementitious materials, have consistently demonstrated enhanced concrete characteristics (Martirena and Monzó, 2018). With corn being a globally cultivated crop, studies explore corncob application in green concrete (Okeke et al., 2023). While mechanical strength is crucial in construction, the utilization of CCA as a supplementary cementing material (SCM) in cement and concrete has garnered attention. Extensive studies of CCA have evidenced its pozzolanic properties. CCA chemical composition consisting primarily of reactive silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3), meets the specification for SCM set out by ASTM C618. A compositional analysis by Singh et al. (2017) showed CCA contains 64.56% SiO_2, 12.0% CaO, 5.12% Fe_2O_3, 9.42% Al_2O_3 and 3.01% MgO. The high amorphous silica content in the ash reacts with calcium hydroxide in cement to form additional calcium silicate hydrate gel that enhances strength and durability. The CS of concrete blocks is vital for assessing load-bearing capacity. Research reports varying outcomes in compressive strength for different replacement percentages of OPC with CCA. Notably, some studies show improved strength with 5-30% replacement, while others report little change or even a decrease in strength. Factors influencing strength include curing time, substitution rate, and concrete mix design (Suwanmaneechot et al., 2015; Patel et al., 2020; Abdul-Manan, 2016; Adesanya and Raheem, 2009).

As the construction industry explores innovative binders and sustainable materials, the successful adoption of CCA hinges on acquiring dependable performance data. Existing reviews offer insights into strength assessments but lack consensus, requiring comprehensive studies for widespread implementation. This study specifically assesses the CS of CCA blended concrete, examining literature published between 2010 and 2023. The study aims to categorize literature, highlight maximum compressive strength, establish the relationship between CCA blended concrete's CS and recommend an optimum substitution percentage for CCA in concrete. The study is guided by the hypothesis that there is no significant difference in the maximum CS of OPC and CCA blended concrete in a standard design mix ratio (M30) at a 28-day curing period. The findings are valuable for researchers, practitioners, and policymakers, providing empirical insights into the actual effects of adding CCA to concrete, crucial for meeting global sustainability demands. Like most review papers relying largely on previously published literature, a limitation of this study is that it only includes published works available at the time of the analysis.

RESEARCH METHODS

This paper is part of a broader investigation of corncob as a sustainable bio-based material. The present study employs a systematic review research design. This methodological choice is underpinned by the recognition of systematic reviews as a robust scientific research approach, facilitating the comprehensive evaluation, synthesis, and communication of a substantial volume of research publications on a specific topic, as advocated by Green (2005). Figure 1 presents a visual representation of the research methodology, delineating five key stages from identifying a global issue and formulating research objectives to conclusions and recommendations.

Figure 1: Flow chart of research methodology.

A growing number of researchers in this field have emphasized the value of evidence-based approaches that integrate scientific knowledge with practical applications (Aprianti, 2017; Naganathan et al., 2014). Inspired by this perspective, the current study adopts a similar evidence-based methodology, leveraging insights from previous scholarly works on corncob-building materials. The primary data sources comprise published literature presenting empirical findings on relevant topics over the period spanning 2010 to 2023. Scopus online database and Google Scholar were chosen as primary repositories due to their extensive coverage and unique features. Scopus, identified as superior in a comparative study by Falagas et al. (2008), excels in diverse journal coverage and a distinctive keyword search feature. Google Scholar was included because of its high volume of articles with free access and to accommodate non-indexed peer-reviewed articles, ensuring a comprehensive literature review coverage.

The search algorithms utilized a combination of text words, specifically "corn cob ash concrete" or "corncob ash concrete," to ensure a comprehensive retrieval of relevant literature. Both journal articles and conference papers were included, considering the importance of these sources in disseminating research findings and staying informed about recent developments. Scopus search yielded a total of 72 items, which underwent a selection process based on criteria such as language (English), subject area (Energy, Engineering, Environmental Science), publication year (2010-2023), source type (Journal and Conference Proceeding) and review of titles/abstracts. This refined selection ensures the inclusion of high-quality and relevant literature for a comprehensive review. Maintaining the same keywords, a Google Scholar search returned 152 items and was content screened to 16 research papers for inclusion. However, review papers were excluded from the selection. A total of 23 published works were reviewed as evidenced in the references section. The selected papers were evaluated in line with research objectives generating qualitative and quantitative data. For the quantitative analysis, statistical tests like linear regression, two-sample t-tests and descriptive statistics, were applied using Minitab software to examine strength trends. Additionally, thematic content analysis enabled qualitative insights. The integrated results encompassing tables, charts and textual discussion communicate the research findings.

