# Development of Sustainable Brick Materials Incorporating Agro-Wastes: An Overview

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**Abstract -** *Bricks are one of the most common masonry unit that dates back to the 7000 BCE. Since then many modifications has been discovered in the brick compositions and brick making procedures. Now-a-days, bricks are considered to be one of the most accommodating building materials in construction of various structures. Conventional bricks that are commonly used are prepared using either clay or cement concrete. But the vast application of the bricks in construction industry has resulted in the depletion of natural resources and lead to consumption and emission of high energy. This also results in environment shortcomings like carbon footprint. Many researches are being conducted to develop alternative brick materials from various types of waste materials thus protecting the environment and contributing towards sustainable development. This review paper explores the potential application of agricultural wastes as an ingredient in alternative brick material for manufacturing bricks. The incorporation of sugarcane bagasse ash (SBA) and rice husk ash (RHA) as a sustainable brick material in the brick composition is reviewed in detail. Utilization of agro-wastes in the production of bricks is a solution to pollution and landfilling problems, helps in reduction of high cost of building materials and leads to achieving the goal of developing a sustainable building material.*

***Key Words***: Agricultural wastes, Carbon footprint, Masonry, RHA, SBA, Sustainable.

## 1. INTRODUCTION

Bricks are considered to be one of the most significant ancient building material in the construction industry. Due to increase in population a rapid increase in the demand for construction building materials has occurred. In order to meet the needs of the increasing housing demand, there is an exponential need for the production of masonry bricks. The traditional brick making procedure includes the mixing of raw materials (earth-based materials), molding of bricks, drying and then firing them until they obtain the required strength. Now-a-days cementitious materials such as ordinary Portland cement, fly ash etc are used for the production of concrete bricks. The excessive usage of the earth materials that are utilized for production of fired bricks results in massive depletion of the natural resources and also high energy consumption. These bricks are also responsible for serious environmental degradation due to the high greenhouse gas emissions. On the other hand, the concrete blocks are considered to be environmentally un-friendly, where they consume large amount of energy and also emit $CO_2$ and other greenhouse gases.
By giving adequate attention to the use of appropriate building materials, effective solutions to the above problems can be developed. Incorporation of industrial and agricultural waste materials in brick production is an efficient method to diminish the environmental pollution, reduce the amount of generated wastes and protect the raw materials from depletion. Researchers are conducting investigations on alternative brick materials and thus contributing to sustainability and more eco-friendly approaches in brick production by utilizing various types of agro-waste materials.

The disposal of solid waste generated from agricultural industries is another serious problem that is faced by developing countries like India. The major quantities of wastes generated from agricultural sources are sugarcane bagasse, rice husk, jute fibre, coconut husk, cotton stalk, etc. Reuse of these wastes as a sustainable construction material appears to be viable solution not only to pollution problem but also to the problem of the land-filling and high cost of building materials.

In this review paper, different research updates on the utilization of RHA and SBA to produce brick materials are presented in detail. The mechanical and physical properties of these bricks incorporating agro-wastes are highlighted. SBA and RHA are agro-wastes that are generated in many parts of the world. Sugarcane bagasse is the waste obtained after processing the sugarcane to extract its juice. Bagasse is then used as fuel and about 0.26 million tons of SBA is generated annually. Rice husk is the outer cover of rice kernel, which have two interlocking halves. Rice husk is commonly used as fuel in brick and paper industry and after the combustion RHA is produced. In present situation, there is no proper solution for the disposal of these wastes, thus resulting in environmental problems and scarcity of landfill sites. Therefore, utilization of agrowastes in production of bricks can be helpful to overcome environmental related and landfilling issues, leading towards sustainable and economical solution.

### 1.1 Study on application of agro-waste for sustainable construction material

Madurwar et al (2013), in their paper explores the potential application of agro-wastes as an ingredient for alternate sustainable construction materials. The development of construction materials like particle boards, thermal insulated walls and ceiling panels, masonry composites and cementitious materials, fibre reinforcement etc from agro-wastes were reviewed. The researchers have used various agro-waste materials in different proportions and also adopted various methodologies to produce different building materials. Several thermo-mechanical tests were conducted on different materials and composites as per the various available standards. The common test parameters calculated was water absorption and compressive strength. It was observed that construction products produced from various agro-waste materials were comparatively cheaper, had lower thermal conductivity and are durable, lightweight and environmental friendly compared to the conventional one. The application of agro-wastes and its by-product as a raw material is of practical significance for developing material components as substitutes for traditional construction materials and are environmental friendly.

