Review Article

Agro–industrial wastes as sustainable resource for the production of bricks

Abstract

There are many challenges faced by the modern brick industry include cost, shortages of raw materials and environmental impacts of production. To meet this challenge many research methods are followed around the world. Production of conventional bricks using soil involves exploitation of black and red soil resources. In order to sustain the availability of soil resources for the agriculture purposes Low Input Sustainable Alternatively Technology (LISAT) was discussed in this review and suggested to the industries. This paper focuses on the recycling and reuse of the solid wastes from the agro–industries for the production of eco–friendly construction and building materials. There is lack of data or very less data are available to determine the feasibility of adding biological waste to bricks. Hence the present review highlights the environmental benefits due to the diversion of solid waste from agro–industries as an inert and useful medium. Discussion based on strength benefits and durability of the fired bricks by adding appropriate agro–waste material act as a fluxing agent within the brick. This review is useful to the future researchers to assess the feasibility of adding waste material as fluxing agent in the production of biobricks. Physico–mechanical and thermal properties of the biomaterials of bricks are reviewed and recommendations are suggested as the outcome of the study.

Keywords: biobricks, solid agro–wastes, additives, fluxing agents, physical, mechanical and thermal properties

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Introduction

Agro–industries such as coir industries, coffee processing industries and sugar industries pile up a huge amount of lignocellulosic wastes (coir pith waste, coffee husk and biogases) that are a menace for the environment. Hence this paper focuses on the recycling and reuse of the solid wastes from the agro–industries for the production of eco–friendly construction and building materials. There is a shortage of natural resources due to the exploitation of various natural resources. One such important resource is soil. It is a high time to think about the sustainability of natural resources for the present and future. Throughout the world, the primary importance of soil is utilization for the agriculture. Black and red soil is highly exploited for the production of construction and building material around the world. Conventional bricks are produced from clay with high temperature kiln firing or from ordinary Portland cement (OPC) concrete, and thus contain high embodied energy and have large carbon footprint. In many areas of the world, there is already a shortage of natural source material for production of the conventional bricks.[1] Low Input Sustainable Alternative Technology (LISAT) was discussed in this review and suggested to the industries. There are many challenges faced by the modern brick industry include cost, shortages of raw materials and environmental impacts of production. To meet this challenge many research methods are followed around the world. Review on methods to identify the solid biowastes based on the properties like particle size, bulk density, pH, porosity and thermal properties like differential thermal analysis (DTA) combined with thermo–gravimetric analysis (TGA) is more suitable for studying the hydration or pozzolanic reaction that takes place at later stages.[2]

Pozzolanic reaction

The particle–binding glue of concrete– Calcium Silica Hydrate (CSH)– is the result of combining water and Portland cement. But that same hydration reaction also produces Calcium Hydroxide (CH) by–products (up to 25% of the hydrated Portland cement) that not only do nothing to contribute to grout strength and density, but actively work against it. Grout is a dense fluid which is used to fill gaps or used as reinforcement in existing structures. Correctly mixed and applied grout forms a waterproof seal.[3] This CH–induced porosity of poor strength, weak resistance to chemical attacks, high permeability and thus shorter life. Replacing some of the Portland cement with a pure natural pumice pozzolan ignites a pozzolanic reaction within the hydrated paste that through molecular–level reclamation process reacts to and melds with the trouble–causing CH, ultimately converting it into additional CSH. This consumptive transformation of the CH mitigates or completely eliminates the problems. And that newly–created CSH densifies and strengthens the grout, welding the grout particles into a dense, durable, virtually impermeable matrix.[3] The ability of clay to form a ceramic bond upon firing is due to the large amounts of silicon–di–oxide present in its particles. Upon heating, this compound softens into a glassy form, which bonds the remaining particles to one another where they are in contact in a process known as sintering, which is depicted in Figure 1. The strength, durability, and absorption of the resulting products are dependent on the state and nature of sintering within the brick. For the purpose of producing fired clay bricks, a silicon dioxide content of between 55 and 70 percent is ideal. Too little will lead to incomplete sintering and a weak finished product, while too much will cause unnecessary deformation and volumetric instability.

