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COMPOSITE MATERIALS USING LOCAL RESOURCES

Prepared by

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for
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Abstract

This papers aims at presenting a consolidated information on the research, development and application of composite materials for low income group mass-housing in developing countries.

Composites based on high-cost and high-energy-consuming fibres such as glass fibre, kevlar, carbon, boron etc. are not within the reach of the common people in developing countries and, therefore, those types of composites are not included in this paper. There are, however, two broad categories of composites which have potentials of very wide applications in buildings. These are: (1) Natural fibre-polymer/cement composites-based mainly on locally available fibres (sisal, jute, mesta, cotton, coir, flax, kenaf etc.) and a polymer (polyester, epoxy, urea formaldehyde etc.) or cement as matrix. (Wood fibres have not been covered in this paper). (2) Particulate/aggregate composites-based mainly on the utilisation of inorganic wastes and by-products (flyash, slag, mine tailings, lime sludges, by-product gypsum, red mud etc.) and a hydraulic binder (cement or lime pozzolana). The two categories of composites have been covered under section A and B respectively.

This paper gives details of resources and composites, their physical and mechanical properties, pilot plant data and about their potential for commercialisation. Annexure 1 gives some examples of several products which are being commercially produced in India.

The problems of technological developments and constraints in popularising use of composites in housing and which must be carefully addressed by planners and builders have also been highlighted. A co-ordinated approach including pilot-plant studies, strengthening data base on natural fibres, efforts for design, development and performance studies on building components may form the scope of a UNIDO SHELTER PROGRAMME. The emphasis in the programme should be on enterprise development and upgradation of the existing know-how in the area of composites for buildings.

1. Introduction

Developing countries face multiple problems of poor economic growth, absence of basic minimum services to the rapidly growing population, chronic unemployment and growing environmental degradation in rural and urban settlements. In attempting to solve the above problems most governments and non-government organisations have found that the building materials and construction industry could play a very important role, particularly through self-help and reliance on local resources.

In spite of some well-meaning attempts during the last three decades, the people in developing countries still remain far from achieving even the modest targets of housing and infrastructural services. Yet there is almost an unanimity that development of building industry is the biggest force in pushing onwards the overall economic development through job creation on a large scale. Infact, with the above background in consideration the General Assembly adopted the resolution 42/191 on the 'Global Strategy for Shelter to the Year 2000', with the objective to provide shelter for all by the end of this century. It is the UNIDO's aim to contribute and organise all possible technological and financial assistance, in a very forceful manner, to help achieving the above objective.

Most developing countries have attempted at augmenting their requirements of cement, steel, brick and timber through imports or through imported technologies in their production units. Often this approach has failed to achieve the desired objectives and has not helped in achieving the goal of self-sufficiency. Many developing countries do not possess fossil fuels. This restricts the growth of building materials industries, of the preferred types, on the lines of those of the advanced countries. Many projects of building materials industries, in the developing world, based on imported technologies, had closed down with colossal financial loss as they proved to be highly energy-intensive and imported technologies were not found compatible with state of development in most of these countries.

It has been fully recognised that the developing countries must adopt the building materials based on local mineral resources and industrial as well as agricultural wastes, residues and by-products. There has to be a consensus in developing indigenous technologies of building materials which could provide self-reliance and sustained growth of housing. HABITAT-II (a follow up of HABITAT-I, 1976) which concluded recently at Istanbul (Turkey) also addressed the issue and recommended that in realising the goal of adequate shelter for all utilisation of local materials could make the crucial contribution. Promotion of the construction and building materials sector is an integral part of the global strategy for self-reliant and self-sustaining development.

A major complimentary role played by UNIDO in the field of building materials and construction industry is through the SHELTER PROGRAMME, as part of their Chemical Industries Development. This PROGRAMME has three broad-based objectives:

* To transfer know-how to developing countries in order to enhance their capacities to exercise the most appropriate choice of technology and maximise operational efficiency.
* To improve product quality and enhance product diversification; and
* To promote the safe uses of technology and products, including mitigation of sub sector-specific adverse environmental effects and the recycling of the wastes of the industries covered by the programme.

With a view to meeting the above objectives there are four levels of capacity building viz (i) policy and strategy (ii) institutions (iii) enterprises and (iv) technology transfer and adoption, preferably among the developing countries themselves.

Thus identification of suitable local building materials and technologies, their meaningful descriptions and documentation become the first priority. This paper makes an attempt in this direction with a particular emphasis on scope of utilisation of all major local technologies, with particular reference to what is called, COMPOSITE BUILDING MATERIALS based on local resources.

2. Local building materials and composite building materials

It is well recognised that mud, stone and timber are some of the main local materials used for shelter since time immemorial. However, the mud mixed with chopped straw to shape mud blocks; stone crushed into suitable sizes and mixed with cements as cast concrete blocks or slabs and timber fragmented and reconstituted/laminated by using a polymer resin into sheets and boards are the traditional technologies of materials which can be called composite building materials.

There have been many note-worthy advancements in composite materials. Composites of modern times are the final category of structural engineering materials which find varied applications in electronics, structural elements, high speed tools, space crafts, advanced ceramics etc. in which there is always a matrix like cement, polymer, clay and certain reinforcing material like steel, polymer fibres, ceramic fibres & vegetable fibre. Thus composites are combinations of two or more components. The key philosophy in defining composite materials is that they provide the 'best of both worlds' that is they incorporate the best property of each component. A classic example of composite materials is FGRP (Fibre Glass Reinforced Plastics) in which strength of small diameter glass fibres is combined with the ductility of the polymeric matrix, to provide a product superior to either component alone.

3. Composite materials for mass housing

Even excluding the scope of such composites in which glass fibre, carbon fibre, kevlar, polyamide etc. are used for highly sophisticated applications there is a variety of composite materials which have great potentials in housing for the masses. These composites include materials like stabilised soil blocks, concrete blocks, asphaltic roofing sheets, to mention a few. They could be broadly divided into two categories:

* Fibre reinforced composites: Mostly natural fibre (like jute, coir, sisal, etc.) or steel fibre reinforced products.
* Inorganic particulate composites: These include utilisation of mostly non-metallic minerals and their beneficiation or upgradation rejects tailings and by-products.

For the purpose of this paper, yet another category of composites covering metals, alloys, industrial and structural ceramic and glass-ceramics which are high energy and high capital-intensive materials and usually are not within the scope of usage in house construction for the poor and hence have not been discussed.

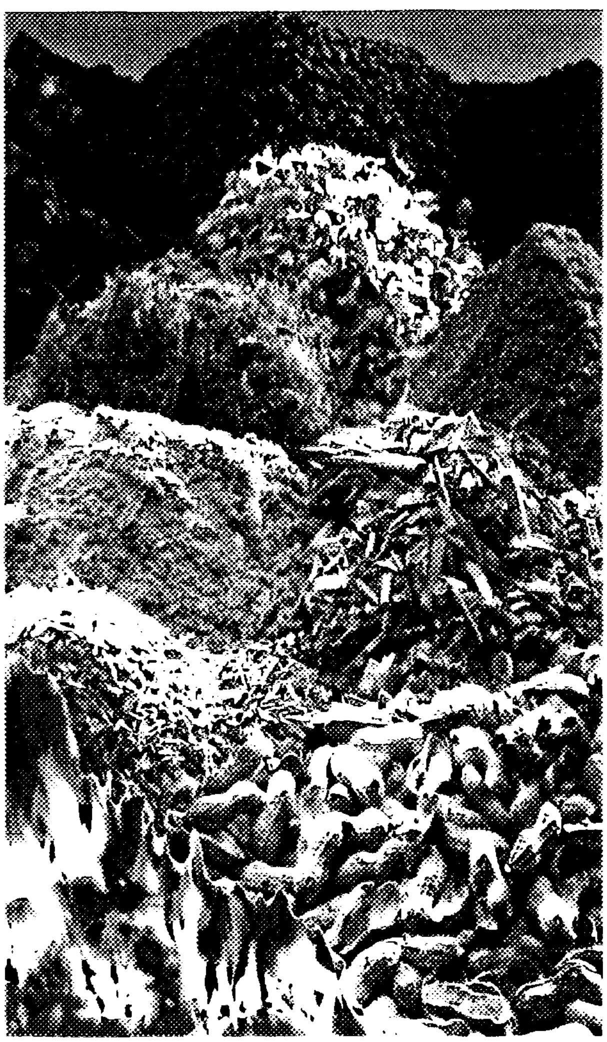
4. The UNIDO Workshop on Industrial Composites-design and applications (30 Oct.-5 Nov., 1994) at Trieste, Italy

In the above mentioned workshop 16 invited papers were presented by eminent scientists and engineers. The paper-themes ranged from reviews of the scientific and technological progress made in the area of composites and future approach.

The basic aspects of characterisation of the fibres and binders; design developments; engineering properties; production technologies and application potentials, were covered in the various presentations made at the Workshop.

From the detailed discussions in the workshop the consensus emerged that (a) natural fibre-reinforced composites materials have vast future potentials as all developing countries have large renewable sources of such fibres, and (b) particulate (inorganic) composites are more universally applicable as the mineral wastes and by-products are available in large quantities in almost all developing countries.

