

Corn Cob Ash as a Partial Cement Replacement in Concrete: A Critical Review of Processing, Fresh Properties, Strength, Durability and Research Needs

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Manuscript type: Critical literature review

Prepared from the submitted M.Tech experimental study and updated peer-reviewed literature through September 2026.

Abstract

The growing demand for concrete has increased interest in supplementary cementitious materials that can reduce dependence on clinker while making use of locally available wastes. Corn cob ash (CCA), obtained by controlled combustion of corn cobs, has attracted attention because its composition can contain appreciable amounts of reactive silica and other oxides. However, the published evidence is not uniform: performance depends strongly on the source of the cob, combustion temperature, residence time, grinding, fineness, chemical composition, replacement level, water demand and curing regime. This paper critically reviews the use of CCA as a partial cement replacement in concrete, with particular attention to workability, compressive strength, durability, microstructural development, processing conditions and practical suitability. The review also relates the literature to the M.Tech experimental programme documented by the author, which used PPC-based M20 concrete, a 1:1.5:3 proportion, a nominal water–cement ratio of 0.55, CCA replacement levels up to 15%, and curing ages of 3, 7 and 28 days. The literature indicates that low replacement levels, commonly around 5–10% by mass of binder, are more consistently associated with acceptable fresh and hardened properties than high replacement levels. At the same time, recent studies show that untreated or poorly controlled CCA can contain high alkali or chloride contents and may behave less effectively than properly calcined ash. The central finding of this review is therefore not that CCA has one universal optimum percentage, but that its performance is process-dependent and must be established for each ash source through chemical, physical, strength and durability testing. Future research should standardize ash production, report complete chemical and physical characterization, evaluate long-term durability, and combine experimental optimization with life-cycle and cost assessment.

Keywords: Corn cob ash; supplementary cementitious material; partial cement replacement; pozzolanic material; concrete; compressive strength; workability; durability; sustainable construction.

1. Introduction

Concrete remains one of the principal materials used in buildings, transportation infrastructure and civil engineering works. Its technical usefulness is closely linked to the availability of cementitious binders, aggregates and water, but the production of Portland clinker is energy intensive and associated with substantial greenhouse-gas emissions. This has encouraged researchers to examine industrial by-products and agricultural residues as supplementary cementitious materials (SCMs). Agricultural ashes are particularly interesting because they can convert a low-value residue into a functional construction material when the ash is produced and characterized appropriately [1–4].

Corn cob is the central fibrous portion of the maize ear that remains after removal of the kernels. It is generated in large quantities in maize-producing regions and is frequently discarded, burned in an uncontrolled manner, or used in low-value applications. Converting the cob into ash and then incorporating the ash into cement-based materials creates a possible route for waste valorization. Earlier work demonstrated that CCA can be incorporated into blended cement and concrete, while later studies have shown that its performance varies substantially with ash preparation and replacement level [5–10].

The subject is particularly relevant to an M.Tech-level investigation because the engineering question is not simply whether CCA can be mixed with cement. The more useful question is under what processing and mixture conditions CCA can

replace part of the binder without unacceptable losses in workability, strength or durability. The distinction is important because two ashes both described as 'corn cob ash' may have very different reactivity. Combustion temperature, uncontrolled carbonization, particle size, chemical composition and storage can all alter performance [7, 11, 12].

The present review was developed from the author's M.Tech experimental document, which describes PPC-based M20 concrete, a 1:1.5:3 proportion, a water–cement ratio of 0.55, CCA replacement levels in the range of 0–15%, and compressive-strength assessment after 3, 7 and 28 days. The thesis also reports preparation of CCA by drying the corn cob, burning it and passing the resulting ash through a 90- μ m sieve. These details provide the practical context for the review.

2. Review Methodology

A critical rather than purely narrative approach was adopted. The review focused on peer-reviewed studies dealing specifically with CCA in cement, mortar, concrete, geopolymers systems and related cementitious materials. Priority was given to studies reporting one or more of the following: ash preparation; oxide composition; fineness; water demand; slump or workability; compressive strength; durability; hydration or microstructure; and environmental implications. Foundational studies were retained because they establish the experimental history of CCA, while recent systematic reviews and 2026 publications were used to identify current research directions.

The literature was compared qualitatively because the published studies do not use a single common experimental protocol. Replacement percentages, cement types, water-to-binder ratios, aggregate grading, curing conditions and ash-processing temperatures vary considerably. A direct numerical meta-analysis would therefore risk treating unlike mixtures as equivalent. Instead, this review identifies recurring trends, explains the mechanisms proposed in the literature, and highlights where apparently conflicting results can be explained by differences in material preparation.

