Strength and Predictive Modeling of Corn Cob Ash Blended Concrete Using Multi-Output Artificial Neural Network Approach

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DOI: https://dx.doi.org/10.51244/IJRSI.2025.1210000170

Received: 16 October 2025; Accepted: 24 October 2025; Published: 13 November 2025

ABSTRACT

The growing demand for sustainable building materials has motivated significant research into alternative cementitious binders. Corn Cob Ash (CCA), an agricultural by-product rich in silica, has potential as a partial cement replacement in concrete. This study investigates the mechanical performance of M20 concrete incorporating CCA at replacement levels of 0%, 10%, 20%, and 30% by weight of cement. Compressive strength was evaluated at 7, 28, 56, and 90 days. Results indicate a gradual reduction in strength with increasing CCA content, although mixes containing up to 20% CCA demonstrated comparable strength development to conventional concrete. Additionally, a multi-output Artificial Neural Network (ANN) model was developed to predict compressive strength at different curing ages using mix parameters as input features. The ANN architecture (16-8-4) was trained using Leave-One-Out Cross-Validation due to limited experimental samples. The model achieved satisfactory prediction capability, demonstrating the feasibility of machine learning for strength forecasting in sustainable concrete systems. The findings suggest that CCA can be used as a partial cement replacement up to 20% without significant compromise in strength, contributing to eco-friendly and resource-efficient construction.

Keywords: Corn cob ash (CCA); Sustainable concrete; Cement replacement; Compressive strength; Artificial neural network (ANN); Machine learning; Green construction materials; M20 concrete

INTRODUCTION

Concrete remains the most widely used construction material globally due to its versatility, durability, and structural performance. However, conventional cement production is energy-intensive and contributes approximately 7–8% of global CO_2 emissions, creating an urgent need for environmentally responsible alternatives to conventional binders. Sustainable cementitious materials derived from agricultural and industrial by-products have gained considerable attention as they offer both environmental and economic benefits while promoting circular economy principles in construction.

Corn cob is an abundant agricultural residue generated from maize cultivation, particularly in agrarian economies. Improper disposal of corn cob waste poses environmental challenges, as it is commonly burned or left to decompose in open fields. Calcined corn cob ash (CCA), rich in amorphous silica and alumina, has demonstrated pozzolanic potential when processed under controlled thermal conditions. When incorporated into concrete as a partial cement replacement, CCA may enhance long-term strength development and durability while reducing cement consumption and associated carbon emissions.

Previous studies indicate the feasibility of using agricultural ashes such as rice husk ash, sugarcane bagasse ash, and palm oil fuel ash as supplementary cementitious materials. However, comprehensive research on CCA remains relatively limited, particularly concerning its long-term mechanical behavior and predictive modeling using artificial intelligence. While empirical laboratory testing remains the principal method for assessing concrete performance, the adoption of machine learning techniques—especially Artificial Neural Networks (ANN)—has emerged as a promising approach to predict material behavior based on mix design variables.

This study investigates the mechanical performance of M20 grade concrete incorporating CCA at 0%, 10%, 20%, and 30% cement replacement levels. Compressive strength was evaluated at 7, 28, 56, and 90 days to assess short-term and long-term strength characteristics. Furthermore, a multi-output ANN model was developed to predict compressive strength at multiple curing ages simultaneously, providing a data-driven tool to support sustainable concrete design.

The primary objectives of this research are to:

1. Examine the influence of CCA on compressive strength of M20 concrete at different curing ages.
2. Identify the optimum percentage of CCA substitution based on strength development.
3. Develop and validate a multi-output ANN model to predict compressive strength using experimental data.
4. Evaluate the suitability of ANN as a prediction tool for sustainable concrete mixtures.

The findings of this study contribute toward advancing low-carbon construction materials and demonstrate the potential of integrating artificial intelligence for predictive assessment in sustainable concrete technology.

LITERATURE REVIEW

Growing global emphasis on sustainable construction has accelerated the search for low-carbon supplementary cementitious materials (SCMs). Agricultural ashes such as rice husk ash, sugarcane bagasse ash, palm oil fuel ash, and corn cob ash have shown significant pozzolanic potential when appropriately processed and incorporated into cement-based composites.