It is well recognised that the development and application of particulate composite materials have reached a stage where mutual cooperation in technology transfer, upgradation and enterprises within the developing countries themselves are achievable. On the other hand natural fibre-reinforced composites although explored extensively, still require meaningful schemes for strengthening and improving the existing capabilities of the product-development, upscaling model project reports through a net work of cooperation among a carefully selected R&D institutions and NGOs.



SECTION A

NATURAL FIBRES COMPOSITES

In the last 20 years there has been tremendous interest in the use of natural fibres for the manufacture of cement or polymer-bonded composites. There are examples of two well established products Tufnol 6F/45 (an epoxy-cotton-made composite in UK) and Trespa (a phenolic/wood fibre composite made in Holland). Yet somewhat poor strength properties of these two materials suggest that there is need for further product-optimization. At the same time many claims have been made that on a weight-for-weight basis, the performance of the best plant fibre-reinforced composites is comparable with that of the conventional glass-epoxy compositions.

The thermosetting polymers matrix and plant fibre composites find application as electrical insulator (Tufnol ltd), semi-structural applications (Hoechst Holland) and wear parts (Tenmat ltd). In India certain jute-phenolic system has been used since 1994. With thermoplastic polymer matrix, sheet moulding component materials such as wood stock and lignotoc BASF AG have recently been introduced as sisal-reinforced composite. Mitsubishi in Japan have also introduced a polypropylene composite with 50% reclaimed newspaper fibre. With substantial cuts in the expenditure in defence and aerospace programmes some multinational companies are reorienting this product-range from high-cost and high-performance composites towards more environmental friendly and lower cost plant fibre-reinforced composites.

With the above background it is interesting to look into the endeavours made in recent past and future prospects of the production and uses of natural fibre-reinforced composites for use in housing solutions for the millions of people in the developing world.

A.1 Availability of natural fibres

Table-1&2 show fibres available in each country and the annual production of natural fibres, in the world, of which the major contributions are from the developing countries. In fact many fibre samples from developing countries of Asia and Africa have been extensively studied. The following list shows some important fibres, and countries of their origin, which were found to possess great promise in the manufacture of composites of low weight and high strength.

Table-1: 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

Plant fibres vary widely in chemical composition, structure and dimensions, as they originate from different parts of the plant. These variations are shown in Table-3 and 5. However, Table-4 gives some comparative data on the specific strength-properties of the plant fibres vis-a-vis those of glass, kevlar and carbon fibres. In fact, many fibres are well known to the consumers of textiles, matting, ropes etc. and some of them are considered useful on the basis of their cellulose content. There is considerable interest in oil palm fruit fibres in Malaysia and elephant grass in some African countries and India. It is reported that there may be about 1000 types to choose from, excluding wood and bamboo. Table-5 and 6 show important properties of dimension, density and mechanical strength which enable a direct comparison of intrinsic values of plant-fibres and those of man-made fibres (glass, steel, boron, silicon carbide etc.)

Table 2: 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

Table 3: Chemical composition and moisture absorption of some natural fibres

Fibre	Cellulose %	Hemicellulose %	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	-	-

Table 4: 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

Fibre-density and dimensions are of specific interest to the manufacturers of composites. In terms of aspect ratio, most individual fibres have values in the range of 100-200. In summary, the advantages of plant-fibres as reinforcement in polymer or cement-bonded composites are their acceptable specific strength, low-cost, low density, high toughness, good thermal properties, reduced dermal and respiratory irritation (as compared to glass fibres) and their biodegradability. Moreover plant fibres require very small energy inputs for processing. These advantages merit full attention about exploiting the plant-fibres for making composites. They actually meet the basic criteria of being locally available, of renewable production and having their proximity to nature.

A.2 Main problems in the design, development and application of plant fibre-reinforced composites

The design of a composite material based mainly on natural fibres depends upon the reliable information on their technical properties. But the data available show wide variations even from one location to another in the same country. There could not, therefore, be one design based on the same fibre for a product which could be applicable for all countries producing that fibre. Thus it is important to take care of this variability factor.

The natural fibres, in general, possess the elasticity modulus (Ef) lower than the elasticity modulus of the matrix (Em). Hence the reinforcing effect is often not good and it can only be increased as the Ef/Em increases. Such difficulty could be overcome by constant monitoring of characterization data of all suitable plant-fibres.

It is well understood that although the young's modulus and tensile strength of a number of natural fibres are comparable to those of asbestos fibre (see Tables 5 & 6) there is poor interaction between natural fibres and cement matrix, unlike that of asbestos. Hence the cost-factor is not always attractive when a compatible polymer matrix is used as it is costly and has to be imported in many developing countries.

Technological improvements suggest that natural fibre and cement composites, made with proper mixing, high pressure in mat-forming and other good quality control measures, make them fire-resistant but those using polymer matrix do not fulfil this requirement, particularly for housing applications.

Almost all natural fibres show poor alkali resistance hence result into unsatisfactory performance in cement matrix. Therefore, further R&D are in progress in improving the alkali-resistance of natural fibres by certain pre-treatments and application of coatings on fibres. On the other hand, bond strength which is just physical between polymer matrix and natural fibre still could not match that of asbestos fibre in cement, the bond which is physico-chemical.

Natural fibres show poor wetting in cement matrix (like glass fibre, Kevlar & carbon fibres) and it is so even in high-profile polymer resin like epoxies matrix. Also many natural fibres, because of high water absorption, change their shape in cement matrix and hence create difficulties in design-developments of various building components. There has to be, therefore, constant vigil in ensuring long-range satisfactory bonding, resistance to deformation and delamination, resistance to attack by pests and termites and an overall durability.

For making further progress in promoting natural fibre cement/polymer matrix composites as acceptable building materials, (a) coordinated data base on the technical properties of natural fibres of different sources, and (b) backup of pilot-plant studies in selected countries are two major follow-up programmes to be formulated carefully.

A.3 Development of plant-fibre composites for housing

Jute-epoxy, jute-polyester, jute-phenolic composites

Table-7 shows comparative bonding properties of natural fibres and glass fibre composites in polymer matrixes. Jute fibre-epoxy composite shows bond strength nearest to that of glass fibre epoxy composite. In an earlier work sisal-epoxy composite was found to possess nearly half the tensile strength than that of glass-fibre-epoxy composite, when both fibres were used in the same wt % ratios. However, because of the low density of jute and sisal fibres their specific strength is comparable to that of glass fibre-epoxy composite.

In fact, jute fibre has adequate strength and is most compatible with polymer matrix. These composites in the form of panels, sheets, tiles, etc. are today most recommended products for low cost housing and also for grain storage bins. Although jute-fibre-polyester composites are now a commercial success certain problems are still to be overcome. The difficulties of absorption and desorption by the composites, decrease in tensile strength upto 25% indicate their susceptibility to temperature and water-resistance and shear failure. The data on weathering properties after 7 years exposure, given in Table-13 confirm the above observations. it is also recommended that jute fibre and glass fibre 'hybrid' composite may be used for better performance.

Coir polyester composites

Many attempts have been made in making laminates and other products from coir fibre and unsaturated polyester. The results of one such experimental values, for using 9 wt % of coir in polyester, have been shown in Table-8. Although several properties are satisfactory but the pull-out stress of the fibre from the sample was found to be very low, suggesting poor bonding between coir fibre and the matrix. Fibres with higher lignin content may behave better.

Banana-cotton-polyester composites

The results of various physical and mechanical properties of banana-cotton-polyester composites are given in Table-9. It is seen that satisfactory tensile and flexural strength and modulus of elasticity could be achieved if the fibre content was at least 14 wt %. However, in this composite also the bond strength between the fibre and the matrix was poor.

Sisal-epoxy and sisal-polyester composites

Sisal is yet another natural fibre extensively investigated as this fibre costs low and needs little efforts in processing. Some of the properties of this fibre are given in Table-5 and the strength data of sisal fibre-polyester resin composite, with or without red mud (an aluminium industry waste) additive, are given in Table-12. It is observed that the best results are obtained if the composite is made as 'hybrid' type using sisal fibre (about 35%) + glass fibre (about 8%) and red mud (about 20%).

Sisal fibre-epoxy composites have also been advocated for application in roofing units and panel products. The mechanical properties of this epoxy matrix composite were found better than those of polyester matrix composite. However, even only on cost consideration polyester matrix is considered preferable to epoxy matrix.

Many more natural fibres other than jute, sisal and coir have been evaluated, almost all given in Tables-2 and 3. The chief among them are mesta, bagasse, kenaf, sun hemp, and flax, in different matrices - polymeric, bitumen cement and gypsum plaster. Wheat straw and rice husk have also been investigated.

Table 5: Mechanical properties of some natural fibres

Fibre	Length mm	Diameter mm	Density kg/m³	Young's modulus	Tensile strength GPa	Elongation break % MPa
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	-

Table 6: Mechanical properties of some fibres other than natural fibres

Fibre	Length mm	Diameter mm	Density kg/m³	Young's modulus	Tensile strength GPa	Elongation break % MPa
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	<15	<0.2	2550	159	210-2000	7-18
Polymer (Polypropylene)		NA	NA	900	6.8	590 210

Table 7: Comparative bending strength properties of natural fibre and glass fibre reinforced composites

Fibre/Matrix	Sp.Gr.	Bending strength GPa	Bending modulus GPa	Fibre volume fraction %
Random wood/ phenolic	1.2	0.110	8.0	65
Woven jute/ polyester	1.2	0.090	8.0	50
Filtered jute/ polyester	1.2	0.100	10.0	60
Parallel jute/ epoxy	1.2	0.450	43.5	70
Cotton/epoxy	1.5	0.170	8.0	55
Parallel Kanef/epoxy	1.2	0.450	58.5	70
Pulruded glass/epoxy	1.7	0.690	43.0	70
Random glass/epoxy	1.9	0.172	10.5	70

Note: The above data are of commercial products (sheets) produced in advanced countries.