The review also uses the author's M.Tech study as a case context rather than as a substitute for published evidence. The thesis itself contains several internally inconsistent descriptions of replacement levels and some tabulated experimental values that require verification before they are used as a standalone publishable dataset. Accordingly, this manuscript does not invent or reconcile missing measurements. The thesis methodology is discussed, but the principal technical conclusions are based on the published literature.

3. Corn Cob Ash: Origin, Processing and Material Characteristics

3.1 Origin and preparation

CCA is produced by burning dried corn cobs and collecting the resulting mineral-rich residue. In the author's experimental programme, the cobs were sun-dried for approximately 10–15 days, burned in a metal container and the ash was passed through a 90- μ m sieve. This procedure is simple and realistic for laboratory-scale work, but it does not by itself establish that the resulting ash is a reactive pozzolan. The thermal history of the ash must be controlled or at least recorded because incomplete combustion leaves carbon-rich material, whereas excessive temperatures can cause sintering or crystallization and reduce the reactive fraction [11, 12].

Suwanmaneechot et al. reported that heat treatment can substantially change CCA characteristics; in their work, CCA treated at 600 °C for four hours reached a combined $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ content of approximately 72%, consistent with the chemical threshold for a Class N pozzolan under ASTM C618. [12] More recent work continues to show that calcination temperature is a major control variable rather than a minor processing detail [13].

3.2 Chemical composition and pozzolanic potential

The main reason CCA is considered for cement replacement is its potential silica-rich character. In a pozzolanic reaction, reactive silica and alumina-bearing phases can react with calcium hydroxide released during cement hydration to form additional calcium-silicate-hydrate and related binding phases. However, the total oxide content alone does not prove pozzolanic activity. Reactivity also depends on whether those oxides are present in an amorphous or otherwise reactive form, together with fineness, surface area, burning conditions and the presence of deleterious constituents [7, 11, 14].

ASTM C618 provides useful reference criteria for natural pozzolans, including limits on combined $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$, loss on ignition, fineness, strength activity index and water requirement. These criteria were developed for specified classes

of pozzolans and should not be treated as a blanket certification that every CCA is compliant. They are, however, a useful framework for characterizing CCA before concrete application. [15]

3.3 Why ash preparation can change the result

Published results demonstrate that CCA is not a single standardized material. Untreated ash can contain relatively high potassium and chloride contents and can produce performance that is less favorable than that of a carefully processed ash. Mikhailenko et al. reported that untreated CCA accelerated hydration but also raised concerns related to potassium and chloride contents, while the concrete strength response was not consistently beneficial. [16] This finding is important for practical work: replacing cement with 'more ash' is not a meaningful optimization strategy unless the ash itself has been controlled.

Table 1. Major variables controlling CCA performance

Variable	Possible influence	Recommended reporting
Combustion temperature	Changes amorphous/reactive phases and carbon content	Temperature range, duration, furnace/open burning
Grinding and fineness	Affects surface area, water demand and reaction rate	Sieve residue and/or particle-size distribution
Chemical composition	Indicates potential pozzolanic and deleterious constituents	SiO ₂ , Al ₂ O ₃ , Fe ₂ O ₃ , CaO, MgO, K ₂ O, SO ₃ , Cl ⁻ , LOI
Replacement level	Controls dilution versus pozzolanic contribution	Mass % of total binder and exact control mix
Water-to-binder ratio	Strongly affects workability and strength	Constant or adjusted w/b and admixture dosage
Curing	Controls hydration and later-age reaction	Temperature, humidity and curing age

4. Effect of CCA on Fresh Concrete Properties

Workability is one of the first properties affected when a fine agricultural ash is introduced into concrete. The literature commonly associates higher CCA contents with increased water demand and reduced slump because ash particles can be finer than cement and can possess irregular shapes and porous surfaces. Adesanya and Raheem observed the effect of CCA on slump and compacting factor across replacement levels up to 25%. [6] Similar reductions in workability have been reported in subsequent studies, although not every investigation has shown the same direction of change.

The disagreement is not necessarily contradictory. Ash produced under different conditions may have different particle sizes, carbon contents, surface textures and chemical compositions. Kamau et al. and other studies have reported cases where CCA-containing mixtures showed different workability trends, illustrating that the response cannot be predicted from replacement percentage alone. Recent reviews similarly identify ash fineness and processing as major reasons for variability [4, 7].

For the M.Tech study, the experimental programme used a nominal water–cement ratio of 0.55 and investigated CCA replacement up to 15%. The thesis reports slump values alongside concrete strength tables and describes workability as a key performance parameter. □filecite□turn0file1□L131-L146□ This is appropriate for an initial investigation, but a publication-quality study should distinguish clearly between water–cement ratio and water–binder ratio once CCA is included, because the ash itself becomes part of the cementitious system.