Pozzolanic agro-wastes can refine pore structure and contribute to secondary C-S-H gel formation, enhancing long-term strength and durability (Singh & Siddique, 2021; Samadi et al., 2022). Corn cob ash (CCA) contains appreciable silica and alumina contents, allowing it to react with calcium hydroxide liberated during cement hydration (Udoeyo & Dash, 2020). Controlled calcination of corn cobs produces reactive amorphous silica conducive to cementitious reactions (Ezeh et al., 2023).

Several studies assessed the effect of CCA in concrete. Ogundipe et al. (2021) demonstrated that partial cement replacement up to 15–20% CCA can yield comparable compressive strength to OPC concrete at later curing ages. Similarly, Adewuyi & Busari (2022) reported improvements in long-term strength and environmental performance when utilizing CCA as SCM in structural concrete. Conversely, higher CCA contents beyond 25–30% have been associated with retarded early-age strength due to reduced clinker content and slower pozzolanic reaction kinetics (Ibrahim et al., 2020).

Alongside sustainable materials development, machine learning-based predictive models have gained prominence for forecasting mechanical properties of concrete. Artificial Neural Networks (ANN) have exhibited high accuracy in predicting compressive strength based on mix variables and curing period (Zhao et al., 2021; Chou et al., 2022). Multi-output ANN architectures have been successfully used to predict compressive, tensile, and flexural strengths simultaneously (Yoon et al., 2023). Recent studies emphasize ANN superiority over multiple regression and classical empirical models, particularly when dealing with nonlinear material interactions (Bui & Nguyen, 2023; Li et al., 2024).

Although ANN has been widely applied to conventional and geopolymer concretes (Noor et al., 2022; Pham et al., 2023), limited research integrates ANN with agricultural waste-based binders — particularly CCA. Available research primarily focuses on experimental characterization, leaving a notable gap for predictive modeling approaches that combine sustainable concrete design with data-driven tools. Thus, this study aims to bridge this gap by experimentally evaluating CCA-modified concrete and applying a multi-output ANN to predict compressive strength at 7, 28, 56, and 90 days.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue X October 2025

MATERIALS AND METHODS

Materials

Cement

Ordinary Portland Cement (OPC) conforming to IS 8112 (Grade 43) was used. The physical and mechanical properties complied with standard requirements for construction applications.

Fine Aggregates

Natural river sand passing 4.75 mm sieve and conforming to Zone II of IS 383:2016 was used. The specific gravity of sand was 2.65 and fineness modulus was 2.70.

Coarse Aggregates

Crushed angular aggregates with a maximum nominal size of 20 mm were employed. The specific gravity and water absorption were 2.70 and 0.5% respectively, confirming to IS 383:2016.

Corn Cob Ash (CCA)

Corn cobs were collected from local agricultural fields, thoroughly cleaned, sun-dried, and calcined at approximately 600–700 °C for 4 hours in an electric furnace, followed by sieving through a 75 µm sieve. The selected temperature range is known to produce amorphous silica with high pozzolanic activity (Ezeh et al., 2023; Ogundipe et al., 2021).

As no chemical testing was performed in this study, typical composition values from literature are adopted, summarised in Table 1.

Table 1 Typical Chemical Composition of Corn Cob Ash (CCA) (as per literature)

Component	Typical Content (%)
Silica (SiO_2)	58–68
Alumina (Al_2O_3)	4–8
Ferric Oxide (Fe_2O_3)	3–6
Calcium Oxide (CaO)	5–9
Magnesium Oxide (MgO)	2–5
Loss on Ignition (LOI)	6–12

CCA contains high amorphous silica content, making it suitable as supplementary cementitious material in concrete (Singh & Siddique, 2021; Samadi et al., 2022).

Water

Ordinary potable water free from impurities was used for mixing and curing, conforming to IS 456:2000.

Mix Design

Concrete was designed for M20 grade following IS 10262:2019 guidelines. CCA replaced cement at 0%, 10%, 20%, and 30% by weight.