The proven formulation for the bricks is:

Ultrafine particle size + Amorphous Aluminium silicate + Portland cement

Water from external sources or bleed water produced during hardening collects on the exterior surfaces of the grout and in the interconnected porous spaces in the grout and begins to dissolve the Portlandite phase (calcium hydroxide) of the grout. This produces an excess of calcium and hydroxyl ions in solution. Mass transfer drives these ions from areas of high concentration to areas of low concentration. This predominately means that the ions exit the external interface between the grout and the host rock, degrading this interface and creating a fluid pathway through the grouted rock. The grout of this invention employs the high amorphous silicon dioxide content pumice to prevent this chemical reaction from occurring. The amorphous silicon dioxide reacts with the calcium and hydroxyl ions in the fluid grout to form calcium tri–silicate (replacing the Portlandite) which has very low solubility. The relatively high fraction of pumice pozzolan decreases the relative amount of Portland cement, thereby reducing hydrational heat during hardening. The ultrafine pozzolan also results in smaller pores in the grout (average diameter is one micron) and causes the pores to be more disconnected as evidenced by mercury Porosimetry and the extremely low hydraulic conductivity exhibited by this grout.[4]

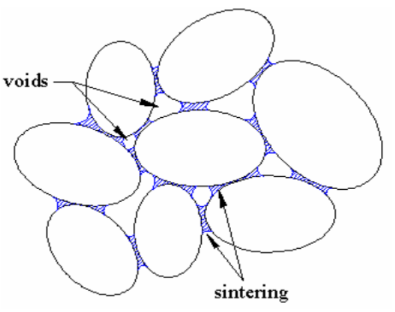

Figure 1 Sintered clay particles.

Solid wastes as alternative to clay brick

A brick is a block or a single unit of a Clay bearing soil, sand and lime or concrete material, fire hardened or air dried used in masonry construction. Light weight bricks are made from expanded clay aggregate. Fired brick are the most numerous types and are laid in courses and numerous patterns known as bonds collectively known as brickwork and may be laid in various kinds of mortar to hold the bricks together to make a durable structure. Brick are produced in numerous classes, types, materials, and sizes which vary with region and time period and are produced in bulk quantities. Many researchers used various solid wastes such as blast furnace slag[5–7] float glass waste,[8–12] sewage sludge ash and fly ash[13–16] have all been tested as possible additives in clay brick. Apart from these solid wastes, the agro bio–wastes like coffee husk /grounds and sugar cane bagasse are reviewed for its potentiality as alternative additives to the clay bricks.

Blast furnace slag

It is a by–product of the steel making industry, and is abundant locally. Slag produced from a variety of metal working furnaces is used extensively as an aggregate in civil engineering applications such as for roadways and cement. Slag consists of dicalcium silicate (Ca_2S) and dicalcium ferrate (Ca_2F), with a SiO_2 content ranging from 10% to 18%.[6,7] The high content of lime can lead to volumetric instability as a result of hydration; however, treatments are available to minimize this effect. Despite the volumetric concerns, lime can act as a very effective flux in the verification process,[5] and it is therefore beneficial to optimize its content. Glass has a high SiO2 content, and has a chemical composition comparable to that of natural shale and clay. The highly vitreous state of glass increases its potential as a sintering agent in clay brick. Biological waste can take many chemical compositions, as there are several point sources, such as water and wastewater treatment facilities, capable of producing a volume of waste that would support the constant supply required for addition into brick. Disposal of biological waste is demanding, as the volume of the waste is large and unstable. Current methods of disposal include landfill and agricultural land spreading. Although some form of pre–treatment is required to remove excess moisture, the incorporation of biological waste into bricks would help ease the current spatial demand for its disposal.

Waste glass

Addition of waste glass showed an increase in strength, and decrease in C/B ratio. Addition of waste glass in an industrial setting in the order of 10% to 15% by mass can be adopted to produce acceptable quality bricks. Addition of glass tends to improve the quality of the bricks using lower firing temperature, thus significantly decreasing energy requirements. It reduces emission by lowering Hydrogen Fluoride by 33%.[8–12]

Sludge ash

Addition of wastewater and water treatment sludge to bricks demonstrated possible benefits to clay brick. According to Anderson et al.,[14] an inconsistency in the tested results and processes, as well as a lack of information with respect to actual chemical composition, consistency in materials, and product durability creates a need for additional laboratory testing representative of production facilities in addition of wastewater sludge to bricks demonstrated possible benefits to clay brick. The suitable burning condition was determined as 600°C for5 hours after trial burnings were made at 400°C,500°C,600 °C,700 and800°C temperature and for 3,5,6 and 8 hours. As per the experimental results of Michael Anderson,[14] Luo et al.,[17] dewatered sewage sludge could be incinerated at 800° C at the rate of 10 to 50% showed improved quality based on physic–mechanical and thermo–gravimetric analysis.