RESULTS AND DISCUSSIONS

Figure 2 illustrates the distribution of the 224 items identified across two databases. While many articles were found in both databases, the majority, totalling 152 items, were retrieved from Google Scholar. This collection comprises review articles, books, research papers, book chapters, and conference proceedings. Among the 152 articles sourced from Google Scholar, only 16 met the filtering criteria for inclusion in the

review. In the Scopus database, 72 items were identified, including 48 research articles, 15 conference papers, 7 reviews, and 2 conference reviews. Examination of the items in Scopus revealed that published material with the word 'corn cob' in its title, and abstract/keywords came out in the search and are about engineering and material science, the main subject of review. Yet, 7 directly addressing the investigation topic were included in the study. In total, 23 studies, representing 9.74% of the total results, were selected for analysis.

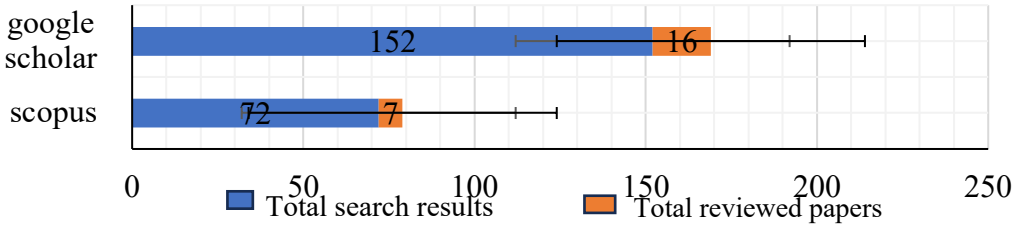

Figure 2: Article distribution by database

The database search results validate a proliferation of studies investigating agricultural residues for building and construction applications and corn waste sub-domain is receiving increasing attention. However, studies centrally examining the integration of CCA as SCM, or binder component remain limited especially works quantifying impacts on concrete compressive strength. Figure 3 shows the global geographic spread of included studies.

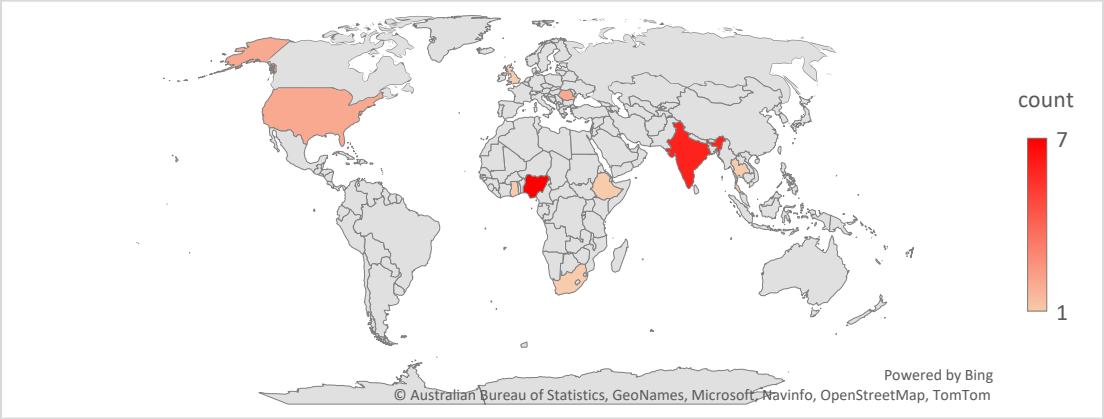

Figure 3. Global analysis of Publication Output of reviewed papers across countries.