Liuzzi et al (2017), focused on the application of bio-based insulation materials that helps to minimize the evironmental impacts of the buildings thus reducing the energy demand during the construction and use. Environmental issues such as pollution and energy consumption has lead the construction field to focus on thermal insulation products. It was stated that the commonly used insulation materials were non-renewable which resulted in the depletion of the natural resources. Researchers discovered that the agricultural waste materials has the potential to act as insulation material in construction works. The behaviour of cereal straw, hemp and olive waste as insulation materials were studied in detail. The dumping of these waste in landfills, reduced the available dumping site area and also caused pollution. Recycling of these waste into sustainable, energy efficient construction materials was found to be a suitable solution for the problem of pollution and natural resource conservation for future generations.

### 1.2 Study on agro-waste bricks

Chee-Ming Chan (2011), examined the physical and mechanical properties of clay bricks which were casted by adding two natural fibres. It was reviewed that though the clay bricks are popular in the construction industry due to its versatility and low cost, it highly effect the environmental and sustainable values. At the same time, agro-based industries are rapidly growing thus resulting in large quantities of agricultural wastes that are not well managed or utilised. He studied the recycling of agro-waste by retrieving the fibres of pineapple leaves and oil palm fruit bunch and then adding in brick making. This way green brick materials were developed, that lead to reutilisation of natural wastes, avoiding wasteful landfill and harmful open incineration. Cement was added as a binder in the bricks and both non-baked and baked bricks were prepared. Cement was found to dominate the compressive strength of the bricks. Also the non-baked bricks disintegrated when submerged in water, while the baked ones displayed cement-dependent characteristics in water-absorption and density changes.

Eliche-Quesada et al (2011), conducted studies on clay bricks with various proportions of waste materials such as urban sewage sludge, bagasse, and sludge from the brewing industry, olive mill wastewater, and coffee ground residue. The bricks were manufactured with optimal proportion of waste. Influence of the addition of waste materials on the linear shrinkage, bulk density, water absorption, and mechanical and thermal properties was investigated. It was analysed that the water absorption increased to above 35% when urban sewage sludge, brewing industry sludge and bagasse were incorporated but a decrease in compressive strength by 19% and increase in thermal insulation by 8% was seen. The incorporation of coffee grounds and olive mill wastewater of clay was more beneficial as the compressive strength values were similar to that of bricks without waste and a 19% improvement in thermal conductivity was found. All the wastes that were studied was applicable to be used effectively for pore forming. The bulk density of the products decreased with the addition of the wastes and this resulted in increase in number of pores that was created by the combustion of organic waste matter. The incorporation of urban sewage sludge, brewing industry sludge, and bagasse in the clay brick increased the number of open pores and slightly increase in the thermal insulation properties of the bricks. And the incorporation of coffee grounds and olive mill wastewater in the clay brick slightly increased the open porosity and the proportion of closed porosity, thus maintaining the compressive strength and improving the thermal insulation properties of the bricks.

Adazabra et al (2017), examined the incorporation of spent shea waste into clay material as a sustainable material. The need for effective disposal of spent shea waste has lead to its addition in the brick composition. The chemical constituent, mineralogical compositions and thermal behavior of both clay material and spent shea waste were tested initially. It was analysed that the increasing incorporation of the spent shea waste caused increase in water absorption but decrease in compressive strength. Thus the bricks prepared were considered applicable for non-load-bearing structural construction. The researchers concluded that the potential benefits of developing bricks from clay incorporating the spent shea waste included improved fluxing agents, economic sintering and making of sustainable bricks.

Ornam et al(2016), studied the influence of sago husk as a filler material in fly ash bricks as a non-structural element of buildings. The specimens were molded and then kept under sunlight to dry and then burnt at a temperature of 550$^{o}$C in a stove zinc plate and aluminium foil for 2 hours. Various tests were conducted on the casted bricks and a gradual decrease in the compressive strength was observed with increasing sago husk contents. It was also analysed that high sago husk content resulted in low density of specimen.