Fly ash

Experimental Results of **Lin et al.,**[13] indicated that the fly ash proportion and firing temperature were the two key factors determining the quality of brick. Increasing the firing temperature and decreasing the amount of ash in the brick resulted in a decrease of water absorption. The appropriate percentage of ash content for producing quality bricks was in the range of 20 to 40% by weight with a 13 to 15% optimum moisture content prepared in the molded mixture and firing at 1,000°C for 6 h. With 10% ash content, the ash–clay bricks exhibited higher compressive strength than normal clay bricks. This study showed that the pulverized sludge ash could be used as brick material. The bricks produced were up to 10.60% lighter than clay bricks. The bricks manufactured from fly ash possessed compressive strength more than 5 N/mm^2 which is more than normal clay bricks. Other important characteristics included water absorption capacity, compressive strength and Efflorescence test. Fly ash bricks absorb less quantity of water which is under I.S. requirement. Fly ash–clay bricks give nil efflorescence. The values of these characteristics for fly ash bricks are excellent and have exceeded those pertaining to clay

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bricks. Moreover, fly ash bricks have been produced with a naturally occurring reddish colour similar to that of normal clay bricks. The new bricks and process have been given the name Fly ash Bricks. Similar kind of experiment are conducted by Gunn et al.,[15] & Lakhao et al.[16]

Agro–industrial wastes

Large amount of agricultural / farm wastes and agro industrial wastes are piled up and these solid wastes contain high amount of lignocellulosic contents. Huge quantities are left unused and it takes long time to degrade .Hence these solid agro wastes could be used as additives and low cost alternatives in building construction materials. Dickinson et al.,[18] Yasodha et al.,[19] Mothe et al.,[20] Jaadu et al.,[21] analysed the characteristics of the coconut fibers and sugarcane fibers by thermal analysis and FTIR which are used as alternative fuels. Quesada et al.,[22] experimented coffee grounds as clay bricks and highlighted it's advantages. Viswanathan et al.,[23] Li et al.,[24] Haque et al.,[25] Prasanna et al.,[26] studied about the coir fiber composites and fibers with reference to physical, mechanical and water absorption behavior of coir wastes. The density, hardness, tensile strength, tensile modulus, flexural strength, impact energy, compressive strength, compressive modulus, inter–laminar shear strength, fracture toughness and percentage of water absorption of the composites were analyzed. The experimental investigation reveals that the void content and percent of water absorption increases with increase in fiber length and fiber content. Zardari et al.,[16] experimented sugar cane biogases as an alternative fuel and tested various mechanical properties viz., compressive strength(13) and water porosity(18%) respectively.

$$C.S = P/BW$$

Where P, is Average compressive force exerted on samples, B, and W are breadth and width of the rectangular specimen

Advantages of using agro–industrial wastes as additives

a. Based on the experimental study reported by Demir,[27] agro wastes have the following advantages to use as potential biobricks
b. Adding organic residues to the clay body increases the required water content for extrusion (apparent plasticity).
c. The fibrous nature of residues did not create problems during shaping when used up to 10% wt. No extrusion
d. Failures were observed.
e. Drying shrinkage of the clay body is strongly increased in addition to the expected stabilization effect of cellulose fibres, mostly due to the very high water content. A residue addition of 10% wt. is found to be unsuitable because of the excessive drying shrinkage.
f. Despite drying shrinkage being strongly increased, the organic residue additions considerably increased the
g. Dry strength of the clay samples. This strength increase is useful for reducing scraps due to handling problems of unfired bricks.
h. The compressive strength of the fired samples is decreased by the addition of residues. Nevertheless, the
i. Values are still higher than required by Turkish standards.
j. The organic residues are easily burnt out from the clay body during firing. There were neither black cores nor bloating after firing.
k. Organic residues can be effectively used for pore–forming for up to 5% residue addition by weight; further
l. Addition is not very effective for decreasing the bulk density of the clay body. The residues increased the open porosity and decreased the bulk density; this effect may improve the thermal insulation properties and lower dead load in buildings.
m. The organic residues can be used as a type of pore–forming additive in the clay body without any damaging effect on the other brick manufacturing parameters (Figure 2 & Table 1).

