CULTIVATING SUSTAINABLE CONSTRUCTION: TRANSFORMING AGRO-WASTE INTO VALUE-ADDED SOLUTIONS

Abstract

Rapid growth of construction industry and its impact on the environment have necessitated the exploration of sustainable and eco-friendly alternatives to conventional building materials. By-product of agricultural practises referred to as agro-waste has gained popularity as a resource for making building materials. This paper presents an overview of the use of agricultural waste in the production of building materials, highlighting the advantages, difficulties, and prospective effects on the construction industry. The development and implementation of such materials could revolutionize the construction industry, making it more environmentally friendly, resource-efficient, and economically viable in the pursuit of a greener and more sustainable future.

Keywords: Agricultural waste; sustainable material; environmentally friendly; eco-material; construction industry.

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I. INTRODUCTION

A nation's economic development depends on the construction and agricultural sectors. Both significantly influence the employment creation and the standard of living for the people. Although, both areas are major consumers of natural resources and producers of harmful emissions due to the development of these sectors [1, 2]. One of the major issues facing these sectors is the generation and handling of agro-waste. Agro-waste materials, also known as agricultural waste materials or agro-residues, are the by-products generated during various agricultural processes that are not used for human consumption or animal feed. These residues are discarded after harvesting crops or during post-harvest operations. They have conventionally been considered as waste with little economic value. However, with advancements in technology and increasing environmental concerns, researchers and industries have started exploring the potential of utilizing agro-waste to develop sustainable and eco-friendly materials.

Agricultural waste is a major environmental pollutant. It is estimated that the India's production of solid waste is over 100,000 metric tons per day [3]. This waste can contain a variety of pollutants, including heavy metals, organic pollutants, and dyes. These pollutants can have a negative impact on the environment, including contaminating water supplies, harming aquatic life, and causing health problems in humans. The Sustainable Development Goals (SDGs) featured in the 2030 Agenda for Sustainable Development (Agenda 2030) comprise some of the 15 SDGs, including SDGs 11 and 12, which encourage sustainable and circular production and consumption. One of the key goals is to reduce waste [4].

