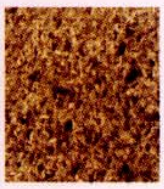
Local Vegetable Fibres + Industrial and Mineral Wastes for Composite Materials

BMTPC Building Materials & Technology Promotion Council

Building Materials from Local Resourses









Historically mankind has been familiar with several applications of composite building materials for their housing and building needs. Most of these were based on timber, bamboo, jute and a large variety of vegetable fibres such as reinforced mud-blocks for walls, panels for partitioning and roofing. In the modern context, the world has seen a total transformation in materials science and technology and a vast variety of industrially produced composites have come into existence.

Continuous progress in metallurgy and materials engineering have remarkably helped in achieving the perfection in behaviour of metals, and other alloys. Multitude of metal composites are now being used with a high degree of confidence for the most intricate structures. Subsequent developments in the discovery of very tough fibres such as glass, carbon, boron and kevlar made it possible to manufacture and use several high performance composites with matrices of synthetic resins such as polyesters, phenolics and epoxies in aircrafts, space ships, machine tools, electronics, biomedical materials etc.

Search for stronger and stiffer fibres and feasibility to utilise widespread inorganic wastes and by-products have provided directions to the production and use of vegetable fibres, such as coir, banana, sunhemp, jute, sisal etc., as quite inexpensive and effective reinforcing fibres, and hydraulic binders as alternative to cements made of industrial wastes like flyash, waste limes, by-product gypsum and mine tailings. These developments have mainly taken place to meet housing and building requirements of ever growing world population, particularly in developing parts of the world.

This brochure provides information on technical properties and availability of a large number of vegetable fibres widely grown in developing countries and broad characteristics of the inorganic wastes and by-products. The information given here is primarily aimed at indicating vast scope and potential for the utilisation of such local resources in the production of fibre reinforced composite building materials for housing and building structures.

The classification of composites into 'advanced' materials or 'low grade' is meaningless as it is the application of a material which decides its class if it is made available in a durable and reliable form at a reasonably affordable cost. Hence the data provided in this brochure should encourage designers to develop low cost, low energy, labour conserving technologies for building materials of required specifications with possibilities for application in housing and building.

Fibres and country of origin

Flax	:	Borneo
Hemp	:	Yugoslavia, China
Sun hemp	:	Nigeria, Guyana, Sieraleone, India
Ramie	:	Hondurus, Mauritius
Jute	:	India, Egypt, Guyana, Jamaica, Ghana, Malawi, Sudan, Tanzania
Kenaf	:	Iraq, Tanzania, Jamaica, South Africa, Cuba, Togo
Roselle	:	Borneo, Guyana, Malaysia, Sri Lanka, Togo, Indonesia, Tanzania
Sisal	:	East Africa, Bahamas, Antigua, Kenya, Tanzania, India
Abaca	:	Malaysia, Uganda, Philippines, Bolivia
Coir	:	India, Sri Lanka, Philippines, Malaysia

Annual production of natural fibres and sources

Fibre source	World production 10^3 tonnes	Origin
Abaca	70	Leaf
Bamboo	10,000	Stem
Banana	200	Stem
Broom	Abundant	Stem
Coir	100	Fruit
Cotton Lint	18,500	Stem
Elephant Grass	Abundant	Stem
Flax	810	Stem
Hemp	215	Stem
Jute	2,500	Stem
Kenaf	770	Stem
Linseed	Abundant	Fruit
Nettles	Abundant	Stem
Oil Palm Fruit	Abundant	Fruit
Palmirah	Abundant	Stem
Ramic	100	Stem
Roselli	250	Stem
Rice Husk	Abundant	Fruit/grain
Rice Straw	Abundant	Stem
Sisal	380	Leaf
Sun Hemp	70	Stem
Wheat Straw	Abundant	Stem
Wood	1,750,000	Stem

Specific strength, cost and energy contents of synthetic and natural fibres

Fibre	Sp.gr.	Specific tensile strength (GPa)	Specific tensile modulus (GPa)	Cost US$/tonne	Energy content Gj/tonne
Plant Fibre	0.6-1.2	1.60-2.95	10-130	200-1000	4
Glass	2.6	1.35	30	1,200-1,800	30
Kevlar	1.4	2.71	90	7,500	25
Carbon	1.8	1.71	130	12.500	130