5. Compressive Strength and Mechanical Performance

Compressive strength is the most frequently reported hardened-property indicator in CCA concrete. Early research showed that CCA can participate in cementitious systems, but the strength response depends on the mixture and processing route. Adesanya and Raheem investigated replacement levels from 0 to 25% and curing ages extending from 3 to 180 days, demonstrating the importance of both replacement level and curing age. [6] Their companion study on blended cement also showed that lower replacement levels were more compatible with cement performance requirements. [5]

A recurring pattern across the literature is an initial region in which a small amount of CCA can maintain or sometimes improve strength, followed by a decline as replacement becomes excessive. At low dosage, particle packing and pozzolanic

reaction may offset some of the cement dilution. At higher dosage, the amount of clinker available for primary hydration decreases, while unreacted or less-reactive ash may increase the volume of weak or porous regions. The balance between these effects explains why a single universal optimum cannot be assigned to all CCA sources.

The 2023 review by Ahmad et al. synthesized evidence on fresh properties, strength, durability and microstructure and reported that typical optimum CCA replacement levels often fall around 5–10% by binder mass, while emphasizing source-to-source variation. [4] A later systematic review of compressive strength reported mixed evidence across 23 studies from 2010–2023, with a substantial share of studies showing reductions in 28-day strength relative to the control. [17] This is a useful corrective to overly positive claims: CCA should be treated as a potentially useful SCM, not as a guaranteed strength enhancer.

The author's thesis follows the same general experimental logic: a control mix is compared with CCA-replaced mixes and specimens are evaluated at 3, 7 and 28 days. □filecite□turn0file1□L44-L53□ The thesis conclusion identifies approximately 5% CCA as a practical low-level replacement in its tested system, while noting that higher replacement levels can reduce strength. □filecite□turn0file1□L158-L173□ This observation is broadly compatible with the lower replacement range reported in several published studies, but it should be described as a result of the tested mixture rather than a universal design recommendation.

Table 2. Selected published evidence on CCA in cementitious materials

Study	Material / system	CCA range	Main observation	Interpretation
Adesanya & Raheem (2009) [5,6]	Blended cement concrete	0–25%	CCA affected workability and strength; curing age was important	Low replacement levels are more practical
Adesanya & Raheem (2010) [8]	Concrete / mortar durability	0–25%	Lower permeability and improved acid resistance were reported at selected replacement levels	Durability response can differ from strength response
Suwanmaneechot et al. (2015) [12]	Processed CCA cement systems	Heat-treated ash	600 °C/4 h ash showed high combined oxide content	Processing strongly affects pozzolanic potential
Mikhailenko et al. (2020) [16]	Untreated CCA cementitious materials	Low replacement	High K and chloride contents; mixed strength response	Untreated ash needs characterization and quality control
Ahmad et al. (2023) [4]	Review of CCA concrete	Literature synthesis	Typical optimum often reported around 5–10%	No universal optimum because sources differ
Oriola et al. (2023) [18]	CCA cement concrete	Partial replacement	Strength and thermal behavior studied together	Thermal performance remains less explored
Fadele & Otieno (2026) [19]	PC–CCA blended systems	Calcined CCA	CCA properties influence hydration kinetics	Hydration mechanism needs better standardization

6. Durability and Long-Term Performance

Strength alone is not sufficient to establish the suitability of an alternative binder. Concrete used in real structures is exposed to water, chlorides, sulphates, acids, carbonation, thermal cycles and drying. Adesanya and Raheem investigated permeability

and acid attack and reported reduced water absorption at selected CCA replacement levels together with improved resistance to HCl and H₂SO₄ exposure in their tested systems. [8] Earlier work by Adesanya also reported favorable water absorption and durability behavior at a 20% replacement level in specific concrete and mortar mixtures. [9]

These findings should be interpreted carefully. Durability benefits may arise when CCA produces a denser matrix through secondary reaction and pore refinement, but excessive replacement or poorly processed ash can produce the opposite effect. Recent reviews have identified alkali-silica reaction, shrinkage, creep and long-term durability as areas where evidence remains less complete than the evidence for compressive strength. [4,7]

The literature therefore supports a performance-based approach: a CCA mix should not be classified as durable merely because its 28-day compressive strength is satisfactory. Water absorption, sorptivity, chloride transport, sulphate resistance, carbonation and dimensional stability should be considered where the intended application requires them.