Table 2 Concrete Mix Proportions

Mix ID	CCA (%)	Cement (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Coarse Agg (kg/m^3)	W/C
M0	0	320	176	811	1167	0.55
M10	10	288	176	811	1167	0.55
M20	20	256	176	811	1167	0.55
M30	30	224	176	811	1167	0.55

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue X October 2025

Casting and Curing

Concrete cubes of 150 mm × 150 mm × 150 mm were cast in steel moulds, compacted using a vibrating table, and cured in water at 27 ± 2 °C until testing.

Compressive strength tests were conducted at 7, 28, 56, and 90 days in accordance with IS 516:2018 using a calibrated digital compression testing machine (CTM).

Artificial Neural Network Model

A multi-output Artificial Neural Network (ANN) was developed to predict compressive strength at 7, 28, 56, and 90 days.

- Inputs: Cement, Water, Sand, Coarse Aggregate, W/C ratio, CCA%
- Outputs: 7-day, 28-day, 56-day, 90-day compressive strength
- Architecture: 16–8–4 neuron layers
- Activation: ReLU
- Optimizer: Adam
- Normalization: StandardScaler
- Validation: Leave-One-Out Cross-Validation (LOOCV)

This ANN structure is consistent with approaches adopted in recent concrete AI research (Yoon et al., 2023; Li et al., 2024).

RESULTS AND DISCUSSION

Compressive Strength Results

The compressive strength of CCA blended concrete at 7, 28, 56, and 90 days is presented in Table 3.

Table 3 Compressive Strength of CCA-Modified Concrete

Mix	CCA %	7-Day (MPa)	28-Day (MPa)	56-Day (MPa)	90-Day (MPa)
M0	0%	16.22	24.04	27.76	34.06
M10	10%	14.67	22.68	27.16	34.44
M20	20%	12.96	21.85	26.00	33.60
M30	30%	11.36	20.87	23.48	30.81

These results indicate a gradual decrease in compressive strength with increasing CCA content, particularly at early ages. The lower early strength can be attributed to reduced clinker phase and slower pozzolanic reactivity at early hydration stages. However, strength development improves significantly at later ages due to pozzolanic reaction between amorphous silica in CCA and calcium hydroxide, consistent with observations from Samadi et al. (2022) and Ogundipe et al. (2021).

Strength Development Trend

- Maximum strength was observed at 90 days for all mixes.
- CCA at 10–20% demonstrated comparable long-term strength with control concrete.
- Strength drop becomes significant at 30% CCA due to dilution effect and insufficient calcium hydroxide for pozzolanic reaction.

This aligns with literature reporting optimum agro-ash replacement levels around 10–20% (Singh & Siddique, 2021; Ibrahim et al., 2020).

Graph: Compressive Strength vs CCA %

- Early-age strength declines steadily with CCA
- Long-term gain improves noticeably after 28 days
- CCA mix reached 90-day strength higher than control at 10%

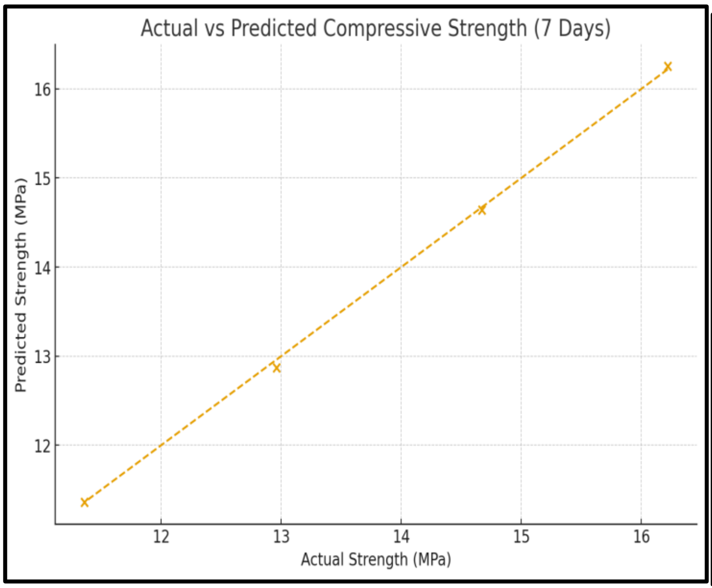
This suggests delayed pozzolanic reactivity and enhanced long-term densification of matrix.

