ANNEXURE 4

ECO-FRIENDLY BUILDING MATERIALS AND TECHNOLOGIES

Eco-housing Assessment Criteria - Version II

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1 INTRODUCTION

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 study these alternatives were researched and the information collected has been provided in the subsequent sections.

2 STRUCTURAL MATERIALS

2.1 Pozzolona Material[1] (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.

Figure 1 *Fly Ash Heap*

[1]Building Materials in India: 50 Years – A Commemorative Volume, Building Materials & Technology Promotion Council, New Delhi, India, 1998, http://www.bmtpc.org/pubs/papers/paper4.htm
Fly ash Utilization Programme (FAUP-Technology Information, Forecasting and Assessment Council (TIFAC) http://flyashindia.tifac.org.in

Studies show that **one tonne of Portland cement production discharges 0.87 tonne of CO_2 into the atmosphere**. One Japanese study indicates that every year barren land area approximately 1.5 times of Indian Territory needs to be afforested to compensate for the total global accumulation of carbon dioxide discharged into the atmosphere because of total global cement production. Utilization of fly ash in cement/concrete minimizes the $C0_2$ emission problem to the extent of its proportion in cement.

*Update for the Indian Standard on "Portland Pozzolona Cement – Specification Part 1- Fly Ash based" (IS 1489 (Part 1): 1991:*In the amended form the Fly Ash constituent to be used shall not be less than 15% and not more than 35% by mass of Portland Pozzolona Cement.

In addition to the above mentioned advantages, use of fly ash provides more durability, saves on clinker cost, conserves mineral resources, provides good compaction, avoids breaking of large lumps, is light in weight, has no subsequent settlement, has no royalty to be paid as excavation of soil is eliminated, normally reduces transportation cost, easy and faster construction leads to overall reduction in construction cost; and supports additional agriculture produce from the land, which would otherwise be excavated for getting soil.

The characterization of the two main mineral admixtures, namely fly ash (FA) and blast furnace slag (BFS), is based on their chemical and mineralogical composition and particle characteristics. The durability performance of concrete with blended cements improves in terms of its resistance to the three deteriorating factors, namely alkali silica reaction (ASR), sulphate attack and the corrosion of steel reinforcement. All the three factors are important from the point of view of selection of appropriate mineral admixture for blending with cement.

The improved resistance towards the ASR is due to the higher retention of alkalis and the refinement of pore structure, and is due to formation of secondary calcium silicate hydrate (C-S-H) during the hydration of FA or BFS components in cement. Blended cements having tricalciumaluminate (C_3A) contents in the range of 5–8% and a FA content of 25–30% or a BFS content of above 60% show moderate to good sulphate resistance. The higher corrosion resistance is attributed to the refinement of pore structure resulting in lower chloride and oxygen diffusivity, greater chloride binding capacity and higher electrical resistance of the concrete made with blended cements. In comparison to concrete with OPC only, early and extended curing are required to obtain higher long term strength and better durability performance; the economic considerations show that the use of blended cement in concrete is the cheapest alternative available to control reinforcement corrosion.

Down Draft Sintering (DDS) process has been employed in manufacture of cement clinkers and light-weight aggregates from the mixture of fly ash-limestone/lime sludge. Use of flyash/bottom ash up to 15% is possible in manufacture of Portland grade cement in which compression strength of 400-450 kg/cm^2 at 28 days of curing can be achieved whereas the minimum requirement of strength at 28 days of Portland grade cement is 330 kg /cm^2. Use of more quantity of flyash/ bottom ash (up to 50%) at the clinkerisation stage is also possible but these cements show slow increase in strength to 300-350 kg/cm^2 - achievable at 90/180 days curing. This process is quite attractive for production of low cost cements using appreciable amount of flyash.

2.2 Sand and Aggregate from Pulverized Debris

Sand and aggregate from pulverized debris is environment friendly as it is obtained from recycled material, utilizes construction debris, minimizes waste and reduces dependence on virgin natural resources. It is also more economical.

In one hour 500 kg of pulverised output can be obtained from the pulverising machine, which utilizes electricity at the rate of 5 KW/hour.[2]

2.3 Sintered Fly Ash for Concrete and Mortar[3]

Sintered light-weight aggregate substitutes stone chips in concrete, reducing dead weight. Although fly ash is suitable for production as a light-weight aggregate, it is used only in small amounts for this purpose. The advantage of fly ash over other light-weight aggregates is that it promotes fuel efficiency because the carbon in the ash provides sufficient heat needed to evaporate the moisture in the pellets and bring the pellets to the sintering temperature.

Initially, fly ash is mixed with water and formed into pellets either in a revolving cone disc or drum or by extrusion. It has been found that a small addition of alkali produces a pellet with better resistance to mechanical and thermal shocks. In the sintering by travelling-grate process, the temperature reaches about 1150 to 1200°C and causes the small particles of fly ash to fuse and form a cake. The fine spherical glassy particles of fly ash particles melt at the surface and cohere to form a vitrified structure which hardens on cooling. Unburnt fuel in fly ash nodules supports ignition. The process of causing this cohesion is termed ‘sintering’ and thus the name sintered flyash. The cake is then broken to obtain discrete pellets.

Concretes made with these aggregates possess 28-day compressive strengths of the order of 40 MN/m^2 and densities of about 1100 to 1800 kg/m^3.

[2] Cidco-Yuva building center, Khargar, Navi Mumbai, 27560990/80
[3] Developed by CBRI, Roorkee, Info available at -Fly ash Utilization Programme (FAUP) Technology Information, Forecasting and Assessment Council (TIFAC) http://flyashindia.tifac.org.in,

Mixing 5, 10, & 20% of plastic clay in fly ash produces good quality light-weight aggregates. The sintered fly ash content is spherical and porous with 5-20 mm size and light grey colour. Water absorption of uncrushed material is 15-19.6 % and of crushed & graded material is 40-50%. It has a bulk density of 640-750 kg/m^3 and aggregate crushing strength 5-8.5 t.

Properties of sintered fly ash aggregate are: cement content 300-519 kg/m^3, bond strength 25-54 kg/cm^2, drying shrinkage 0.059-0.084 %.

Figure 2 *Sintered Fly Ash aggregates*

As these aggregates have good shape, strength and moderate water absorption, they are suitable for producing light-weight concrete blocks and structural light-weight concrete. The suitability of fly ash for the pelletization and sintering processes is difficult to predict because many physio-chemical factors are involved. Generally, aggregates of suitable quality can be obtained by keeping the carbon content between 3 and 10%. Excessive amounts of iron cause staining of the concrete. Sintered light-weight aggregate offers better thermal and acoustical insulation, high fire resistance, easy cutting, drilling and nailability. The use of LWA offers architects and engineers greater freedom in designing longer spans, larger floor areas and added height.

2.4 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 defence 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.

The primary criterion to be satisfied by steel reinforcement bars is mass per meter run. The IS 1786 specifies batch rolling tolerances in the range of +/- 7 to 3 percent, depending on the diameter of the bar. It is very well possible to control the weight of the reinforcement bars within these limits and if it is specified that steel should be supplied in the minus tolerance range only then substantial savings in the weight of steel could be achieved.

Though a premium of 1to 2 percent may be charged for this, it is possible to save up to 7 percent of the cost of steel. Steel bars may be purchased in standard lengths of 11 m, so that wastage can be reduced to a minimum. If the bars are purchased in random lengths (anything between 5 to 13 m) then wastage to the tune of 5 to 7 percent may be encountered. IS 1786: 1985 permits tolerances of +75/-25 mm when bars are cut to specified lengths but when minimum lengths are specified than minus tolerance is reduced to zero.

About 40% of the world's steel is produced by electrically melting recycled steel. The key significance of recycled steel in the global steel industry has made it into a strategic raw material, and it has a price on the world market. Some steel products such as galvanized studs, cladding and roofing panels and tube assemblies may verifiably come from electric "mini-mill" processes where recycled content claims of 40% or more are justifiable. Strength is high, non-combustibility and the added advantage of not producing smoke or toxic gases when subjected to elevated temperatures, availability in a form that permits efficient and uniform application, sufficient bond strength and durability, resistant to weathering and erosion resulting from atmospheric conditions, resistant to termite infestation.

2.5 Ferro Cement and Precast Components[4]

Precast Components are 85% recyclable, have low carbon dioxide generation and are energy efficient. They are eco-friendly, 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-storeyed 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.

Precast spacers designed as per I.S. code give benefits of improved performance of RCC due to exact position of reinforcements and larger life of the structure. Spacers are made of M30 grade concrete.

Precast slabs and beams are designed to carry live load of 2kn/sq.m without any additional reinforcement; they can carry load up to 10kn/sq.m if additional reinforcement is placed while filling up joints, the slabs are provided with interlocking system to avoid independent displacement of slabs. Slabs are manufactured with M40 Grade concrete to give durable and stronger slabs than cast in situ slabs. No curing from inner side of the slabs is required which helps early utilization of construction.

