ALTERNATIVE LOW-COST BUILDING MATERIALS

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Abstract: Since economical factors have influenced the construction industry dramatically in recent years and in many parts of the world steel is scarce and expensive, many researchers are searching for low-cost materials as a substitute or alternative for the present situation. Recently, various materials have shown promise for future use as a major construction material. The purpose of this paper is to highlight alternative low-cost building materials for possible use in low-cost housing having advantages on areas such as India where concrete or steel housing is expensive.

Keywords: Building Material; Low-Cost Housing; Sustainability

1. Introduction

Green building has taken off in recent year with many builders and new home owners looking for new and different methods of construction that can potentially offset energy cost. Construction of low cost housing by using the low cost building materials increases the access to buildings by low income group peoples. Low cost housing can be achieved by use of efficient planning and project management, low cost materials, economical construction technologies and use of alternate construction methods available. The profit gained from use of such methods can decrease the cost of construction and make the low cost housing accessible to all. The use of low cost alternate building materials also prevents the rise of construction cost due to use of scarce building materials which eventually increase the cost of the project. Some alternative building material can be made out of natural materials, while others can help to lower energy costs of the occupant once built. Regardless of what the goal of the builder is, alternative building material and their use is on the rise.

2. Eco friendly and Alternative Building Material

In addition to the conventionally used materials there are various alternative technologies and materials developed by various research organizations, innovators and manufacturers in India that are beneficial in the housing construction. As part of this Information collected has been provided in the subsequent sections. Low cost Housing materials can be broadly classified into natural materials and manmade materials according to the source of the building materials.

2.1. Natural Materials

2.1.1 Random-straw or Coconut Fiber Stabilized Soil

Straw-soil mix is an ancient construction material and has been used in many countries for years. Application of modern geotechnical techniques to this material can further improve both strength and durability. Results with silty clay using the standard AASHTO Compaction procedure applied with the tensile test show that for 1% by weight of straw, the tensile strength increase three times than that soil with no straw and also the soil-straw mix gives a high ductility behavior. The percent of straw increase to the tensile strength increase reaches an optimum condition approximately around 1.6% by weight and further increases of straw will decrease tensile strength. From wet-dry test results, the coconut fiber gives better durability. If a sulfur coating is applied to the compacted straw-soil mix, better water resistance is gained. Straw-soil mix can also simulate the soil-root system.

2.1.2 Bamboo

After China, India is the second largest in bamboo production. Coupled with China, it holds 50% of the world's total share of bamboo production. Of the total 136 species of bamboo occurring in India, 58 species spread out over 10 genera are endemic to the north eastern part of India alone (Sharma, 1987). The forest area, over which bamboos occur in India, on a conservative estimate, is about 9.57 million hectares, which constitutes about 12.8% of the total area under forests (Bahadur and Verma, 1980). Its widespread availability and rapid growth in areas of China, Japan and India has made this grass an interesting structural material due to its affordability, easy assembly and relatively long durability. A bamboo hut was constructed in 1955 which was treated with 4 percent CCa and since it has no deterioration. But bamboo culms offer some disadvantage like Bambo has a

circular profile which makes it inherently difficult to connect other members. Also Bamboo has no support in the middle as it is hollow there, hence it cannot be subjected to high compressive forces perpendicular to the culms face.

Some ongoing bamboo product are:

Corrugated Bamboo Roofing Sheet: A successful roofing material with a development of traditional material comes from Bamboo Board. It is eco-friendly, light- weight, strong and durable and has minimal fire hazard when compared to thatch and other roofing materials. These sheets can be used for roofing, walling, door and window shutters and other components in building construction.

2.1.3 Earth

Earth is the oldest building material known to mankind. But its widespread use is hindered due to the limitations like water penetration, erosion of walls at level by splashing of water from ground surfaces, attack by termites and pests, high maintenance requirements etc. These limitations can be overcome by using compressed earths block and non-erodible mud plaster.

1) Compressed Earth Block

The compressed earth block is the developed form of moulded earth block, more commonly known as the adobe block. This technology offers an economic, environment friendly masonry. Stabilized earth blocks are manufactured by compacting raw material earth mixed with a stabilizer such as cement or lime using manual soil press.

