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Eco-crafting: Utilizing sugar mill waste in construction innovations

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Abstract

As environmental concerns and resource depletion intensify, finding sustainable construction materials is crucial. Sugarcane Bagasse Ash (SCBA), a byproduct of the sugar industry, offers a promising alternative cementitious material. In India, approximately 44,220 tons of SCBA are generated daily, yet much remains unutilized due to limited research on its industrial availability. This study explores SCBA's potential as a partial replacement for cement, assessing its availability and integration within the current cement production infrastructure. Through field surveys and literature review, the research identifies SCBA as a largely untapped resource with significant potential for reducing the environmental impact of the construction industry. Key challenges include logistical and informational gaps in industrial use. To address these barriers, the study recommends incentivizing SCBA-focused research, enhancing industry awareness, implementing supportive policies, and investing in processing infrastructure. These measures can promote SCBA's adoption, guiding stakeholders and policymakers toward a more sustainable, economically viable construction sector.

Keywords: Cement; sugarcane bagasse ash; sugar mill; sustainability

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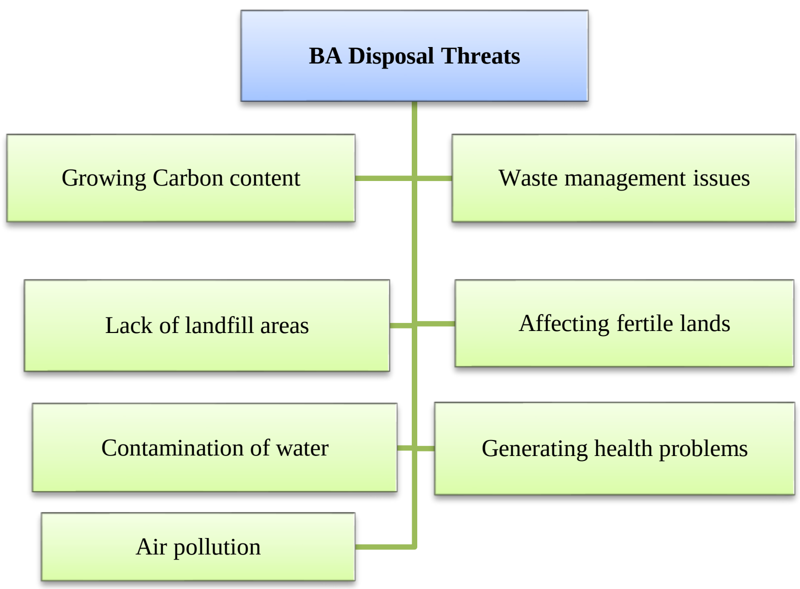
1. INTRODUCTION

With the increasing demand for conventional building construction materials and the depletion of natural resources, the construction industry faces a critical shortfall. The traditional production processes of these materials not only pose environmental hazards but also impact human health (Hu et al., 2023). Compounded by the challenges of finding suitable landfill sites due to rapid urbanization, there is a pressing need for sustainable alternatives in waste disposal methods (Khumla et al., 2024). The utilization of incinerated bagasse ash, a byproduct of sugarcane industry waste, can be a valuable engineering construction material (Beheshti et al., 2024).

If not properly disposed of, industrial waste poses a serious threat to both the environment and public health (Roy Choudhury & Chakraborty 2023). "Bagasse," the fibrous waste left over from crushing and extracting the juice from sugarcane, is one of the most common agricultural byproducts worldwide (Abdollahi Moghaddam et al., 2023). While bagasse is commonly utilized as biomass fuel for boilers, the byproduct left after burning is often inadequately disposed of into rivers, resulting in detrimental effects on human health, the environment, fertile land, and water sources. The study delves into the potential uses of sugarcane bagasse ash waste in construction, exploring sustainable solutions to the dual challenges of waste management and resource scarcity in construction. Figure 1 displays problems associated with the disposal of bagasse ash.

Figure 1

Problems associated with the disposal of bagasse ash



Source: Sakib et al. (2023).

Governments and other regulatory authorities around the world have been trying to reach a practical solution to the ever-increasing solid waste, pollution, and energy demand problems. According to the information given by India in its Third Biennial Update Report (BUR), which was submitted to the UNFCCC on February 20, 2021, the building and construction industry is responsible for 32% of the nation's total inventory of greenhouse gas emissions, which includes both operational and embodied emissions. The Reserve Bank of India (RBI), in a recent report, advocated the adoption of technology, such as carbon capture, to contribute to India's net-zero carbon emission target. The Reserve Bank of India promoted low-interest loans, proactive outreach to premier research institutes, and collaborations with countries setting the standard for green technology-related innovation in the cement industry as a means of augmenting financing for environmentally friendly, sustainable solutions. India is the second-biggest cement producer in the world, behind China. India declared net-zero carbon emissions by 2070 at the Glasgow Climate Summit in November 2021.

Understanding the effects of growing cement production on the environment is a crucial aspect of this investigation, as it is a major cause of excessive greenhouse gas emissions. As industries interconnect and influence one another, addressing the environmental toll of cement production requires an innovative perspective. Eco-crafting emerges as a promising avenue, suggesting that the integration of sugar mill waste into construction practices could be a pivotal element in the broader strategy for sustainable industrial ecosystems.