[4] Nandadeep Building Center, Aurangabad; HUDCO, Build Tech, Taking technologies to the doorstep. www.hudco.org; SERC, Chennai; Auroville Building Centre, Pondicherry.

Precast brick panels used in combination with partially precast joists save in economic use of steel and cement and provide an alternative to reinforced cement concrete roofing/flooring where good quality bricks are available. Precast L- Panel Elements provide a better alternative to RCC sloping roofs. Water seepage can be eliminated in these panels where better quality control is possible. Precast technology also results in saving on expensive shuttering.

Precast plank and joist for flooring/roofing consisting of precast RC planks supported over partially precast RCC joists with in-situ concrete are suitable up to a span of 4.0 m and ensure 12% overall saving in cost and 20% reduction in construction time.

Precast chamber covers are provided with welded reinforcement to increase its life and avoid breakage at site after installation. They are cheaper and stronger than cast iron chamber covers.

Precast waffle units provide speedy construction with overall saving of up to 10% besides avoiding shuttering work. The shape is like an inverted trough with a square or rectangular plan having lateral dimension up to 1.2 m suitable for large spans beyond 6m in either direction.

Precast channel units are easy to construct roofing/flooring with an effective saving in cost and time. These units are reinforced cement concrete elements, channel shaped in section and 2.5 to 4.2 m long providing for ceilings that looks like one-way rib beams.

Precast cored units are simple to manufacture and provide a speedy and economical flush ceiling. They consist of extruded concrete section units with circular hollows and can be used up to 4.2m span and can be used for floors or roof in load bearing walls and framed structures.

Figure 3 *Ferro Cement Roofing Channels*

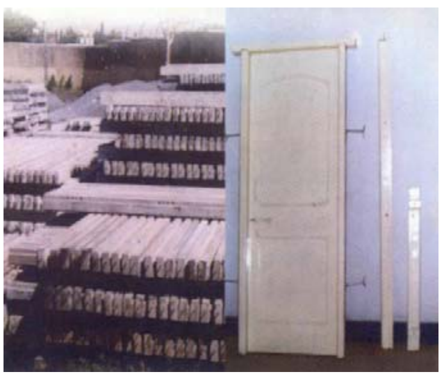
Precast in-situ thin ribbed slab are available, which are made from precast/in-situ ribs provided at a spacing of 1.2 m with cast-in-situ RC flange. These can be used for floor/roof slab. As the ribbed slab is thin, roof treatment should be provided over the slab for better thermal insulation. It is cheaper and easy to construct in comparison to conventional cast-in-situ RCC slab.

Ferro cement structures (i.e. rich mortar reinforced with chicken mesh and welded wire- mesh) are simple to construct. These reduce the wall thickness and allow larger carpet area. Precast ferro- cement units in trough shape can be integrated with RCC columns.

Ferro- cement units serve as a permanent skin unit and as a diagonal strut between columns. Inside cladding can be done with mud blocks or any locally available material. Ferro cement channel/shell units provide an economic solution to RCC slab by providing 30-40% cost reduction on floor/roof units over RCC slabs without compromising the strength.

These being precast, construction is speedy and economical due to avoidance of shuttering. Ferro cement structures are cost effective, durable, have high strength and are have maintenance.

2.6 Precast R.C.C. / Ferro-cement Frames[5]



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.

Figure 4 *Precast Door and Window Frames*

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 1/3[rd] 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 nos, stirrup 6 mm (welded to main reinforcement).[6]

[5] Environment Friendly Materials & Technologies Brochure, BMTPC, New Delhi
[6] Nandadeep Building Center, Brochure, Hudco Assisted Project.

2.7 Ready Mix Concrete[7]

The greatest advantage of Ready Mix Concrete (RMC) is its quality. RMC is a water reducer, workability enhancer, has improved resistance, higher strength, lesser possibility of thermal cracking, is economic and has increased durability.

Quality of sand, coarse aggregates, cement and water in the concrete mix can be managed better in the factories since there are facilities to check the silt content and bio waste level in the sand. There is little wastage at the RMC plants and less manpower is required in operational phases.

[7] ACC, BIRLA, RAMCO, L&T

3 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.

3.1 Fly Ash – Sand – Lime Bricks[8]

To bridge the huge shortfall of bricks and to maximise reuse of fly ash waste, these fly ash- sand-lime bricks should be used. These bricks provide the advantage of being available in several load bearing grades, savings in mortar plastering, and in giving smart looking brickwork.

Figure 5 *Fly Ash Based Bricks and Blocks*

High compressive strength eliminates breakages/wastages during transport and handling, and thus cracking of plaster is reduced due to lower thickness of joints and plaster and basic material of the bricks, which is more compatible with cement mortar.

After proper pointing of joints, the bricks can be directly painted in dry distemper, cement paints, without the backing coating of plaster. Plaster of Paris /gypsum plaster can be directly applied without any backing coat of plaster. Due to low water absorption property, only sprinkling of water is enough and bricks do not need soaking in water.

[8]Technology developed by TIFAC, New Delhi; CBRI, Roorkee; Local Vegetable Fibres+Industrial and Mineral Wastes for Composite Material by BMTPC. C'cure Building Products Pvt.Ltd, Pune.

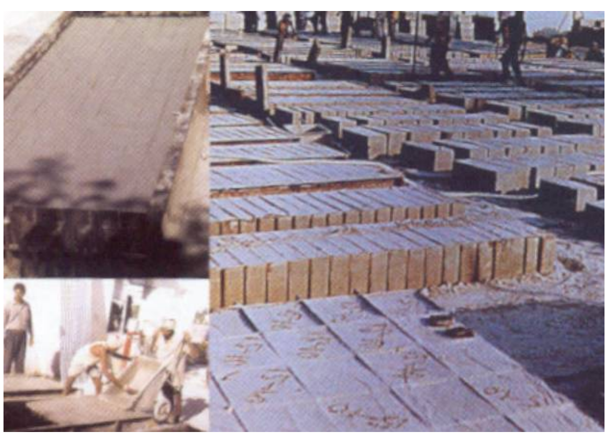
The bricks do not cause any extra load for design of structure, have better resistance for earthquakes due to panel action with high strength bricks, provide an acceptable degree of sound insulation, give maximum light reflection without glare, and have good fire resistance and high durability.

Compressive strength of fly ash sand lime bricks is avg. 9.00 N/mm^2 (as against 3.50 N/mm^2 for handmade clay bricks). Water absorption is 6-12% as against 20-25% for handmade clay bricks, reducing dampness of the walls, thermal conductivity is 0.90-1.05 W/m2 0 C (20-30% less than those of concrete blocks). These bricks do not absorb heat, they reflect heat. Maximum average drying test shrinkage is 0.035-0.04%, coefficient of expansion is 10-14 x 10-6, and density is 1800-1850 kg /m$^{3.}$

Figure 6 *Bricks and Blocks manufacturing machine*

3.2 Aerated Light-weight Concrete Blocks[9]

These are manufactured by a process involving mixing of fly ash, quicklime or cement and gypsum and foaming agents such as aluminium powder. These are considered excellent products for walling blocks and prefab floor slabs. They reduce dead loads on the super structure, thus indirectly helping cut costs significantly.



[9]Developed by CBRI, Roorkee

Figure 7 *Light-weight Concrete Components (blocks and pavers)*

3.3 Phospho Gypsum Based Blocks[10]

Phospogypsum is generated as a by-product of the phosphoric acid based fertilizer industry. The interaction of ground phosphate rock with sulphuric acid produces 10-40% free moisture along with Phospho Gypsum. Nearly 4.5 million tonnes is generated per year. The fluoride content in Phospho Gypsum causes land and water pollution

Phospho Gypsum based blocks are eco-friendly, utilise waste and reduces air, land and water pollution.

They are energy efficient, cost effective and have a bulk density of 1000-1100 kg/m^3. The compressive strength is 2.5-3.0 MPa

3.4 Burnt Clay Fly Ash Bricks[11]

The fly ash content can be 20-60% depending on the quality of clay. Energy/coal saving in firing up to 30% can be achieved, since fly ash already contains some percentage of un-burnt carbon. These bricks have better thermal insulation, are cost effective and environment friendly. Fuel saving in the range of 15%-35% (coal consumption) can be achieved, resulting in saving of coal up to 3-7 tonne per lakh bricks.

Drying losses are checked in case of plastic black and red soils. Excessive linear drying shrinkage is reduced. Thirty to forty tonnes of fly ash per lakh bricks can be utilized in case of alluvial soils, and 100-125 tonne per lakh bricks in case of red and black soils. Clay, a valuable and irreplaceable economic resource, is conserved to the extent of 40% by weight.