The reviewed papers exhibit a global geographic distribution, spanning multiple continents. Notably, developing nations such as Nigeria and India have the highest contribution, likely driven by challenges in waste management (Anerobi et al., 2021), housing shortages, and rapid urbanization trends (Okeke et al., 2023) prevalent in these regions. Moreover, there is a predominant focus on tropical climates in the research, indicating a concerted effort to address the challenges posed by extreme heat conditions affecting buildings in these areas. The abundance of studies from emerging economies and tropical regions underscores the dual objectives of expanding sustainable housing access for growing populations and adapting habitats to the escalating impacts of climate change. These imperatives align with contemporary challenges, including

enhancing thermal comfort to promote human health and productivity (Mba et al., 2023)

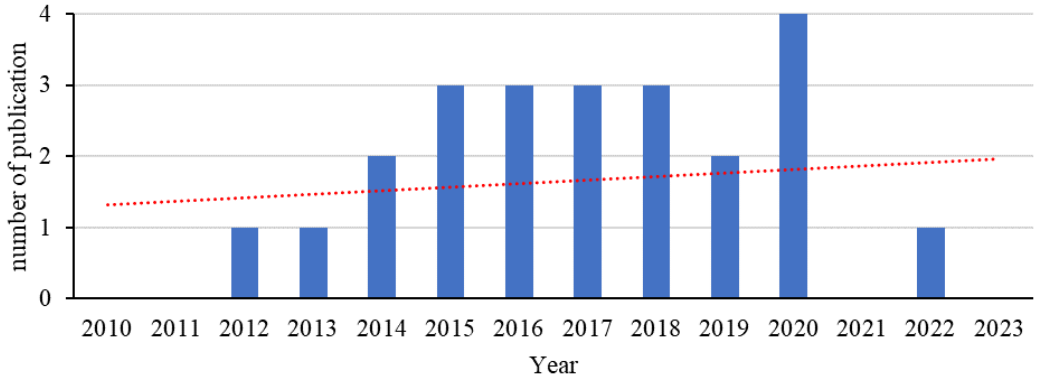

Figure 4. Yearly publications output from 2010-2023 of the included review articles.

Figure 4 charts the annual distribution of publications on compressive strength of concrete with CCA replacing cement over 2010-2023. Output remained low from 2012-2014 with just one paper yearly. This was followed by fluctuating activity of 2-4 studies per annum up to 2020. A noticeable decrease in the subsequent years implies focus has temporarily plateaued. Overall, while yearly variability exists, the graph linear trendline of the included reviewed papers provide information, highlighting both stable and gradual rise of research interest.

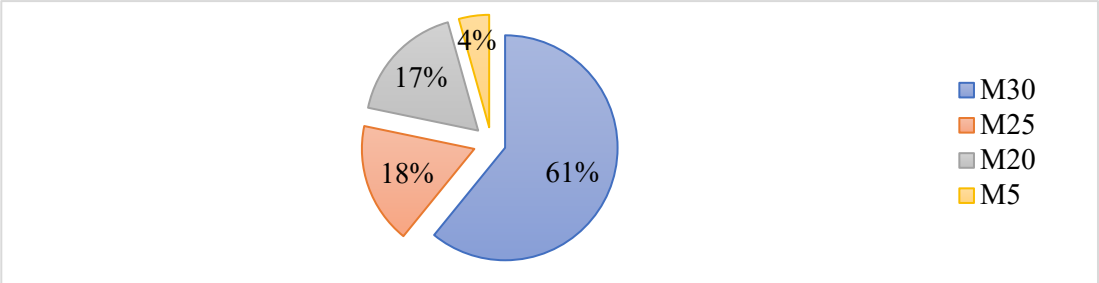

Figure 5. Categories of concrete grade tested.

Figure 5 shows the distribution of concrete grades examined across publications evaluating CCA as a substitute for cement. The most frequently studied variant was standard M30 structural concrete, with 14 studies employing this benchmark. Lower strength grades such as M20 and M25 were the second preference, while only one paper investigated the minimally resistant M5 concrete. The notable emphasis on moderate and higher compressive strength classes underscores a predominant research focus on establishing the viability of CCA as a sustainable alternative for mainstream construction applications where robust strength and durability are crucial considerations. The limited attention given to low-grade formulations suggests minimal interest in specialized applications that tolerate reduced structural capacities. Therefore, in analysing the relationship between CCA proportion and strength, the study employed the M30 concrete grade.

Table 1. shows the CS details of included review papers.