Chemical composition and moisture absorption of some natural fibres

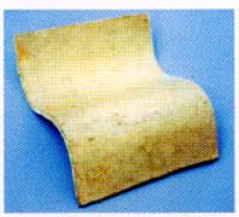
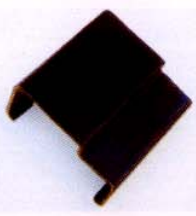
Fibre	Cellulose %	Hemi-cellulose %	Lignin %	Moisture regain at 65% R.H.	Transverse swelling in water %
Banana	60-65	6-8	5-10	10-15	16-20
Coir	43	<1	45	10-12	5-15
Cotton Lint	90	6	-	7	20-22
Flax	70-72	14	4-5	7	20-25
Jute	61-63	13	5-13	12.5	20-22
Mesta	60	15	10	13	20-22
Palmirah	40-50	15	42-45	10-12	-
Pine Apple Leaf	80	-	12	10-13	18-20
Ramic	80-85	3-4	0.5	5-6	12-15
Sisal	60-67	10-15	8-12	10-12	18-20
Straw	40	28	18	-	-
Sun Hemp	70-78	18-19	4-5	10-11	18-20
Wood	45-50	23	27	-	-

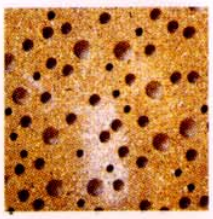
Mechanical properties of some natural fibres

Fibre	Length mm	Diameter mm	Density kg/m^3	Young's modulus GPa	Tensile strength MPa	Elongation break %
Bagasse	NA	0.2-0.4	1250	17	290	NA
Bamboo	NA	0.1-0.4	1500	27	575	3
Banana	NA	0.8-2.5	1350	1.4	95	5.9
Coir	50-350	0.1-0.4	1440	0.9	200	29
Elephant-grass	NA	0.4	NA	5	178	5.6
Flax	500	NA	1540	100	1000	2.0
Jute	1800-3000	0.1-0.2	1500	32	350	1.7
Kenaf	30-750	0.04-0.09	NA	22	295	NA
Mesta	NA	0.2	1470	13	180-570	NA
Pineapple	NA	0.2-8.8	NA	14.5	413-1627	NA
Sisal	-	0.5-2.0	1450	100	1100	-

Mechanical properties of some fibres other than natural fibres

Fibre	Length mm	Diameter mm	Density kg/m^3	Young's modulus GPa	Tensile strength MPa	Elongation break %
Glass 'C'	NA	NA	2700	70	3100	4.5
Glass 'E'	NA	NA	2900	72.5	3400	4.8
Steel	5-200	0.1-0.4	7860	207	700-2100	3.5
Boron	NA	NA	-	410	3800	2.8
SiC	NA	NA	-	430	240-2400	-
Asbestos Polymer	<15	<0.2	2550	159	210-2000	7-18
(Polypropylene)	NA	NA	900	6.8	590	210



Industrial, mining and mineral waste having potential for utilisation in the production of composites