Bricks conforming to IS: 3102-1976 can be manufactured, uniformly in shape and size. Comparatively less quantity of cement mortar by about 20%-25% is required. Water absorption is 13% to 15% as compared to 20% for conventional bricks. Outside wall plastering could be avoided, as these bricks are smooth. Fly ash lime bricks are more resistant to salinity and water seepage. Lower bulk density of fly ash bricks help to minimize the load on load-bearing walls.

[10]Developed by CBRI, Roorkee, www.cbri.org Promoted by BMTPC, www.bmtpc.org.

[11]. TIFAC, Fly ash Utilisation Programme, http://www.bmtpc.org/pubs/papers/paper4.htm BMTPC, Publication: Fly ash: A Resource Material for Innovative Building Material- Indian Perspective, by C.N.JHA and J.K. PRASAD. Local Vegetable Fibres + Industrial and Mineral Wastes for Composite Material by BMTPC.

3.5 Sun-Dried Brick

It's an eco-friendly technique, energy efficient, reduces air, water and land pollution It is economic and energy required for firing is saved. In hot and dry and temperate zone countries sun-dried brick have been the most widespread building material through the centuries. One third of mankind still lives in such houses. In spite of the fact that loam is rarely taken into account, it is a plastic material and can be worked easily.

Figure 8 *Bricks Drying in the Sun*

Sun dried bricks can be built in at the construction site with manual force, thereby reducing the building and transporting expenses, and also reducing the embodied energy of the bricks.

3.6 Bricks from Coal Washery Rejects[12]

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. With a suitable binder such as cement or lime, bricks and blocks similar to those made using fly ash can be made using this coal washery reject material. These bricks are eco-friendly and waste utilizing. They reduce air, land and water pollution, are energy efficient and cost effective.

3.7 Building Blocks from Mine Waste and Industrial Waste[13]

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. For example, more than 100 tonnes fly ash is produced annually in India (from thermal power plants) and only 2–3% is being utilized. Similarly millions of tonnes of red-mud is stored near aluminium manufacturing units (~ 20×10^6 tonnes of red-mud is heaped into hillocks at the

[12] Developed by BMTPC, www.bmtpc.org

[13] Developed by Structural Engineering Research Centre, Chennai, Booklet by SERC. krs@sercm.org ; http://www.iisc.ernet.in/currsci/oct102004/899.pdf

aluminium manufacturing unit at Belgaum in Karnataka state). Such huge heaps of wastes concentrated in certain specific localities cause environmental and pollution hazards. 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. Generally, mine tailings are accumulated in heaps near the mines resulting into huge hillocks. For example Bharat Gold Mines Limited at Kolar Gold Fields (KGF) has created 33×10^6 tonnes of tailings (which are non-toxic) heaped into 13 hillocks. Similarly, the iron-ore tailings of the Kudremukh Iron Ore Company in Karnataka, amounting to ~ 150×10^6 tonnes are stored in huge dams created for collecting the iron-ore slurry washings. Coal mines, copper mines, etc. generate and store huge quantities of solid wastes.

There is a large scope for utilizing mine wastes for the manufacture of building materials and products. For example 33×10^6 tonnes of gold mine tailings at KGF can be converted into bricks/blocks, which can satisfy the demand for bricks at Bangalore city for the next 30 years or more. Similarly utilizing the 150×10^6 tonnes of iron ore tailings can meet the requirement of sand and bricks and blocks of Karnataka State for decades. Thus there is a great potential for utilizing industrial and mine wastes for the manufacture of building materials and products.

3.8 C-Brick[14]

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-sand- aggregate. The bricks manufactured have properties such as compressive strength of 40-80 kg/sq.cm, water absorption less than 20%, and efflorescence free product.

3.9 Calcium Silicate Brick[15]

Utilization of fly ash in place of quartz sands in sand lime bricks produces calcium silicate bricks. The process involves compaction either by low pressure or high pressure followed by autoclaving under elevated hydrothermal conditions. The product from high pressure compacting is much superior but requires larger capital investment. Calcium silicate bricks made from sand of siliceous waste and hydrated lime, generally known as sand lime bricks, are advanced building materials that give higher strength, uniform surface and sharp corners.

These bricks can make beautiful walls that may eliminate plastering and painting, thus providing economical and superior alternative to conventional clay bricks. Manufacturing these bricks where sand or siliceous waste and lime are readily available, may, in fact, produce these bricks cheaper than clay bricks. Production of these bricks consumes about 30% less energy as compared to traditional clay bricks. About 30,000 million calcium silicate bricks, solid as well as

[14]Technology Offers from CBRI, http://www.tifac.org.in/offer/tsw/cbri19.htm
[15]http://www.eco-web.com/cgi-local/sfc?a=/editorial/index.html&b=/editorial/041201.html, Promoted by BMTPC, www.bmtpc.org

perforated, in different colours, are produced annually all over the world by the developed countries using completely automatic plants. Popularity of these bricks in developing nations has not picked up mainly due to ignorance, uneconomical local cost factors and non-availability of raw materials at few places.

3.10 Fly Ash Lime Gypsum Brick[16]

Fly ash-lime-gypsum bricks / blocks are very good products, giving the highest strength among various bricks. These require relatively higher investment and expensive raw materials to give a range of high strength products. This is most suitable for mechanized operations, though semi-mechanized operations are also possible. Fly ash lime gypsum bricks are made up of 60% fly ash, 10-20% lime and 10-20% gypsum. These bricks have medium range strength.

Minimum compressive strength (28 days) of 70 kg/cm^2 can easily be achieved and this can go up to 250 Kg/cm^2 (in autoclaved type).

Advantage of these bricks over burnt clay bricks: Lower requirement of mortar in construction, Plastering over brick can be avoided, Controlled dimensions, edges, smooth and fine finish & can be in different colours using pigments and cost effective, energy-efficient & environment friendly (This avoids the use of fertile clay).

3.11 Stabilised Compressed Earth Block[17]

The Stabilized Compressed Earth Block (SCEB) Technology offers a cost effective, environmentally sound masonry system. The product, a stabilized Compressed Earth Block has wide application in construction for walling, roofing, arched openings, corbels etc. Stabilized Earth Blocks are manufactured by compacting raw material earth mixed with a stabilizer such as cement or lime under a pressure of 20 - 40 kg/cm^2 using manual soil press such as Balram. A number of manual and hydraulic machines are available in India. The basic principal of all the machines is the compaction of raw earth to attain dense, even sized masonry. Some of the hydraulic machines can even manufacture interlocking blocks. These interlocking blocks are highly suitable for speedy and mortar less construction. Stabilized Compressed Earth Block (SCEB) Technology helps in offsetting the use of fuel wood as they are sun dried and use cement for stabilization for gaining the required strength.

The Stabilized Compressed Earth Block is a masonry unit of cubical shape. This may be solid or hollow or interlocking. The equipment used in its manufacture defines the shape and size of a block. SCEBs can be used for load bearing construction up to 3 storeys. The cost of Compressed Earth Block depends upon a variety of factors including quality and price of available soil, amount of stabilization, labour productivity, equipment and overhead costs. The degree of stabilization has the maximum influence on the cost of the product.

[16] http://www.tifac.org.in/offer/tlbo/rep/TMS085.htm
[17] http://www.devalt.org

The primary raw material for the production of SCEB is raw earth or soil. OPC cement in small quantities and water are other constituents. Coarse sand or stone dust may be added depending on soil quality. Soil is made up of grains of various sizes. The grain size distribution of a soil determines its suitability for the manufacture of SCEB.

About six to ten persons are required to operate a manual machine. For hydraulic machines the manpower required is six to eight persons. In both the systems one skilled worker is required while the rest are semiskilled. The workers can be trained to operate any machine in 10-12 days.

Fired bricks have a potential of 460 billion bricks every year, which has been proven by NCAER and a leading brick association and is increasing steadily by 3-5% growth rate every year. Even 5% market share will lead to 23 million bricks per year. Compressed earth blocks can be used for almost all the applications of burnt clay bricks.

3.12 Rice Husk Ash Based Insulating Brick[18]

These bricks are eco friendly, economical, waste utilizing and energy efficient. CG & CRI has developed insulating bricks from rice husk ash, which can be used for insulation of all types of industrial furnaces, particularly ceramic kilns and furnaces in steel and cement plants as well as in non-ferrous and petrochemical industries.

Rice husk is unusually high in ash compared to other biomass fuels – close to 20%. The ash is 92 to 95% silica, highly porous and light-weight, with a very high external surface area. Its absorbent and insulating properties are useful to many industrial applications.

RHA is a general term describing all types of ash produced from burning rice husks. In practice, the type of ash varies considerably according to the burning technique. The silica in the ash undergoes structural transformations depending on the conditions (time, temperature etc) of combustion. At 550°C – 800°C amorphous ash is formed and at temperatures greater than this, crystalline ash is formed. These types of silica have different properties and it is important to produce ash of the correct specification for the particular end use. Substantial research has been carried out on the use of amorphous silica in the manufacture of concrete. There are two areas for which RHA is used, in the manufacture of low cost building blocks and in the production of high quality cement. Due to its insulating properties, RHA has been used in the manufacture of refractory bricks.