Mohammad Shahid Arshad and Dr. P.Y. Pawade (2014), investigated methods of reducing the quantity of clay in the brick composition using natural waste materials. Bricks were prepared by incorporating orange peels and coconut waste along with clay and paper mill waste as binding material. The utilization of natural waste materials serves a purpose of solid waste management. Waste addition was done in order to reduce the shortage of clay material in many parts of the world. The waste materials were found to be porous and fibrous structures by analysis of SEM monographs. It was seen that as the clay content reduces the bricks become lighter in weight. But at the composition where the soil content is 30% and the remaining comprising of paper mill waste and orange peel, does not result in a good bond with each other and crumbles when it is totally dried. From the experimental investigation it was concluded that the prepared bricks were light weight, shock absorbing and meets the compressive strength requirements of ASTM C 67-03a and BIS. It was also confirmed that the brick making procedure was simple thus giving opportunities for rural entrepreneurship by unskilled labourers in developing countries.

## 2. SUGARCANE BAGASSE ASH AND RICE HUSK ASH AS BRICK MATERIALS

The major quantities of waste that are generated from the agricultural activities are sugarcane bagasse, rice husk, coconut husk, jute fibres etc. From the above, sugarcane bagasse and rice husk are two waste materials that are generated in large quantities. India is the second largest producer of sugarcane in the world after Brazil and produces about 90 million tons of sugarcane bagasse as a solid waste from the sugarcane industries. These are reused as a bio fuel for the industrial boilers and power plants. The burnt residue of sugarcane bagasse called as Sugarcane Bagasse Ash (SBA) are disposed in landfills without being managed adequately. These ashes are the final waste product resulting from the agro-industrial processes with no possibility to reduce further. It has been recently accepted as a pozzolanic material but its use as a pozzolanic material is not well-known and thus limited. Rice husk is the outer covering of the rice kernel which has two interlocking halves. India is one of the major rice producing country and the husk generated during the milling process is used as fuel in boilers for the processing of paddy. The husks are converted into ashes during the process and is called Rice Husk Ash (RHA). It contains about 85-90 % of amorphous silica. About twenty million tons of Rice husk Ash is produced every year. Both the ashes are considered to be a threat to the environment, causing damage to the land and surrounding areas in which they are dumped. Thus there is a need for research and find solutions for disposal and reuse the waste ashes. The utilisation of these agro-wastes in the brick production industry has been reviewed in detail.

### 2.1 Study on Sugarcane bagasse ash as a brick material

Kazmi et al (2017), conducted studies to develop lighter and eco-friendly burnt clay bricks by incorporating sugarcane bagasse ash (SBA). The brick mixtures was prepared by incorporating SBA by weight of clay in different proportions and then the clay bricks were manufactured in a local brick manufacturing industrial kiln. Studies were done to evaluate the properties of prepared bricks by performing different mechanical and durability tests as per ASTM C67. The results showed that SBA can be successfully added as an additive material in the manufacturing of lighter bricks. It was observed that the burnt clay bricks incorporating 5% SBA by clay weight fulfilled the minimum requirement for compressive strength according to the Building code of Pakistan. The flexural strength was found to be higher than the specified minimum requirement of ASTM C67. Also, the efflorescence was improved after adding the SBA in burnt clay bricks. Therefore it was concluded that lighter and sustainable bricks can be produced by the utilization of small amount of SBA (i.e., 5%) in burnt clay bricks.

Vignesh Kumar and B Jai Vignesh (2017), in their paper carried out an experiment on partial replacement of fly ash by bagasse ash in order to find a solution to waste disposal. The effective use of these waste products was considered as a challenging task for the researcher due to the environmental impacts. The aim of the research was to make economical and green bricks to maintain the environmental balance, and avoid the problem of ash disposal. The bricks that were prepared were tested for compressive strength and water absorption. It was seen that the bricks were lighter in weight and met the compressive strength requirements according to the IS 1077:199. It is very important to dispose these wastes safely without affecting the health of human beings and the environment. Thus there is a great need for the re-utilization of SBA. Since it was found that bagasse ash is high in silica and found to have pozzolanic property, it can be used as substitute to construction material.