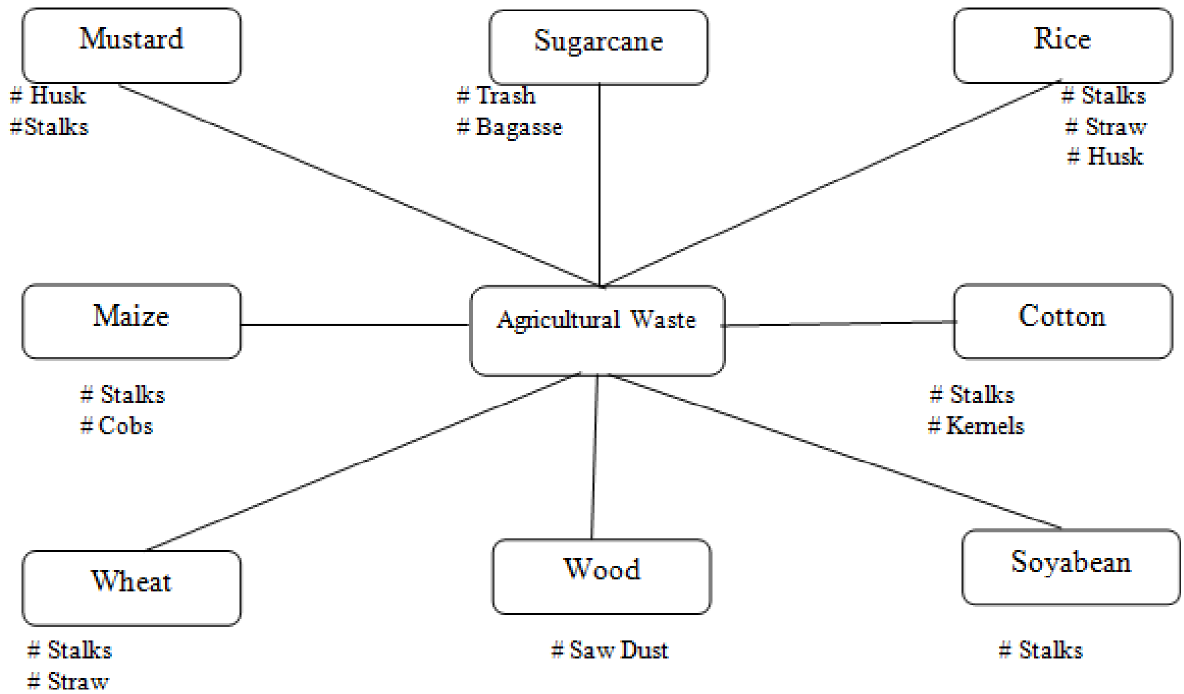

Figure 1: Varieties of Agricultural Residues

In developing countries, it is critical to properly dispose of agro-waste. This type of waste includes coconut shells, wheat husks, sugarcane bagasse, and rice husks and represented in Figure 1. In India, for example, it is estimated that more than 600 million tonnes of agricultural waste are produced each year [5]. As agricultural practices have intensified in recent years, this amount is expected to increase. The most common methods for disposing of agro-waste are dumping, incineration, and composting. However, these methods have serious adverse effects on the environment [6]. Dumping can pollute waterways and soil, while incineration releases harmful pollutants into the air. Composting can also release pollutants, and it can be a slow and inefficient process. There are a number of alternative methods for disposing of agro-waste that are more environmentally friendly. These methods include using agro-waste to produce biogas, ethanol, and other fuels; using it to make building materials; and using it to create biochar, which can be used to improve soil quality. It is important to develop and implement sustainable methods for disposing of agro-waste in developing countries. These methods will help to protect the environment and improve the health and well-being of people living in these countries [7, 8]. The recent research efforts have demonstrated that agro-waste can be used to provide a feasible solution to the problems outlined.

II. INNOVATING CONSTRUCTION MATERIALS THROUGH AGRO-WASTE UTILIZATION

This section delves into the exploration of diverse construction materials derived from agro-waste resources.

1. **Agro-Wastes Used in Bricks:** The construction sector uses agro-wastes to minimize the ecological effect of waste dumping in landfills, which also minimizes the pollution created by the traditional building materials like cement. Agro-wastes including rice straws, peanut shells, and coconut shells etc. have partially replaced the sand used to make cement blocks [9]. In terms of product strength, the use of agro-wastes in the production of blocks complies with ASTM criteria. Additionally, it has been determined that using agro-wastes as construction materials is allowed and can support in achieving the sustainability objectives. Simultaneously, it minimises pollution and other negative impacts [10-19].

   According to experiments conducted in 2016, it is feasible to produce bricks using coffee waste. Coffee waste ratio and temperature were the experimental variables. Also, Compressive strength and shrinking density were taken into consideration. This approach involved manufacturing and firing at 1050 ^{0}C three different percentage (1%, 3%, 5%) of coffee waste bricks. Shrinkage, density, and compressive strength were recorded and discussed in addition to fundamental properties. Also, the toxicity characteristics leaching process was used to examine the leaching of heavy metals from the brick. It was observed that the shrinkage increased linearly with the addition of coffee waste within the acceptable range of 8% and high-quality brick was produced. Therefore, the coffee waste might have a potential low price waste additive and different proportion of coffee waste can be used to produce fire clay bricks and providing alternate solution on discarding of coffee waste [20].

   The outer protective layer that shields the rice grains is called rice husk. It burns to generate rice husk ash, which has a high silica concentration. Rice husk ash is a good binder to boost the strength and durability of bricks because silica holds particles together when bricks are being formed. Rahman, Muntohar, Pakrashi, Nagaratnam, Sujan have been investigated on the use of rice husk ash in the production of self-compacting concrete [21]. In an another study, Kazmi, Abbas, Munir, Khitab employed sugarcane bagasse and rice husk ash for the manufacturing of bricks by integrating 5% sugarcane bagasse ash and rice husk ash by clay weight [22]. The results revealed that as more amounts of sugarcane bagasse and rice husk were added to the clay-burned bricks, the compressive strength and rapture modulus of the bricks declined. The developed bricks were found to be minimal weight. As a result building's structural load will be reduced. Further, the study also indicated that developed bricks were weather resistance, and sugarcane bagasse ash and rice husk ash also improved their efflorescence resistance.

Researchers mixed wine wastes such as grape seeds, stalks, and wine lees with clay to produce lightweight bricks [23]. The researchers altered the proportion of Wine wastes and assessed the bricks that were produced. Based on the research, it was determined that the flexural strength and the density of the bricks were reduced based on the proportion of wine wastes used. These bricks have highest mechanical physical properties. Also, Researchers claimed that the increased porosity of the bricks resulted in a corresponding increase in their light weight and thermal insulating qualities, making them suitable for use in green buildings [23].