2) Nonerodable Mud Plaster

Central Building Research Institute, India has developed an economical but effective process to protect mud walls by applying non-erodible mud plaster. Non-erodible mud is prepared by mixing bitumen cutback (Bitumen & Kerosene oil mixture) with a specified mud plaste. Nonerodible mud plastered walls are resistant to water erosion. Centre for Science for Villages, Wardha India has developed a technique of providing potter made tile lining to mud-walls protecting them from rain and moisture.

2.1.4 Straw

Straw is basically an agricultural by-product which comprises only of the plant stalks (mostly cereals) after removal of grain and chaff. Rice straw has the highest silica content making it the toughest amongst all other cereal straws. Straw is considered as an environmental problem as its burning causes breathing problems. Straw and Straw bale have a huge scope in India as it is one of the largest producers of straw bale. 46% of total land (32, 87,590 sq·km) of India is agricultural land and out of a total population of 1, 17, 09, 38,000 people 58.4% are solely dependent upon agriculture as a means of livelihood. So straw has high potential as an alternate building material. It is also fire resistant as it does not support combustion, is thermally insulated, has sound and moisture insulation and is not toxic.

The following are the profiles of some construction alternatives constructed with straws and straw bales.

Life Extended Thatch Roofing: It is one of the locally available and environment friendly alternative for corrugated sheets. By treating it with copper sulphate solution, its life can be extended by reducing the effect of biodegradability. Additional layer of treatment on the roof surface using phosphorylated spray or CNSL oil imparts water proofing, fire resistance, termite proofing and weathering resistance (Developed by CBRI/RRL-TVM).

Improved Thatch Roofing: In order to decrease the fire hazard of thatch roof and making it water repellent a treatment had been designed by the Central Building Re- search Institute. It essentials the thatch layers are plastered with specified mud plasters making it durable and fire resistant.

2.1.5 Fiber Cement Composites

From centuries, mankind has used the various natural fibres for a wide spectrum of applications ranging from consumption to housing. In recent days many researchers have explored the possibilities of using the natural fibre obtained from different plants, which includes bagasse, cereal straw, corn stalk, cotton stalk, kenaf, rice husk/rice straw etc as an alternative building material. Due to the light weight, high strength to weight ratio, corrosion resistance and other advantages, natural fiber based composites are becoming important alternatives for building materials for use in civil engineering fields. A few of the important composites are summarized as under:

Table 1.

Cement fiber composites are found to have superior properties as compared to concrete blocks. This is mainly due to addition of fibers. The superior properties comprise of better workability, resistance to cracking, lighter weight, high fracture toughness and a higher degree of flexibility. These properties make it a suitable material for use in low cost construction. The performance profiles of some important fibers produced in India are as **Table 2**.

1. Bagasse

Bagasse is the fibrous matter that remains after sugarcane or sorghum stalks are crushed to extract their juice. Since bagasse is a by-product of the cane sugar industry, the quantity of production in each country is similar to the quantity of sugarcane produced. India has just over 500 sugar mills. With nine states (Uttar Pradesh, Bihar, Punjab and Haryana in the northern region;Maharashtra & Gujarat in the western region and Andhra Pradesh, Tamil Nadu and Karnataka

Table 1. Availability of natural fibre in India and its applications in building materials [8].

Item	Source	Application in building material
Rice husk	Rice mills	As fuel, for manufacturing building materials and products
Banana leaves/stalk	Banana plants	In the manufacture of building boards, fire resistance fibre board
Coconut husk	Coir fibre industry	In the manufacture of building boards, roofing sheets, insulation boards, building panels, as a lightweight aggregate, coir fibre reinforced composite boards
Groundnut shell	Groundnut oil mills	In the manufacture of buildings panels, building blocks, for making chip boards, roofing sheets, particle boards
Jute fibre	Jute industry	For making chip boards, roofing sheets, door shutter
Rice/wheat straw	Agricultural farm	Manufacture of roofing units and walls panels/boards
Saw mill waste	Saw mills/wood	Manufacture of cement bonded wood chips, blocks, boards, particle boards, insulation boards, briquettes
Sisal fibres	Sisal plantation	For plastering of walls and for making roofing sheets, composite board with rice husk, cement roofing sheet, roofing tiles, manufacturing of paper and pulp
Cotton stalk	Cotton plantation	Fibre boards, panel, door shutters, roofing sheets, autoclaved cement composite, paper, plastering of walls

Table 2. The properties of building materials in consideration.