	References	Concrete grade	CS of OPC concrete @28 days (N/mm^2)	CS of CCA blended concrete @28 days (N/mm^2)	Percentage of OPC replaced with CCA (%)
1	Serbanoiu et al., 2022	M30	31.33	26.83	2.5
2	Shakouri et al., 2020	M30	43	36	3
3	Selina et al., 2020	M30	29.33	28.4	5
4	Keerthi Gowda & Dakshayini, 2020	M30	36	32.04	5
5	Olukotun et al., 2019	M30	26.1	24.2	5
6	Grădinaru et al., 2018	M30	31.33	21.93	5
7	Olonade et al., 2017	M30	23.97	20.09	5
8	Ahangba and Tiza 2016	M30	30.31	28.78	5
9	Kamau et al., 2016	M30	61.6	51.3	7.5
10	Oluborode & Olofintuyi, 2015	M30	17.78	18.44	30
11	Bala et al., 2015	M30	32.1	29.4	3
12	Eisa, 2014	M30	30.67	19.67	5
13	Ettu et al., 2013	M30	23	22.1	5
14	Olafusi and Olutoge, 2012	M30	34	29.11	10
15	Sintayehu and Mamaru, 2019	M25	34.53	31.28	5
16	Olafusi et al., 2018	M25	21.51	20.13	5
17	Singh et al., 2017	M25	36.43	32.47	5
18	Anjaneyulu, 2017	M25	24.2	24	5
19	Suwanmaneechot et al., 2015	M25	38	45	10
20	Kumari et al., 2018	M20	27.51	27.13	2.5
21	Patel et al., 2020	M20	24.04	24.90	8
22	Anjaneyulu, 2017	M20	19.95	19.80	5
23	Price et al., 2014	M5	33.5 @ 90days	35.90 @ 90days	10% @90days

Table 1 presents a compilation of tested formulations spanning from low M5 to conventional M30 grades, with a predominant focus on the latter. CCA substitution levels investigated ranged from 0% to 30%, representing control and experimental batches, respectively. The reviewed papers reveal varying impacts on concrete compressive strength resulting from partial cement displacement using corn cob ash (CCA). Approximately 17% of the studies reported significant reductions ranging from 16% to 35.8%. However, 43.5% of the works documented minor drops in strength, ranging from 6% to 15%, which were deemed acceptable for practical structural applications. Promisingly, approximately 21.7% of the publications demonstrated negligible changes, ranging from 0% to 3%, while 17.4% recorded strength improvements of up to 18% with higher CCA proportions. Such variability is likely attributed to differences in chemical characteristics and replacement levels. Figure 6 illustrates the distribution and spread of compressive strength values from the studied literature.

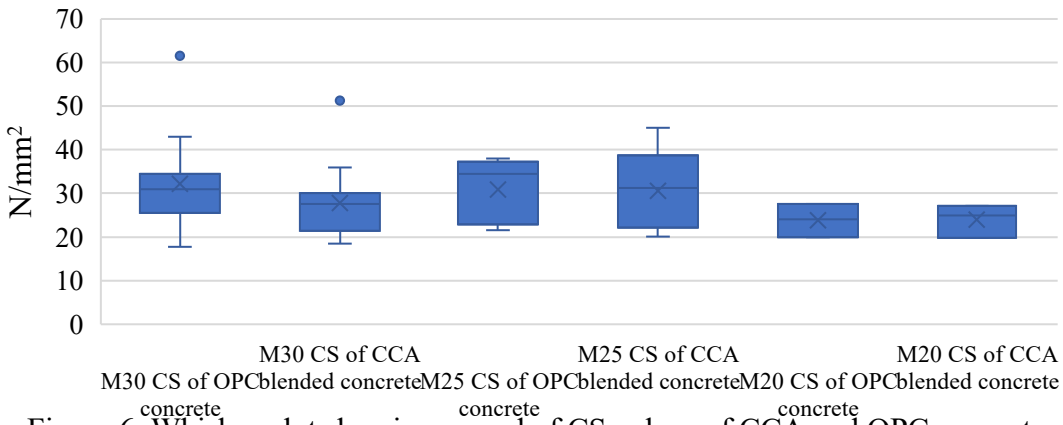

Figure 6. Whisker plot showing spread of CS values of CCA and OPC concrete grades.

Compressive strength values for control OPC concrete display a wider spread relative to CCA-containing batches across the assessed grades. However, the higher M30 variants exhibit distinct trends, with ordinary cement mixes averaging 32.1 N/mm^2 exceeding the mean of 27.7 N/mm^2 for blended concretes. Furthermore, CCA composite datasets are clustered within a narrower band between 21.47-30 N/mm^2 compared to pure forms. For lower M25 and M20 grades, both standard and experimental mixtures record identical strength means, although spread varies for M25.