In 2018, De Silva and Perera conducted a comprehensive study investigating the influence of rice husk ash on the structural, thermal, and acoustic properties of fired clay bricks [24]. The research involved incorporating six different proportions of rice husk ash waste (0%, 2%, 4%, 6%, 8%, and 10%) with clay in their experiments. Properties comprising the chemical composition of material, distribution of particle sizes and Atterberg's limits, compressive strength, thermal and acoustic behaviour were observed. The findings revealed that the most favorable brick characteristics were achieved with a 4% rice husk ash blend, showcasing remarkable compressive strength of 3.55 N/mm²—32% higher than conventional clay-fired bricks—and exhibiting a notable water absorption rate of 19%. Moreover, these bricks demonstrated a noise reduction of 10 dB and improved indoor temperature regulation by 6°C compared to conventional clay bricks.

In 2017, a study by Deraman, Abdullah, Shahidan, Nagapan, and Hamzah, the effects of incorporating coconut fiber and empty fruit bunch as pouring agents in clay brick production were investigated [25]. Three different concentrations of wastes (0%, 5%, and 10%) were combined with clay, and the physical and mechanical properties of the bricks were assessed. The outcomes revealed that a 5% concentration of empty fruit bunch exhibited superior properties in terms of compressive strength, water absorption rates, and thermal conductivity compared to other concentrations.

2. **Agro-Waste Used in Concrete:** In construction sector, concrete is also extensively employed. The production of concrete by employing agro-wastes has received the greatest attention from researchers. Ash and fibres from agro-waste have been studied for use as a partial substitute for cement and aggregates. The effects of employing agro-waste materials on the strength, thermal characteristics, and durability of concrete are discussed in this section.

The economic effectiveness of novel technology in a sustainable construction must be understood and interpreted correctly. He, Kawasaki, and Achal in 2020 studied the economics of making concrete that contains agricultural wastes [26]. Therefore, attempts have been made to exploit various agro-wastes integrated with concrete as sustainable materials. Further, Rao and Prabhat conducted a study to investigate the influence of partially substituting sugarcane bagasse ash for cement in concrete production [27]. They used five different concentrations of SCBA: 0%, 5%, 10%, 15%, and 25%. In order to achieve specific surface area of 4716 cm2/gm. They first pulverised the sugarcane bagasse ash to a size of below 90 µm sieve. Prescribed ratio of ash was used in place of Portland cement. The ratio of Water to cement was kept at 0.42. The mechanical properties of dried concrete, including flexural strength, split tensile strength, and compressive strength, were assessed at 7, 21, and 90 days. The cement mixture containing 10% sugarcane bagasse ash produced best results.

In 2013, Modani and Vyawahare conducted a similar study to explore the effects of partially replacing fine aggregate with sugarcane bagasse ash (SCBA) in concrete production. They used five different proportions of SCBA: 0%, 10%, 20%, 30%, and 40%. The water-to-cement ratio was kept at 0.40 and the superplasticizer dose was kept at 0.8%. The casted concrete samples were allowed to dry in standard laboratory atmosphere. Tensile strength, sorptivity test, and compressive strength were examined over periods of 7 and 28 days. The results revealed that the sample with 10% of replaced sugarcane bagasse ash achieve best result in terms of compressive strength. The experiments also revealed that the sorptivity and tensile strength reduced as the level of sugarcane bagasse ash was increased.

The best quality bricks were obtained at 10% sugarcane bagasse ash ratio is a notable similarity between the two studies. Therefore, it may be concluded that high-quality concrete could be produced with a very small amount of agro-waste. In contrast, Rao and Prabath substituted sugarcane bagasse ash with amount of cement, whereas Modani and Vyawahare replaced sugarcane bagasse ash with volume of fine aggregate in concrete [27, 28]. This was the first of several variances that were discovered. In contrast, Modani and Vyawahare conducted the drying process for concrete only at two time periods: seven and twenty-eight days. On the other hand, Rao and Prabath extended the drying period to three distinct time intervals: seven, twenty-eight, and ninety days [27, 28]. The economic impact of employing agricultural waste in the manufacturing of concrete is significantly impacted by the two distinctions. Due to the fact that they show sugarcane bagasse ash can be utilised to replace both fine aggregates and cement. It is also necessary for building industry practitioners who profit from such expertise.

One of the innovative cements that has attracted the cement industry's interest in recent years is magnesium oxysulfate cement. It comprised of fixed concentration of $MgSO_4$ and active MgO. Good temperature resistance, Low power consumption, and low thermal conductivity are the main properties [29]. Many scientists have shown keen interest in employing magnesium oxysulfate cement to recycle the fly ash in recent times [30, 31]. To optimize the utilization of forest waste, composites were prepared by mixing locust powder with 0-25% of MgO by mass and then dried for both 3 days and 100 days. The maximum dosage of locust powder was determined to be 25% based on the fluidity of the composites. Investigations were conducted on microstructure, mechanical characteristics, and water resistance of the composites [32, 33].