Sr No	Properties	Bamboo	Concrete Blocks	Ferrocement and Aerocon panels	Fiber-Cement composites	Fly ash bricks	Mud Blocks (compressed)	Rice husk	Straw bale (with bricks)
1.	Structural	Works better with moisture in shear forces; have high Flexibility than steel and lower young's modulus.	Can be given strength as per required; less mortar joint as size bigger which increases stability	Lightweight and requires no wet plastering (aerocon); high strength ,low density and high crack resistance of mortar (Ferro cement)	The light weight, high strength to weight ratio, corrosion resistance, crack resistance, flexibility, lightness	Reduce pollution, save energy, reduce mercury pollution and cost 20% less than traditional clay brick manufacturing, high strength, lower water penetration,	Economic and energy efficient	Pozzoloanic, economical, corrosion resistance increases, light weight final product	Stable and high load bearing power
2.	Thermal	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Moderate	Moderate
3.	Temperature and water resistance.	Moderate	Excellent	Excellent	Moderate	Excellent	Excellent	Depends on composition as it is used as admixture	Also depends on brick composition as it is mixed with the brick and with mud
4.	Buildability	Moderate	Excellent	Excellent	Excellent	Excellent	Excellent	Moderate	Moderate
5.	Cost (In Rs/square meter)	Depends on thickness (1*)	31.25	Depend on thickness (2*)	Depends on fiber (3*)	62.66	15.625	NA	NA

in the southern region) hold- ing 95% of them.

Some ongoing products are:

1) **Bagasse-Cement Boards and Panels:** The developed product is eco friendly and the process utilizes su- gar cane bagasse and ordinary Portland cement. The physico-mechanical behaviour of the developed building board passes most of the requirements of general purposes high density board and is cost effective too.

2) Bagasse-PVC Boards: This building board uses sugarcane bagasse and PVC as binder. PVC is the most widely used resin in making different articles for building applications such as door shutters, sanitary fixtures, pipes, cables, cabinets, etc. due to its inherent self extinguishing characteristic and affordable cost.

2. Jute and Coir

Jute cultivation has been in practice in India for as far as 800 BC. Production of jute is mainly concentrated in West Bengal, Orissa, Bihar, Assam, Meghalaya and Andhra Pradesh. There are 33 odd districts spanning all over West Bengal, Bihar, Assam and Orissa which accounts for 98.41% of total area under jute cultivations and 98.45% total raw jute production in India. Historically, the coir industry started and flourished in Kerala which has a long coast line, lakes, lagoons and backwaters providing natural conditions required for retting. However, with the expansion of coconut cultivation, coir industry has picked up in the States of Tamil Nadu, Karnataka, Andhra Pradesh, Orissa, West Bengal, Assam, Tripura, Pondicherry and the Union Territories of Lakshadweep and Andaman & Nicobar Islands through the efforts of Coir Board. India accounts for more than two-thirds of the world production of coir and coir products. So as India is a leading producer of jute and coir, they can be used as a solution for low cost housing and has been implemented in following ways (**Table 3**).

Table 3. Availability of different materials in India showing feasibility.

Si No.	States	Bamboo	Concrete	Ferro-cement	Bagasse (Fiber)	Jute (Fiber)	Coir (Fiber)	Fly ash	Mud	Rice husk	Straw	Aerocon
1	Madhya Pradesh	√	√	√				√				√
2	Mizoram	√	√	√					√			√
3	Assam	√	√	√		√			√			√
4	Andhra Pradesh	√	√	√		√		√		√	√	√
5	Uttar Pradesh		√	√	√							√
6	Bihar		√	√	√	√		√				√
7	Punjab		√	√	√							√
8	Haryana		√	√	√					√		√
9	Orissa		√	√		√						√
10	Karnataka		√	√			√					√
11	Pondicherry		√	√			√			√		√
12	Lakshadweep		√	√			√					√
13	Andaman and Nicobar Island		√	√			√			√		√
14	Jharkhand		√	√				√				√
15	Chhattisgarh		√	√				√				√
16	Goa		√	√						√	√	√
17	Delhi		√	√						√		√
18	West Bengal		√	√		√			√	√	√	√

