

Application of Agro-Waste for Sustainable Construction Materials

Mrs. Varsha D. Kapgate ¹, Dr. Samyak D. Parekar ²

¹ PhD scholar, Department of Civil Engineering, G. H. Rasoni University, Saikheda

² Assistant Professor, Department of Civil Engineering, School of Engineering & Technology, G. H. Rasoni University, Saikheda

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ABSTRACT

Rapid population growth and the resulting surge in infrastructure demand have led to the extensive use of conventional construction materials, exerting severe pressure on natural resources and contributing to environmental degradation. Aggregates, which constitute over 70% of the concrete matrix, are extracted in large quantities, resulting in land depletion, biodiversity loss, and increased carbon emissions. To address these sustainability challenges, this study explores the application of agro-waste materials namely corn cob, coconut fiber, and rice husk ash as partial re-placements for conventional constituents in concrete. The research aims to evaluate the mechanical and durability performance of M30 grade concrete incorporating these agro-wastes in varying proportions ranging from 1.5% to 21%. Laboratory experiments are conducted to determine compressive strength, splitting tensile strength, and durability using standard cube and cylinder specimens. The study also examines the physical and mechanical properties of the selected agro-wastes to assess their suitability for sustainable concrete production.

Keywords:- Agro-Waste, concrete, Sustainable, Rice Husk Ash, Coconut Fiber, Corn Cob.

I. INTRODUCTION

Since the dawn of civilization, humans have constructed shelters to protect themselves from environmental hazards. The materials used for building these shelters have evolved over time, transitioning from wood and stone to modern structures made of concrete and metal. Concrete, composed of cement, water, and aggregates, has been in use for several centuries.[3]

With the expansion of the construction industry, there arose a need to improve the management and sustainability of concrete production. One significant development in this area is the creation of a new generation of sustainable, or “green,” concrete. Green concrete is generally defined as a type of concrete that incorporates waste materials in its composition, minimizes environmental damage during production, or offers enhanced performance and long-term sustainability. [5] A major motivation behind the adoption of green concrete is to reduce the environmental and social impacts associated with conventional concrete. Previous research has shown that traditional concrete production contributes substantially to environmental degradation, primarily due to its high carbon footprint, which accelerates global warming and climate change. [16] Meanwhile, the growth of various industries has led to the generation of substantial amounts of waste alongside product production. This study focuses on the potential use of agricultural wastes in the construction sector. Many of these wastes can serve as partial replacements for conventional building materials, providing a sustainable alternative in an industry that is often resource-intensive. [15]

The construction sector has a considerable impact on biodiversity each year through land use, air pollution, and other environmental disturbances. This has prompted researchers to explore innovative approaches to mitigate such effects. Integrating agricultural waste into building materials not only supports effective waste management and energy conservation but also reduces environmental pollution associated with construction and material production. Moreover, the agricultural industry continually produces large volumes of by-products and residues, offering an ongoing, renewable source of raw materials for sectors like construction. [20]

A. Problem Statement

With a population exceeding 1.3 billion, India is the second-most populous country in the world, representing over one-sixth of the global population. It currently accounts for 17.5% of the world's population and is projected to surpass China, becoming the most populous nation by 2025. By 2050, India's population is expected to reach approximately 1.6 billion, driving a rapidly increasing demand for infrastructure. [25] Aggregates, which make up more than 70% of concrete by volume, play a crucial role in meeting this demand. However, the construction industry has significant environmental impacts, including land occupation, air pollution, and other disruptions to biodiversity. This has prompted researchers to explore sustainable alternatives

in construction materials. [18] The continuous production of agricultural waste provides an abundant and renewable source of raw material that can be utilized in the construction industry, helping to reduce environmental impacts while supporting resource efficiency.[23]

B. Corn Cob

Corn (maize) is one of the most widely cultivated crops in the world. The corn cob, the rigid cylindrical central core of the maize ear that holds the kernels, is an agricultural by-product. Corn cob is abundantly available and can serve as a potential energy source.[9] If not properly managed, however, it can pose environmental hazards. Corn cobs are highly absorbent, biodegradable, renewable, and abrasive in nature. When converted into ash, corn cob contains significant amounts of SiO_2 , Fe_2O_3 , and Al_2O_3 , making it suitable as a pozzolanic material in construction applications. The maize plant produces two main by-products: the corn cob (central core) and the corn husk (leafy outer covering), which together account for 20–30% of the plant's biomass. Corn cobs also exhibit good compressive and bending strength, with a bulk density ranging from 160 to 210 kg/m^3 [10]