The most promising approaches to the solution of the problem of rice husk disposal fall into two basic categories. The first category includes methods for using the heating value and the silica content of the rice husk as elements in the manufacture of industrial products such as Portland cement, water glass, and porous silicate structural materials. The other category includes the chemical or physical bonding of rice husk into board for architectural use.

[18] CG & CRI, Jadavpur, Central Glass & Ceramic Research Institute, Jadavpur, Calcutta. http://www.bmtpc.org/fibre.pdf

3.13 Fly Ash Lime Cellular Concrete[19]

Pelletization or nodulisation of fly ash and sintering of the pellets or nodules at 1000 - 1300 degree centigrade produces this material. Un-burnt fuel in fly ash nodules supports ignition.

Sintered light-weight aggregate substitutes stone chips in concrete, reducing dead weight. It has a density ~1/5 of concrete. It is used for load bearing walls, low-rise buildings, and partition and curtain walls.

Cellular Light Weight Concrete (CLC) blocks are substitute to bricks and conventional concrete blocks in building with density varying from 800 kg/m^3 to 1800 kg/m^3. The normal constituents of this Foaming Agent based technology from Germany are cement, Fly Ash (to the extent 1/4th to 1/3rd of total materials constituent), sand, water and foam (generated from biodegradable foaming agent). Using CLC walling & roofing panels can also be produced. Foaming agent and the Foam generator, if used for production of CLC with over 25% fly ash content invites concession on import duty by Govt. of India.

[19] http://www.eco-web.com/cgi-local/sfc?a=/editorial/index.html&b=/editorial/041201.html, http://www.ucis.pitt.edu/global/gap/environmental/presentations/Neufeld.pdf

4 PLASTER

4.1 Calcium Silicate Plaster[20]

Calcium silicate refractories are usually derived from calcium silicate or silicate bearing minerals such as hornblende, epidote and diopside, often with calcite or dolomite or wollastonite. Wollastonite is a naturally occurring form of calcium silicate commonly used as a filler. Portland cements are also based on calcium silicate.

Calcium silicate plasters are economic, eco-friendly, produce less wastage, have wide usage, give a smart finish, are less energy consuming, do not emit VOC and other toxic fumes and gases after application and are recyclable.

They are safe in handling and usage, do not need skilled man power, are fast drying, durable, and have less water consumption.

4.2 Fibre Reinforced Clay Plaster

Clay Plaster can achieve better sticking properties by reinforcing it with fibres. These fibres can be natural plant (cellulose) fibre or artificial fibres of polypropylene**.**

Plant fibres in fibre 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.[21]

Fibres made from 100% virgin polypropylene fibres are also available and can be used to achieve the similar properties. Use of these fibres can reduce plastic shrinkage, reduce permeability, and provide increased impact and abrasion resistance.[22]

4.3 Phospho Gypsum Plaster[23]

Phospho gypsum is the waste generated by manufacturing plants of phosphoric acid, ammonium phosphate and hydrofluoric acid. In India, about 4-5 million tonnes of phosphor gypsum is generated every year.

The fluoride content of phospho gypsum is a source of land and water pollution. It is possible to profitably utilize this pollutant for making cement, gypsum boards, partitions, ceiling tiles, artificial marble, fibreboards etc. Phospho gypsum can be gainfully utilized in the manufacture of expansive and non-shrinking cement, super sulphated and anhydride cement, simultaneous manufacture of cement and sulphuric acid, as a hydraulic binder, as set controller in the

[20] Developed by CBRI, Roorkee; SERC, Chennai
[21] http://naturalbuildingproductscouk.ntitemp.com/datasheet_clay_undercoat.htm
[22] Genuine Fiber mesh – Nina Concrete Systems Pvt. Ltd. – www.fibermesh.com
[23] Developed CBRI, Roorkee, www.cbri.org.

manufacturing of Portland cement, as a mineraliser and in making gypsum plaster boards and slotted tiles. This plaster is eco friendly, economic, energy efficient, waste utilising and prevents water and soil pollution.

Material Properties are as follows –

Properties	**Unprocessed phospho gypsum**	**Beneficiated phospho gypsum**
Setting time	5 minutes (un retarded) 15 minutes (retarded)	11 minutes (un retarded) 30 minutes (retarded)
IS specification	Conforms to IS: 8272,1984,	Conforms to IS: 8272,1984,
Bulk Density	1220 kg/m^3 (un retarded) 1210 kg/m^3(retarded)	1250 kg/m^3(un retarded), 1225 kg/m^3(retarded)
Compressive Strength	9.80 MPa (un retarded) 8.90 MPa (retarded)	10.60 MPa(un retarded) 9.60 MPa (retarded)

4.4 Non Erodible Mud Plaster

Mud walls are common especially in rural areas. Erosion of mud walls is the most common problem. The plaster requires costly annual repairs. CBRI has developed non-erodible mud plaster, which is non-erodible and water repellent. Mud plaster stabilised with bitumen cutback and kerosene lasts longer, depending upon the intensity of rain and also provides waterproofing, insect and abrasion resistance, hygienic and maintenance free walls. It is easy to prepare and apply on walls. It is economic and durable, thus reducing annual maintenance cost.

5 ROOFING

5.1 Bamboo Matt Corrugated Roofing Sheet[24]

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, aluminium and asbestos cement, etc. Of these, for semi permanent structures corrugated sheets are preferred. However, one of the major roofing materials, viz., ACCS is being replaced with other alternative materials in many countries. Considering the need for developing alternate eco-friendly, energy efficient and cost effective roofing sheets, 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).

Table 1. ***Comparison of Load Bearing Strength of BMCS and Other Sheets***

Type	Thickness mm	Width mm	Max. Load N	Load bearing Capacity N/mm	Wt of Sheet (1.05m x 1.8m) Kg's.
Bamboo Mat Corrugated Sheet (4 –Layers)	3.7	400	1907	4.77	7.2
G. I. Sheet	0.6	400	1937	4.84	7.7
Aluminium Sheet	0.6	405	669	1.97	2.9
ACCS	6	330	1800	5.45	15.85

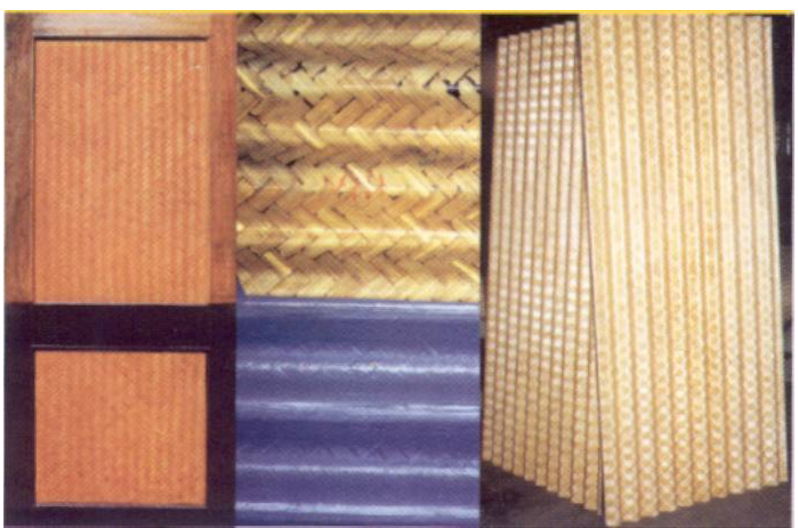


Figure 9 *Bamboo Matt Corrugated Sheets*

[24] Developed by BMTPC, New Delhi, www.bmtpc.org

BMCS produced at pilot scale facility established at the IPIRTI have been used in several demonstration buildings. The sheets have been found to be resistant to water, fire, decay, termites, insects, etc. They are light but strong and possess high resilience and offer better thermal comforts. A comparison of properties of BMCS with other alternatives is shown in the table above. The main raw material for the production of BMCS is bamboo, which is the fastest growing plant and occurs naturally in the forests and is also suitable for plantation even over degraded lands. For manufacturing BMCS, bamboo is to be converted into mats that are hand woven by rural/tribal people, particularly women. Thus, the product is both environment and people friendly

5.2 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. MCR tiles undergo stringent quality control at every step. They are put through rigorous tests for water tightness, strength, shape and size. MCR technology is a result of global research and development effort. In India, TARA, Development Alternatives in association with SKAT of Switzerland, promotes MCR technology.