Table 8: Properties of coir-polyester composites with 9wt% coir

Density, kg/m³	1160
Strength tensile MN/m² flexural	18.61
Strength flexural MN/m² flexural	38.51
Modulus of elasticity, GN/m²	4.045
Impact resistance, kgm/m²	391.0
Water absorption (24 hr) %	1.36
Dielectric strength, 2.5 mm thick	10KV/min

Table 9: Properties of various fibre-polyester resin composites

Property	Type of fibre used in composite						
	Glass	Cotton fabric	Banana fabric	Coir	Banana Cotton		
	Polyester wt% not known				Polyester wt%		
					8	14	18
Density kg/m³	1500-1900	1400	1215	1160	-	-	-
Strength MN/m²							
Tensile	241-689	34.5-689	35.92	18.61	25.86	30.96	29.50
Flexural	344-662	62.1-124	50.60	38.15	52.38	61.24	60.40
Modulus of elasticity GN/m²	6.9-41.4	2.76-4.2	3.33	4.05	1.36	2.03	1.80
Impact resistance kgm/m²	3116-8475	257.3-428	748.5	391	-	-	-
Water absorption %	0.2-1.0	0.8	1.93	1.36	-	-	-

Source: International Encyclopedia of Composites Volume 4, Editor Stuart M Lee, VCH, Newyork

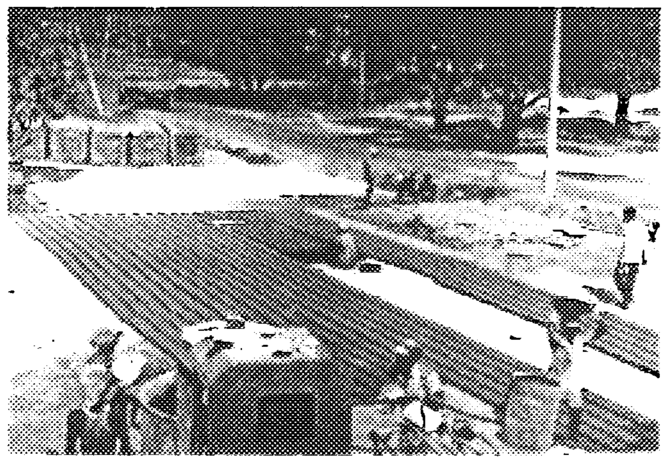
Table 10: Mechanical properties of jute-fibre reinforced composites

Resin	Jute wt %	E-glass wt %	Ultimate tensile strength MN/m²	Young' mudulus GN/m²	Ultimate flexural strength MN/m²	Fracture strain %
Epoxy	32.9	-	104	15.04	150	0.69
Epoxy	18	40	157	25.41	445	0.62
Epoxy	-	68	429	44.30	938	1.04
Polyester	21.8	-	84	12.12	125	1.69
Polyester	10.1	38.5	200	18.15	229	1.10
Polyester	-	69.14	391	38.77	816	1.01

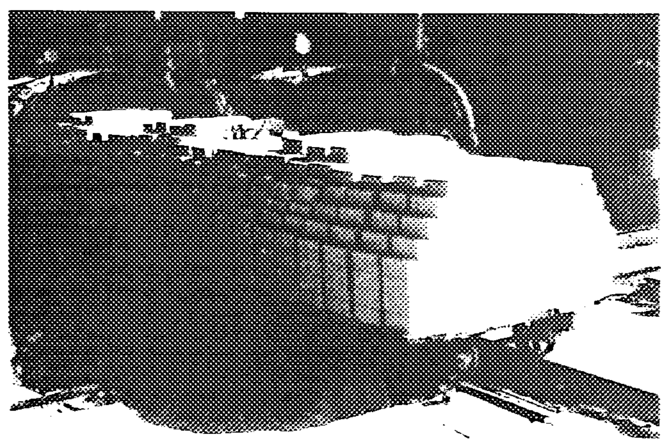
Note: Strength of basic materials when tested individually show quite low values

Manual mixing of raw materials for production of Clay-Flyash Bricks

Manaul casting of Flyash-Lime-Gypsum Bricks at a small scale unit



Sand Lime Flyash Bricks under autoclaving



House constructed with Sand Lime Flyash Bricks

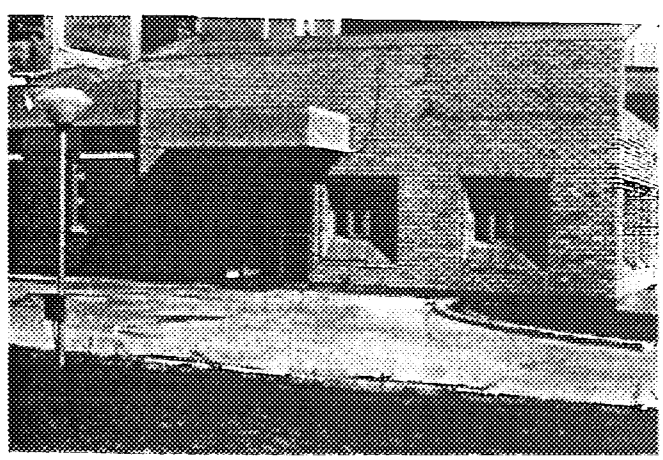


Table 11: Basic data on fibre (natural) reinforced cement roofing sheets and tiles

Country	Type of element	Dimensions mm	Cement Sand ratio	Type of fibre & length mm	Produced since	Fibre volume %	Type of compaction in manual/ mechanical production
Africa							
Mozambique	Tile	240x500x7	1:2	Sisal 12	1985	1.7	Vibration
Zambia	Sheet	670x1000x6	1:1	Sisal 10-20	1984	1.1	Tamping
Tanzania	Sheet	750x750x7.5	1:1	Sisal 20-50	1978	3.0	Vibration
Kenya (1)	Tile	Parry ITW tile	1:3	Sisal 12	1983	1.5	Vibration
Kenya (2)	Tile	-do-	1:3	Sisal 12	1985	1.1	Vibration
Zimbabwe	Sheet	NA	1:1	Sisal 15-20	1979	0.9	Tamping
Ghana	Tile	760x1000x10-15	1:1	Elephant 20-50	1985	NA	Vibration
Malawi	Sheet			Sisal 20-30	1980	NA	Tamping
Asia							
Bangladesh (1)	Sheet	790x1000x6.5	1:08	Jute 18-25	1983	1.1	Tamping
Bangladesh (2)	Tile	Parry ITW tile	-	Jute 10-20	1983	1.9	Tamping
India (1)	Sheet	650x1000x10	1:1	Coir 12	1982	1.9	Vibration + Pressure
India (2)	Sheet	1000x2000x7	1:0	Coir 100-200	1980	16	Tamping
Indonesia	Sheet	920x1150x7	1:067	Ijuk 30	1983	3.4	Tamping
Sri Lanka	Sheet	390x1000x10-15	NA	Coir 20-30	1984	NA	Vibration

Table 11 Contd.

Country	Type of element	Dimensions mm	Cement Sand ratio	Type of fibre & length mm	Produced since	Fibre volume %	Type of compaction in manual/ mechanical production
South America							
Dominican Republic (1)	Sheet	750x1350x6.9	1:1	Sisal 25	1984	1.2	Tamping
Dominican Republic (2)	Sheet	1000x1450x10-15	1:1	Sisal 50-75	1982	1.27	Tamping
Nicaragua	Sheet	840x1000x6.9	1:1	Sisal 25	1984	3.5	Tamping
Soloman Islands	Tile	Parry ITW tile	1:3	Coir 20	1984	1.1	Vibration
Haiti	Tile	Parry ITW tile	2:5	Sisal 20	1984	NA	Vibration
Guatemala	Sheet	770x990x6.9	NA	Sisal 20-30	1981	NA	Vibration
Colombia	Sheet	610x1140x10	1:2	Sisal 20-30	1982	0.6	Vibration

Note: The data of Table 11 are based on questionairs and some personal contacts. These information need updating.