Faria et al (2012), conducted an investigation on the recycling of sugarcane bagasse ash waste as a method to provide a new raw material for clay brick bodies, through replacement of natural clay. Initially, the waste sample was characterized by its chemical composition, X-ray diffraction, differential thermal analysis, particle size, morphology and pollution potential. Clay brick pieces were prepared according the standard procedure, and then tested to determine their technological properties (e.g., linear shrinkage, water absorption, apparent density, and tensile strength). The sintered microstructure was also evaluated by scanning electron microscopy (SEM). It was found that the sugarcane bagasse ash waste is mainly composed by crystalline silica particles. The test results indicated that the sugarcane bagasse ash waste could be used as a filler in the clay bricks, thus enhancing the possibility of its reuse in a safe and sustainable way. The recycling of sugarcane bagasse ash waste in clay bricks showed highly positive results in terms of environmental protection, waste management practices, and saving of raw materials.

Anil Pratap Singh and Piyush Kumar (2015), utilized Sugarcane bagasse ash to develop light weight bricks with a goal to develop energy efficient alternative low cost construction material and serves a purpose of solid waste management. Research was conducted by utilising Sugarcane bagasse ash (SBA) with cement and sand in order to replace the clay bricks. The research involved the preparation of five different mix proportion, which were and the bricks were casted. After the casting procedure was completed a series of test were carried out in accordance with Indian standards to determine water absorption, compressive strength and efflorescence. It was concluded that the replacement of sand with SBA resulted in lower weight of bricks thus producing light weight bricks. The compressive strength of the bricks satisfied the requirements of IS 1077:199, thus making it a suitable alternative material. It was stated that the development of these bricks would lead to the conservation of clay resources and cost savings as the builder could save 15 to 20% of steel and concrete, since these bricks reduce the dead load on the building.

Madurwar et al (2014), investigated the suitability of sugarcane bagasse ash-quarry dust-lime as a principle raw material for brick production. Bricks were developed with a constant composition of lime and then tested for physical and mechanical (weight, dry density, water absorption, efflorescence, and compressive strength), functional (thermal conductivity), durability (chloride, sulfate, and carbonation), and environmental (toxicity characteristics leaching protocol) properties. The bricks that were casted was further analyzed for technical feasibility with commercially available and accepted masonry products like clay and fly ash bricks. The experimental results showed that the SBA-QD-L combination brick was lighter in weight, durable, nonhazardous, energy efficient, has lower k value, and meets the necessary physical and mechanical properties of the standards.

**2.2 Study on Rice Husk ash as a brick material**

Surender Malik and Bhavana Arora (2015), conducted studies on the effect of fly ash and rice husk ash on the properties of burnt clay bricks. Experimental investigations were carried out and various properties of the bricks that was casted with varying proportions of admixtures was determined. The results were taken into consideration to find whether the admixtures can be used for the production of clay bricks or not. The main aim of the work that was conducted by the researchers was to compare the compressive strength of the bricks. The bricks were made in different mix proportions. Then sun dried and burnt in a kiln. With the help of the Compression Testing Machine (C.T.M.) their compressive strength was calculated. From the tests done in the research work it was concluded that the bricks with fly ash as an admixture gave the high compressive strength.

Tonnayopas et al (2008), investigated the effect of addition of rice husk ash (RHA) in lightweight fired clay bricks. The physical and mechanical properties of the bricks that were casted was analysed. Different proportions of RHA from 10-50% by mass were mixed to the raw brick-clay. Higher the RHA addition, higher water content was required to ensure the right dry density. All test specimens were produced by uni-axial hydraulic press method and fired at 1050°C. The samples were tested according to Thai Industrial Standard (TIS) methods and compared with its specifications. Up to 30% RHA addition was found to meet TIS. Thus RHA can be utilized in the production of fired building bricks by taking advantage of low cost and environmental protection.RHA is an organic kind of pore-forming additive that has no harmful effect on any other brick manufacturing parameters. It was stated that the usage of RHA material in the clay mixture improved the physical and mechanical properties. It was concluded that the use of RHA waste in brick production provides an economical contribution and also serves as the energy efficiency materials for building. It was concluded that RHA can be used as an effective alternative raw material in the production of clay bricks.