MCR tiles offer many advantages over other sloping roof materials such as G.I. sheets, Mangalore tiles, wooden shingles, slate and asbestos. MCR tiles are: highly cost effective, durable-they have the life of concrete, lighter than other roofing tiles-they require less under-structure, easily installed, can be coloured to specification, reduce heat gain, do not make noise during rains. Cost of roof varies according to span and roof form. A variety of roof designs for farm and country houses, bungalows, verandas and pavilions are possible with MCR tiles. They have also been used on industrial sheds, workshops and restaurants.

MCR roofs are constructed in a conventional manner using rafters and purlins made from wood or steel. Rafters are typically spaced at 90 cm to 110 cm apart. The purlins are at a distance of 40 cm from each other. MCR tiles are secured to purlins by tying them to the purlins with G.I. wire. The angle of roof slope should be at least 22°. Greater inclination of up to 30° is preferred for more aesthetic appeal.

Standard architectural details for gable and hipped roof ridges, eaves, side over-hangs and valleys can be used for MCR roofs.

Technical Data

Clear length of tile	488 mm
Length after overlap	400 mm
Clear width of tile	240 mm
Width after overlap	200 mm
Thickness	8 mm
Corrugated depth	50 mm
Nominal weight	2.25 kg
Load bearing capacity of tile	80 kg

Design Data for MCR Roofs:

Tiles per m^2	13 nos.
Wt. per m^2	32 kg
Tiles along 10 m of roof length	50 nos.
10 m of width	25 nos.

Figure 10 *Micro Concrete roofing tiles*

MCR technology has been validated and certified by: Building Materials and Technology Promotion Council, Ministry of Urban Development, Govt. of India. Certificate No. 95/1.

Production of 200 tiles per day by four workmen, including one trained mason is achievable.

The micro concrete tiles can be considered satisfactory against leaks as per the specifications of IS: 654, 1992. The average value of breaking load is 104.80kg. 10mm thickness tiles are 10% stronger and the life span of MCR tile is about 25 years.

5.3 Clay Tiles[25]

These tiles are uniform, more durable, fire resistant, environment friendly, energy efficient and low cost. Due to their low self-weight, the dead loading on the super structure reduces significantly, thus indirectly reducing costs.

Figure 11 *Clay Tiles – designs and application*

Tiles made using locally available clay should be encouraged rather than insisting only on the Mangalore pattern clay tile for the purpose of roofing. Fibre reinforced clay tile is a good alternative material, displaying high aesthetic performance and durability. The fibres could be any locally available agro waste.

[25].Developed by BMTPC, New Delhi, Clay Roofing Tiles Collection, Morbi Galicha Tiles CO.

6 FLOORING

6.1 Phospho Gypsum Tiles

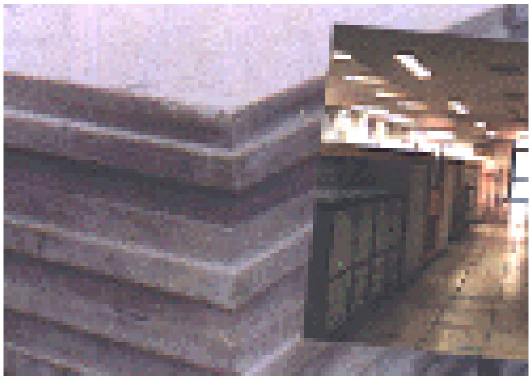


Figure 12 *Phospho Gypsum Tiles*

Phospho gypsum can be used for making gypsum tiles. The use of waste gypsum is recommended for producing value added building materials which would definitely alleviate the pollution generated by the waste gypsum and will provide low cost eco friendly building materials with novel properties of lightness, fire resistance and acoustic effects.

They show the following properties: flexural strength-11-15 N/mm^2, compressive strength-30-40 N/mm^2, water absorption-2.0-3.5%, wear resistance-2.0-4.0 mm, porosity-5.0-8.0.

6.2 Bamboo Board Flooring

Bamboo is a critical renewable raw material resource which is environment friendly, energy-efficient, cost effective, and can be used for disaster resistant housing. Bamboo Board flooring is a good alternative to wooden flooring. The flooring blends elegance with toughness, water resistance and ease of installation. There are bamboo boards designed with a interlocking design and available in various shades and with vertical or horizontal grains in 15 mm size.

Figure 13 *Bamboo Flooring*

6.3 Terrazzo / Marble Mosaic Flooring

Terrazzo flooring is an eco-friendly alternative, made using waste and recycled material. It is primarily made using chips of broken tiles, stones and various other ceramic articles. Cement and epoxy resins are the most widely used binders for such type of flooring. Since this type of flooring can be laid out seamlessly, it helps form a good waterproofing layer on exposed surfaces such as terraces and balconies. Moreover, variations in its component materials by adding polystyrene beads can increase its insulating properties.

Figure 14 *Terrazzo / Marble Mosaic Flooring*

7 WOOD ALTERNATIVES

7.1 Timber from Certified Forests / Plantations

With growing public awareness and leaning towards environment friendly products, architects and builders are using less and less of wood in construction. The Central Public Works Department (CPWD) banned the use of wood in building constructions since April 1993. Even so, about 4 million cubic meter of timber is annually used in the country for housing purposes and there is an additional annual demand of about 1.5 million cubic meters.

The use of plantation timbers and rubber wood and poplar wood have been recognised as sustainable timber species which will be available without any future scarcity. They are planted in order to save our virgin wood resources like rainforests. These are planted according to the need and demand with improved varieties, shorter life cycle and economic feasibility. It reduces deforestation to a large extent and saves forest cover and reduces environment pollution while taking care of the growing need of timber in the construction market. Owing to the nature of plantation timber, processing of the wood is necessary to enable its use in shutters and other building applications. Such machines have been developed by BMTPC and other organizations. Various timber products such as shutters are available using certified wood.

7.2 Salvaged Wood

Timber can be salvaged through furniture reuse, railway sleeper wood, construction debris wood or other timber. When using salvaged timber it needs to be treated for any water absorption, UV damage, wood rot, mould and mildew. Based on the source of timber to be used it needs to be treated as follows:

- Wood from furniture reuse needs re-surfacing using laminate or veneer, or polishing, paintwork etc.
- For sleeper wood, chemical treatment is compulsory when human contact persists. Reuse also requires surface finishing. The structural strength is very low and it has only decorative value. It also is a limited resource.
- Construction debris wood requires surface finishing, its structural strength varies based on its past usage and treatment. It is also a limited resource and available sizes, shapes and forms are indeterminable.

Timber (used) from any source can be re-used by converting into chips and particles for particleboards and chipboards. Larger size chips can sometimes be directly used in landscaping elements such as walkways and lawn sides. “Mulch” can be used to prevent soil erosion, enrich soil and help limit water loss. Sawdust and chipped wood can be used as a bulking agent in composting to improve air flow and decomposition

Chemicals such as Creosote and Chromated Copper Arsenate used for treating timber can be hazardous in nature and therefore reuse of timber treated with these chemicals needs to be done with caution. Borate and Copper based chemicals are less toxic. Care should be taken while handling and disposal of treated wood, such that it does not come in constant human contact and that it is not burnt.

7.3 Fibre Reinforced Polymer Plastics[26]

Fibre reinforced polymer plastics are made from plastic components, are cheaper and look elegant and pleasing and compete with wood products. Made from fibre glass, reinforced plastics are characterized by low installation and maintenance cost, high strength, light-weight, translucency or opaqueness, good resistance to weathering and fire and versatility of fabrication methods.

7.4 Red Mud Based Composite Door Shutters[27]

The Building Materials and Technology Promotion Council has produced a composite, popularly known as Composite Doors & Panels, made out of "Red Mud" (a waste product from aluminium industries), polymer and natural fibres, to replace wood and wood based products in the building industry. Technically known as **Red Mud Jute Fibre Polymer Composite** (REPC), this versatile composite, contains ferric oxide, alumina and titanium oxide from red mud and 82.5% cellulose and 11.3% lignin from its jute component. Some of the inherent properties of the product which make it technically superior to other conventional products are - Environment friendly technology, three times stronger than wood, weather resistant and durable, corrosion resistant, termite, fungus, rot and rodent resistant, and fire resistant. Composite doors & panels possess properties which are comparable to natural wood and thus could be used as a wood substitute for doors, windows, ceilings, floorings, partitions and furniture.