Sl. No.	Type of the Waste	Source	Type of particulate composites	Appropriate technology available
1.	Flyash/pulverised fuelash	Thermal power stations using pulverised coal as fuel	Portland-pozzolana cement (using upto 20% of flyash) cement concrete, lime-flyash mortar, plaster, cellular concrete, brick and tiles, flyash-sand-lime bricks, stabilised soil bricks (using lime or cement and flyash)	India China UK Russia
2.	Blast furnace slag	Steel Plants		
	(a) Air cooled type	-do-	As dense aggregate replacing natural stone aggregate in concrete.	
	(b) Foamed type	-do-	As light weight aggregate in concrete and concrete products	India, China, South Africa, UK, Russia
	(c) Granulated type	-do-	As part replacement in Portland cement for Portland-blast furnace slag cement; in super sulphated cement	
3.	By-products gypsum	Ammonium phosphate fertiliser, hydrofluoric acid and boric acid industries	As replacement of natural gypsum in making fibrous gypsum plaster boards, blocks, composite mortar etc.	India UK Russia
4.	Mine tailings	Beneficiation of the zinc, copper, iron, gold, feldspar, fluorspar, bauxite ores and minerals	As part replacement in composite mortar, concretes, masonry cement, cellular concrete sand-lime bricks, as replacement of sand	India China Germany
5.	By-product lime sludges	Sugar, paper, acetylene, tannery fertilizer industries	After calcination used in composite mortar, plaster and lime-pozzolana composites	India Indonesia
6.	Laterite wastes	Cutting and dressing of laterite blocks	For stabilised laterite bricks/blocks using cement or lime as stabiliser and a fibre as reinforcement	Ghana India
7.	Red mud	Aluminium industry	For blended cement, bricks/tiles compositions and fibre-reinforced panel products	India Russia
8.	Basic or acidic metallurgical slags	Metals and alloys industries	Masonry cement compositions and in cement-concrete replacing natural aggregates, cementitious binders etc.	India China UK
9.	Broken glass and ceramics	Glass and ceramic industries	Insulating bricks and tiles, flooring tiles, decorative panels	China India, Russia
10.	Inorganic ashes of plants	Incineration (in boilers) of rice husk type materials	Replacement of natural or clay pozzolana in lime-pozzolana composites, pozzolana cement, bricks etc.	India Sri Lanka Malaysia
11.	Wastes from mica, slate, vermiculete	In the mining of the respective mineral	Utilisation after calcination in lime-pozzolana	India

Chemical analysis and mineralogical constituents of Indian flyashes

Constituent	% by wt.
SiO_2	37.15-66.75
Al_2O_3	18.30-28.90
Fe_2O_3	3.2-21.90
TiO_2	-
CaO	1.3-10.80
MgO	0.8-5.25
SO_3	0.94-2.91
$Na_2O + K_2O$	0.04-1.30
Loss on ignition	0.05-16.60

General uses of flyash in inorganic composites

Material	Description
Aggregates (for concrete & concrete products)	Production of light weight aggregate of sp.gr.<1 is carried out by palletization and sintering at 1050°-1100°C. The residual carbon content of flyash on burning provides energy for sintering and thus the process needs very little energy.
Cement (as Portland-flyash pozzolana cement for concrete and also as raw mix)	Flyash finds a substitute for clay or other argillaceous material in cement manufacture; particularly where high MgO containing limestone is used. In ordinary portland cement, the blending proportion again depends on the fineness, carbon content (low % preferred) and lime-reactivity. These properties also govern flyash application in roads and stabilised blocks.
Cellular concrete and other concrete	Flyash is an excellent material as the substitute for ground sand in the manufacture of sand-cement/lime based light weight cellular concrete for structural as well as filler and insulation grades. Flyash is also a replacement for sand in concrete.
Bricks (Calcium-silicate sand-lime type - steam cured, and clay-flyash burnt brick type)	Flyash-sand-lime bricks are as good as other sand-lime bricks, in the former flyash replaces sand upto 70%. Flyash is also blended with plastic clays for burnt-clay bricks where it works as opening materials reducing drying shrinkage cracks and providing saving in coal for firing.

Chemical composition (%) of blast furnace slag

Source	CaO	SiO_2	Al_2O_3	MgO	FeO	MnO	S
British	48	31	10	3	1.0	0.5	1.5
German	45	35	12	4	0.5	0.5	2.0
Indian	40	35	18	5-8	0.5	1.0	1.5

Constituents, factor and suitability of slags

Constituents	Factor	Suitability for
High SiO_2 or high Al_2O_3	Cools to glassy granulated form easily	Slag wool composites
High CaO and low Al_2O_3	Makes suitable composition but tends to dust	Portland blast furnace slag cements but not aggregates
High MgO or high MnO	Makes unsuitable composition	Not so good for slag cement