Source: SKAT, Switzerland publications

Table 12: Physio-mechanical properties of polyester-redmud-sisal fibre composites

Material	Red mud %	Sisal fibre %	Density kg/m³	Water absorption %	Tensile strength MPa	Elongation %	E GPa	Flexural strength MPa
Unsaturated polyester (USP)-	-	1118	0.13	26.40	2.38	1.11	61.26	
Redmud-USP 20	-	1310	0.203	17.30	1.49	0.97	58.79	
Sisal Polyester (SP)	-	50	1110	8 .03	45.10	2.33	3.11	85.03
Sisal Polyester (USP)	20	38	1086	4.71	23.50	7.69	0.64	40.02
Sisal fibre-Polyester (SP) (glass content 8%)	20	34	1240	3.65	45.20	8.10	5.95	98.10

Source: B.Singh, Personal Communication

Table 13: Physical properties of jute fibre and glass fibre reinforced polyester composites before and after weathering for seven years

Property	Unweathered jute fibre reinforced sheet	Weathered jute fibre reinforced sheet	Unweathered jute fibre reinforced sheet	Weathered jute fibre reinforced sheet
Bulk density kg/m³	1160	1025	1300	1250
Fibre content %	12-15	-	28-32	30-35
Water absorption % (24 hr.)	2.35	3.23	1.03	1.28
Flexural strength MN/m²				
Dry	23	11.60	107	103
7 days soaking	34	19.10	74.10	
Tensile strength MN/m²	24.20	9-20.6	76.00	63.00

Table 14: General properties of some commercial roofing sheets made from fibre reinforced composites, in India

Property	Using waste paper board and asphalt	Pine shingle waste pulp & asphalt	Redmud waste and PVC	Cut steel wine and cement
Density kg/m³	700-1100	900-1100	200-400	
Dimensions (mm)	1200x750x4	400x150x10	2000x1000x3	1500-1800
Flexural strength (MPa)	80-85	15-20	50-60	1200x750x10
Permeability of water	Nil	Nil	Nil	Trace
Water absorption (%)	8-10	8-10	0.2-025	5-10

A.4. Natural fibre-cement matrix composites

Polymers are definitely very costly as compared to portland cement and gypsum plaster for use as matrix in the development of natural-fibre reinforced composites, for use as panelling, roofing and ceiling components in low cost housing. Even when both the matrixes are compared, on the basis of imported costs, it would be preferable to use cement in spite of its some serious limitations in combinations with the plant fibres.

Many sincere efforts have, however, been made in the development of roofing sheets and tiles using various natural fibres and cement. Technologies, plant and machinery designs of different types were developed. The components like large size sheets and tiles were manufactured and used and the performance studies were carried out and the data carefully compiled.

The results of all these attempts of cement-bonded natural fibre composites are given in Table-11. There have been preferences for making sheets, plain and corrugated, of the geometry similar to that of asbestos-cement roofing sheets. There has also been some recent preference for making tiles instead of sheets with certain advantages in overall costs and performance of roofing structure. The nett results are not quite encouraging and there maybe endless academic discussions on cement vs polymers, sheets vs tiles, pressing vs vibration and lamination techniques, use of fibre surface modifying chemicals and about a general agreement on the durability in terms of loading and exposure parameters. Several standard specifications have been brought out. Coir fibre and rice husk were found as two compatible fibres/particles to suit cement matrix or vice-versa. There is some success stories and one among them is rice-husk-cement composite. Some other composites commercially marketed and used are given in Table 14.

Rice husk-polymer/cement composites

As already stated particle boards manufactured from wood fibres are relatively costly, much beyond the reach of the poor people. Also wood particle boards show poor performance when exposed to atmosphere in tropical climates. Asia and Africa produce about 100 million tonnes rice husk per year. Rice husk as it comes from the mill has a bulk density of about 120 kg/m^3. A whole range of rice husk boards of density 300 kg/m^3 to 1300 kg/m^3 is now manufactured commercially. The bonding resin is phenolformaldehyde or a blend of phenolformaldehyde and cashew nut shell liquid resin. Portland cement is also a compatible matrix material for rice husk.

Rice husk contains about 18 percent silica which makes the boards totally resistant to termites, wood boring insects and rodants. The boards can be used for wall panelling, ceiling, partitioning etc. Rice husk boards can be used in damp and humid locations like in bathrooms without fear of crumbling by decay. Rice husk board does not show flaming combustion but only smoulders slowly when ignited. It resists flame propogation and also flame penetration though it. The board has very good water-resistance.

Rice husk-polymer composites (boards) are at present manufactured of density 500 kg/m^3 to 900 kg/m^3. They show water absorption 3.5 to 10 percent and swelling in thickness 3 to 10 percent. Lower density rice husk boards are easy to nail and screw; they have better nail-holding property and also show better thermal and acoustic properties than wood particle boards.

Rice husk, although an agricultural product, is available all through the year. The cost of rice husk is not expected to go higher than the cost of fibre wood, and this factor goes in its favour for a variety of uses as wall panels, door shutter, ceiling tiles and furniture items. The technology of production of rice-husk-polymer/cement bonded boards, in small or large scale has been sufficiently developed at Indian Plywood Industry Research and Training Institute (IPIRTI) and is available through the National Research Development Corporation of India, 20-22 Jamroodpur, Kailash Colony Extension, New Delhi-110 049, India.

Rubber wood composite

Wood substitutes have national priority in resource mobilisation in housing as many governments have totally banned use of traditional timber in housing and other uses.

Rubber wood is the only sustainable supply of plantation wood all over the world and particularly tropical zone countries of Asia, Africa and South America. Seasoning and preservative treatment make rubber wood free from some of its inherent defects and further engineering technologies in lamination of splint lumber, with a polymer (PF type) make it an ideal substitute for wood lumber. Some of the comparative properties are shown in Tables 15 and 16.

The Building Materials and Technology Promotion Council (BMTPC), Ministry of Urban Affairs and Employment, Govt. of India have recently promoted this innovative technology. The rubber wood laminated splint lumber could be an excellent material for doors and windows. The product has good market potential and can be sold at a very attractive price.

The BMTPC has also promoted technological processes for the utilisation of yet another plantation timber called 'Poplar'. The technology includes densification, fabrication and application as wood substitutes in buildings. The properties of 'Poplar' veneer lumber as compared to those of teak wood are shown in Table 17.

Table 15: Comparative engineering properties of rubber wood & teak

	Source of rubber wood			
	India	Malaysia	Sri Lanka	Comparative teak (India)
Moisture content %	12.0	17.20	12.0	12.0
B.D. kg/m^3	624	690	582	696
Max crushing strength (kg/cm^2 parallel to grain)	374	329	396	532
Screw withdrawal power (kg)	296	-	-	399

Source: BMTPC, New Delhi, India, Internal Report, 1995

Table 16: Mechanical & physical properties of laminated rubber splint lumber

Property	Average value for LSL	Value for solid rubber wood
Sp.gr	0.56	0.5 to 0.66
Volumetric shrinkage %	5.21	N.A.
Modulus in rupture (kg/cm^2)	720	570
Modulus of elasticity (kg/cm^2)	70800	72000
Compressive strength parallel to glue line (kg/cm^2)	326	320
Compressive strength perpendicular to grain (kg/cm^2) (parallel to glue line)	80	N.A.
Shear strength parallel to glue line (kg/cm^2)	119	N.A.
Screw holding strength (kg) (parallel to glue line)	165	176
Nail holding strength, kg (parallel to glue line)	98	93

Source: BMTPC, New Delhi, India, Internal Report, 1995

Table 17: Mechanical properties of 'poplar' wood veneer lumber & teak

	Poplar wood	Teak
Moisture content %	8.2	12
Sp.gr	0.704	0.551
Compressive strength perpendicular to grain (kg/cm^2)	183	83
Maximum shear strength (kg/cm^2)	176	92
Modulus of elasticity (kg/cm^2)	870	665
Screw holding power (kg)	260	N.A.
Nail holding power (kg)	200	N.A.

Source: BMTPC, New Delhi, India, Internal Report, 1995

SECTION B

PARTICULATE COMPOSITES (INORGANIC TYPES)

Particulate composites are essentially the materials which are formed by the aggregation of the particulates or particles of two or more components. Concrete is an excellent example of a particulate composite. Since agglomeration or aggregation of the particles is the basic feature, the resultant products are also called 'aggregate' composites.

The matrix in almost all inorganic particulate composites is cement or lime-pozzolana. However, there could not be a very rigid demarcation as even the cement matrix-properties are modified, for better results, by incorporation of small inorganic as well as organic admixtures. Surface modifier, setting time regulators, workability aids, plasticiser and superplasticiser or early/ultimate strength developing additives are often organic materials. Nevertheless the bulk in the inorganic particulate composites is the inorganic materials. (See Table 18).

Stabilised-soil block is another classical example of particulate composite in which soil and cement or lime are the two major components. A small quantity (1-2%) chopped fibres is also added which contribute towards adhesive strength and durability of the blocks.

Today, inexhaustive information is available on the utilisation of a variety of industrial wastes and by-products for the manufacture of walling, partitioning, roofing and flooring materials. Pulverised fuel ash (flyash), blast furnace slags, stone processing wastes, laterites, ore beneficiation tailings, by-products gypsum, lime sludges have been considered as excellent alternative aggregate materials which combined with cement or lime-pozzolana or other alternative matrix materials produce many new aggregate composites.

Table-18: 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 in which	Appropriate technology available
1.	Flyash/pulverised fuelash	Thermal power station using pulverised coalsh 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

Table 18 Contd..

Sl. No.	Type of the Waste	Source	Type of particulate composites in which	Appropriate technology available
5.	By-product lime sludges	Sugar, paper, acetylene, tannery fertilizer industries	After calcination used in composite mortar, pluster 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 etc.	In the mining of the respective mineral	Utilisation after calcination in lime-pozzolana	India

Extensive data on various physical, chemical, mineralogical and mechanical properties of the industrial wastes and by-products have been compiled. These data provide a high degree of confidence in designing tailor-made composite materials suitable for highly cost-effective construction technologies. Utilisation of the waste materials effect saving in naturally occurring rocks and minerals, reduction in the use of cement, and pollution abatement through profitable and safe disposal of the wastes.