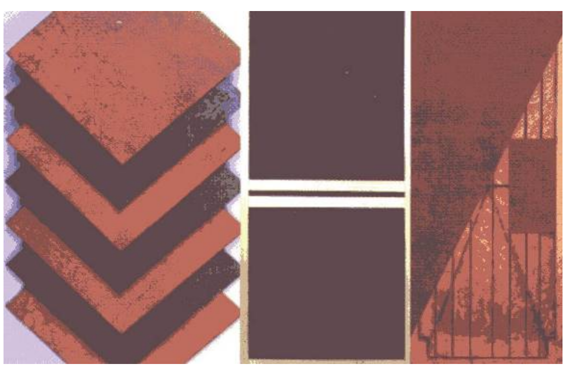


Figure 15 *Red Mud Based Composite Products tiles, boards and shutter from L to R)*

[26] Developed by CBRI, Roorkee, www.cbri.org.
[27] Local Vegetable Fibres+Industrial and Mineral Wastes for Composite Material by BMTPC.http://www.bmtpc.org/building/redmud.htm,

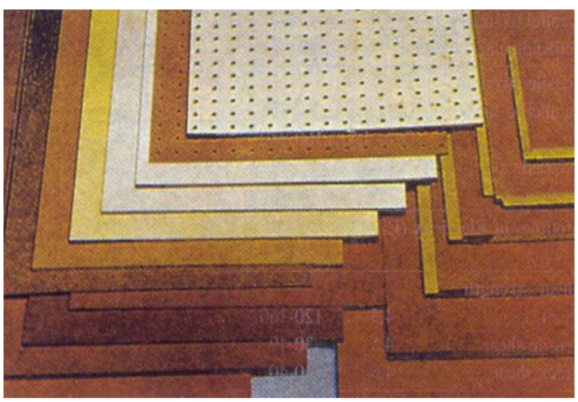
A product such as **Composite Doors & Panels** helps the environment in two ways: Firstly by helping to prevent further deforestation and secondly by effectively using waste products and in the process reducing pollution hazards. The market for a corrosion proof doors, windows, partitions etc. already exists in the country.

7.5 Coir Composite board

These are panels with low thermal conductivity, better sound insulation and fire resistance, low water absorption, paintable, can be laminated, cost effective alternative to timber, particle boards and fibre boards, suitable for walling, door panelling, windows, partitions and false ceiling.

7.6 Baggase Board

It acts as a timber substitute for wood based products. It is strong, light-weight, finds aesthetic acceptance, and controls pollution of environment by minimizing the amount of agro waste. Manufactured with fibrous baggase (sugar cane waste) along with suitable binder under pressure, baggase boards are suitable for making insulation boards, panels, roofing sheets etc.



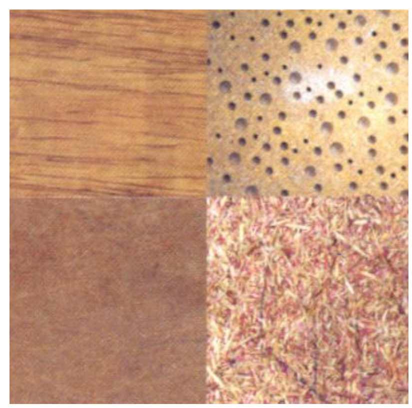


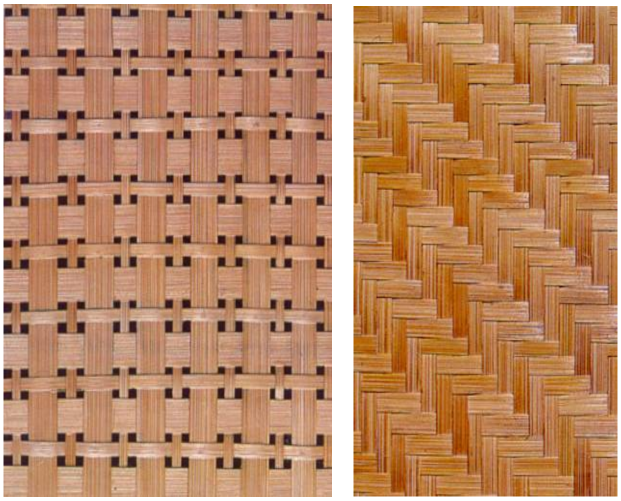
Figure 16 *Bagasse Board (left) and Agro-waste recycled boards (right)*

7.7 Bamboo matt boards[28]

Scientists at the Indian Plywood Industries Research and Training Institute (IPIRTI) have developed a cost-effective way of making plywood-like boards from bamboo mats woven by low income, rural women. The mats are coated with glue and hot-pressed to produce the mat boards, which can then be used to build houses, packing cases, storage bins and carts, among other things. This new industry has helped revive traditional mat weaving in tribal areas and raised

[28] International Network for Bamboo and Rattan, New Delhi.

women's incomes. Moreover, it has reduced the pressure on shrinking tropical forests by replacing wood with faster-growing bamboo, which regenerates in four to five years.



Bamboo mat boards are currently being used in house construction (walls, doors, ceilings), transportation (roof and sides of carts), packing cases, storage bins, furniture and, more recently, in concrete formwork. Other potential applications include constructing prefabricated houses for use during earthquakes, floods, and other natural disasters. Bamboo mat boards are an ideal substitute for thin plywood, which is expensive because prime quality logs are increasingly scarce and priced very high.

Figure 17 *Bamboo Matt*

IPIRTI is carrying out a number of research efforts aimed at refining BMB production and the final product. This includes efforts to: refine the glue and glue applicator; explore options for reducing the cost of glue; develop bamboo mat wood veneer suitable for structural uses; develop composition boards based on other plant or wood materials in combination with bamboo mats for various applications; determine, through a market survey, the bamboo mat board characteristics necessary for various applications.

7.8 Bamboo mat veneer composites[29]:

These are economical compared to bamboo mat board for thickness greater than 6mm, can substitute wood by about 50%, give the choice of having surfaces with bamboo mat look and have higher strength than veneer plywood alone.

Availability of industrial wood from natural forests has been on decline for many years now, creating a raw material crisis for the wood based panel industry in the country. The national forest policy 1988 lays emphasis on development of wood substitute. Timber from fast growing plantation species generally has lower strength properties, dimensional stability and service life. IPIRTI, a premier research institute of the MOEF, GOL, in the field of composites based on wood and other lignocelluloses material has developed environmentally sustainable technologies for making plywood like sheet materials from Bamboo. Extensive research using Bamboo Mat in

[29] http://www.bamboocomposites.com/bamboo%20mat%20veneer%20composite.htm

combination with plantation wood for sheet material has resulted in development of Bamboo mat Veneer composites.

Figure 18 *Application of Bamboo Matt Boards and Composites*

BMVC is a preferable panel material due to its superior physical mechanical properties compared to Bamboo Mat Board (BMB) and general-purpose plywood and on par with structural plywood. Bureau of Indian Standard has already brought out a standard on "Bamboo mat veneer composite for general purpose IS: 14588/1999". Bamboo mat Veneer composite boards can be made in existing plywood or Bamboo mat board manufacturing factories without major additional capital investment

7.9 Finger-jointed plantation board

These boards utilise a process whereby small pieces of timber and off-cuts, which might otherwise have been discarded, are joined together to form longer members. Finger-jointed floorboards are a better alternative to long, single-length floorboards because long boards usually have to come from very large, very old, majestic trees - and there are too few of these left!

Figure 19 *Plantation Timber Boards*

7.10 Recycled laminated tube board

It is a board made from recycled empty toothpaste containers. These plastics are shredded and hot pressed into desired form and thickness. The advantages of these boards are - use of recycled waste, water resistant chipboard, substitute for plywood, formaldehyde free, sound proof, termite resistant, self decorative, thermo formable, expansion resistant, borer and powder free, can be cut, sawn, glued, screwed, nailed, drilled etc. It has application in false ceiling, partitions, wall panelling, cabinets, chairs, tables, computer tables, pelmets, beds, TV, speaker boxes, packing boxes, panels etc.

Figure 20 *"Ecolink" Board and its usage in Door Shutters*

7.11 Aluminum foil-paper-plastic composite board[30]

These are produced using waste aluminium foil paper (tetra pack cartons). These waste products are shredded and hot pressed into desired form and thickness. They can be used for exterior applications and exhibit qualities of perfect weatherability, high strength, convenient installation, easy maintenance, excellent heat insulation, sound insulation, fireproof performance, high plasticity, good impact resistance, quakeproof performance and reduction in building load. They are available in various colours. Specifications are as follows:

1) Panel thickness: 4mm
2) Aluminium thickness: 0.3mm
3) Max. Width: 1220mm
4) Max. Length: 6000mm
5) Coating: PVDF
6) Packing: in bulk or wooden case

[30] DELUXE RECYCLING (INDIA) PVT. LTD., TETRA PAK INDIA LTD, www.ecolinkindia.com, http://chinasuppliers.alibaba.com/search/china_products/Aluminium_Plastic_Composite_Panel.html

7.12 Fibre Reinforced Polymer Board

These boards endure high temperature and aging. They are characterised by durability, corrosion resistance, and light-weight and high strength. They can be used in cold-storage and as heat-keeping containers, cold storehouses and so on.

7.13 Mica Laminates and Veneer on Composite Boards[31]

Mica Laminates and veneers are very durable products and applying them on composite boards provides a good alternative to using natural timber.