Ore Beneficiation tailings and their Uses

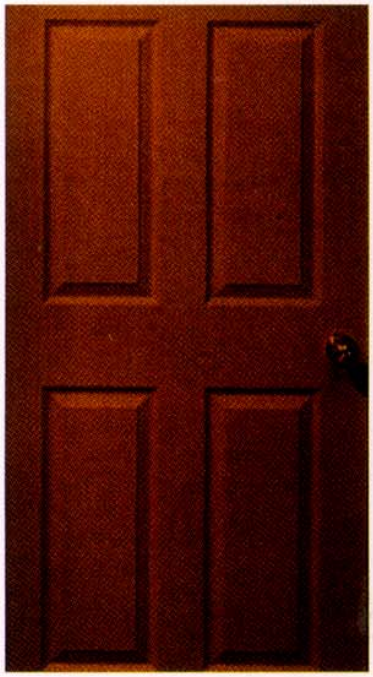
Chemical	Zinc Tailings	Copper Tailings	Gold Tailings	Iron Tailings
Loss on ignition	14.75	2.24	5.31	3.58
SiO_2	60.63	59.42	61.63	58.53
AL_2O_3	0.54	12.06	11.63	9.21
Fe_2O_3	3.02	19.82	9.85	21.08
CaO	12.68	2.11	10.36	4.08
MgO	7.27	1.86	2.32	2.76
NA_2O+K_2O	-	-	-	-
Physical Properties				
Fineness modulus	0.342	0.637	0.103	0.416
Sp.gr.	2.85	2.95	2.85	3.04
Bulk density (kg/l)	1.51	1.45	1.56	1.60
Specific surface (Blaine's)cm^2/g	3500	3500	4000	3500
Mineralogical constituents	Quartz and Dolomite	Quartz and Biotite	Quartz and Calcite	Quartz and Haematite
Recommend utilisation in building materials	Cellular concrete Calcium silicate bricks Masonry cement Mortar Fine filler in concrete Filler in bitumen mastics -- --	Cellular concrete Calcium silicate bricks Masonry cement Mortar Fine filler in concrete Filler in bitumen mastics As opening material in brick making Filler in acid resistant cement	Cellular concrete Calcium silicate bricks Masonry cement Mortar Fine filler in concrete Filler in bitumen mastics -- --	-- Calcium silicate bricks Masonry cement Mortar Fine filler in concrete --- Burnt clay bricks Filler in acid resistant cement

Chemical	Feldspar Tailings	Fluorspar Tailings	China Clay Waste Tailings	Coal Washery Tailings Burnt	Unburnt
Loss on ignition	1.30	0.85	11.20	01.8	16.90
SiO_2	63.84	73.00	50.30	57.60	60.40
Al_2O_3	18.32	5.70	32.70	31.30	18.10
Fe_2O_3	1.42	7.00	2.37	3.86	7.03
CaO	1.45	1.30	0.07	0.36	0.66
MgO	0.50	-	0.35	0.92	0.44
Na_2O+K_2O	12.13	-	0.59	2.73	2.35
Ca_2F_2	-	12.80	-	-	-
Physical Properties					
Fineness moudulus	-	0.4-0.8	0.56	-	-
Sp.gr	2.53	2.75	2.85	2.66	2.40
Bulk density (kg/l)	1.45	1.8	2.63	1.32	1.25
Sp. srface (Blaine's) cm^2/g	2550	2500	2800	2200	1900
Mineralogical constituents	Feldspar Quartz	Calcium fluoride Quartz	Quartz Feldspar	Quartz, Albite, Feldspar	
Recommend utilisation in building materials	Burnt-clay brick, Calcium Silicate bricks, Ceramics concrete blocks	Calcium silicate bricks Aerated concrete, Concrete blocks	Ceramics tiles, bricks, calcium silicate bricks	Burnt clay bricks, sintered light - weight aggregate, concrete blocks.	

Chemical composition of red mud

Constituent %	Red mud samples from aluminium plants of						
	India			Australia	Hungary & Yugoslavia	Jamaica	Surinam
	Hindalco	Indalco	Alcorpon				
Loss on ignition	9-10	10-12	10-13	13-15	10	13	13
SiO2	6.8-7.7	6-8	6-8	14-18	60	-	12
Al_2O_3	18-20	25-29	24-26	24-28	20	15	19
Fe_2O_3	33-35	24-27	22-25	18-22	48	52	25
TiO_2	18-20	22-25	18-21	6-8	5	5	12
CaO	4-4.5	-	-	7-10	3	5	3
Na_2O	5-5.75	4-5	-	8-10	5	-	10
Cr_2O_3	-	-	-	0.1-0.2	0.3	-	-
V_2O_5	0.24-0.26	-	-	0.07-0.1	0.2	-	-
P_2O_5	0.26-0.28	-	-	0.08-0.1	0-2	-	-