Like cement, the sugar sector in India is the second largest in the world. The utilization of cogeneration boilers in sugar mills represents an efficient and sustainable practice in the sugar industry. These boilers leverage the leftover stem portion of harvested sugarcane, known as bagasse, as a primary fuel source. The process involves burning bagasse to produce steam, which is then used to generate electricity. However, the residual ash that remains in the boilers after the combustion of bagasse is referred to as sugarcane bagasse ash (SCBA). Sugarcane Bagasse Ash (SCBA) is increasingly being recognized as a valuable supplementary cementitious material due to its pozzolanic properties. There are several applications and benefits of using Sugarcane Bagasse Ash in cement construction.

1.1. Conceptual background

India has humorous sugarcane industries that eliminate vast amounts of sugar mill waste which many times dispose of in the form of ash directly. Traditional materials like cement and clay bricks are economically burdensome and environmentally harmful, necessitating the exploration of sustainable alternatives. Disposal of waste, including burning and direct release of hazardous ash into water sources, raises environmental concerns, requiring effective waste management solutions.

Considering the above problems, there is a need to explore the recycling and utilization of sugar mill waste in construction practices. Utilizing recycled sugar mill waste in construction materials aims to bring about positive change in the construction industry, offering environmentally friendly alternatives and addressing disposal problems.

1.2. Purpose of study

This research aims to bridge this knowledge gap about bagasse ash's accessibility in India. Additionally, it examines the economic and environmental benefits associated with utilizing sugar mill waste in construction. The reduction of waste disposal costs and carbon footprint, coupled with the potential for local economic development, highlights the broader positive impacts of this eco-crafting approach. In the latter portion of the study, a strategic framework for the efficient use of bagasse ash in the Indian construction industry is built and explained. The objective of this study is to:

i. To minimize the environmental impact of sugar mill waste by recycling and repurposing it in construction applications.

ii. To conserve natural resources by substituting conventional construction materials with sugar mill waste, promoting sustainable resource use.

iii. Ensure the safe and responsible disposal of sugar mill waste, minimizing environmental and health risks associated with its handling.

iv. Advocate for the adoption of sugar mill waste in construction innovations to enhance eco-friendly practices and contribute to the development of green building solutions.

v. To decrease the carbon footprint associated with construction activities by adopting materials with lower embodied carbon.

2. MATERIALS AND METHODS

This study employs an experimental research design to investigate the potential applications of Sugarcane Bagasse Ash (SCBA) as a sustainable construction material. A multi-phase approach is applied to analyze SCBA's properties, examine its feasibility as a replacement material in cement-based construction applications, and evaluate the performance of SCBA-incorporated materials through various tests.

The primary material used in this study is Sugarcane Bagasse Ash (SCBA), obtained from sugar mills where bagasse, a sugarcane byproduct, is incinerated to generate biomass energy. The SCBA samples were collected from sugar mills in Maharashtra, India, as this region has a high concentration of sugarcane production and processing industries. After collection, the SCBA was dried at 105–110°C for 24 hours to remove any residual moisture and then incinerated in the laboratory at temperatures ranging from 600 to 800°C to produce ash with suitable pozzolanic properties.

3. RESULTS

The use of sugar mill waste, specifically Sugarcane Bagasse Ash (SCBA), in construction innovations presents a sustainable approach to repurposing industrial byproducts. Here's a detailed exploration of how SCBA can be utilized in various construction applications:

3.1. Partial cement replacement

Sugarcane Bagasse Ash (SCBA) is employed as a sustainable alternative to partially replace cement in concrete mixtures. The process begins with the collection of sugarcane bagasse, a byproduct from sugar mills. Through controlled incineration, the bagasse is transformed into ash (SCBA). The incineration temperature is closely monitored to maintain the pozzolanic properties of SCBA. Rigorous quality control measures are implemented to ensure the ash's suitability, involving tests for chemical and physical properties. Tests may include X-ray fluorescence (XRF) for elemental analysis and X-ray diffraction (XRD) for mineralogical composition. Figure 2 displays the steps included in fine sugarcane bagasse ash.

Figure 2

Steps included in Fine sugarcane bagasse ash

Source: Yadav (2019).

Mix design trials are then conducted to determine the optimal percentage of SCBA that can replace traditional cement while maintaining the desired concrete properties. Partial replacement typically ranges from 10% to 30% of the cement content. During concrete mixing, SCBA is added to the mixture, and the batch undergoes thorough blending to achieve a uniform distribution. The subsequent curing and setting processes ensure proper hydration and strength development of the cementitious materials, including SCBA. Comprehensive testing, including compressive strength evaluations, contributes to refining the mix design for optimal performance. This innovative approach not only maximizes the utilization of a waste byproduct but also mitigates the environmental impact associated with cement production by reducing carbon emissions.