Table 1 – Physical composition – Corn Cob (ref – Mujahid Khan et. Al. 2022)

Properties	Corn Cob
Specific Gravity	0.957
Bulk Density	160 to 210 kg/m^3
Moisture Content	4.51%
Porosity	46.54%

C. Coir Fiber

Coir fiber is the natural fiber extracted from the husk of the coconut. The coir fiber is the thickest and most Coir fiber, derived from the husk of coconuts, is one of the most durable natural fibers due to its high resistance and low decomposition rate, making it ideal for long-lasting products. Historical evidence shows that coir fiber has been used for rope production for centuries, primarily because of its high strength.[19] There are two main types of coir fiber: brown coir, obtained from mature coconuts, and finer white coir, extracted from immature green coconuts after soaking for up to ten months. Coir is one of the lignin-rich natural fibers, which contributes to its durability. [31]

Coconut coir fiber is a rigid structural fiber and an important commercial product. The type of fiber obtained depends on the method of extraction and the maturity of the coconut. Brown coir, sourced from ripe coconuts, is commonly used in products such as brushes and floor mats, whereas white coir, obtained from immature coconuts, is finer and softer.[26] The chemical composition of coir fiber includes cellulose, hemicelluloses (sugar chains), lignin, pectin, and some water-soluble components. [23] The detailed physical and chemical properties are summarized in Table 2

Table 2 – Physical composition – Coconut fiber (ref-Deepjyoti Das et. Al. 2016)

Properties	Coconut Fiber
Length (mm)	15 – 280
Density (g/ cc)	1.15 – 1.40
Breaking elongation (%)	29.04
Diameter (mm)	0.1 -0.5
Specific Gravity	1.15
Young's modulus (GN/m ²)	4.5

D. RICE HUSK ASH

Rice is one of the major crops cultivated in India. Rice husk, an agricultural by-product, is obtained during the milling process of paddy, where the outer husk is removed. It typically consists of approximately 50% cellulose, 30% lignin, and 20% silica. During incineration at high temperatures, the cellulose and lignin components are burned off, leaving behind rice husk ash (RHA). [12] Rice husk is commonly used as a fuel in boilers and for power generation, and the resulting RHA accounts for roughly 25% of the rice husk's weight. Rice husk ash is valued in construction due to its high silica content and pozzolanic reactivity, making it suitable for use in concrete. According to the Indian Standard IS 456-2000, RHA can be incorporated in both reinforced and plain concrete, contributing to improved strength and durability while promoting the use of sustainable construction materials.[26]

Table 3 – Physical composition – Rice Husk Ash (ref- Insha Ali et. Al. 2020)

Properties	Rice husk Ash
Density	495 kg/m^3

Specific Gravity	2.53
Mean Partial size	0.15 -0.25 μm
Color	Grey
Moisture Contain	2.15%

II. STATE OF DEVELOPMENT

The literature review provides a detailed overview of recent research on the incorporation of agricultural waste in sustainable construction materials. It summarizes key findings, experimental methods, and identified knowledge gaps from previous studies on rice husk ash, coconut fiber, and corn cob. This review establishes a strong foundation for the experimental investigations conducted in the present study, highlighting the potential of agro-waste to enhance concrete's sustainability, performance, and environmental compatibility.