Hindalco : Hindustan Aluminium Co., Renukoot, (UP) India
Indalco : Indian Aluminium Co., Alwaye, Kerala, India
Alcorpon : Aluminium Corporation, Asansol, West Bengal, India

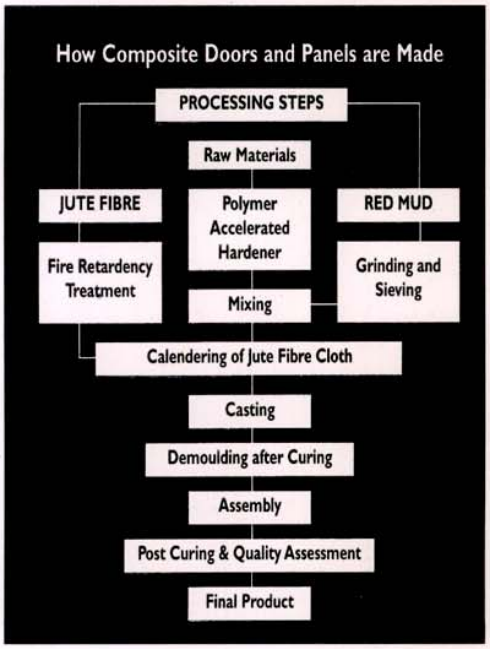


Physical and mineralogical properties of red mud

Sp.gr	2.6-3.1
pH	11.7-12.3
Bulk density (g/cm^3)	1.1-1.3
Initial solids in mud slurry%	7.8-35.9
Settling rate, cm/kg	0.014-0.015

Mineralogical constituents of red mud

INDIAN	EUROPEAN	RUSSIAN
Quartz	Natrolite	Alkali-alumino silicates
Gibbsite	Boehmite	Kaolinite
Goethite	Goethite	Halloysite
Rutile	Haematite	Feldspar
Unatase	Unatase	Limonite



Commercial products of some companies in India

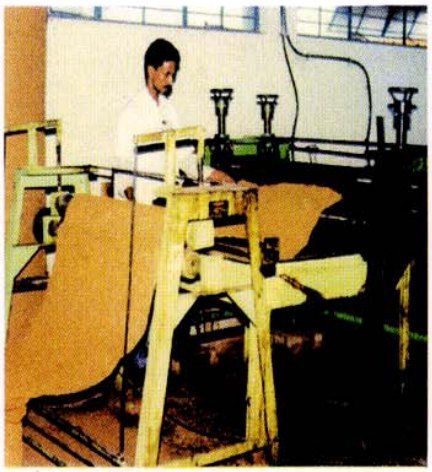
	Name of the composite	Composition of the composite	Type of building materials	Manufacturer in India
ORGANIC COMPOSITES				
1	Red mud-PVC jute fibre	Red mud PVC Fibre	Corrugated roofing sheet, panels	Lotus Roofing Pvt. Ltd 40/23, Sedurapet P.O. Pondicherry-605 111
2	Jute polymer composite	Jute, Synthetic resin	Door / window shutters, frames	TIPCO Polymers Ltd. Rahi Sali Marg, Malad (E) Mumbai - 400097
3	Redmud-polyester sisal-glass fibres	Red mud, polyester, sisal	Panels, tiles, roofing sheet	Neoluxe India Ltd. 75, Altanta, 7th Floor 209, Nariman Point Mumbai-400 021
4	Bitumen bonded paper fibre or pulp	Paper fibre felt, bitumen	Corrugated roofing sheet	Light Roofing Ltd No.2/87, GST Road Kancheepuram (Dt.) Tamil Nadu - 603204
5	Gypsum plaster-fibre glass	Glass fibre gypsum plaster	Partitions, false ceilings	India Gypsum Ltd. 815, Tolstoy House 15-17 Tolstoy Marg New Delhi 110 001
6	Borotik	Rubber wood	Door shutter, partition	Borax Morarji ltd. Jolly Bhawan, No.2, New Marine Lines Mumbai 400 020
7	Bamboo Mat composite	Bamboo, synthetic resin	Ceiling, partition, panels roofing sheets	Timpack Pvt. Ltd. 15, GS Road Byrnihat, Meghalaya
8	Rice husk board	Rice husk, synthetic resin	Wall panelling, false ceiling, partitioning, door/window shutters, roofing panels, flooring	Padmavathy Panel Boards P.Ltd. 32A, Anathasanahalli Industrial Estate, Tumkur - 572 106
9	Bagasse board	Baggase, synthetic resin	Wall panelling, false ceiling, partitioning, door/window shutters, flooring furniture	ECO Board Industries Ltd. 65/1-A, Akarshak Opp.Nal Stop Karve Road Pune-411 004
10	Cement bonded particle board	Cement wood like eucalyptus and casurine	Partitioning, wall lining, false ceiling, roofing, flooring, doors, panelling	NCL Industries Ltd. 7th Floor, Raghava Ratna Towers, Chirag Ali Lane, Abids Hyderabad - 500 001
11	Medium density fibre board	Cotton plant scantling, wood fibre, resin	Door frame, doors, furniture, partitioning, panelling, flooring, ceiling	NUCHEM Limited 20/6, Mathura Road Faridabad - 121 006