Mica Laminates show low cost, high machinability, excellent punchability, superior arc strength, unique flexural strength, radiation resistance, stability at high temperatures, excellent mechanical strength, outstanding electrical properties, low out gassing characteristics, superior edge resistance and outstanding moisture resistance.

The structure of these Mica plates is almost homogeneous & therefore the plates are greatly resistant to delamination. Combustion of its bonding agent will not result in exudations of deleterious nature. The plates can withstand temperatures up to 500°C in continuous service and up to 800°C in intermittent service. They virtually release no smoke or odour when exposed to heat.

If they are chipped, however, there is little that can be done to repair it invisibly. Mica Laminates are very easy to care for, but scratches and stains still can occur. Care should be taken to not allow water or cleaning solution to linger in the seams where the mica is joined.

7.14 Coir Polymer Composite[32]

It is a substitute for wood, metal or masonry and an alternate to tropical timber products. Made using coir fibre, it is eco friendly and economic.

It has better stiffness, specific strength, flexibility, reduced wear of processing machinery, strong and rigid, termite and insect resistant, flame retardant, water resistant, smooth surface finish and natural textured design. It has low consumption of paint, varnish and glue, can also be laminated, carpenter friendly, clear cut edges with standard tools, nail and screw holding properties and maintenance free.

Figure 21 *Applications of Coir Ply Board*

[31] http://www.tradeindia.com/Exporters_Manufacturers/Indianexporters/Construction_and_Real_Estate/Decorative_Laminates, http://www.parsonsfurniture.com/understandingfaqs.htm
[32] Developed by BMTPC, http://www.bmtpc.org/fibre.pdf , www.naturaindia.co.in

7.15 Jute Fibre Polyester Composite[33]

Such composites can be used as a substitute for timber as well as in a number of less demanding applications. Jute fibre due to its adequate tensile strength and good specific modulus enjoys the right potential for usage in composites. Jute composites can thus ensure a very effective and value-added application avenue for the natural fibre. Recent reports indicate that plant-based natural fibres can very well be used as reinforcement in polymer composites, replacing to some extent more expensive and non-renewable synthetic fibres such as glass.

Figure 22 *Jute Composite Board Tiles*

Cellulose fibres are obtained from different parts of plants such as sisal, banana and pineapple, e.g. jute and ramie are obtained from the stem; cotton from the seed; coir from the fruit, and so on. The maximum tensile, impact and flexural strengths for natural fibre reinforced plastic (NFRP) composites reported so far are 104.0 MN/m^2 (jute-epoxy), 22.0 kJ/m^2 (jute-polyester) and 64.0 MN/m^2 (banana-polyester), respectively.

Although the tensile strength and Young's modulus of jute are lower than those of glass fibres, the specific modulus of jute fibre is superior to that of glass and on a modulus per cost basis, jute is far superior. The specific strength per unit cost of jute, too, approaches that of glass. Therefore, where high strength is not a priority, jute may be used to fully or partially replace glass fibre without entailing the introduction of new techniques of composite fabrication. The need for using jute fibres in place of the traditional glass fibre, partly or fully, as reinforcing agents in composites, stems from its lower specific gravity (1.29) and higher specific modulus (40 Gpa) of jute compared with those of glass (2.5 & 30 Gpa respectively).

[33] http://www.tifac.org.in/news/jute.htm, National Institute of Research on Jute and Allied Fibre Technology http://www.tifac.org.in/news/jutehindu.htm.

Figure 23 *Door Shutter*

Apart from much lower cost and renewable nature of jute, much lower energy requirement for the production of jute (only 2% of that for glass) makes it attractive as a reinforcing fibre in composites. The jute composites may be used in everyday applications such as lampshades, suitcases, paperweights, helmets, shower and bath units. They can also be used for covers of electrical appliances, pipes, post-boxes, roof tiles, grain storage silos, panels for partition & false ceilings, bio-gas containers, and in the construction of low cost, mobile or pre-fabricated buildings which can be used in times of natural calamities such as floods, cyclones, earthquakes, etc. Polyester resin forms an intimate bond with jute fibres up to a maximum fibre-resin ratio (volume/volume) of 60:40.

In order to overcome the poor adhesion between resin matrix and jute fibres, a multifunctional resin like polyesteramide polyol has reportedly been used as an interfacial agent. Significant improvement in mechanical properties of jute fibre composites was observed by incorporation of polyesteramide polyol. Also, hybrid composites of glass (facing) and modified jute fibre (core) can be a good alternative.

There are several types of unsaturated polyester resin - general purpose, flexible, resilient, low-shrinkage (low profile), weather resistant, chemical resistant and fire resistant varieties. These polyester resins are prepared from a blend of phthalic anhydride and maleic anhydride esterified with propylene glycol to form linear polyester. For Curing of such unsaturated polyester resin with fibre, azo type initiators (R-N=N-R) and organic peroxides (R-O-O-R) are generally used.

7.16 Fly Ash Jute Polymer Composite[34]

Fly ash based composites have been developed using fly ash as filler and jute cloth as reinforcement. After treatment, the jute cloth is passed into the matrix for lamination. The laminates are cured at specific temperature and pressure. A number of laminates are used for required thickness. The technology on fly ash polymer composite using jute cloth as reinforcement for wood substitute material can be applied in many applications like door shutters, partition panels, flooring tiles, wall panelling, ceiling, etc. With regard to wood substitute products, it may be noted that the developed components / materials are stronger, more durable, resistant to corrosion and above all cost effective as compared to the conventional material i.e. wood. Regional Research Laboratory, Bhopal in collaboration with BMTPC and TIFAC, has developed this technology. One commercial plant has also been set up based on this technology near Chennai.

[34] Developed by BMTPC, New Delhi, www.bmtpc.org, Developed by TIFAC, New Delhi

8 PIPES

8.1 Unplasticised PVC and HDPE Products[35]

Unplasticised PVC is an eco-friendly type of plastic that can be easily recycled. It is cheap and exhibits qualities of good acid and alkali resistance, flame-retardant, stiff and strong, can be transparent, has good vapour barrier properties and good UV resistance. It however, has a limited solvent stress cracking resistance and becomes brittle at (5°C (40°F)) unless impact modified.

It is used in applications of pipe and pipe fittings, building products e.g. gutters, cladding, window frames, etc. High-density polyethylene (**HDPE**) plastics perform similar to the UPVC compound.

9 BOARDS & PANELS

9.1 Calcined Phospho Gypsum Wall Panels[36]

These panels are environment friendly, durable, cost effective, water resistant and pest resistant. They have dry construction, using bonding plaster, are quick and easy to install and have easy workability. They are precise, smooth and there is no need of plastering. They have the ability to take add-ons like wall paper, painting, decorative laminates preferably of 0.6mm thickness with rubber solution or surface texture, can be used in wet areas such as bathrooms/toilets etc, take paint directly without any Plaster of Paris application, are fire resistant and provide easy laying of electrical conduits. Only water soluble primers and paints should normally be applied.

Panels are manufactured to meet the international standards DIN: 18163. Standard panel dimensions being - 666x500x100 mm. With a density of about 900kg/cubic meter, the panels weigh about 30 kg each. Coefficient of thermal conductivity is about 0.35 kcal/sq.m/hour/^{0}C. The panels display a fire resistance till about F180^D, a sound absorption value of about 38DB and compression strength of about 70 kg/sq.cm. Approximately 3 Panels make up 1 m^2 of surface area.

Bonding Plaster is used to install calcined phospho gypsum wall panels. This bonding plaster is used to join two wall panels and also the panels to the floor and the wall. Care should be taken to ensure that the floor surface is level, before laying the first course. If the floor is not level, a layer of bonding plaster has to be applied first to make the floor level. If partial panels are needed they can be cut with a saw. Under no circumstances are chisels or similar tools to be used.

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[35] http://www.azom.com/details.asp?ArticleID=770
[36] Promoted by BMTPC, New Delhi

9.2 Fibre Reinforced Phospho Gypsum Composite[37]

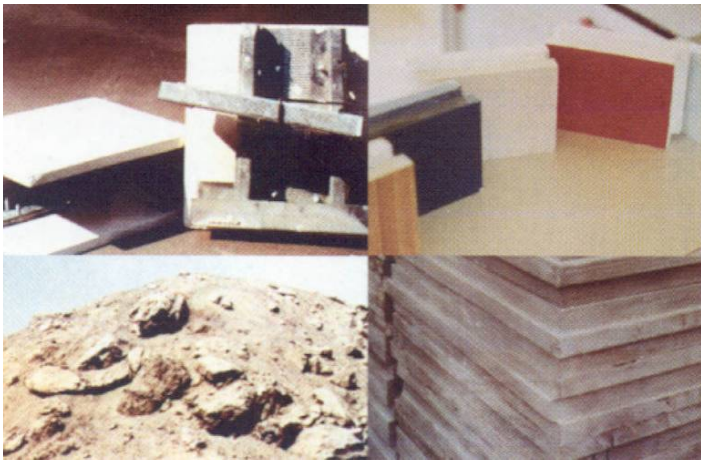

Figure 24 *Phospho Gypsum Utilisation*

Fibre reinforced phospho-gypsum composites are made up of purified phospho-gypsum plaster and glass fibre and coir. It is used for walling, roofing panels and blocks. These can be easily cut, drilled, screwed and other wood working operations can be carried out with the conventional wood working tools. These boards can be painted, polished and decorated by conventional means. It offers advantage over wood and other conventional board materials, such as: It can be made to the required size and thickness, thereby reducing labour, wastage and jointing cost. Being isotropic in nature, it has equal strength in all directions. Any ornamental design can be incorporated at nominal cost. These panels are about 50% cheaper than teak wood. The cost also compares favourably with plywood and particleboards.