3. **Agro-Wastes Used in Insulation Materials:** The production of construction insulation materials by employing agro-wastes has received the greatest attention from researchers. Asdrubali, D'Alessandro, and Schiavoni in 2015, have been reported that construction insulating materials made from natural resources [34]. The study discovered that a broad range of agro-residue materials have been utilised for the production of thermal insulation products. Some of them were very popular in use such as straw, wood, flax, hemp, and coconut. The occasionally employed residues were sisal, reed, grass, and pineapple [35].

   A study was investigated by Rojas, Cea, Iriarte, Zaldés, Navia, and Cárdenas-R in 2019, have been observed the production of construction insulation materials by employing widely implemented agricultural residues such as corn husk and whe at straw [36]. The Taguchi technique was used in an L-9 orthogonal array to investigate the effects of four control variables (NaOH concentration, fiber length, blending time, and boiling duration) on the thermal conductivity, density, flexural strength, and compressive strength of blocks. The research findings indicated that the thermal conductivity of the composites fell within the range of 0.046 W/mK, while the flexural strength was found to be notably strong. Interestingly, the incorporation of linseed oil as a flame retardant showed promising results in preventing flame propagation and subsequent composite degradation. Moreover, a comparative analysis between wheat and barley straw-based composites revealed that barley-based composites exhibited milder fire behavior compared to their wheat counterparts [37]. This study highlights the potential of using wheat and barley straw fibres in the production of lightweight composites for construction insulation, where the Taguchi technique provided valuable insights into optimizing the control variables to achieve desirable material properties. The effective flame-retardant properties of linseed oil could contribute to enhancing the fire safety performance of such composites in various applications.

   Composite materials were made by mixing rice straws, a foaming agent, and a magnesium cement adhesive. Thermal and mechanical characteristics were examined on these composites blocks by Wang, Zuo, Xiao, Li, and Wu [38]. The results revealed that after mixing the straw with 3% sodium hydroxide for 150 minutes, the composite block's mechanical characteristics reached their peak value. Also, the composite block was light in weight, incombustible, and offered thermal insulation.

   The practical uses of insulating products made from agricultural waste are discussed. In order to demonstrate their effectiveness and applicability, case studies and examples of their application in construction projects are presented. Consequently, it can be inferred that those working in the construction sector have a variety of options for improving the sustainability of thermal insulation construction materials.

4. **Agro-wastes Used in Reinforcement materials:** In order to strengthen buildings and other structures, the worldwide construction industry has long depended on traditional materials like steel and concrete. However, there is growing interest in looking into alternative materials that can minimise the environmental impact of building due to concerns about environmental sustainability and the depletion of natural resources. A

feasible alternative to conventional reinforcement materials is the utilisation of agro-wastes, which is a promising strategy. Researchers have recognized the possibility of converting agricultural waste into sustainable building materials, including reinforcement components. In the research conducted by Pacheco-Torgal and Jalali [39], it was demonstrated that vegetable fibers play a crucial role in enhancing the durability and properties of cementitious materials. The study further revealed that a diverse range of plant fibers, such as bamboo, sisal, coconut, and hemp, can effectively serve as reinforcements for cement-based products.

According to Sharda, Singh, and Singh, Fiber proved to be a successful substitute for steel bars in reinforcement applications in concrete [40]. They stressed the need for prudence and competence in the implementation of the fiber. In order to make hybrid polypropylene bio-composites for building materials, Guna et al. examined the utilisation of untreated rice husk and groundnut shell [41]. The study results showcased favorable outcomes for the reinforced products, exhibiting commendable tensile and flexural strength. The maximum recorded values were 15.6 MPa and 37.6 MPa, respectively. Additionally, the maximum sound absorption coefficient attained an impressive value of 0.48, while the thermal conductivity ranged between 0.156 and 0.270 W/mK.

In a closely related study, Hassan, Oghenevweta, and Aigbodion investigated the morphological and mechanical properties of carbonized maize stalk. This material was utilized as a reinforcement in polyester composites, contributing to the production of eco-friendly materials [42]. The generated products were examined to evaluate the effect of various proportion of carbonized maize stalk ash. According to the findings, as the content of maize stalk ash increased, the compressive strength, tensile strength, and elastic modulus of the composites showed proportional improvements. However, there was a steady reduction in the impact strength with the increasing amount of maize stalk ash. The outcomes suggested that carbonised maize stalk might be employed to improve polymer matrix products used in construction and automotive industries.