B.1 Resources of waste materials for use in particulate composites

Flyash (pulverised fuel ash)

Flyash is the residue from thermal power stations using pulverised coal in the boilers. Flyash is evaluated for its chemical composition which is almost in the same range as of calcined clay-pozzolana. The specific surface of many flyashes is about 4000 cm^2/g (Blaine's) and residual carbon content is 0.5 to 5% by wt. Dry flyash as collected from the chimneys of the boilers is highly reactive with lime to produce hydraulic (cementitious) binder composite material. Hence reactivity of flyash towards lime is very important. Flyashes contain about 60% silica (SiO_2) most of which is reactive.

Today annual world consumption of coal in thermal power stations is about 2500 million tonnes which on burning generate about 250-300 million tonnes flyash per year. There are, however, only a few developing countries which have enough coal to burn and produce flyash. China and India are major flyash producing developing countries. It is, therefore, but natural that these two countries are most forward in finding a number for uses of flyash as construction materials. The major uses found out are flyash-blended cements, called portland-flyash pozzolana cement, in mass concrete in construction of dams, precast concrete products, light weight sintered aggregate and flyash-lime (sand-lime type) bricks and blocks.

China and India have so far carried out most outstanding research and development in the utilisation of flyash. Yet, unfortunately, because of many logistic and administrative bottlenecks not even 10% of the 80 and 50 million tonnes flyashes, produced yearly in China and India respectively, find actual utilisation. Among African countries South Africa is the foremost in presenting flyash based technologies for various composite materials. When the production of flyash in some of the developing countries is likely to touch still higher figures by the end of the century, very gigantic efforts are required to accelerate the utilisation of flyash. Perhaps it would be useful to get a few tips from the UNIDO assisted project on flyash utilisation carried out in the Shanghai Research Institute of Building Sciences.

In India, today the emphasis is on development of technologies of stabilisation of flyashes in their collection ponds and then develop selective forming and forests which could provide much needed cellulosic materials for reconstituted wood products. Another promising way could be to manufacture flyash-lime bricks, either steam-cured or using cement for adequate compressive strength of the bricks. A third major application could be in road construction. It is almost certain that in India not more than 5% of flyash produced could be absorbed in cement and concrete products.

Table 19 shows range of chemical composition and mineralogical constituents of Indian flyashes. Table 20 shows some important uses of flyash in inorganic composite materials.

Mineral composition

Quartz, Mullite, glassy phase, Ferrous oxide (FeO), Magnetite (Fe_3O_4), Haematite (Fe_2O_3)

The above table shows wide variability of flyash composition which does not have any control as the quality of coal varies and power production parameters also vary. The mineralogical make-up also differ considerably. These factors restrict general application of flyash as building material.

Table 19: 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

Table 20: 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.

Byproducts blast furnace slags

The developing countries which have large steel plants also produce slags. Slags if air-cooled is suitable as dense aggregate for cement-concrete; foamed type slag finds use in light weight concrete products and granulated type slag for portland blast furnace slag cement. These materials are based on very well established technologies. However, some recent research and development work have shown that slags, flyash and byproduct chemical gypsum (from ammonium phosphate and fluorine industries) could be blended and interground to produce a hydraulic binder for making concrete blocks, bricks and as mortar and plaster. Again, most of the developing countries do not have steel plants and therefore no slags; and even if they have iron ores suitable for steel production they do not have fuel resources to meet the demand of large steel plants. Hence flyash and slags are important resources only for a few developing countries.

Table 21 shows chemical composition of blast furnace slags. Table 22 describes constituents, factors and suitability of slags for building materials. Blast furnace slag produced in any country has similar characteristics and uses.

Thus suitability and processing of slags are important factors. Most of the technical aspects have, however, been resolved. Slags are also used for making ceramic composites for wall cladding and one name given for it is 'Slag Cital'.

Coal washery rejects

Depending upon the coal deposits and their quality, many high ash coals need washing, in large washeries, producing huge quantities of the rejects. Coal washery reject is usually silicious-argillaceous in composition with about 15-20% coal particles. Indian experience is to utilise the washery rejects for blending with clays, moulding into bricks and then burning in small or large kilns.

Mine tailings

Unlike the limited scope of availability and utilisation of flyash and slags in majority of the developing countries, there are enormous quantities of mining operation rejects available for profitable utilisation. Upgradation and beneficiation of ores of copper, zinc, tin, gold, silver, nickel etc. produce tailings which are either silicious or calcareous-dolomitic depending upon the composition of the parent rocks containing the ores. These tailings have found application in several aggregate composites-such as fine filler in concrete, admixture in mortar and plaster, for blending with portland cement to produce masonry cements and in the production of lime-stabilised bricks, sand-lime type autoclaved bricks and cellular concrete units. These composites have been fully evaluated for their performance and service life.

Table 21: 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

Table 22: 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 wood 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

Table 23: 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	Cellular concrete	Cellular concrete	--
	Calcium silicate bricks	Calcium silicate bricks	Calcium silicate bricks	Calcium silicate bricks
	Masonry cement	Masonry cement	Masonry cement	Masonry cement
	Mortar	Mortar	Mortar	Mortar
	Fine filler in concrete	Fine filler in concrete	Fine filler in concrete	Fine filler in concrete
	Filler in bitumen mastics	Filler in bitumen mastics	Filler in bitumen mastics	---
	--	As opening material in brick making	--	Burnt clay bricks
	--	Filler in acid resistant cement	---	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.	

Table 24: Properties of calcium silicate bricks made by using tailings 70-90%, sand 10-20% and lime 7-10%

Forming pressure	160-240 kg/cm^2
Steam autoclaving	6, 8, 11 and 14 kg/cm^2 pressure
Duration of autoclaving	3-6 hours
Compressure strength of bricks	115-140 kg/cm^2 based on variations in forming pressure and steam curing parameters
Drying shrinkage of bricks	0.01 to 0.055% of length
Thermal conductivity of 11.5 cm thick wall	9.3 to 9.7 gram-cal/cm^2/hr/°C/cm
Water absorption	15-20% by weight

Table 25: Results of cellular concrete produced on pilot-plant using tailings 50-80%, cement/lime 30-50%, gypsum 5-15%, aluminium powder 0.05%

Process parameters	Autoclaving at 10kg/cm^2 steam pressure for 10 hr
Compressive strength of cellular concrete blocks	36-60 kg/cm^2
Drying shrinkage, %	0.05 to 0.08
Thermal conductivity	0.35 gram-cal/cm^2/hr/°C/cm
Fire resistance	Good

Table 26 gives results of masonry cement produced by using tailings and portland cement, by intergrinding.

Table 26: Results of masonry cement composite using tailings 60% + portland cement 40% (pilot-plant data)

Fineness (cm^2/g) (Blaine's)	5,600
Setting time (minutes)	Initial 150 Final 480
Compressive strength of 1:6 masonry cement-sand mix, (kg/cm^2)	7 days 28 28 days 52
Water retention %	72
Soundness La'chatelier expansion	1 mm

Table 23 shows physical, chemical and mineralogical properties of 10 types of mineral tailings including coal washery rejects. The main uses of these tailings in the production of alternative/ new building materials are also indicated. Mine and mineral tailings can feed the requirements of large or small-scale manufacture of sand-lime type calcium silicate bricks and cellular concrete and thus contribute to the saving of precious primary minerals and also energy.

Table 24 presents data of pilot-plant production of sand-lime-type calcium silicate bricks and Table 25 for cellular concrete.

All the above three materials viz. calcium-silicate bricks, cellular concrete and masonry cement based on the utilisation of mine-mineral tailings conform to international standard specifications.

Red mud

Red mud is the name given to the waste material thrown in the manufacture of alumina from bauxite. Composition of red mud depends upon the overall chemical constituents in bauxites. Red mud is red colour slime with high iron oxide, (Fe_2O_3), titanium dioxide (TiO_2) and small quantities of aluminimum oxide (Al_2O_3) and silica (SiO_2). Red mud has been used in several cement plants as flux material, in making bricks & tiles of high strength and in composites with polymeric matrix reinforced with natural or man-made fibres, into shapes of boards, roofing sheets, tiles, cladding materials and door and window shutters. However, difficulties in collection, washing, processing, drying and grinding are some of the constraints in major consumption of red mud into composite materials for housing. Some red muds were also suspected to be mildly radio-active but it has not been corroborated on detailed testing.

Table 27 gives chemical composition and Table 28 gives physical and mineralogical constituents of red mud from different countries.

Table 27: 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

From the chemical composition it is seen that in some red mud samples precious titanium dioxide is wasted. Some samples are rich in iron oxide content or very high alkali (Na_2O). Red mud has to be processed for removal of alkalies to render it suitable for making bricks & tiles in combination with flyash and/or fibres. Now red mud is causing serious pollution problems because it is getting piled up and its toxic soluble constituents are flowing into ground water, lakes and rivers.

Red mud presents difficulties in settling and its colloidal suspended particulates continue to float for a long time. The particle-composition related properties of red mud are given in Table 28. Table 29 presents data on red mud flyash bricks.