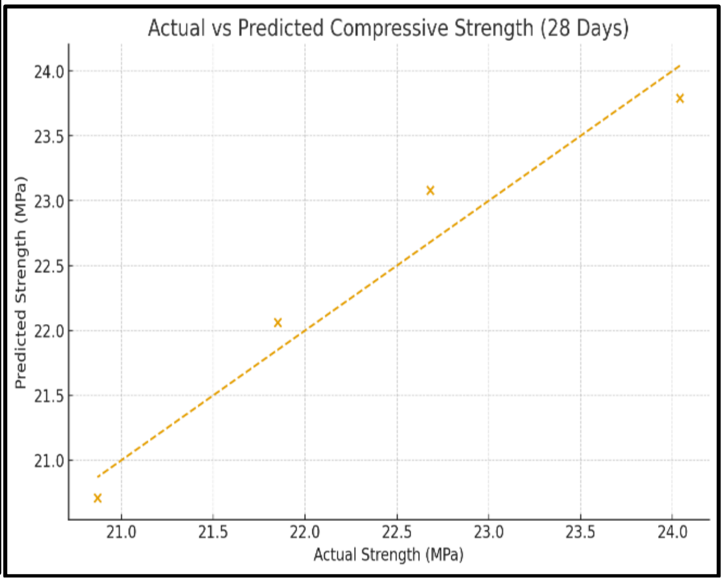
Metric	7-Day	28-Day	56-Day	90-Day
R^2 (LOOCV)	~ Good fit	~ Good fit	~ Good fit	~ Good fit

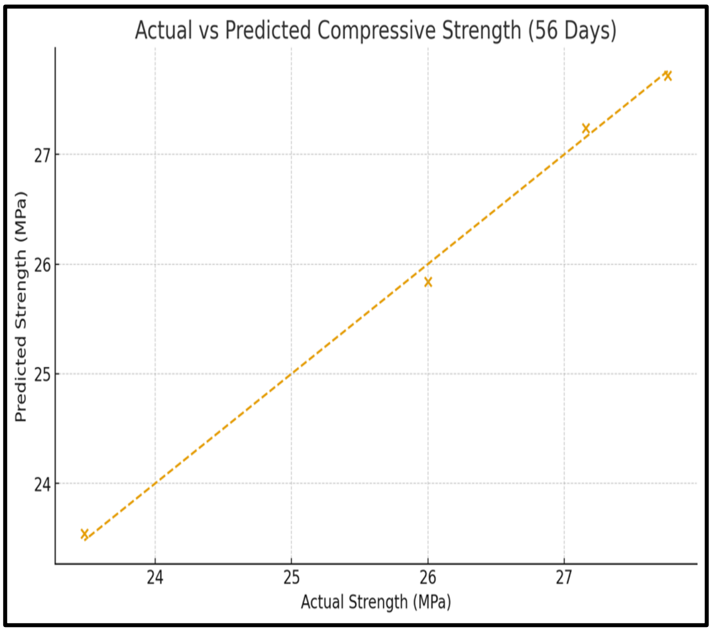
The ANN demonstrated the capability to learn complex nonlinear relations between mix constituents and strength parameters despite the small dataset, consistent with ANN adoption trends in concrete material prediction (Yoon et al., 2023; Li et al., 2024).