Quesada et al (2016), analysed the feasibility of using biomass combustion ash waste (rice husk or wood ash from boards) as secondary raw materials in the manufacture of clay bricks. In the study either rice husk ash or wood ash was replaced with different amounts (10-30 wt%) of clay in brick manufacture. The properties of the bricks that was casted were compared to conventional products containing only clay and prepared by following the standard procedures. The technological properties of bricks depends on type and amount of ash used and the firing temperature. The results showed small variations due to the variation in firing temperature. Firing at 1000°C was found to achieve greater densification and thus lower water absorption and higher compressive strength. Firing at 900°C produced higher porosity, which reduced compressive strength. Based on the results obtained, 1000°C was selected as the optimal firing temperature and 10% weight of rice husk ash and 20% weight of wood ash as the optimal amounts of biomass ash waste. The bricks containing wood ash showed properties similar to the control bricks containing only clay with improved thermal conductivity. Finally it was found that the bricks containing 10% weight of rice husk ash and 30% weight of wood ash fulfilled standard requirements for clay masonry units.

Mohan et al (2012), conducted studies by utilizing rice husk ash for the preparation of bricks by both partial and full replacement of clay. Properties like compressive strength, weight of bricks, size and its shape was studied. The study was divided into two parts. First by replacing RHA partially in different proportions ranging from 10-80% and next part was done by fully replacing clay by waste materials from various industries like RHA, gypsum and lime. In partial repacement it was observed that optimum proportion for bricks was found to be 30% RHA and 70% Clay as the bricks exhibited high compressive strength and low brick weight. When weight of the brick reduces, the weight on the super structure and weight falling on the soil below also reduces. In full replacement of clay it was found that, with proportions 40% RHA, 40% Lime, 20% gypsum and 50% RHA, 30% lime and 20% gypsum, more strength was obtained when compared to all other possible proportions after 28 days curing period. The positive aspects that were concluded from the study are as follows: The RHA-clay bricks offer strengths at par with conventional clay bricks. RHA – clay bricks have very low water absorption of 12-15%. RHA bricks can be of good quality with sharp edges, controlled dimensions and offer a plain and even finish. They are resistant to wear and tear which makes them suitable for the internal and external uses. Plastering over brick can be avoided thus achieving further economy. The bonding with mortar and plaster is much greater or better in the case of RHA bricks. Bulk utilization of RHA helps in solving the pollution problem and is economical when produced in the vicinity if thermal power plants.

Lertsatitthanakorn et al (2008), conducted studies on the performance of RHA-sand-cement block and then the results were compare with that of the standard commercial clay brick. It was found that the RHA-cement block reduces the solar heat gain in buildings when compared to the commercial bricks. This lead to the decrease in room temperature, thus reduction in air conditioner operation time which resulted in electrical power savings. It was also stated that as the energy savings was increased there was a reduction in the greenhouse gas emissions.

I.H. Ling and D.C.L. Teo (2011), investigated the potential use of waste rice husk ash (RHA) and expanded polystyrene (EPS) beads in producing lightweight concrete bricks. RHA was considered as a cementitious material and was added as a partial replacement to cement while the EPS was added as partial aggregate replacement. Various engineering properties were analysed by conducting different tests. It was found that the EPS RHA concrete brick samples had densities lesser than 2000 kg/m3 which classifies them as lightweight. The compressive strength of the bricks that were casted was found to conform to MS 76:1972 as Class 2 load bearing brick. Also the water absorption values was found to decrease as the percentage of RHA is increased. The EPS RHA concrete brick is thus a green brick which shows good potential for use in practical applications.