The above mineralogical composition shows the suitability of red mud of Russia for use in cement - raw meal composition as its iron oxide content is quite low. Other red muds are more suitable for ceramics.

Table 28: 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

Table 29 : Properties of red mud - flyash bricks

Composition	Compressive strength range (kg/cm^2)		Water absorption %	
	Temp. of firing			
	1000°C	1050°C	1000°C	1050°C
Flyash-red mud (50:50)	175-210	240-275	18.5-19	16.5-17
Flyash-red mud-clay (50:30:20)	185-225)	380-425	17.5-18	16.0-17

Byproduct gypsum

Substantial quantities (about 2.5 million tonnes per year in India) of byproduct high grade gypsum (chemically 99% $CaSO_4$ $2H_2O$) are produced from ammonium phosphate fertilizer, fluorine/hydrofluoric acid and boric acid production plants; and accordingly they are designated as 'phospho gypsum', 'fluoro gypsum', and 'boro gypsum'. This gyupsum, after washing to remove its acidic impurities, is calcined to produce gypsum plaster which, as matrix, in turn, gets reinforced with vegetable fibres or glass fibres to produce composites such as boards, blocks, tiles, door shutters etc. Extensive R&D and industrial production experience have been generated in several Indian institutions.

Gypsum plaster is soluble in water and therefore it is not suitable for outdoor applications. Byproduct gypsum, after necessary neutralization of acidity, purification and upgradation, is classified to determine its suitability for various uses. In several countries, including India, byproduct phosphogypsum, fluorogypsum, and borogypsum have now found use in the preparation of a water resistant binder using flyash, granulated blast furnace slag and small quantity of lime or cement. Table 30 gives physical properties and Table 31 gives chemical properties of this binder.

This binder can be used for plastering and also for building blocks - solid and hollow for load bearing and no-load bearing applications.

Glass fibre-reinforced gypsum binder (water-resistant) has been prepared, using E-type glass fibre. This glass fibre has diameter (of the fibre filament) 8-10 µm, number of filaments in a strand is about 200, tensile strength of the fibre is 17500 kg/cm² and its young's modulus is 68900-76000 kg/cm². The composites using the binder in 67% consistency and in thickness of 5 mm are made, using chopped glass fibre, about 4% by wt. The typical properties of glass fibre-reinforced gypsum binder - composite are given in Table 32.

Table 30: Physical properties of water resistant gypsum binder

Fineness cm²/g	3200
Setting time, minutes	Initial 75 Final 155
Bulk density (kg/m³)	1200
Compressive strength (28 days) kg/cm²	350
Soundness (La'chatelier)mm	1.6
Water absorption (%)	6
pH	11.5

Table 31: Chemical properties of water resistant gypsum binder

Constituent	% by wt.
Loss on ignition	4.11
SiO_2 + insoluble in HCL	8.5
Al_2O_3	9.00
CaO	37.30
MgO	1.80
SO_3	39.65
P_2O_5	0.15
F	0.09

Table 32: Properties of glass fibre-reinforced gypsum binder composite

Property		Gypsum-binder composite (E glass 4%)	Gypsum plaster composite (E glass 4%)
Bulk density kg/m³		1.628	1.20
Consistency, %		65	81
Flexural strength (kg/cm²)	3 days	121.7	49.7
	7 days	132.1	49.8
	28 days	220.0	29.6
Tensile strength (28 days) (kg/cm²)		180	27.5
Impact strength (28 days) (kg/cm²)		186	102.0
Thermal conductivity Kcal/mh°c		0.09	0.12

Note: There is progressive increase in strength of the 'binder' as it is hydraulic due to its flyash, slag and lime/cement content.

Miscellaneous lime-sludge wastes

Waste lime-sludge in large quantities are obtained from sugar, paper, tanning, fertilizer and acetylene gas industries which consume high grade lime in their production processes. Most of the waste lime-sludges are in the form of calcium carbonate ($CaCO_3$). On briquetting and calcination the sludge produces lime (CaO) which mixed with calcined clay or flyash or natural pozzolana makes low-cost mortar/plaster materials. This lime could also be used for producing stabilized - soil bricks and sand-lime type bricks or in road construction.

Lime sludge from calcium carbide-acetylene plant is obtained as calcium hydroxide [$Ca(OH)_2$], which if kept protected from atmospheric carbonation by storage under water, can be an excellent material for direct blending with a natural or artificial pozzolana or rice husk ash for making lime-pozzolana composite mixtures.

The lime-pozzolana mixtures must be protected from atmospheric carbonation during storage, by packing in water-proof bags. A summary of the lime-pozzolana mixtures, using calcined lime sludge and a pozzolana, for 28 days (wet curing) compressive strength of 1:3 mortar (ILP:3 sand), is given in Table 33. These alternative binders are, although, in use for many years, as one of the best locally available alternatives to cement-binder. They, however, need further technological support in standardisation as well as fiscal incentives like those given for the use of flyash or red mud or any other waste.

In addition to the major groups of industrial wastes mentioned above many others find use in composite building materials. Major advantages in the utilisation of the waste materials are well known and hence the emphasis should be on future planning on the following lines:

(a) **Planned construction project:** Large public sector construction projects should be undertaken in which use of industrial wastes has an integral component.

(b) **Removal of logistic difficulties:** Wastes continue to be accumulated, in spite of all available knowledge about the benefits of their utilisation, because of lack of proper infrastructural facilities, lack of roads and unplanned storage systems. These difficulties must be removed to have proper access to the solid waste management.

(c) **Identification of well proven technologies and their dissemination:** Correct sources of the technologies must be identified and mutual cooperation among the developing nations should be encouraged instead of looking towards only import from the developed world

(d) **Standards, validation and certification:** For these regulatory measures there is a need to constitute one central agency in each country for the processes based on waste materials.

Table 33: Recommended lime-pozzolana mixtures as alternative to cement binder

Blend	Cementitious material (%)			Total aggregate	Recommended use
		OPC	Lime	Pozzolana	
OPC - pozzolana	50	-	50	9-12	Low strength concrete
	50	-	50	4-8	Mortars and plasters
	66	-	34	6-10	Medium strength concrete and concrete blocks
	75	-	25	6-8	Structural concrete
Lime - pozzolana	-	34	66	6-8	Low strength concrete and concrete blocks
	-	34	66	3-6	Mortars, plasters and load bearing blocks
OPC- lime-pozzolana	20	-	60	6-9	Medium strength concrete and concrete blocks
	10	25	65	6-8	Low strength concrete and concrete blocks
	5	30	65	4-7	Mortars & plasters

Source: UNCHS, A Compendium of Information on Selected Low-Cost Building Materials, UNCHS (Habitat) Nairobi (Kenya) p.39

CONCLUDING REMARKS

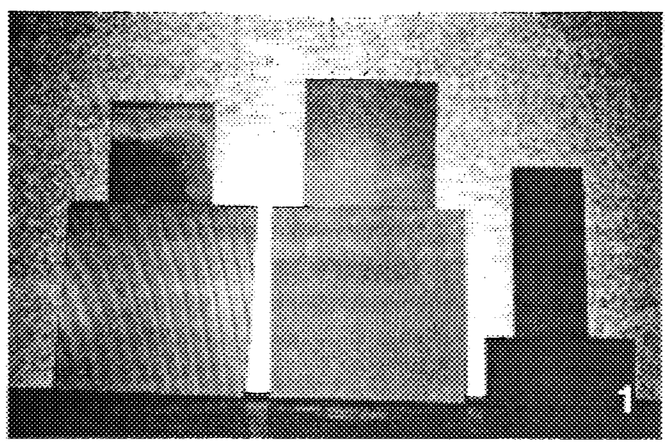
Aggregate composites, based on inorganic industrial wastes, and natural fibre-reinforced composites both are the materials for cost-reduction in housing and a possible answer to meeting requirements of building materials for millions of shelters to be constructed in all developing countries.

Some of the composites, like flyash-lime, portland-slag cement, gypsum plaster fibre board, are now well proven. So is now the indicator in the manufacture of jute fibre-polyester, red mud-PVC and rice husk-cement boards and blocks (see Annexure 1). Yet, there are several gaps in the scientific and technological developments of natural fibre based composites, using polymer or cement matrix, perhaps a little more problems with the latter matrix.

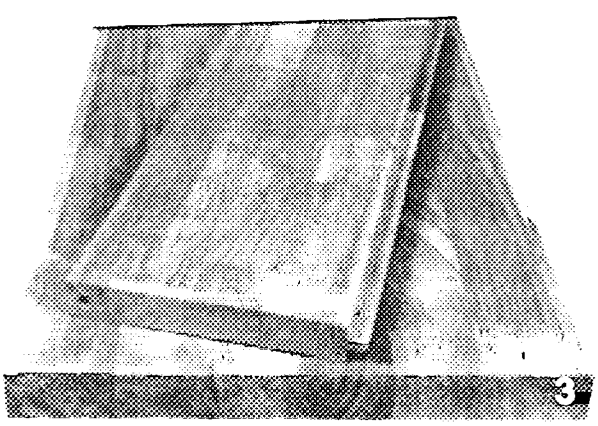
There could be some well defined projects on the collection and compilation of data on wastes and natural fibres. There appears to be need for improving manufacturing technologies in flyash-lime bricks, laterite blocks, phosphogypsum boards. Also for improved performance of the natural fibre composites a data base on the aspects of technological properties, improvements in lamination and sandwiching of fibres, recycling processes, use of additives for improving bond strength of fibres in cement matrix and studies on durability of building products are the key areas for future research and development, rapid prototyping and engineering design of the products.