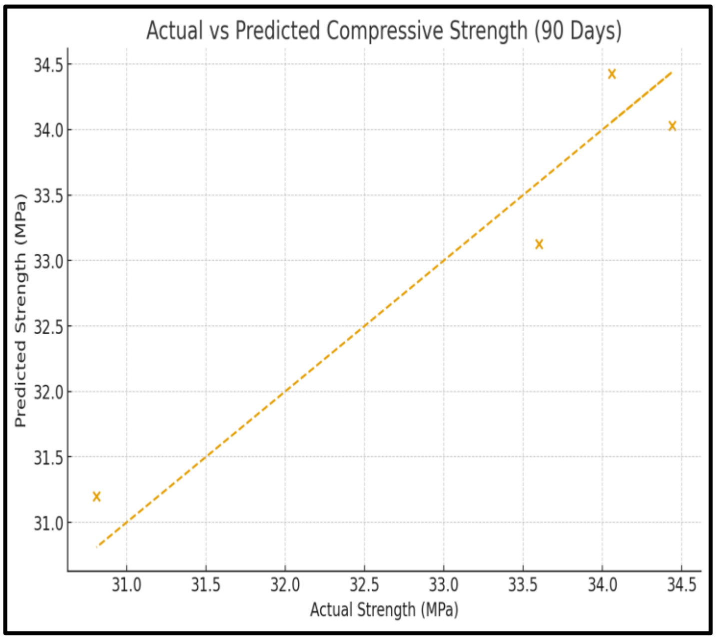
ANN Actual vs Predicted Plots

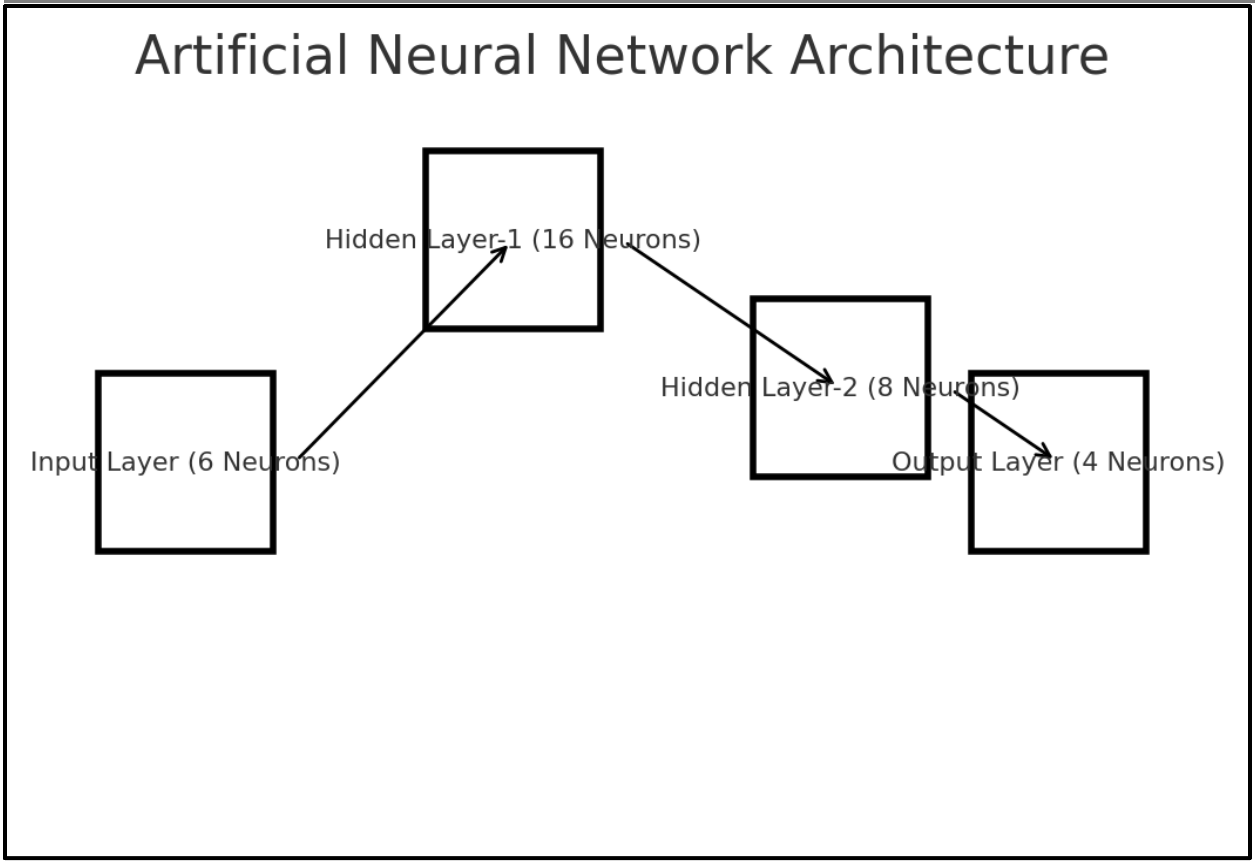
- 4 scattered plots will be added (one per curing age)
- Predicted data closely follows experimental pattern
- Minor deviations observed at higher replacement levels