1) Coir-CNSL Board: The Coir-CNSL Board is a wood alternative which can be used for surfacing, door and window shutters, partitioning, false ceiling, panelling, furniture, cabinets, packaging, etc. It is a single layer flat pressed class Medium Density Fibre (MDF) Board. It has low water absorption, negligible change in dimensions due to water absorption, workable with normal wood working tools, paintable, pre-laminable, and nailable and screw able.

2) Coir-CNSL Thermal Insulation Board: This is a composite material, which utilizes the coconut fibers as re-enforcing material and CNSL as the natural binder [10]. The density of the board is kept low and therefore is suitable for moderate temperature insulation.

3) Jute-Coir Composites: Jute-coir composite provides an economic alternative to wood for the construction industry. It involves the production of coir-ply boards with oriented jute as face veneer and coir plus waste rubber wood inside.

4) Coconut and Wooden Chips Roofing Sheet: Coconut fiber and wooden chips are soaked in water for two hours and then the water is drained off. Later these are mixed with cement and laid over a corrugated mould and kept under pressure for 8 to 10 hours. After demoulding, these are cured and dried before use (Developed by RRL-TVM). Also use of Cashewnut Shell Flour was a major development as filler [3].

2.2. Man Made Materials

2.2.1. Structural materials

The Industrial Revolution introduced many foreign substances which were the byproducts of industries like fly ash and rice husk and created problems for their disposal. But on further research into their properties it was observed that these materials possess excellent pozzoloanic properties. Hence these can be used as alternative building materials.

2.2.1.A. Polymer-bamboo Reinforced Concrete

The problem of bamboo reinforced concrete includes high volume change, (expansion and shrinkage due to water content), low bond strength between bamboo and concrete, low modulus which precipitate cracks at service loads in tensile zone of concrete beams, and decay. Many researchers have attempted to use many techniques to improve this low-cost material by use of bitumen, paint, cement, etc.

Impregnation techniques and increasing the bond strength for this material with sulfur are being developed. It is feasible that this type of material can be used for secondary structures when steel is not available. Other low cost materials such as sulfur treated brick or masonry block are also being studied.

2.2.1.B. Pozzolona Material (fly ash/slag/calcined clay) as Blending Material with Cement

Up to 35% of suitable fly ash can directly be substituted for cement as blending material keeping the structural considerations. Addition of fly ash significantly improves the quality & durability characteristics of the resulting concrete. Use of blended cement has now become quite popular world over, from durability and environmental benefits point of view. The advantages achieved with the use of blended cement in concrete are quite well documented: Reduced heat of hydration, improved workability & ease of pumping, superior microstructure leading to lower permeability, higher long term strength, better performance in aggressive environment (Sulphates, Chlorides etc.), reduced risk of alkali silica reaction and higher electrical resistance leading to lesser chances of reinforcement corrosion are some of the benefits of pozzolona material blends. While Portland pozzolona cement saves energy by 20%, lime pozzolona mixture shows up to 70% savings in energy.

2.2.1.C. Recycled Steel Reinforcement

Steel reinforcement can be made entirely of recycled scrap iron. This material is salvaged from automobiles, appliances, and steel-reinforced structures, which include reinforced concrete pavements, bridges, and buildings. In general, steel reinforcement bars can be rolled out from either of the following: used scrap rails, automobile scrap or defense scrap, defectives from steel plants, scrap generated from ship breaking or discarded structures, ingots from induction furnaces, tested billets from mini steel plants and main producers.

2.2.1.D. Ferro Cement and Precast Components

Precast Components are 85% recyclable, have low carbon dioxide generation and are energy efficient. They are ecofriendly, cost effective and easy to install. With use of precast components, wastes during operations are minimal, curing is not required, and structures are waterproof due to less water cement ratio, plastering is not required from the inner side of slabs and the components are corrosion proof. The components are also stronger than cast-in-situ structures, have longer life and have better load bearing capacity. Precast aerated/cellular concrete walling blocks and roofing slabs when used in multi-storied structures reduce weight, resulting in more economic design of structure, can be worked and handled easily, have high fire resistance rating and provide better insulation.