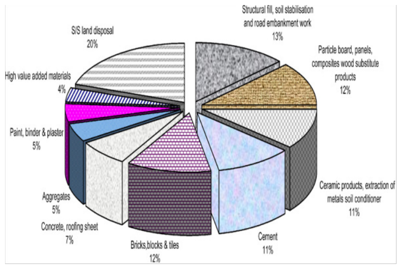

Figure 2 Industrial solid waste recycling and its use as potential sustainable resources of bricks.

Table 1 Comparative data on physical properties of brick materials

S. no	Building materials	Physical properties				References
		particle size (mm)	bulk density(g/cc)	pH	Porosity (%)	
1	Clay	300–600	1.48	7.6	36.3	Kay et al.,[40] Cruz et al.[41]
2	Bagasse	0.12–0.55	110.86	5.6	77.58	Yasodha et al.,[42] Mothe et al.,[20] Jaadu et al.,[21] Zardari et al.,[16]. Faria et al.[43]
3	Coffee husk	0.2–0.67	349.06	5.9	64.85	Jaddu et al.[21]
4	Coir pith wastes	0.6– 20	748	6.5	82	Dickinson et al.,[18] Viswanathan et al.,[23] Li et., al[24] Haque et al.,[25] Prasanna et al .[26]

Physico mechanical characterization

The physical properties of the composite play an important role in the measured mechanical properties. There is a direct dependence of mechanical properties on the physical properties. With this background various physico – chemical and mechanical properties of the composites and bricks[28–30] from various sources were reviewed as follows.

Preparation of samples and brick fabrication

Particles digested with 2M caustic soda at temperature range of 135°C –150°C in volumetric flask. The homogenous mixture was allowed to cool at ambient temperature and allowed to sediment. The liquid phase was decanted and residue (RM) dried in autoclave at 110 °C for 48 hours. The samples were then allowed to cool to room temperature.

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Physico– chemical characterization

Plasticity Index is the numerical difference between the liquid limit and the plastic limit for a particular material and indicates the magnitude of the range of moisture content over which the soil remains plastic. The Cassagrande device, ELLE international was used for plasticity index (PI) testing. It has a cup and grooving tool and is mechanically operated. Equation (1) below was used in the computations.

Plasticity Index,

Plasticity Index (PI) = LL– PL (1)

Where,

LL is liquid limit and

PL, plastic limit.

The water of absorption value gives a rough measure of the extent to which the product is susceptible to seepage of water through its pores when immersed in water. In this work, the average weight of fired briquette is measured, and that when soaked in water for an hour is also weighed. ASTM C830–09 and ASTM D6111–09 standard tests were followed to determine the porosity and bulk density respectively. Computed values of bulk density and apparent porosity plotted for various batch formulations. Water of absorption data and apparent porosity variation as the content of AC increases are presented and discussed.

Flexural strength

Using three point bending testing (ASTM C99/C99M–09 standard protocols), the flexural strength of the test bars were determined. The test configuration for specimen dimension of (20 x 1 x 1) cm3 and distance 7.6cm (between supports), monotonic loading was done at 1.85kg/min till point of fracture. Geethamma et al.,[31] Bujang et al.,[32] used coir pith as reinforce composites.

Flexural strength $\sigma = 3FL/2hd$ (2)

Where,

F is load,

d is thickness, h is width

And L is distance between supports used.

Review on testing methods

There are several test methods are available for the quality assessment of composite materials and the bricks. These assessments are available at Indian standards and at international standards. A series of tests were performed on Fly ash Bricks and organic residue bricks in order to compare their qualities as load bearing bricks with those made from clay. The Bureau of Indian Standards 12894 & 13757 – 1993 were applied in most of the tests.