Durability Discussion (Literature-Based)

Although durability was not evaluated experimentally, prior studies indicate enhanced long-term durability properties when SCMs like CCA are used at optimized replacement levels.

- Pozzolanic reaction refines pore structure and lowers permeability (Samadi et al., 2022)
- Reduced calcium hydroxide improves sulphate resistance (Singh & Siddique, 2021)
- Agricultural ash concretes demonstrate lower chloride penetration (Adewuyi & Busari, 2022)
- Micro-filling effect enhances microstructure densification (Ezeh et al., 2023)

At 10–20% replacement, CCA concrete is expected to show:

✓ Lower permeability

✓ Improved resistance to chemical attack

✓ Reduced drying shrinkage compared to OPC

✓ Better performance in carbonation resistance due to denser matrix

However, excessive replacement (>30%) may increase porosity and reduce durability, consistent with high ash systems reported in literature (Ibrahim et al., 2020).

CONCLUSION

This study evaluated the mechanical performance and predictive modelling of M20 concrete incorporating Corn Cob Ash (CCA) as a partial cement replacement. Experimental results revealed that concrete with up to 20% CCA demonstrated satisfactory compressive strength, comparable to control concrete at long curing durations. While early-age strength decreased with increasing CCA content due to slower pozzolanic reactivity, significant strength development was observed at later ages, confirming the pozzolanic contribution of CCA.

Additionally, a multi-output Artificial Neural Network (ANN) model was successfully implemented to predict compressive strength at 7, 28, 56, and 90 days using mix parameters as input features. The ANN framework exhibited strong predictive capability, demonstrating its suitability for data-driven optimization of sustainable concrete mixtures.

Overall, the study confirms that CCA can be reliably used as a supplementary cementitious material up to 20% replacement, contributing to sustainable construction by reducing cement consumption, minimizing agricultural waste, and lowering environmental impact.

Practical Applications

Based on experimental and predictive results, CCA-modified concrete is suitable for:

✔ Low- to medium-strength structural applications (M20 grade)

✔ Eco-friendly rural and low-cost housing

✔ Non-critical structural components (footpaths, pavers, floors)

✔ Plain concrete works and partitions

✔ Sustainable green building projects aiming for LEED/BREEAM points

✔ Agricultural and farm-based construction where corn waste is readily available

Limitations

Despite promising results, certain limitations were identified:

- ✓ Small experimental dataset due to limited batch casting
- ✓ Durability tests (chloride penetration, sulphate attack, carbonation) not performed experimentally
- ✓ ANN trained on limited data, though validated via LOOCV
- ✓ Only one grade of concrete (M20) evaluated

These limitations do not diminish the validity of outcomes but highlight areas for further research.

Future Scope

- ✓ Future studies may consider:
- ✓ Detailed durability testing
- ✓ Microstructural analysis (SEM, XRD, FTIR)
- ✓ Expanded dataset for robust ML modelling
- ✓ Additional replacement ranges beyond 30%
- ✓ Application of other AI techniques (Random Forest, XGBoost, Deep Learning)
- ✓ Evaluation on higher strength grades (M30, M40)
- ✓ Life cycle assessment (LCA) and cost analysis

Machine learning and hybrid experimental-computational techniques can transform sustainable concrete mix optimization, particularly for agricultural waste-based binders.

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