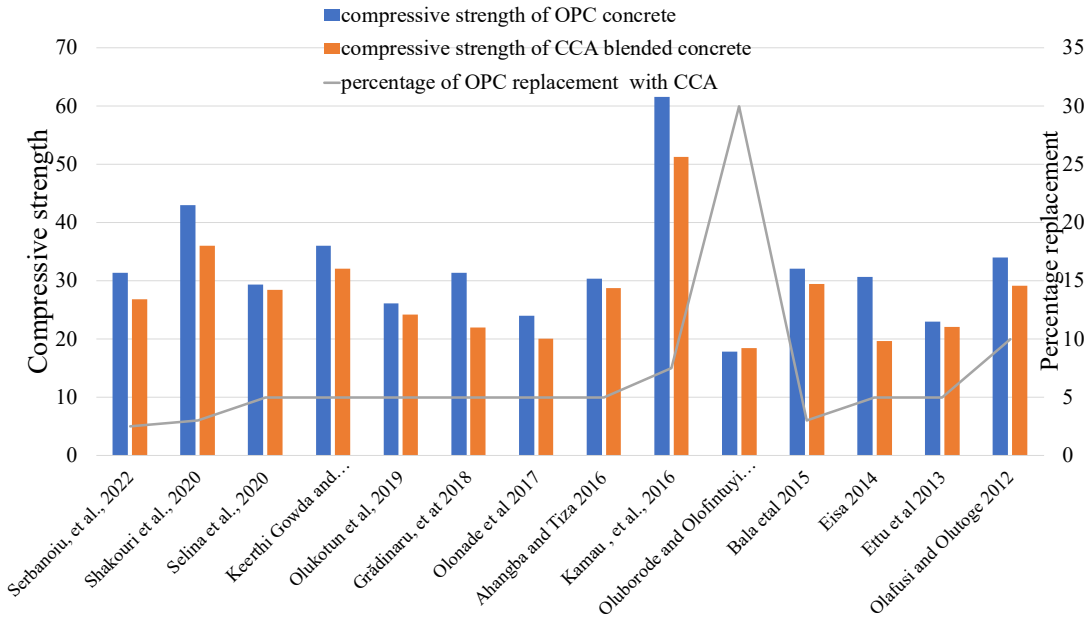

Figure 7. Comparison of literature on CS of CCA and OPC concrete at 28-days of curing

Resultant values in Figure 7 demonstrate high variability across different investigations even at equivalent ash substitution ratios. However, CCA-blended mixtures exhibit lower compressive performance than OPC specimens, with margins narrowing at reduced replacement levels. While the formulated concretes generally retain adequate strength for certain structural works as observed in some studies, the declining linear

trends validate that higher cinder proportions progressively diminish mechanical integrity. This may be assumed to be due to variations in the quality of materials, mix proportions, curing conditions, and testing methods used in the studies that require further investigation.

Descriptive Statistics

Descriptive Statistics of results obtained from the reviewed paper to further understand and analyse the change in compressive strength of concrete owing to CCA addition, and percentage of OPC replacement is shown in table 2.

Table 2. Descriptive analysis.

Variable	N	N*	Mean	SE Mean	StDev	Min	Max	Q1	Median	Q3
CS of OPC concrete	14	0	32.18	2.79	10.42	17.78	61.60	25.57	31.00	34.50
CS of CCA blended concrete	14	0	27.73	2.27	8.49	18.44	51.30	21.47	27.61	30.06
percentage of OPC replacement	14	0	6.86	1.85	6.92	2.50	30.00	4.50	5.00	5.63

From Table 2, it can be observed that the mean compressive strength of OPC concrete from the literature is 32.18 N/mm^2, while that of CCA blended concrete is 27.73 N/mm^2. This indicates that the compressive strength of CCA blended concrete is lower than that of OPC concrete with average of 4.45 percent. However, it is important to note that the difference in mean CS is approximately 4.5 and the standard deviation of the CCA blended concrete compressive strength is lower than that of OPC concrete, indicating less variability in the CCA blended concrete results. The table also shows the mean percentage of OPC replacement, which is 6.86% suggests that the CS of CCA blended concrete was tested at a relatively low level of OPC replacement to get optimum strength, and it is possible that a higher percentage of replacement result in further reductions in CS. Conversely, a Maximum percentage of OPC replacement with CCA was reported in Oluborode and Olofintuyi, (2015) and their result could be attributed to other factors such as the intensity and burning conditions of corncob, the mixing process, and or the curing conditions to impact the CS of the concrete.