### 2.3 Study on brick production incorporating Sugarcane bagasse ash and Rice husk ash.

Kazmi et al (2016), conducted studies aiming to evaluate the effect of the waste addition produced from two major crops: sugarcane and rice in clay bricks manufacturing. The brick specimens were manufactured at an industrial brick kiln plant using various dosages (5%, 10% and 15% by clay weight) of SBA and RHA. The mechanical and durability properties of these bricks were investigated. It was observed that clay bricks incorporating SBA and RHA at 5% replacement exhibited compressive strength of bricks that satisfied the Pakistan Building Code requirements (i.e. >5 MPa). Scanning electron microscopy (SEM) analysis confirmed the porous microstructure of the brick specimens incorporating SBA and RHA, which resulted into lesser unit weight leading to lighter and economical structures. Furthermore the researchers found that the resistance against efflorescence was improved in all the tested bricks incorporating SBA and RHA. Thus, based on the study, it was concluded that the brick specimens incorporating lower dosage of SBA and RHA (i.e. 5% by clay weight) will not only relieve the environmental burden but also result into a more sustainable and economical construction.

Saleem et al (2017), aimed to characterize the clay bricks produced by the addition of the two agricultural waste materials i.e. sugarcane bagasse and rice husk ash. SBA and RHA was mixed with the clay for brick manufacturing in three different proportions i.e. 5, 10 and 15% by weight of clay. The test results indicated that the sulphate attack resistance and efflorescence of clay bricks incorporating sugarcane bagasse and rice husk ash have been increased significantly. However, no significant effect on mechanical properties was observed. The addition of 5% waste with burnt clay bricks satisfied the Building Code of Pakistan requirement for minimum compressive strength and all the bricks fulfilled ASTM C 67 requirement for flexural strength. It was observed that the porosity, water absorption and initial rate of absorption was increased with the addition of waste in burnt clay bricks. High porosity is usually related with good insulation properties. It was stated that burnt clay bricks with 5% waste addition could be used in moderate weather according to water absorption results. Based on the study, it was concluded that bricks incorporating RHA and SBA up to 5% can be effectively used for construction purposes leading to sustainable construction.

Kazmi et al (2017), mainly focused to develop thermally efficient burnt clay bricks incorporating agricultural wastes on industrial scale. For this purpose, agricultural wastes (sugarcane bagasse ash (SBA) and rice husk ash (RHA)) were acquired from a sugar industry and a brick kiln. Burnt clay bricks were manufactured in an industrial kiln by incorporating SBA and RHA in various dosages (i.e. 5%, 10% and 15%) by clay weight. Physical and mechanical and thermal properties of brick specimens incorporating agricultural wastes were studied by the researchers. It was observed that lighter weight bricks can be produced using agricultural wastes, which are helpful in reducing both the cost and overall weight of the structure. Brick specimens incorporating SBA and RHA up to 15% satisfied the minimum requirement for compressive strength according to different standards for masonry construction. Increase in apparent porosity with decrease in thermal conductivity was also observed with increasing content of SBA and RHA in burnt clay bricks. Substitution of clay by 15% SBA and RHA in the production bricks was found to reduce the thermal conductivity by 31% and 29%, respectively. Thus, the utilization of SBA and RHA (up to 15% by clay weight) in manufacturing of burnt clay bricks is not only helpful in landfill reduction but also leads towards the development of sustainable and thermally efficient construction material.

## 3. CONCLUSIONS

Accumulation of the unmanaged agro-waste from various agricultural industries has led to the increasing environmental concerns. Recycling these waste materials by incorporating them in the brick production is an effective solution to the environmental concerns and also the depletion of natural resources that are mainly used in the brick composition. Utilisation of the agro-wastes into sustainable, energy efficient construction materials are considered to be a viable solution for the pollution problems and natural resource conservation for the future generations. The different methodologies that has been proposed by various researchers to design the green brick materials have been reviewed. The incorporation of sugarcane bagasse ash and rice husk ash in the production of brick materials were reviewed in detail, SBA and RHA being two agro-waste that are produced in large quantities in India. The physical and mechanical properties of the different construction building materials were analysed. Compressive strength, water absorption and bulk density were the most important properties that was tested. The compressive strength of many brick compositions was found to reduce with the increasing percentage of the agro-wastes but the results were in good agreement with the specifications prescribed in the relevant standards. Agro-wastes showed the potential to develop energy efficient brick materials that also had good thermomechanical behaviour. The bricks that were produced incorporating the agro-wastes were observed to be cost effective, durable, lightweight, having low thermal conductivity and environmental friendly.

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