Table 4 – literature Study

Author (Year)	Findings / Key Points
Margarida Soares et al. (2025)	This study emphasizes the shift from a linear to a circular economy through the utilization of agri-food waste. It is estimated that approximately 500 million tons of agricultural waste are generated globally each year. Incorporating these agri-food residues into construction materials not only promotes sustainability and resource efficiency but also improves the durability of the resulting products while significantly reducing their environmental impact.[37]
M. Indumathi et al. (2024)	Rice husk ash (RHA), rich in silica, enhances the strength, durability, and workability of concrete. Partial replacement of cement with RHA not only reduces carbon emissions and construction costs but also promotes sustainability by aligning with circular economy principles. [34]
Masoumeh Kordi et al. (2024)	The literature highlights various applications of rice husk and its derivatives, including rice husk ash (RHA), biochar, and activated carbon. RHA, in particular, demonstrates significant potential across multiple industries, especially in construction. Utilizing these agricultural by-products supports innovation in the circular bioeconomy by promoting their reuse and reducing waste, thereby enhancing sustainability and resource efficiency. [35]
Ana Torre et al. (2024)	Studies have explored the partial replacement of sand with crushed corn cob at levels ranging from 5% to 30%. The results indicated that a 5% replacement using G2 particle size achieved optimal performance, with compressive strength reaching at least 21.9 MPa. These findings demonstrate the feasibility of using corn cob as a sustainable alternative in mortar production. [36]
Bilal Messahel et al. (2023)	Research has examined the combined use of agricultural and plastic waste in construction materials. Results indicate that moderate incorporation of these wastes can enhance compressive and tensile strength, reduce material density, and improve thermal insulation. Such findings highlight the potential for using these materials in non-structural applications while also contributing to cost savings and sustainable construction practices. [31]
Krishna Biswas et al. (2022)	India generates a substantial amount of agricultural waste, estimated at approximately 400 million tons per year. These agro-wastes have significant potential for diverse applications, including as fuel, fertilizers, in nanomaterial synthesis, and in construction materials. Promoting their effective utilization can help reduce environmental issues associated with open burning and landfill disposal, thereby advancing sustainability in the agricultural and industrial sectors. [28]
Mujahid Khan et al. (2022)	Studies have demonstrated that corn cob can be used as a partial replacement for coarse aggregates in concrete. Experimental results indicated that the 7-, 14-, and 28-day compressive strengths of the modified concrete were comparable to those of conventional concrete. Based on these findings, an optimal replacement ratio was suggested to maintain both workability and structural strength. [29]
Duque-Acevedo et al. (2022)	Bibliometric and systematic analyses of Agricultural Waste Biomass (AWB) have highlighted its potential for valorization within the construction sector as part of a circular economy strategy. These studies provide valuable guidance for integrating research findings into policy development and promoting sustainable practices across industries. [30]

Beatryz C. Mendes et al. (2020)	Studies have examined the use of agricultural and industrial wastes as eco- friendly activators in alkali-activated materials. The results indicate that these wastes can achieve mechanical performance comparable to traditional binders while offering the added benefit of significantly reducing CO ₂ emissions, supporting more sustainable construction practices. [23]
K. Kochova et al. (2020)	Research on coir fiber composites has shown that untreated coir fibers can reduce mechanical strength due to weak bonding with the matrix. However, proper pre-treatment of the fibers improves the fiber–matrix interface, enhancing overall performance. This makes coir fiber composites suitable for applications such as insulation materials and panels, promoting sustainable construction solutions. [24]
S. Gunarathne et al. (2018)	The literature emphasizes the importance of resource recovery in agricultural production, advocating the use of bio-based waste in construction. Utilizing such wastes not only enhances economic efficiency but also promotes environmental sustainability, particularly in developing countries where resource management and sustainable construction practices are critical. [14]
Jerry M. Paris et al. (2016)	Various studies have summarized the use of agricultural and industrial wastes, such as rice husk ash, bagasse ash, and glass waste, as supplementary cementitious materials in concrete. Incorporating these materials has been shown to improve mechanical performance while reducing the environmental footprint of construction, promoting more sustainable building practices. [9]
Deepjyoti Das et al. (2016)	Studies have shown that the addition of coconut (coir) fiber can increase the shear strength of sandy soils by up to 21.5%. This highlights the potential of coir fibers as effective reinforcing materials in geotechnical applications, offering a sustainable alternative for soil stabilization. [10]
Evi Aprianti S. et al. (2015)	Comprehensive reviews have examined the use of industrial and agricultural wastes such as fly ash, rice husk ash (RHA), and corn cob ash as supplementary cementitious materials (SCMs) in concrete. These studies report positive effects on strength, durability, and overall sustainability, encouraging the large-scale adoption of such materials in the construction industry to promote environmentally friendly practices. [5]