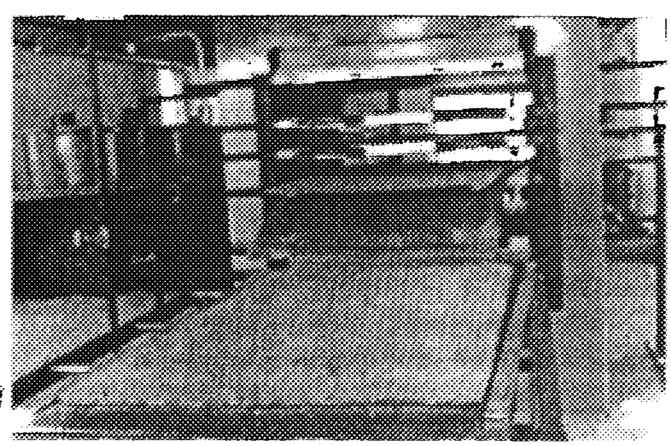
NAME AND ADDRESSES OF SOME ORGANISATIONS DISSEMINATING INFORMATION ON COMPOSITES

- GATE - German Appropriate Technology Exchange, Germany.
- ITDG - Intermediate Technology Development Group, UK
- SKAT - Swiss Centre for Appropriate Technology, Switzerland
- GRATerre - International Centre for Earth Construction, France
- BMTPC - Building Materials & Technology Promotion Council, India
- NRDC - National Research Development Corporation, India
- SRIBS - Shanghai Research Institute of Building Science, Shanghai
- UN-ESCAP, UN-ECLAC, UN-ECA, UNCHS, UN-ESCWA, FAO, UNIDO



1. Red Mud Polymer Composites for door/ window shutters
2. Manufacture of Rice husk boards
3. Laminated Splint Lumber from Rubber wood for manufacture of door/window shutters





Annexure-1

COMMERCIAL PRODUCTS OF SOME COMPOSITES IN INDIA

Sl. No.	Name of the composite	Composition of the composite	Type of the building materials	Name and address of the manufacturer in India
ORGANIC COMPOSITES				
1.	Red mud-PVC jute fibre	Red mud PVC Fibre	Corrugated roofing sheet panels	Lotus Roofing Pvt. Ltd Sedurapet P.O. Pondicherry-605 101
2.	Jute Fibre-polyester	Polyester Jute fibre	Panels	Jupiter Board Industries 93, Pilkhana Road Berhampore, Mushidabad-742 101 (WB)
3.	Redmud-polyester sisal-glass fibres	Red mud polyester sisal	Panels, tiles, roofing sheet	Neolux India Ltd. 75, Altanta, 7th Floor 209, Nariman Point Bombay-400 021
4.	Bitumen bonded paper fibre or pulp	Paper fibre felt bitumen	Corrugated roofing sheet	Light Roofing Ltd No.2/87, GST Road Chettipunniyam 603 200 Chengai, MGR, Distt Tamil Nadu
5.	Bitumen-pine needle fibre	Pine needle fibre bitumen	Shingles for roofing	Light Roofing Ltd No.2/87, GST Road Chettipunniyam 603 200 Chengai, MGR, Distt Tamil Nadu
6.	Gypsum plaster-fibre jute/sisal & glass	Sisal/glass fibre gypsum plaster	Partitions Door Shutters	Ganesh Agro Industries Pvt. Ltd. 636, Mundka, Delhi-110 041
7	Borotik	Rubber wood	Door shutter partition	Borox Morarji ltd. Jolley Bhawan No.2, New Marine Lines Bombay 400 020 (India)
8	Coir-oxychloride composite	Coir fibres magnisium	Ceiling, partition, panels	Anutone Boards (P) Ltd. Bangalore (India)
9	Rice husk board	Rice husk, synthetic resin	Wall panelling, false ceiling, partitioning, door/window shutters, roofing panels, flooring	Padmavathy Panel Boards Pvt.Ltd. 114, 4th Cross 1st, N Block Rajaji Nagar Bangalore - 560 010 (India)
10	Bagasse board	Baggase, synthetic resin	Wall panelling, false ceiling, partitioning, door/window shutters, flooring furniture	Western Bio system Ltd. ECO HOUSE 65/1-A, Akarshak Opp.Nal Stop Karne Road Pune-411 004
11	Cement bonded particle board	Cement 62% wood like eucalyptus and casurine 28%	Partitioning, wall lining, false ceiling, roofing, flooring, doors, panelling	NCL Industries Ltd. 7th Floor, Raghava Ratna Towers Chirag Ali Lane Abids Hyderabad - 500 001

Sl. No.	Name of the composite	Composition of the composite	Type of the building materials	Name and address of the manufacturer in India
12	Medium density fibre board	Cotton plant scantling, wood fibre, resin	Chaukhats, doors, mouldings, furniture, partitioning, panelling, flooring, ceiling	NUCHEM Limited E-46/12, Okhla Industrial Area Phase-I New Delhi - 110 020
13	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
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(India)
15	Flyash-red mud polymer composite	Flyash, redmud and polester	Door shutter	Dual Build Tech (P) Ltd. Madras (India)
16	Clay flyash bricks	Flyash 30-40% Clay 60-70%	General purpose	Calcutta Mech. Brick (P) Ltd. Calcutta 700 020 (India)
17	Flyash-sand-lime bricks	Flyash 70% Sand 20% Lime 10%	General purpose bricks	Damodar Valley Corporation DVC Power Plant Baria, Durgapur West Bengal (India)
18	Flyash-sand-lime bricks	Flyash 70% Sand 10-20% Lime 7-10%	General purpose bricks	Pulver Ash Ltd. Bundel West Bengal (India)
19	Flyash cellular concrete	Flyash cement/ lime gypsum aluminium powder	Light weight blocks and slabs	Ballarpur Industries Ltd. Palval Haryana (India)
20	Fibre reinforced phosphogypsum composite	Purified phosphogypsum plaster and glass fibre or coir	Walling, roofing panels and blocks	IDL Salzbau Visakhapatnam Andhra Pradesh (India)
21	Sand-lime bricks and flyash-lime brick	Sand 90% Lime 10% Flyash 10-90% Lime 35-40%	General purpose, white & coloured bricks, hollow blocks	Sand Plast India Ltd. Behroor, Alwar Rajasthan (India)
22	Clay-flyash bricks	Clay 60-65% Flyash 35-40%	General purpose bricks	Kolaghat Power Station Kolaghat West Bengal (India)
23	Flyash-lime gypsum brick (Fal-G)	Flyash 60% Lime 10-20% Gypsum 10-20%	Bricks of medium range strength	Bhadrachalam Paper Board Ltd. Bhadrachalam Andhra Pradesh (India)
24	Flyash cement brick/blocks	Flyash 60-80% Lime/ Cement 10-20%	Walling, foundation etc.	Gujarat Electricity Board Flyash Company Ahmedabad Gujarat (India)
25	Fibre-flyash cement boards	Agro wastes fibres Cement 65% Flyash 30%	Roofing, partition and panels	Everest Roofing 'Eternit' Ltd. Bombay (India)

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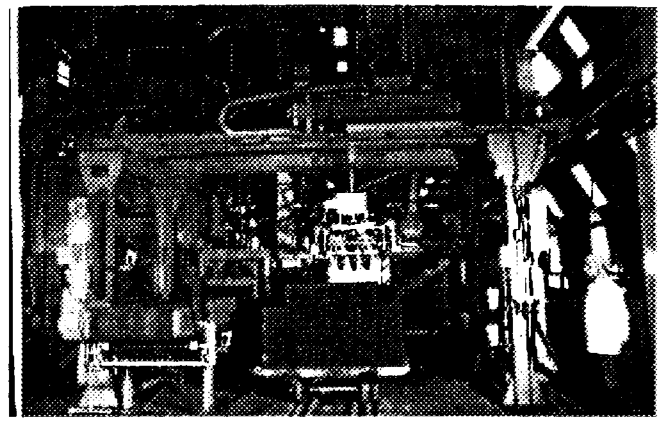
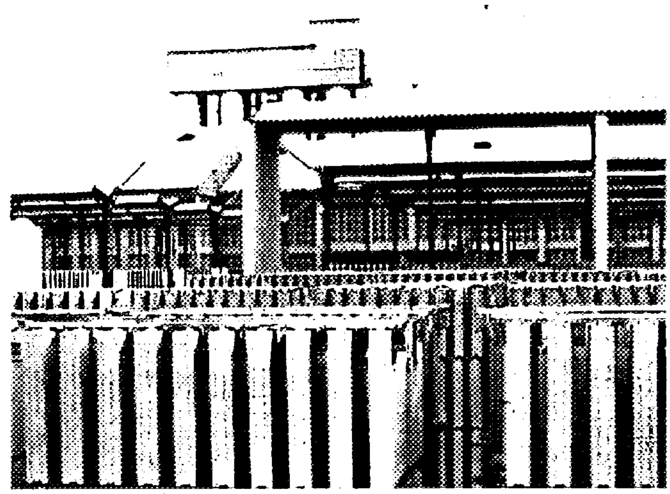
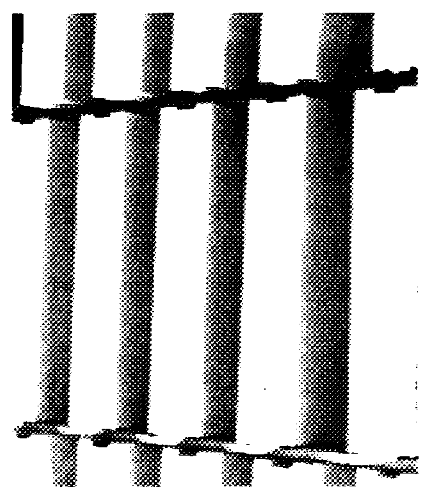