3.2. Sustainable mortars

The incorporation of Sugarcane Bagasse Ash (SCBA) in the production of sustainable mortars involves a meticulous process aimed at enhancing innovation and environmental sustainability in construction. The process commences with the collection of sugarcane bagasse, a byproduct from sugar mills, followed by controlled incineration at temperatures typically ranging from 600 to 800ºC. This transforms the bagasse into high-quality SCBA. Rigorous testing procedures, including chemical composition analysis and evaluation of physical properties such as particle size distribution, ensure the quality and suitability of SCBA for mortar production. Subsequent mix design studies define the proportions of SCBA, cement, aggregates (typically sand), and water in the design mix to achieve the desired properties of sustainable mortars. The mix is assigned a specific grade based on factors such as compressive strength, setting time, and durability, ensuring compliance with industry standards. Key parameters like incineration temperature, setting time, and the percentage of SCBA replacement are carefully controlled during production, with trial testing aimed at finding the optimal balance between sustainability and structural integrity. The final sustainable mortars undergo standard curing processes to attain the necessary structural strength and durability, resulting in an eco-friendly alternative that maximizes the utilization of a byproduct and minimizes environmental waste.

3.3. Lightweight concrete

In the production of lightweight concrete using sugar bagasse ash or sugar mill waste, the material selection involves choosing appropriate lightweight aggregates or fillers based on their density and particle size distribution. The production of lightweight concrete with Sugarcane Bagasse Ash (SCBA) involves a thorough process to harness its potential to reduce structural weight. Initially, Sugarcane bagasse ash contains some moisture which can be removed by heating at 105–110°C for 24 h in a few studies and incinerating at 600–800°C for 4–6 h. Low specific gravity was influenced by the presence of unburned carbon particles. The study of proportions and material characteristics is then undertaken to determine the optimal mix design for lightweight concrete. The mix design is a critical step, determining the proportions of lightweight materials to achieve the desired reduction in concrete density, typically targeting a range of 15% to 25% lighter than conventional concrete.

During the concrete mixing phase, SCBA is carefully incorporated into the mixture, ensuring a uniform distribution throughout. The resulting lightweight concrete offers advantages in applications where a reduction in structural weight is desirable, such as in precast components and specific building structures. The reduced density of the concrete not only facilitates ease of handling during construction but also contributes to energy savings in transportation and construction processes. Thorough testing and quality control measures are implemented to ensure the lightweight concrete meets the required strength and durability standards. This innovative use of SCBA in lightweight concrete aligns with sustainable construction practices, offering a promising solution for projects that prioritize both structural integrity and environmental impact.

3.4. Construction blocks and panels

Incorporating Sugarcane Bagasse Ash (SCBA) into the production of construction blocks or panels involves a multi-step process to ensure both the quality and sustainability of the resulting materials. The journey begins with the collection of sugarcane bagasse, a byproduct obtained from sugar mills, followed by its controlled incineration. This incineration process is carried out at elevated temperatures, typically around 600-800ºC, to produce high-quality SCBA. Rigorous testing ensues to assess the chemical composition of the ash, identifying elements present and ensuring compliance with quality standards. Particle size analysis is also conducted to determine the distribution of particle sizes in the ash. Figure 3 displays the utilization of sugar mill waste in the manufacturing of bricks.

Figure 3

Utilization of sugar mill waste in the manufacturing of bricks

Source: Kishore et al. (2019).

Once the SCBA passes quality assurance checks, mix design studies are undertaken to optimize the structural and thermal properties of the construction blocks or panels. The percentage of SCBA in the mix is carefully determined through trials, considering factors such as time of setting, compressive strength, and thermal conductivity. In the subsequent stages of production, SCBA is seamlessly integrated into the material mix, ensuring uniform distribution during the manufacturing of blocks or panels.

The manufacturing process involves additional components, including cement, aggregates (sand and gravel), and water. Standard curing and setting processes are applied to allow the blocks or panels to achieve the desired structural integrity. Subsequently, the finalized products undergo a series of tests, including compressive strength tests and thermal conductivity tests, to evaluate their performance. Visual inspections and dimensional checks are conducted as part of quality control measures to ensure the blocks or panels meet industry standards.

This innovative application of SCBA in construction blocks or panels not only provides sustainable alternatives to traditional building materials but also maximizes the use of a byproduct that would otherwise be discarded. The optimization of structural and thermal properties contributes to eco-friendly construction practices and supports the creation of efficient and resilient structures (Wang et al., 2024).

4. CONCLUSION

The eco-crafting approach to the utilization of sugar mill waste in construction innovations presents a compelling solution to India's environmental challenges. With an annual production of 75-90 million tons of bagasse waste, the country possesses a vast and renewable resource that can be harnessed for sustainable construction practices. By incorporating these waste materials into various construction applications, the research not only addresses the issue of waste management but also contributes to the reduction of carbon emissions and the overall environmental impact of the construction industry.

This paradigm shift towards eco-crafting signifies a holistic approach, emphasizing regional integration and localized solutions tailored to the concentration of sugar mills. The study calls for collective action and the widespread adoption of these innovative practices to pave the way for a more eco-friendly and resilient construction sector in India.

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