A. Remarks of Literature Review

- Utilizing agricultural waste in the construction industry provides economic benefits by offering an effective method for waste management.
- Agro-wastes can be applied across various industrial sectors, depending on their physical characteristics such as size, shape, and type as well as their mechanical properties.
- The use of agro-waste as an insulating material has shown excellent performance, particularly in applications involving thermal and acoustic insulation.
- The properties of rice, including its external appearance and intrinsic characteristics, influence the type of ash produced, which in turn affects the durability and performance of the resulting concrete. [22] [8]

B. Research Gap

- In the processing of agricultural waste, careful control and precise operation are crucial. Uncontrolled processes can introduce significant impurities, which may adversely affect the hydration and performance of concrete.
- Most studies have focused on agricultural wastes such as rice husk, sugarcane bagasse ash, and rice husk ash. However, many other agro-waste materials such as corn cob, coconut fiber, and rice husk also have potential for use as partial replacements in construction materials.

III. STATE OF DEVELOPMENT

A. Compressive Test for the Rice Husk Ash 28 Days

To assess the effect of rice husk ash (RHA) on concrete performance, compressive strength tests were conducted on concrete samples with varying percentages of RHA as a partial replacement for cement. Different replacement levels were considered to identify the optimum RHA content that maximizes compressive strength while enhancing sustainability. Generally, small amounts of RHA improve concrete strength due to the pozzolanic reaction, whereas higher replacement levels can negatively affect workability and reduce strength.

Table 5 – Compressive Strength of Rics Husk Ash – 28 Days

Sr. No.	Type of Concrete	Average Compressive Strength (MPa)
1	0% RHA	30.15
2	1.5% RHA	30.79
3	3% RHA	31.3
4	4.5% RHA	31.87
5	6% RHA	32.74
6	7.5% RHA	33.23
7	9% RHA	33.67
8	10.5% RHA	34.26
9	12% RHA	34.27
10	13.5% RHA	33.63
11	15% RHA	32.81
12	16.5% RHA	31.97
13	18% RHA	30.86
14	19.5% RHA	29.89
15	21% RHA	28.67



Figure 1 Rice Husk Ash Cube Testing



Figure 2 Rice Husk Ash Cube after Test

The Figure 1 shows the experimental setup for the compressive strength test of concrete cubes containing Rice Husk Ash (RHA). A universal compression testing machine is used to apply a gradually increasing load on the concrete cube until failure. The Figure 2 shows the crushed concrete cubes after testing, which visually indicate the failure pattern of the samples.

B. Compressive Test for the Corn Cob 28 Days

For the study, corn cob replaced coarse aggregates at varying percentages, and compressive strength was tested at 28 days to determine the structural viability of the mixes. The compressive test aims to identify the optimum replacement level where corn cob can be used without significantly compromising strength, while achieving benefits such as reduced weight and increased sustainability.

Table 6 – Compressive Strength of Corn Cob – 28 Days

Sr. No.	Type of Concrete	Average Compressive Strength (MPa)
1	0% CC	30.15
2	1.5% CC	30.12

3	3% CC	29.78
4	4.5% CC	29.56
5	6% CC	28.34
6	7.5% CC	27.66
7	9% CC	27.01
8	10.5% CC	26.26
9	12% CC	25.6
10	13.5% CC	24.99
11	15% CC	24.34
12	16.5% CC	23.45
13	18% CC	22.56
14	19.5% CC	21.88
15	21% CC	21.23

IV. CONCLUSION

- The optimum replacement level of cement with RHA is 12%, achieving a 13.67% increase in compressive strength over the control mix.
- Concrete with RHA up to 15% still performs better than the control.
- Beyond 15%, strength begins to drop but remains within acceptable structural limits up to 18%.
- At 19.5% and 21% RHA, the strength falls below the control, suggesting that high RHA percentages reduce binding quality
- At 0% replacement, the average compressive strength was 30.15 MPa, which serves as the control mix.
- Up to 4.5% replacement, the compressive strength remained relatively stable, with only minor variations, indicating that the inclusion of a small percentage of corn cob aggregate does not significantly affect concrete performance.
- Corn cob aggregate can be safely used in concrete up to a 4.5% replacement level without significant loss of compressive strength.

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