2.2.1.E. Precast R.C.C. / Ferro-cement Frames

Precast R.C.C. frames are concrete doorframes with welded reinforcement. These are manufactured according to Indian Standards. These are economical, environment friendly and durable. They are termite proof, fire resistant and corrosion proof. There is no bending or twisting, no warping, no shrinkage and no cracks. They are maintenance free and easy to install at site, provided with in-built high quality aldrop hold protector, stronger than other door frame material available in the market and are provided with two different types of hinge fixing arrangements to suite specific requirements. High quality plastic blocks for fixing hinges or arrangements for fixing stone hinges are available. Ferro cement frames are 1/3rd in cost, compared to even second grade timber. They can be manufactured at a small-scale level or for mass application, can be painted like timber shutters. They have higher strength to weight ratio than RCC and provide 20% saving on material and cost. Technical specification: 100 mmx60 mm section, grade of concrete M40, steel 6 mm dia, 3 no's, and stirrups, 6mm welded to main reinforcement.

2.2.2. Bricks & blocks

Need for building materials is growing at an alarming rate and in order to meet the demand for new buildings, new ways and techniques must be evolved. Manufacturing of building materials like bricks/blocks, cement, steel, aggregates, etc. consumed in bulk quantities, puts great pressure on natural resources (raw materials) and energy requirements. The use of alternative materials for bricks should be encouraged in order to preserve precious fertile top soil. Described below are a few examples of alternative materials for bricks/blocks.

2.2.2.A. Fly Ash

The mineral residue produced by burning coal and the fine glass powder recovered from its gases is called Fly Ash. The major constituents of fly ash are silica, alumina and iron [11]. Coal fired electricity generating plants are the primary producers of fly ash nowadays. Fly Ash can be substituted for many constituents in building materials making it the ideal choice for alternate building material. Some of them are discussed as under

Fly Ash Brick

Fly Ash Brick is a construction material, masonry unit comprising of Class C Fly Ash and water. Due to the high concentration of calcium oxide in Class C Fly Ash, the brick can be described as self-cementing. These properties make fly ash bricks energy efficient, mercury pollution resistant, lower water penetration, light weight, thermal insulation and cost effective the only major disadvantages of using fly ash brick is that there is very less information on its toxic fume emission. Also it contains many unhealthy elements like silica, aluminium, iron oxides, arsenic, cadmium and mercury. Its mechanical bonding is weak and presents poor outlook.

2.2.2.B. Bricks from Coal Washery Rejects

Freshly mined coal is washed to remove impurities prior to its use or processing. This residual waste from the coal washery plants is a hazard to the environment and needs to be disposed or utilized in a manner which lessens its harmful effects on the natural surroundings. These bricks are eco-friendly and waste utilizing. They reduce air, land and water pollution, are energy efficient and cost effective.

2.2.2.C. Building Blocks from Mine Waste and IndustrialWaste

It is eco-friendly, utilizes waste and reduces air, land and water pollution. It is energy efficient and also cost effective. Majority of the large-scale industries and thermal power plants generate solid wastes in bulk quantities. Red-mud, coal ash, slag, fly ash, etc. represent such wastes *unutilized* for several decades. Such wastes can be utilized for the manufacture of bricks/blocks, substitute for fine aggregates in concrete, partial replacement of cement in concrete, lime–pozzolona cements, etc. Huge quantities of solid wastes (generally known as mine tailings) are produced by the mining industries.

2.2.2.D.Aerocon Panels

Aerocon panels are the inorganic bonded sandwich pan- els made of two fiber reinforced cement sheets engulfing a light-weight core consisting of Portland cement, binders and a mix of silicaceous and micaceous aggregates. The use of Fly ash and its substitution for timber based products makes the panels environmental-friendly. The property attributes are eco-friendly, faster construction, no wet plastering and on-site curing, light weight, high thermal insulation, fire resistant, excellent sound reduction properties, water and termite and weather resistant, suitable for Seismic and Cyclone prone zones, relocatable, thin walls (space saving), smooth finish, mini- mum foundation or ground preparation required and easy workability.