9.3 Fibrous Gypsum Plaster Board[38]

Fibrous Gypsum Plaster Board can be used as light-weight partition panels, false ceiling lining and interior decoration panelling, boxing, cladding etc. The manufacturing process involves sandwiching teased sisal fibres between layers of moist calcined gypsum. Viable dimensions of the board are about 1200x600x12 mm. These boards are light in weight, fire resistant and have good thermal and sound insulation properties.

No special measures are needed except for the methodical purification of phosphor gypsum. The raw materials required are gypsum from natural source or phosphor gypsum, sisal / coir fibres, water and a good de-moulding agent.

[37] http://www.bmtpc.org/fibre.pdf, http://nerdatabank.nic.in/csircomboard.htm
[38] http://punjabgovt.nic.in/INDUSTRY/build4.pdf, http://www.tifac.org.in/offer/tsw/cbri1.htm

9.4 Calcium Silicate Boards and Tiles[39]

These boards and tiles have high strength, practically no breakage during transportation and use, high compressive strength and low water penetration. They are steam cured under pressure and are energy efficient, economic, fire resistant, do not discharge toxic gas or smoke, are light weight, rigid, robust and are 100% asbestos free.

Moisture will not cause any leaching or efflorescence and they are not affected by insects, vermin, and micro-organisms and will not nourish mould growth.

They have dimensional stability, provide heat and sound insulation and are impact resistant.

9.5 Fibre Fly Ash Cement Board[40]

Fibre fly ash cement board consists of 5% agro waste fibre, 65% cement and 30% fly ash. It is used for roofing, partition, and panels. Cement board, a water-durable, multiuse panel commonly used as a backer for ceramic tile, is made from approximately 20 percent recycled materials, including fly ash. Fly ash is a waste stream material from power plant emission control processes that features cement-like properties. It is produced by electrical power companies in the combustion of coal and other solid fuels, and is subsequently purchased by cement board producers and used to manufacture the cement board panel core. Extruded fibre-reinforced cementitious composites are excellent materials to replace conventional building enclosure products. Compared with conventional materials, extruded composites can be stronger, more cost effective, and improve safety in the event of natural hazards. Up to 80% of the cement can be replaced by fly ash, reducing material cost and making the material more environmentally friendly.

9.6 Fly Ash Red Mud Polymer Composite[41]

Fly ash red mud polymer composite is made up of fly ash, red mud and polyester. It is used in making door shutters. Composites are able to meet diverse design requirements with significant weight savings as well as high strength-to-weight ratio as compared to conventional materials.

Some advantages of the composites over conventional ones are: Tensile strength of composites is four to six times greater than that of steel or aluminium, has improved torsional stiffness and impact properties. It has higher fatigue endurance limit (up to 60% of the ultimate tensile strength). It is 30-45% lighter than aluminium structures designed to the same functional requirements. It has lower embodied energy compared to other structural materials like steel, aluminium etc.

[39] Ramco Industries Limited, HILUX, Calcium Silicate Board brochure.
[40] http://www.bmtpc.org/fibre.pdf, www.cgcinc.com, http://www.pathnet.org/si.asp?id=1087
[41] http://www.tifac.org.in/news/compvis.htm

The composites are less noisy while in operation and provide lower vibration transmission than metals. They are more versatile than metals and can be tailored to meet performance needs and complex design requirements. Long life offers excellent fatigue, impact and environmental resistance and reduced maintenance. These products enjoy reduced life cycle cost compared to metals. They exhibit excellent corrosion resistance and fire retardant properties. Improved appearance with smooth surfaces and readily incorporable integral decorative melamine are other characteristics of composites. Composite parts can eliminate joints/fasteners, providing part simplification and integrated design compared to conventional metallic parts.

9.7 Rice Husk Board[42]

While the conservation of wood and forests is of prime importance throughout the world, the technology for manufacture of cost effective wood substitute is also of significance.

The development of technology for manufacture of particleboard from rice husk, by Indian Plywood Research Institute, Bangalore, India has emerged as one of the best solutions to it. This board has emerged as a versatile substitute for wood in a wide range of applications. Moreover these boards can also be made decorative with elegant looks by incorporating suitable colours and, therefore, can be more attractive than any wood/plywood substitute.

It utilizes the most abundantly available agricultural waste - rice husk. The board has an edge over wood/plywood owing to its following distinct advantages: Termite resistance, high decay resistance, improved fire resistance, excellent mechanical properties like internal bond strength, elasticity, dimensional stability, screw and nail holding capacity, abrasion resistance, surface hardness, etc., improved water resistance and high durability.

The process has been licensed to several firms in India and recently in Malaysia. The boards produced by these firms have shown excellent market acceptance and gained popularity due to their aesthetic looks, better mechanical properties and much cheaper prices than corresponding wood.

Raw materials required per ton of the product are 1.1 ton of rice husk and about 0.11 ton of a suitable resinous binder. In the production of 1 ton of the product about 300 kWh of power, 2250 litre of water and 0.45 ton of coal are consumed.

[42] http://www.nrdcindia.com/pages/ricebord.htm, Developed by TIFAC, New Delhi, http://www.tifac.org.in/news/eqtifac.htm

9.8 EPS Composite Door Shutters[43]

Expanded polystyrene composite (EPS Composite) door shutters are being fabricated in two sizes: 2050 mm x 900 mm x 37 mm and 2050 mm x 1050 mm x 37 mm, comprising expanded polystyrene as the core sandwiched between medium density boards with polystyrene modified cashew-nut shells liquid or polyurethane resin as binder. The product has low water absorption value (6-7 per cent) and has a density, nearly half of that of timber door shutters. Salient technical features are: environment friendly wood substitute; easy installation and maintenance; can be painted, polished and / or laminated; light-weight; economical; approved by CPWD for adoption in their construction works. Major components / raw materials required are EPS Sheets, adhesive, MDF sheets, agro-forestry products like rubber eucalyptus etc. Major plant equipment and machinery required are hydraulic press, planer cutter, mixer, laboratory equipment, adhesive applicator etc.

[43] http://www.tifac.org.in/offer/tsw/cbri3.htm, http://www.techno-preneur.net/new-timeis/New-technologies/Building-tec/epscomposite.htm

10 WATER PROOFING CHEMICALS, ADDITIVES, SEALANTS AND ADHESIVES

10.1 Water based compounds

Water based compounds have the same performance and durability properties as their conventional solvent based counterparts. All chemicals, water proofing compounds, sealants, paints and adhesives have two basic components – base compound and curing agent. On application, the curing agent evaporates, triggering a chemical reaction that leaves the base compound as a residual layer. These evaporating components have high harmful levels of volatile organic compounds and other pollutants and contaminants. These emissions can be reduced or eliminated through alternative curing agents.

Water as a curing agent has absolutely no harmful emissions and thus out performs the other category of compounds such as acrylic, phenol or oil based. A wide range of water based products and compounds available in the market have no cost variations from the conventional ones.

10.2 Epoxy Resins

Tar felt / paper and pitch have always been associated with water proofing in structures. The bitumen-based products basically have a high energy consuming manufacturing process and use huge amounts of natural resources. An eco-friendly replacement for such applications is through the use of epoxy resin systems. These resins are an eco-friendly alternative, consuming lower energies throughout their lives and are easily disposable or recyclable. Lower occupational hazards and emission levels add to its advantages. The only drawback is the 7-10 times increase in costs. This increase can be justified by the overall life cycle performance of the alternative.

11 PAINTS

11.1 Cement Paint[44]

This product is environment friendly, has very low VOC, and is easy to apply, while being highly economic. Its applications and uses include, exterior and interior coating for cement concrete, cement plastered walls, A.C. sheets, brickwork etc. It has good water resistance properties and can be used as a decorative element. It also has a good covering capacity, easy mixing character, better resistance to crazing, map cracking and microbial growth.

The main components of cement paint are cement, pigments, accelerators, water repellents and hydrated lime.

[44] Developed by CBRI, Roorkee

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