1. Compressive Strength
2. Water Absorption
3. Efflorescence test
4. Thermal analysis techniques

Compressive strength

According to BSI and ASTM ,Compressive strength Compressive strength of the specimen brick was calculated after 7, 14 & 28 days of curing using the formula as follows, Compressive strength = Applied Max load x 1000 (N)/Cross sectional Area (mm2). The universal testing machine is used for testing the compressive strength of bricks. After the curing period gets over bricks are kept for testing. To test the specimens, the bricks are placed in the calibrated compression testing machine of capacity 3000 KN (Kilo Newton) and applied a load uniform at the rate of 2.9 kN/min. The load at failure is the maximum load at which specimen fails to produce any further increase in the indicator reading on the testing machine.

Compressive Strength C= (W/A)

Where,

W= Calibrated maximum load

A= Average of the gross areas of the upper and lower bearing surfaces of the specimen.[33,34]

Water absorption

Bricks should not absorb water more than 12% by its weight. The bricks to be tested should be dried in an oven at a temperature of 105°C to 115°C till attains constant weight cool the bricks to room temperature and weight (W1). Immerse completely dried and weighed (W1) brick in clean water for 24 hrs at a temperature of 27±20°C. Remove the bricks and wipe out any traces of water and weigh immediately (W2). Water absorption in % by weight = (W2 – W1/ W1) x 100.[35–37]

Efflorescence test

For this test, brick has to be placed vertically in water with one end immersed. The depth of immersion in water being 2.5 cm, then the whole arrangement should be kept in a warm–well–ventilated room temperature of 20–30o C until all evaporates. When the water in the dish is absorbed by the brick and surplus water evaporates. When the water is completely absorbed and evaporated place similar quantity of water in dish and allows it to absorb and evaporate as before. Examine the brick after this and find out the percentage of white spots to the surface area of brick. If any difference is observed because of presence of any salt deposit, then the rating is reported as ‘’effloresced‟. If no difference is noted, the rating is reported as not ‘’effloresced‟ .[38,39]

Thermal analysis techniques

Thermal analysis comprises a group of techniques in which a physical property of a substance is measured as a function of temperature, while the substance is subjected to a controlled temperature programme. In differential thermal analysis, the temperature difference that develops between a sample and an inert reference material is measured, when both are subjected to identical heat–treatments. The related technique of differential scanning calorimetry relies on differences in energy required to maintain the sample and reference at an identical temperature. Length or volume changes that occur on subjecting materials to heat treatment are detected in dilatometry; X–ray or neutron diffraction can also be used to measure dimensional changes. Both thermogravimetry and evolved–gas analysis are techniques which rely on samples which decompose at elevated temperatures. The former monitors changes in the mass of the specimen on heating, whereas the latter is based on the gases evolved on heating the sample. Electrical conductivity measurements can be related to changes in the defect density of materials or to study phase transitions. TG results indicate that the clay ceramic pastes had a total mass loss in the 13.1–13.6 % range, and are dependent on the sugarcane bagasse ash waste amount added. It was

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found that the replacement of natural clay with sugarcane bagasse ash waste, in the range up to 20 wt%, influenced the thermal behavior and technological properties of the clay ceramic pastes.

Differential thermal analysis (DTA)

DTA involves heating or cooling a test sample and an inert reference under identical conditions, while recording any temperature difference between the sample and reference. This differential temperature is then plotted against time, or against temperature. Changes in the sample which lead to the absorption or evolution of heat can be detected relative to the inert reference. DTA can be used to study thermal properties and phase changes .

A DTA curve can be used as a finger print for identification purposes, for example, in the study of clays where the structural similarity of different forms renders diffraction experiments difficult to interpret. The area under a DTA peak can be to the enthalpy change and is not affected by the heat capacity of the sample. DTA may be defined as a technique for recording the difference in temperature between a substance and a reference material against either time or temperature as the two specimens are subjected to identical temperature regimes in an environment heated or cooled at a controlled rate.[44–52]

Conclusion

Review on various parameters of testing methods, characterization of raw materials and bricks revealed and focused the standards of national and international level in the brick industry. The present review study is useful to design and develop the sustainable technology by using agro industrial wastes in the production of bricks. This could be an alternative Low Input sustainable Technology in the building and construction industry.[14,27]

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Conflict of interest

The author declares there is no conflict of interest.

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