The geopolymer compounds have weak tensile and bending strengths, which makes them brittle and ceramic in nature. In 2011, Natali, Manzi, and Bignozzi studied the practise of fiber to reinforce them. The results demonstrated that both inorganic and organic fibres improved the flexural strength of the geopolymers. Also, geopolymers were found to boost their strength. Further, research was carried out by Saxena, Morchhale, Asokan, and Prasad, on the possibility of replacing traditional wood products with reinforced polymer composites [43]. The results demonstrated that composites made from natural fiber or industrial wastes achieved excellent mechanical characteristics and were also resistant to fire, chemical attack, abrasive wear, and water absorption. The researchers also claimed that the technological viability of composite materials made of plant fiber and industrial residues polymers allowed them to potentially replace wood by saving money and energy.

III. BENEFITS AND DRAWBACKS ASSOCIATED WITH AGRO-WASTE

There are two primary categories for the benefits of using agricultural waste in the production of building materials. Firstly, recycling agricultural waste that would otherwise be disposed in the environment. Secondly, use of the agro-waste materials in the actual development of construction resources. Recycling of agro-waste in the production processes provides considerable benefits since it reduces pollution problems associated with traditional disposal methods like composting, incineration, and landfilling [45]. Research discovered that various agricultural operations produced considerable amounts of waste that posed difficulties in disposal and efficient management. More than 600 metric tonnes (MT) of residues from agro-based items has been recorded in India. Since, smaller amounts of waste items need to have discarded, recycling the waste materials indicates that less resources are required to handle agro-waste activities. Agro waste products can be used in place of conventional resources like sand, gravel, or wood in order to preserve natural resources and minimise the exploitation of non-renewable materials. Several agricultural waste products, such straw and rice husk ash, have good thermal and acoustic insulation qualities, which improve building energy efficiency and acoustic comfort. To ensure a product's widespread adoption in the industry, aspects like product performance, durability, and long-term sustainability must be taken into account. To maximise the advantages of these materials and encourage their usage on a greater scale, proper research, development, and quality control are essential.

While there are many benefits to employing agro-waste in the production of building materials, there are also some potential drawbacks and difficulties to be taken into account. Some agro-waste products, especially those with a high level of organic matter, may be prone to moisture absorption, which over time could result in swelling, warping, or deterioration. In construction applications where fire protection is crucial, certain agro-waste products may only have a limited ability to resist fire. When compared to traditional building materials, some agro-waste materials could not be as durable or long-lasting. When designing and applying them, designers must carefully take into account factors including susceptibility to decay, insect infestations, and moisture absorption that may affect their service life. Building codes and regulations may need to be followed in order to incorporate agro-waste products into construction, and they may not always take non-traditional resources into account. It might be difficult and time-consuming to get certifications and approvals. Although using agro-waste materials in construction has many advantages, there are also some restrictions and difficulties that must be resolved through research, development, and standardisation activities to enable their safe and efficient integration into the construction sector.

IV. CONCLUSIONS

Agro-waste can be converted into sustainable building materials, which has a number of advantages for addressing environmental issues and advancing sustainable development. The following conclusions can be drawn after examining the information accessible up to 2022:

1. Agro-wastes are prevalent and frequently seen as waste, which causes disposal and environmental problems. We can minimise their environmental impact and keep them out of landfills and burning, both of which can emit hazardous emissions, by using these agricultural wastes as building materials.
2. The basic materials for construction can be sourced from agro-wastes, which are renewable and inexpensive. Utilization of these materials in place of more traditional resources like sand, gravel, or wood can help to protect natural resources and decrease the depletion of non-renewable materials.

3. It may be possible to reduce the carbon footprint of conventional building materials by using agricultural waste in construction materials. Some of the emissions produced during the manufacture of cement and other energy-intensive construction procedures can be partially mitigated by sequestering carbon in these materials.
4. Agro-waste-based sustainable building materials have outstanding moisture-regulating and thermal-insulating qualities. They can assist to produce cosy and healthy living spaces and improve the energy efficiency of buildings.
5. Construction materials made from agricultural waste can open up business prospects in rural areas where agriculture is a major industry. It may result in the development of new industries, the creation of jobs, and increased income for the farmers and nearby towns that are a part of the supply chain.
6. Governments and stakeholders in the construction industry must encourage agro-wastes based construction materials through rules and regulations. Building codes, incentive programmes, and certification programmes that promote the use of sustainable materials might accelerate the implementation of those materials into conventional construction methods.

In conclusion, the manufacturing of sustainable building materials from agricultural wastes offers a practical solution to address environmental issues, enhance resource efficiency, and promote a greener building sector. To fully realise the potential of agro-waste materials and assure their widespread acceptance in the building industry, further research, innovation, and supportive legislation are required.

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