7. Microstructural and Hydration Considerations

The principal mechanism proposed for beneficial CCA behavior is pozzolanic reaction. Cement hydration produces calcium hydroxide as one of its products. Reactive silica and alumina in a suitable ash can interact with calcium hydroxide and contribute to additional binding phases. The resulting changes may reduce pore connectivity and improve the paste-aggregate interface. However, the magnitude of this effect depends on the proportion of reactive material actually present in the ash.

Microstructural characterization is therefore important. X-ray diffraction (XRD) can help distinguish crystalline and less-crystalline phases; scanning electron microscopy (SEM) can reveal particle morphology and interfacial features; thermogravimetric analysis (TGA/DTG) can assist in studying bound water and calcium hydroxide consumption; and particle-size or surface-area measurements can clarify the relationship between fineness and water demand. Recent work on CCA hydration kinetics reinforces the need to connect ash processing with actual hydration behavior rather than relying only on bulk oxide chemistry. [19]

For an M.Tech experimental programme, adding even a limited XRD/SEM component would substantially strengthen the scientific explanation of why a particular replacement level performs better. Without such evidence, the statement that 'CCA improves strength because of pozzolanic action' remains a reasonable mechanism but should be presented as an interpretation supported by the broader literature, not as a directly demonstrated fact for every ash batch.

8. Sustainability, Cost and Practical Significance

The environmental argument for CCA has two parts. First, replacing a portion of cement can reduce clinker demand. Second, converting agricultural residue into a useful material can reduce the need for disposal or uncontrolled burning. The actual environmental benefit, however, depends on how the ash is produced. If the cob is transported over long distances or burned inefficiently, the energy and emissions associated with ash preparation may reduce the benefit.

A meaningful sustainability assessment should therefore compare the complete system: avoided cement production, collection and transport of cobs, drying energy, combustion energy, grinding, sieving, storage and final concrete performance. A simple statement that CCA is 'eco-friendly' is insufficient for publication. Life-cycle assessment and cost analysis are needed to establish the net benefit under a specific regional supply chain.

For the practical Indian context described in the M.Tech work, the use of locally available agricultural waste is attractive because it can potentially reduce material consumption and create a value stream for a residue. The thesis explicitly frames the concept as waste-to-useful-wealth and links it to reduction of cement consumption and environmental burden. □filecite□turn0file0□L47-L63□ These are appropriate motivations, but the final economic claim should be supported by actual local material prices and processing costs before publication.

9. Relevance to PPC-Based M20 Concrete

The author's experimental programme is particularly interesting because it uses PPC rather than OPC. The thesis identifies PPC as the cement used and describes CCA as an additional partial replacement.

□filecite□turn0file0□L36-L42□ This creates a scientifically important question: the system is not simply 'CCA versus OPC', but a blended binder in which PPC already contains a pozzolanic component.

Consequently, the response of CCA may differ from results obtained in OPC-only systems.

This distinction should be made explicit in any publication derived from the thesis. The control mixture should be defined as PPC concrete without CCA, and all CCA mixtures should be described as PPC–CCA blended systems. The replacement percentage should be stated unambiguously as a percentage by mass of the original cement/binder quantity. The terminology should also remain consistent throughout the paper.

The thesis describes an M20 target, a 1:1.5:3 volume-based proportion and a water–cement ratio of 0.55.

□filecite□turn0file1□L141-L146□ From a modern publication perspective, it would be preferable to describe the mixture as a nominal proportioning study unless a formal IS 10262-based design calculation was actually performed. A 1:1.5:3 ratio should not automatically be described as a complete 'mix design' in the same sense as a documented design procedure based on target mean strength, material specific gravity, water demand and trial mixes.

10. Critical Synthesis of the Literature

Four conclusions emerge when the studies are read together. First, CCA is a promising but highly variable material. The literature contains both positive and negative strength results, and this variation is not a weakness of the concept itself; it indicates that ash production is a major experimental variable. Second, workability generally becomes more difficult as the content of fine ash increases, although the direction and magnitude of the change depend on ash properties and mixture design. Third, low replacement levels, particularly around 5–10% in many concrete studies, are the most defensible starting range, while higher replacement levels require stronger experimental justification. Fourth, durability and microstructural evidence is still less standardized than compressive-strength evidence.

A useful way to understand the strength trend is through the competition between three effects: dilution of clinker, physical filler/packing action, and pozzolanic reaction. At very low replacement, filler and reactive effects can partially compensate for cement dilution. At intermediate replacement, the balance may become favorable if the ash is reactive and sufficiently fine. At high replacement, dilution and water-demand effects can dominate. This framework explains why different studies can report different optimum percentages without necessarily invalidating one another.