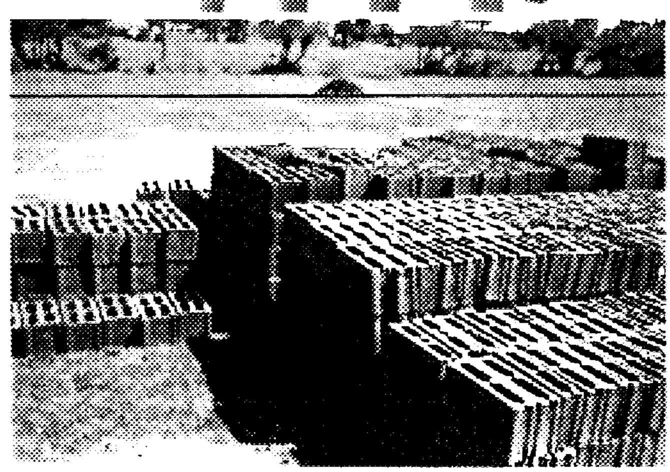
Production of Flyash-Sand-Lime Bricks



Production of Phosphogypsum Panles

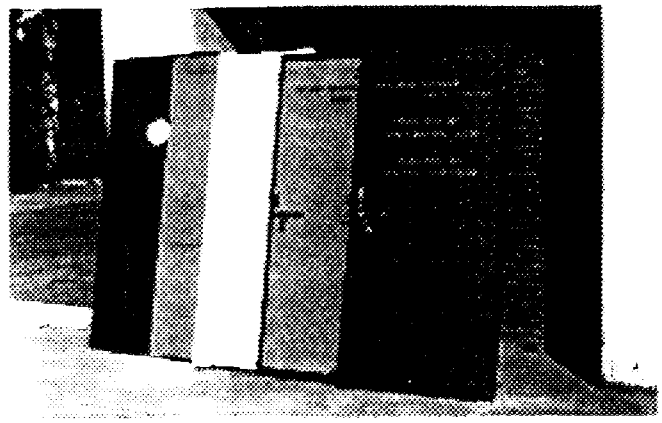


Phosphogypsum Panels for Walling and Partitioning

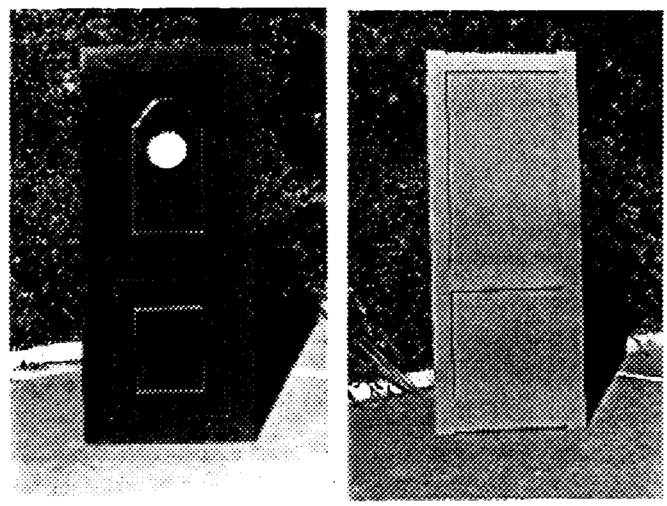


Production of Flyash-Lime-Gypsum-Cement- Concrete Hollow Blcoks . The Coloured blocks are manufactured by adding Red-oxide pigment

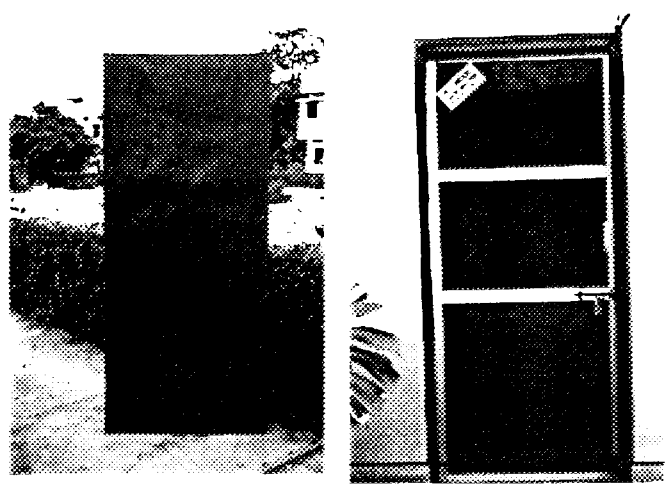
Door-shutters from agro-industrial wastes



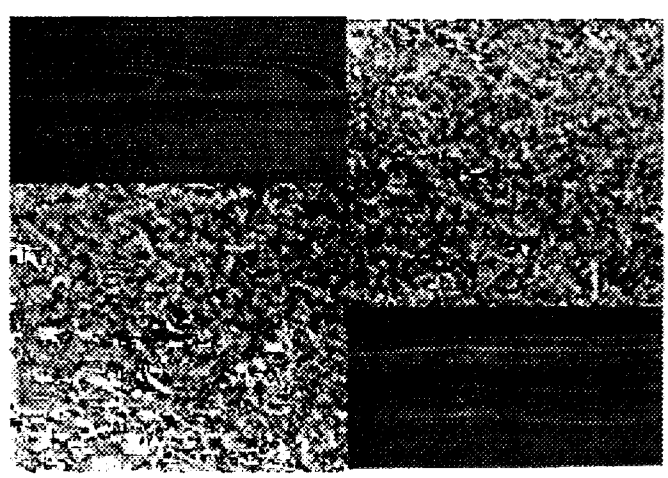
Medium-Density-Fibre (MDF) Door Shutters



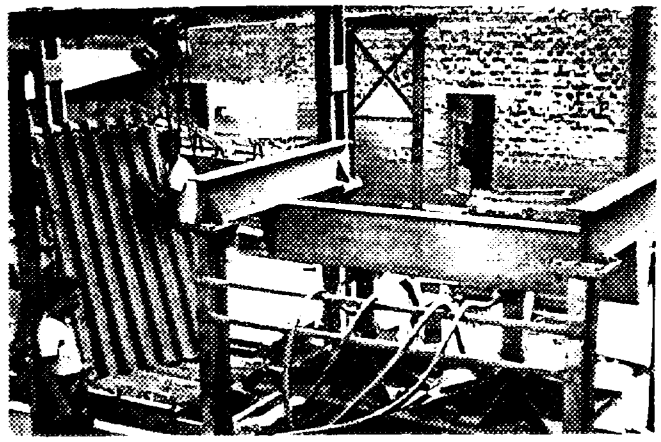
Red-Mud-Polymer (RMP) Door Shutters



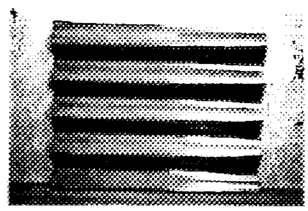
Bagasse boards for false ceiling, paneling etc.

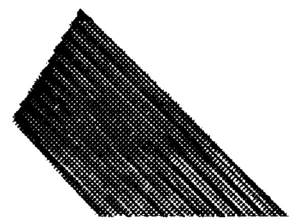


Production of Red-Mud-Polymer (RMP) roofing sheets

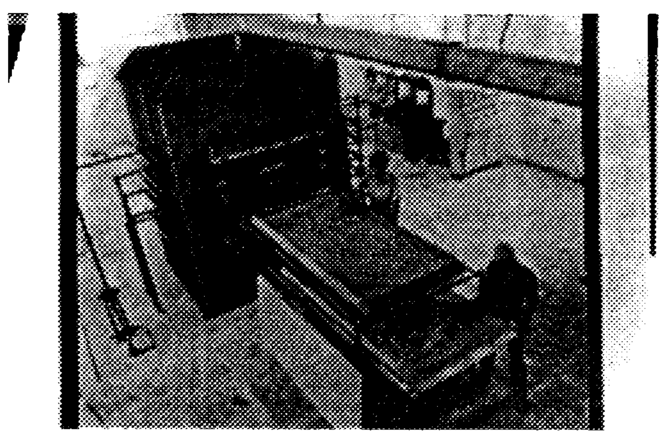


Red-Mud-Polymer roofing sheets





Production of Rice-husk boards



Laminated - Splint Lumber from Rubber Wood