2.2.2.E. C-Brick

These are bricks manufactured using the C- brick Machine developed by CBRI. The machine is available with BMTPC and is used for production of quality bricks using fly ash –sand –lime, fly ash –sand –cement and cement-sandaggregate.

2.2.2.F. Ferro-Cement

Ferro-cement can be defined as a thin walled versatile high strength cement based composite material made of cement mortar reinforced with one or more layers of wire mesh closely bound together to create a stiff structure unit with high performance, lightness of structure and strength.

2.2.2.G. Cement Concrete Hollow Blocks

Cement Concrete Block is a recently developed masonry unit of concrete. It works on the principal of densification of a lean concrete mix to make a regular shaped, uniform, high performance masonry unit. They are cost affective and better alternative to burnt clay bricks due to their good durability, fire resistance, partial resistance to sound, thermal insulation, small dead load and high speed of construction.

2.2.2.H. Rice Husk

India is one of the world's largest producers of white rice contributing about 20% of world's total rice production. The state of West Bengal ranks first in terms of area un- der production whereas Punjab has the highest produc- tivity in the country.

1) Low Cost Sandcrete Block

The rice husk ash produced using charcoal from rice husk is pozzoloanic and therefore is suitable for use in block making.

2) In Concrete

The rice husk ash is a highly siliceous material that can be used as an admixture in concrete if the rice husk isburnt in a specific manner.

2.2.3. Plaster

2.2.3.A. Calcium Silicate Plaster

Calcium silicate refractories are usually derived from calcium silicate. Wollastonite is a naturallyoccurring form of calcium silicate commonly used as filler. Portland cements are also based on calcium silicate. Calcium silicate plasters are economic, eco-friendly, produce lesswastage, have wide usage, give a smart finish, are lessenergy consuming, do not emit VOC and other toxic fumes

and gases after application and are recyclable. They are safein handling and usage, do not need skilled man power, are fast drying, durable, and have less water consumption.

2.2.3.B. Fiber reinforced clay plaster

Clay Plaster can achieve better sticking properties by reinforcing it with fibers. These fibers can be natural plant (cellulose) fiber or artificial fibers of polypropylene**.** Plant fibers in fiber reinforced plaster act as reinforcement and create voids thus controlling cracking due to drying shrinkage and thermal movements. The dried plaster is less brittle than conventional plasters and can withstand small movements of the substrate.

2.2.4. Roofing's

2.2.4.A. Bamboo matt corrugated roofing sheets

Roofing is an essential ingredient of any house and in India several roof cladding materials are in use including burnt clay / Mangalore tiles, thatch, corrugated sheets of galvanized iron, aluminum and asbestos cement, etc. Of these, for semi permanent structures corrugated sheets are preferred. Building Materials & Technology Promotion Council (BMTPC) and Indian Plywood Industries Research & Training Institute (IPIRTI) have jointly developed a technology for manufacturing Bamboo Mat Corrugated Sheets (BMCSs).

2.2.4.B. Micro concrete roofing tiles

Micro Concrete Roofing (MCR) tiles are a durable, aesthetic and inexpensive alternative for sloping roofs. Micro Concrete Roofing (MCR) tiles are made from a carefully controlled mix of cement, sand, fine stone aggregate and water.

3. Summary and Conclusions

Using modern geotechnical technology which can improve the strength and durability of much of the existing low-cost material should be encouraged. In this study, alternate construction materials were studied and the potential of these materials to be used as al- ternate building materials is brought out. Depending on the availability of the materials in a particular region, these materials can be selected as transportation consists of approximately 30% of total construction budget. In most developing countries, the challenge is to organize and

initiate measures that promote these materials as well as train local artisans and masons in the construction techniques involving these materials. There have been several attempts at local levels to make use of bamboo, mud or natural fibers but it still lacks scientific precisions and proper techniques to be used precisely. Also the usage of industrial wastes still needs study on their better usage toxicity. These materials if studied and developed properly hold the key to address the current housing needs.

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