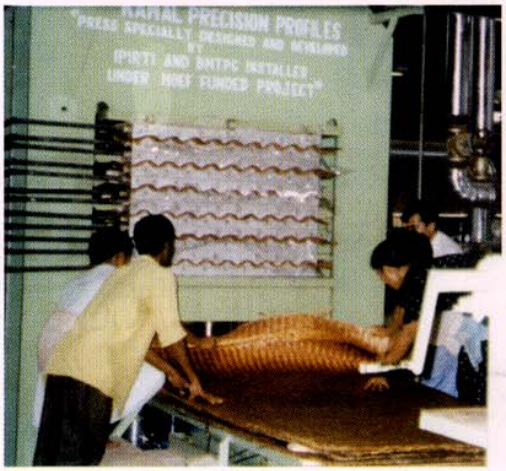
	Name of the composite	Composition of the composite	Type of building materials	Manufacturer in India
12	Stramit board	Dry un-pulped straw and paper	False ceiling, doors, partitions, non load bearing walls, flooring, roofing, wall cladding	Ballarpur Industries Ltd. Thapar House, 124, Janpath New Delhi - 110 001
13.	Coir Polymer Composite	Coir Fibre, Polymer	Wall Panelling, False Ceiling, Partitioning,Door/ window shutters, Roofing Panels	Natura Fibretech Pvt. Ltd No.239, 18th Main 6th Block, Koramangala Bangalore - 560 095
Inorganic Composites				
14	Elatomation bonding plant	Technology for cement/ polymer bonded boards	Roofing sheet, partition, panelling, door shutter & frames	Synergy International B-17, Defence Colony New Delhi - 110 024
15	Flyash-red mud polymer composite	Flyash, redmud and polester	Door shutter	Dual Build Tech (P) Ltd. Chennai
16	Clay flyash bricks	Flyash 30-40% Clay 60-70%	General purpose bricks	Calcutta Mech. Brick (P) Ltd., Calcutta 700 020
17	Flyash-sand-lime bricks	Flyash 70% Sand 20% Lime 10%	General purpose bricks	Damodar Valley Corporation, DVC Power Plant, Baria, Durgapur West Bengal
18	Flyash-sand-lime bricks	Flyash 70% Sand 10-20% Lime 7-10%	General purpose bricks	Pulver Ash Ltd. Bandel West Bengal
19	Flyash cellular concrete	Flyash cement/ lime gypsum aluminium powder	Light weight blocks and slabs	Ballarpur Industries Ltd. Palval Haryana
20	Fibre reinforced phosphogypsum composite	Purified phosphogypsum plaster & glass fibre or coir	Walling, roofing panels and blocks	IDL Salzbau India Ltd. 163-66 AIE, Gajuwaka, Visakhapatnam Andhra Pradesh
21	Sand-lime bricks & flyash-lime brick	Sand 90% Lime 10% or Flyash 60-70% Lime 30-40%	General purpose, white & coloured bricks, hollow blocks	Sand Plast India Ltd. Behroor, Alwar Rajasthan
22	Flyash-lime gypsum brick (Fal-G)	Flyash 60% Lime 10-20% Gypsum 10-20%	Bricks of medium range strength	NTPC-NCPS Vidyut Nagar Dadri 201 008 (UP)
23	Flyash cement brick/blocks	Flyash 80-90% Lime/or Cement 10-20%	Walling, foundation etc.	Gujarat Electricity Board Flyash Company, Ahmedabad, Gujarat
24	Fibre-flyash cement boards	Agro-waste fibre 5% Cement 65% Flyash 30%	Roofing, partition and panels	Eternit Everest Ltd. Worli, Mumbai - 400 018
25	Cellular light weight concrete	Flyash, Sand, lime/cement foaming agent	Light weight blocks, slabs	Berg India Ltd. R-17, Hauz Khas New Delhi - 110 016