CS Regression analysis of OPC & CCA blended M30 concrete grade cured at 28 days.

A linear regression linear regression analysis was carried out and the equation obtained is shown below.

$$CS\ of\ OPC\ concrete = 0.05 + 1.158 \times CS\ of\ CCA\ blended\ concrete$$

Table 3. Regression coefficients

Term	Coef	SE Coef	T-Value	P-Value	R-sq
Constant	0.05	3.39	0.02	0.988	0.8905
CS of CCA blended concrete	1.158	0.117	9.88	0.000	

The equation predicts that for every unit increase in the CS of CCA blended concrete, there is a corresponding increase of 1.158 units in the CS of OPC concrete. The intercept of 0.05 indicates the predicted CS of OPC concrete when the CS of CCA blended concrete is zero. The R-squared value of 0.8905 indicates that 89.05% of the variance in the CS of OPC concrete can be explained by the CS of CCA blended concrete.

Table 4. Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	1257.3	1257.28	97.60	0.000
CS of CCA blended concrete	1	1257.3	1257.28	97.60	0.000

The P-value for regression was less than 0.05 providing evidence that the CS of CCA blended concrete has a significant effect on the CS of OPC concrete. This suggests that using CCA as a partial replacement for OPC in concrete mixtures has the potential to improve the CS of the resulting concrete.

Two-Sample T-Test of Hypothesis

The hypothesis states that there is no significant difference in the maximum CS of OPC and CCA blended Standard design (M30) grade of concrete at the 28-day curing period.
μ_1: population mean of CS of OPC concrete
μ_2: population mean of CS of CCA blended concrete
Difference: $\mu_1 - \mu_2$
Equal variances are not assumed for this analysis.

Difference	95% CI for Difference
4.45	(-2.97, 11.86)

Test

Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$
Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
1.24	24	0.228

The two-sample t-test compares the means of two independent groups, with the null hypothesis (H_0) positing that the difference between their population means is zero, and the alternative hypothesis (H_1) suggesting otherwise. Since the p-value exceeds the conventional alpha level of 0.05, we fail to reject the null hypothesis, indicating insufficient evidence to support a statistically significant difference between the means of the groups. T-value along with p-value (greater than 0.05) suggests comparable means and any observed distinctions likely stem from chance. Noteworthy, CCA's inert filler behaviour might lead to strength reductions, possibly due to its high alkali content hindering cement hydration. Variations in burning conditions, plant design, and engineering parameters, as observed by Abdul-Manan (2016), Kamau et al. (2016), and Suwanmaneechot et al. (2015), further contribute to strength variations. While strength enhancement with CCA addition is plausible, burning conditions significantly influence burned ash properties crucial for concrete strength. Suwanmaneechot et al.

(2015) highlight that higher firing temperatures reduce amorphous silica content, critical for pozzolanic reactions essential to concrete strength and durability. Additionally, elevated temperatures eliminate carbon fractions, which can impede hydration and weaken concrete. Thus, precise control of burning conditions is imperative to optimize burned ash properties for high-quality supplementary cementitious material in concrete production.

CONCLUSION

This study conducted a systematic review of published experimental articles concerning the CS performance of CCA blended concrete. Analysis of 23 studies revealed that 60.9% of the reviewed studies reported a generally lower CS of CCA blended concrete compared to OPC concrete, with a strength reduction ranging from 6% to 35.8%. However, 17.4% of the studies indicated that increasing the percentage of OPC replacement with CCA could result in higher compressive strength, with a rise ranging from 3.6% to 18.4%. Literature also suggests that burning conditions significantly influence the physical characteristics and chemical compositions of burned ash. Results show that utilizing corncob ash as a partial replacement for OPC in concrete mixtures can have significant ($p<0.05$) potential to enhance the CS of the resulting concrete. Based on our findings, we recommend an optimum substitution percentage of 6.86% for CCA in concrete without optimization to maintain structural integrity and promote sustainable practices in the concrete industry. The incorporation of waste materials in concrete production presents a promising avenue for reducing reliance on traditional cementitious materials and addressing waste management concerns. The implications of the study for the construction industry are significant, contributing to the growing body of knowledge on the use of CCA blended concrete as a sustainable alternative to OPC in concrete production. Furthermore, our findings warrant further investigation into the underlying reasons for the variability in experimental research findings reported by different authors.

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