Recent systematic reviews reinforce this interpretation. The 2023 CCA review places many reported optimum values around 5–10%, while a 2025 systematic review emphasizes the breadth of CCA applications and the continuing need to understand material-processing effects. [4,7] Newer 2026 research is moving toward controlled calcination, hydration kinetics, binary blends and performance optimization rather than simply increasing or decreasing replacement percentage. [13,19,20]

11. Research Gaps and Recommended Experimental Framework

The following research gaps are particularly relevant for future M.Tech, Ph.D. and publication-level investigations:

- Standardization of CCA production: report drying method, combustion atmosphere, peak temperature, holding time, cooling method, grinding and sieve residue.
- Complete chemical characterization: report SiO₂, Al₂O₃, Fe₂O₃, CaO, MgO, SO₃, Na₂O, K₂O, chloride and loss on ignition where facilities permit.
- Reactivity rather than chemistry alone: determine strength activity and/or recognized pozzolanic activity indicators instead of assuming reactivity from total oxide content.
- Particle characterization: include particle-size distribution, specific surface area and density so that differences in water demand can be interpreted.
- Consistent replacement basis: clearly state whether replacement is by mass of cement, total binder or volume.
- Longer curing: retain 3, 7 and 28 days for continuity with the thesis, but add 56 and 90 days where possible because pozzolanic systems can continue reacting at later ages.
- Durability programme: add water absorption/sorptivity, sulphate exposure, chloride penetration, carbonation and shrinkage according to the intended application.
- Microstructure: combine strength results with XRD, SEM and, where available, TGA/DTG to support mechanistic interpretation.
- PPC-specific research: compare PPC control, PPC + CCA and OPC + CCA so that the interaction between pre-existing pozzolanic cement and CCA can be isolated.
- Sustainability assessment: quantify cement saved, ash-processing energy, transport distance, cost per cubic metre and estimated embodied-carbon change.

- Statistical treatment: use replicate specimens, report mean $\pm$ standard deviation, coefficient of variation and appropriate significance testing.
- Field validation: after laboratory optimization, assess batching, storage, transport, placement and curing under realistic site conditions.

For the specific M.Tech system documented by the author, a useful next experiment would retain the same aggregate source and PPC but compare 0%, 2.5%, 5%, 7.5%, 10% and 12.5% CCA using a controlled calcination procedure. The study should maintain a clearly defined water-to-binder ratio and, if necessary, use a compatible water-reducing admixture so that workability can be separated from strength effects. Such a design would provide a stronger basis for identifying a local optimum than simply testing a wide replacement range once.

12. Conclusions

Corn cob ash has credible potential as a supplementary cementitious material, but its usefulness is conditional rather than automatic. The literature shows that CCA can contribute to sustainable concrete by reducing cement demand and valorizing agricultural residue, while properly processed ash can contribute to pozzolanic reaction and matrix refinement. At the same time, untreated or poorly controlled ash can have high alkali, chloride or unburnt-carbon contents and may reduce workability or compressive strength.

Across the literature, low replacement levels around 5–10% are repeatedly identified as a practical range for further investigation, although the optimum cannot be fixed independently of ash source, processing, cement type and mixture design. The author's M.Tech work, which uses PPC-based M20 concrete and investigates CCA replacement up to 15%, fits within this research direction. Its reported observation that a low replacement level performs favorably is consistent with the broader literature, but it should remain a system-specific conclusion.

The most important requirement for future publication-quality work is therefore reproducibility. A paper should allow another researcher to reproduce the ash, understand its chemistry and fineness, reproduce the concrete mixture, and evaluate both strength and durability. If these details are controlled, CCA can move from a general waste-utilization concept toward a technically defensible supplementary cementitious material for selected concrete applications.

13. Declarations

Funding: No external funding is reported for this review draft. **Conflict of interest:** The author declares no known conflict of interest.

Data availability: This is a critical review. No new experimental dataset is claimed in this manuscript. The M.Tech study used as contextual source is separately documented.

Ethical statement: No human or animal subjects are involved.

Originality statement: This manuscript is newly written as a critical synthesis. Published findings are paraphrased and cited; no claim is made that the underlying experimental results are original to this review.

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Editorial Note Before Submission

This manuscript is a publication-oriented rewrite and critical synthesis, not a claim that the attached thesis itself is already publication-ready. Before submission, the author should verify every bibliographic entry against the publisher database, replace any incomplete reference metadata, confirm the experimental tables in the thesis against laboratory records, and format the manuscript according to the target journal's author guidelines. In particular, the thesis contains differing descriptions of replacement percentages in different sections; the final paper should use one verified experimental matrix only.