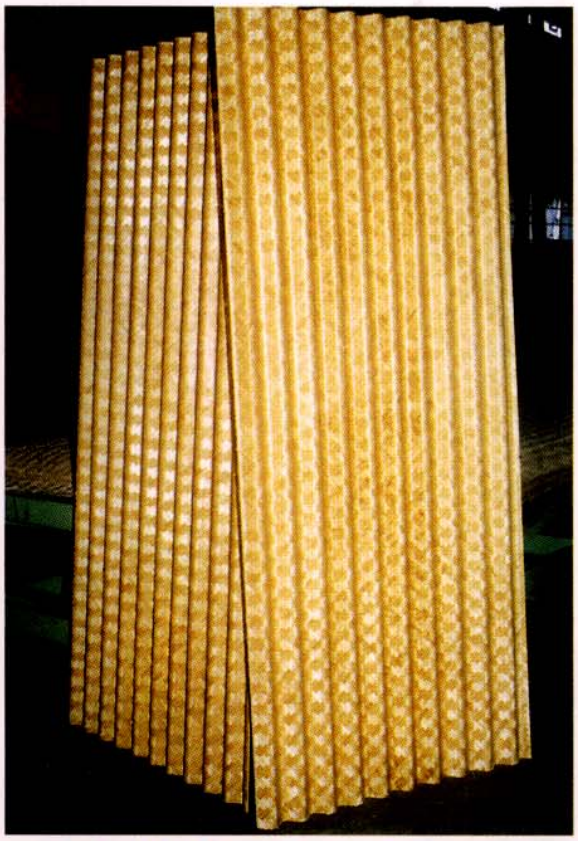
Recommended equipment* required for research, development and manufacture of natural fibre composites

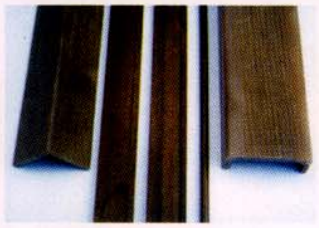
- Fibre Extraction Equipment
- Fibre Sorting Equipment
- Low Load Fibre Strength Testing Equipment
- Fibre Pretreatment Unit
- Fibre Weaving or Knitting Equipment
- Filament Winding Equipment
- Hand Layup Composite Fabrication Equipment
- Polymer-Fibre Spray Unit for Spray Formed Composites
  - Database on Properties of Fibres and Composites of Different Compositions-Carpet Plots
  - Computers and Computer Aided Design Programs for Design of Composites
- Composite Testing Equipment
  - Optical Microscopes
  - Scanning Microscopes
  - Density Measurement Equipment
  - Moisture Absorption Equipment
  - Tensiometer or Instron or MTS Equipment for Measuring Strength, Modulus and Fracture Toughness
  - Impact Energy Tester, Radiographic Equipment, IR Equipment
  - Weatherability Test Chambers to Test Deterioration Due to Exposure to Elements of Weather
  - Flammability Testing Equipment
  - Dilatometer for Measurement of Co-efficient Expansion
  - Simple Machining Equipment to Shape Composite Components

* *All this equipment may not be necessary in all locations. Only a small portion of the equipment, listed may be required where for instance simple pressing or hand layup techniques are being used for manufacture of simple components and where high performance is not required.*









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Building Materials & Technology Promotion Council

Ministry of Urban Development and Poverty Alleviation, Government of India
G-Wing, Nirman Bhawan, New Delhi - 11
Tel: +91-11-2301 9367
Fax: 91-11-2301 0145
OR
Core 5A, 1st Floor, India Habitat Centre,
Lodhi Road, New Delhi-110 003
Tel: 91-11-2463 8097, 2463 6747
Fax: 91-11-2464 2849
E-Mail: *bmtpc@del2.vsnl.net.in*
Website : *www.bmtpc.org*